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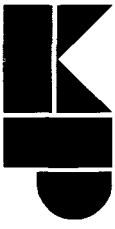

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IPS Proceeding Preface

This volume contains a selection of papers and posters presented at the Tenth International Visual Field Symposium. The symposium was organized by the International Perimetric Society (IPS) and was held in Kyoto, Japan, October 20-23, 1992.

Interest in perimetric research continues to be strong. The dues-paying membership of the IPS now numbers 300, representing 24 countries worldwide. Of 146 abstracts submitted for the meeting, 48 read papers and 84 posters were selected for presentation.

The read papers were given in seven 90-minute sessions devoted to neuro-ophthalmology, ophthalmic imaging, computer-assisted interpretation, follow-up of glaucoma, screening, and other topics. The posters were on display during the entire meeting, and authors were asked to defend their findings during four 90-minute general sessions devoted exclusively to open poster discussion.

Once again, a special invitation to attend the meeting was extended to the international imaging community. They were encouraged to submit abstracts of their work, to become members, and to adopt the IPS meetings as a forum for their future work. As witness to the success of that initiative, the treasurer of the informal Ocular Image Analysis Group transferred the balance of their account to the IPS treasury to support a young investigator's travel to the next IPS meeting.

This volume represents a compendium of the presentations from the Tenth IPS meeting. Through the hard work of the IPS editorial committee consisting of William Hart, Yoshiaki Kitazawa, Christine Langerhorst, and myself, peer review of each submitted manuscript was accomplished. Of the 127 presentations at the meeting, the 103 papers appearing herein are those for which manuscripts were submitted in a timely fashion and passed peer review. It is our hope that this and past Proceedings of the IPS will remain important and convenient references for those who seek up-to-date information and current opinion in the field.

The organization of the meeting was superb in all respects, and we owe a great debt to the hard work of Yoshi Kitazawa and the local organizing committee. On behalf of the Editorial Committee, I want to thank the authors for their timeliness, their attention to detail, and their expertise with the English language, especially those for whom English is not a native tongue.

We are all looking forward to the next meeting, scheduled for July 3-7, 1994, in Washington, DC, hosted by myself and my North American colleagues. It promises to be a stimulating meeting, as the previous ten IPS symposia have been.

Richard P. Mills, MD
IPS Secretary and Editor

Obituary

Hans Goldmann (1899-1991)

We mourn the loss of Professor Hans Goldmann who died on November 19, 1991 one day before his 92nd birthday.

Hans Goldmann was born in 1899 at Komotau (a small town in Bohemia), near Prague, which belonged at that time to the Austro-Hungarian monarchy. His outstanding talents for mathematics and physics were apparent early in life. Quite logically, he decided to become an astronomer. However, he was persuaded to do "something more practical". Ophthalmology appeared as the next best choice. Franz Fankhauser once found in an old notebook, lying around, a number of complex computations by Dr. Goldmann about the traverses of Alpha Centauri.

While Hans Goldmann built his main reputation as a glaucoma researcher, he was an expert in visual physiology and psychophysics. The invention of his famous cupola perimeter, his dark adaptometer (with Weekers), and his experiments related to the Stiles-Crawford effect are just some of his many activities.

He initiated his medical studies at the well-known German Charles University at Prague (now Czechoslovakia) during the First World War. He was "discovered" by his Professor of Physiology, Tschermak von Seysenegg and was "hired" first as a demonstrator and later as an Assistant at the Institute of Physiology. From then on the work at the Institute and psychophysical experiments kept him so busy that he only sporadically, or not at all, visited the lectures at the faculty of medicine. As a consequence, he completed his medical studies almost exclusively by reading. Due to his excellent mind, he readily passed his final examinations in medicine.

Color vision research was one of a number of the major research topics at the Institute at that time. His very first activity was reassembling Ewald Herings' colorimeter. It so happened that the former chairman of the Institute of Physiology had left this apparatus in a highly disordered state when he left Prague to become Chairman of the Physiological Institute at the University of Leipzig. Hans Goldmann told Franz Fankhauser repeatedly that this was the most important lesson in practical physics he had ever had. He had observed earlier that his color sense was in some way deficient, because he was unable to see tuberculosis bacilli present in a stained microscope slide. Now Herings' apparatus, especially designed to study such cases, provided Goldmann with the means to prove that he himself was an anomalous trichromat. This gave rise to his first publication in physiology and he was mentioned in a handbook of physiology as the "protanomalous Goldmann". During Jay Enoch's lectures to residents on color vision in St. Louis, Goldmann would often try to describe the problems that he encountered because of his color deficiency. He also demonstrated how he matched specific hues.

The time in Prague was one of the most stimulating periods of his life. Einstein's theory of relativity (Special theory; General theory: 1919) was the order of the day. Discussions with young physicists followed each other. The ghost and ideas of Ernst Mach who taught at the University of Prague until 1885, and who had influenced Albert Einstein were present. A number of great ideas which later helped to form the scientific thinking of this century were born at that time in Prague. This round included Philip Frank, Professor of Theoretical Physics, Moritz Schlick, leader at that time in "Erkenntnistheorie", the great philosopher, Karl Raimund Popper, and the father of ethology, Konrad Lorenz. Hans Goldmann, already well known for his sharp intellect, participated in, and was accepted at, their round table discussions. In the light of this background, Hans Goldmann's universality appears understandable.

He left Prague in 1923 in order to become an Assistant at the University Eye Clinic, Bern and became a Swiss citizen and Chief of this Institute in 1935 as the successor of Professor August Siegrist. In 1936 he married Erma Renfer from Bern. It could not have been easy to be the wife of a famous scientist with a wondrous creature spirit, who worked day and night and who was driven by an inner compulsion to "know". She cared about him as Lao-tse said in his book, Tao-the-king, "the best ruler is the one whose existence you hardly realize". Among Goldmann's many practical contributions was the creation of the first easy to use and clinically practicable slit lamp, his three-mirror contact lens, the applanation tonometer, and adaptometer. In 1946 he presented his famous cupola perimeter to the Swiss Ophthalmological Society and reformulated the law of spatial summation. Because of the breadth and extent of his contribu-

tions, it is impossible to summarize his many basic research efforts.

Franz Fankhauser worked for him from 1954 until his retirement in 1968, first as an assistant, and later as an "Oberarzt" or "Chef de Clinic". Goldmann was a true friend and in his modesty he proved his real greatness. He also had a warm heart for his patients.

Stephen Drance recalls that he first visited Hans Goldmann in Bern in the late 1950s. Hans Goldmann was not only an accomplished scientist, but a caring clinician. He was friendly, hospitable even to a stranger, and every junior colleague. He would happily discuss glaucoma research problems, was helpful with suggestions, and of course was encyclopedic in his knowledge of the literature. During the many subsequent meetings with Hans Goldmann, it became increasingly clear that his knowledge not only encompassed the sciences but was almost universal. He was able to discuss without preparation, Northwest Indian culture, the origins of Western cowboys, the arts, and archaeology. It was a humbling experience to visit a museum or art gallery with him because of his tremendous grasp of almost all subjects.

Although Hans Goldmann was a very serious person, he had a delightful sense of humor. His face would suddenly light up with a broad smile as he chuckled over something that amused him. After a symposium in Los Angeles, we were all entertained by our local host at the Playboy Club. The "bunnies" made a tremendous fuss of Hans Goldmann throughout the evening, who by this time was in his late 70s, but he clearly enjoyed every minute of it.

On the serious side, he was always ready to acknowledge the evolution of new ideas even if they were contrary to strongly held opinions which he had previously championed.

Jay Enoch's interactions with Goldmann started in the early 1960s through mutual interactions between the Bern and St. Louis groups. Enoch served as the liaison between the two groups for almost a decade. The friendships that evolved were lasting. To characterize some dimensions of this man, Enoch remembers well the year Goldmann spent in St. Louis - so that his successor, Peter Niesel, would have a freer hand. During that period, Goldmann made daily "research rounds" to all the labs in St. Louis. In every case he wanted to know what new findings had been achieved during the previous day. He examined each researcher closely on data, assumptions, experimental design, and implications. If there was nothing new, he always had a topic for discussion. Of course, it was always easier if the researcher had some new insight or finding! Every morning, the technicians lined up at the doors signalling, "he's coming" while the researchers worked madly to be ready. Goldmann literally created a research frenzy. What fun, what excitement, what extraordinary intellect! Realize that he never asked of anyone less than he asked of himself.

Many times, he would discuss with colleagues pathophysiology of disease processes - covering a broad range of disorders and topics. He would often come back to debates on glaucoma, ocular hypertension and low-tension glaucoma. He was troubled by logical gaps in our understanding of the mechanisms of this group of disorders. He worried whether ocular hypertension was, in part, a "quiet period" in the development of glaucoma and how to differentiate the initiation of such a quiet period before overt manifestations occurred.

He was the complete scientist-physician-humanist. He cared and put that care into practice. Those of us who knew and interacted with this giant of a person were, indeed, fortunate. In Europe, the Chancellor or President of University is termed a magnificence. Hans Goldmann served in this role at the University of Bern. Ophthalmology and the world at large have most assuredly lost a magnificence.

Jay Enoch, PhD
Franz Fankhauser, MD
Stephen Drance, MD

VISUAL FIELD ANALYSIS AND DATA MANAGEMENT

The "bracketing fluctuation" index in normal and glaucomatous subjects

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Introduction

The sensitivity of the visual system, like every other psychophysical function, is subjected to a physiological instability. If the light sensitivity is repeatedly measured at the same point of the visual field (VF) using static perimetry, a series of different threshold values are obtained. The standard deviation, which represents the dispersion of the results around the mean value, is called short-term fluctuation (SF), according to Bebie *et al.*[1].

This parameter is usually calculated by computerized perimetry on the basis of a double measurement of light sensitivity at ten positions of VF or at each point examined, such as in G1 and M1 Octopus programs. The inconvenience of these procedures is prolonged examination time.

The short-term fluctuation, expressed by the root mean square (RMS) of the two values obtained for each point retested, represents a useful index of stability of the visual system and visual field[2,3]. We studied the possibility of obtaining a new fluctuation index without prolonging the examination time.

This new index is determined by evaluating the incoherency of the responses registered during threshold measurement at each single point of VF. In computerized perimetry, the threshold is measured by using the "up and down" staircase method, where a first series of stimuli presented with an increasing luminance with 4 dB intervals is followed by a second series of stimuli presented with a decreasing luminance with 2 dB intervals. This causes a double crossing of the threshold, called "bracketing"[4]. Not always do the responses provided by the patient during the second phase correspond to those of the first phase.

Our new index, called "bracketing fluctuation" (BF), takes into account the above-mentioned threshold incoherency, which is indicated by the discrepancy between the last positive response in the ascending phase and the first positive response during the descending phase of stimuli presentation (Fig. 1).

The BF is determined by the root mean square (RMS) of the difference between those values obtained during the two phases. In comparison to the SF, which requires re-testing in ten positions, the new index is calculated without additional testing, for every point examined.

A comparative study on BF and SF indexes in normal and glaucoma subjects is the aim of this paper.

Methods

Using the Perikon PCL90 perimeter[5,6], we compared BF to SF values obtained by the perimetric program 30-II in 214 eyes of normal subjects and in 101 eyes of glaucoma patients. In both groups no systemic diseases were present, nor were general therapies assumed.

The refraction did not exceed ±3 D and the pupillary diameter was not below 2.5 mm; IOP was under 21 mmHg and visual acuity was 8/10 or more with the best correction.

In the glaucomatous patients miotics were not used and only minor perimetric defects were present.

For the statistical assessment of the correlations between age, sex and each single index (BF and SF), the linear regression method and the relevant Pearson's "r" correlation coefficient

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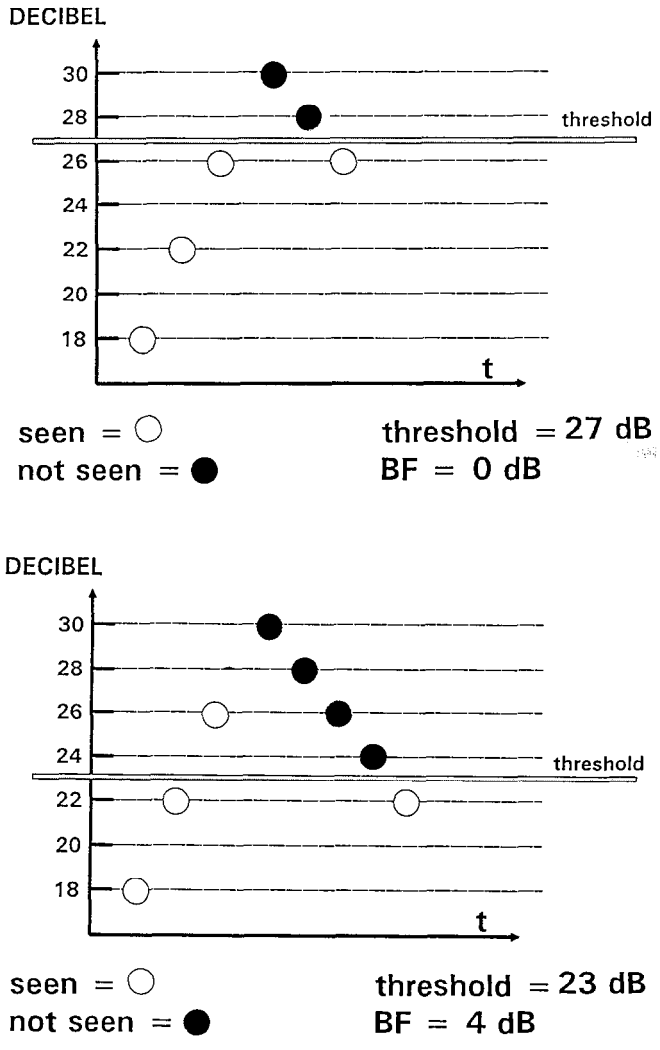

Fig. 1. Two different degrees of discrepancy between the last positive response (seen) during the ascending phase and the first positive response during the descending phase of the first up-and-down procedure.

were used. To analyze the correlations between the two indexes, BF and SF, Spearman's rank correlation test was used.

The differences between normals and glaucoma patients for each single index were assessed with the Mann-Whitney test and the relevant "z" coefficient.

Results

Table 1 shows the mean values for SF and BF of both normal and glaucomatous subjects, subdivided according to age classes. In the normal group, the SF values were above 2 dB in less than 10% of cases and the BF values were above 1.7 dB in less than 13% of cases. In the glaucoma group, about 70% of SF values were above 2 dB and 63% of BF were above 1.7 dB.

Table 1. Bracketing fluctuation index

Age groups (years)	*Normal subjects*		*Glaucomatous patients*	
	BF	*SF*	*BF*	*SF*
	(dB ± SD)		*(dB ± SD)*	
10-20	1 5±0 5	1.6±1.2	1 9±1 0	1.6±1.8
21-30	1 2±0 4	1.7±0 9	2.5±0 9	2.0±1.7
31-40	1 1±0.4	1 4±1 0	2.1±1 0	4.0±2.0
41-50	1.4±0.6	1 7±1 0	2.0±0.9	2 4±1 6
51-60	1.4±0.5	1.5±0.9	1.8±0 9	3.1±1.7
61-70	1 4±0.5	1.3±1.0	2.1±1.0	3 0±1.8
>70	1 5±0 5	2 4±1.0	2 0±0 9	3.0±1.6

Mean values: Normal subjects: BF = 1.3±0 5; SF = 1 5±1; BF (males) = 1.4; BF (females) = 1 2. Glaucomatous patients: BF = 2 1±0.9; SF = 3.1±1 7; BF (males) = 2.1; BF (females) = 2

A significant correlation was found between the two indices, using Spearman's rank test, in both normal and glaucomatous subjects ($p<0.0001$).

The difference between the values obtained from normal and glaucomatous subjects was statistically significant for both the BF index ($z=3.551$; $p<0.0004$) and the SF index ($z=4.864$; $p<0.0001$). No age-related or sex-related differences were observed in the fluctuation values of either the BF or the SF index.

Conclusions

Bracketing fluctuation (BF) is an estimate of threshold fluctuation obtained from a single threshold measurement at every point explored. The distribution of its values in the normal population and in glaucomatous subjects is less asymmetrical and leptocurtic than that of short-term fluctuation (SF). Nevertheless, these two indices are correlated in a statistically significant manner; which means that high BF values frequently correspond to high SF values.

Normal BF values are between 0.5 and 1.7 dB. BF values in subjects with evolving damage of VF are higher than those of normal subjects.

The topographic "point by point" map of BF, supplied by the PCL90 perimeter, represents a useful diagnostic means for the assessment of disturbed or damaged areas of VF and it is more informative than the global value of BF or SF. However, further studies are required in this respect.

Finally, it is worthwhile considering that FB can be automatically calculated by the PCL90 perimeter for any threshold program, and does not require additional examination time, which is important when examining elderly or psychologically disturbed patients.

References

1. Bebié H, Fankhauser F, Spahr J: Static perimetry accuracy and fluctuations. Acta Ophthalmol 54:339-343, 1976
2. Flammer J, Drance SM, Fankhauser F et al: Differential light threshold in automatic static perimetry: factor influencing short-term fluctuation. Arch Ophthalmol 102:876-879, 1984
3. Flammer J, Drance SM, Zulauf M: Differential light threshold: short-term fluctuation in patients with glaucoma, normal control patients and patients with suspected glaucoma. Arch Ophthalmol 102:704-706, 1984
4. Bebié H, Fankhauser F, Spahr J: Static perimetry: strategies. Acta Ophthalmol 54:325-338, 1976
5. Zingirian M, Gandolfo E, Capris P, Mattioli R: Computerized system for static and kinetic automatic perimetry. Eur J Ophthalmol 1:181-186, 1991
6. Zingirian M, Gandolfo E, Capris P, Mattioli R: Perikon PCL90: a new automatic perimeter. In: Mills RP, Heijl A (eds) Perimetry Update 1990/91, pp 403-407. Amsterdam: Kugler Publ 1991

Short-term fluctuation versus bracketing fluctuation in normal, hypertensive and glaucomatous eyes

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Abstract

Bracketing fluctuation is a new perimetric index available with the PCL90 computerized perimeter This index is calculated during normal threshold determination and indicates the intra-measurement threshold variation registered at each test point. In the present study, the authors compare bracketing fluctuation with short-term fluctuation calculated at ten test points. Ten normal volunteers, ten subjects with ocular hypertension and ten glaucomatous patients with advanced visual field defects were enrolled. No statistical difference, with respect to age, was present in any of the groups examined. The visual field was examined with a PCL90 computerized perimeter using program 30 II. In normal and ocular hypertension subjects, no significant difference between SF and BF was noted. In glaucoma patients with severe VF defects, BF showed a higher value than SF, with a mean of p=0.001.

Introduction

Since Flammer introduced perimetric indices in 1984, short-term fluctuation is of those most often investigated.

A previous paper reported that the normal value for this index ranges from 0 to 2 dB and that this value may vary greatly in many pathological conditions. It was also stressed that this index has a predictive value: early VF defects may be preceded by high values of SF[1]. Other papers[2,3] found SF more important, considering this index as a signal of visual field instability.

Since 1990, PCL90, a new computerized perimeter, offers the possibility of a new perimetric index, bracketing fluctuation (BF). This index is obtained during normal bracketing threshold strategy[4,5]. The aim of the present study was to compare bracketing fluctuation with short-term fluctuation calculated normally at ten test points in three groups of patients: *1.* normal, *2.* hypertensive and *3.* glaucomatous.

Material and methods

A group of ten healthy volunteers, ten patients with ocular hypertension and ten patients with primary open angle glaucoma with severe visual field defects were enrolled in this study. Twelve women and 18 men were studied. The mean age of the healthy volunteers was 39 years with a range of from 24 to 51; the mean age of the ocular hypertension group was 41 years with a range of from 35 to 45; and the mean age of the glaucoma patients was 44 years with a range of from 39 to 50. Visual acuity in the first two groups was 1.0 with a range of from 0.9 to 1.2; the glaucoma group showed a mean visual acuity of 0.7 with a range of from 0.6 to 0.9. IOP was 15±4 mmHg in the healthy volunteers, 21±5 mmHg in the hypertensive group without therapy and 18±6 mmHg in the glaucoma patients. This last group was treated with beta-blockers and other adrenergic drugs administered topically. None of the selected subjects presented with systemic hypertension or diabetes mellitus.

The visual fields of all healthy volunteers, hypertensive and glaucoma patients were examined with the PCL90 computerized perimeter using program 30 II. This program explores

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the central 30° with a full strategy and calculates the perimetric indices SF and BF (short-term fluctuation and bracketing fluctuation). These two perimetric indices were compared among patients to verify whether they had a different trend in any of the three groups considered. A statistical analysis was carried out using Student's *t* test.

Results

Short-term fluctuation in normal subjects showed a mean value of 0.9, ranging from 0.7 to 1.2 dB; in the same group, the mean value of bracketing fluctuation was 1.1 with a range of from 0.9 to 1.3 dB. Student's *t* test did not indicate a statistical difference between the mean values of the two indices.

In the hypertensive group, SF had a mean value of 1.6 with a range of from 1.1 to 1.8 dB, while BF showed a mean value of 1.5 with a range of from 0.8 to 1.7 dB. No statistical differences were noted with Student's *t* test. In the glaucomatous eyes group, the mean value of SF was 2 with a range of from 1.8 to 2.3 dB, while the mean value of BF was 2.6 with a range of from 2.3 to 3 dB. In this last group, Student's *t* test indicated a highly significant difference ($p \leq 0.001$) between SF and BF.

Discussion

Fluctuation of the differential light threshold is one of the most often investigated perimetric indices. Short-term as well as long-term fluctuation are especially observed for their potential diagnostic and prognostic significance. Fluctuation may be influenced by a training effect and it may vary greatly from normal subjects to pathological ones.

The bracketing fluctuation calculated by the PCL90 is measured during the normal "up and down" staircase strategy at each test point. Due to this method, its calculation does not require further examination time except that for normal threshold determination. This last point seems to us a first advantage offered by this index.

We compared SF and BF in three groups: normal, hypertensive and glaucomatous subjects. From a comparison of these two indices, no statistical difference was noted in normals and hypertensive subjects. In glaucoma patients BF showed a statistically significant higher value than SF ($p \leq 0.001$). This could suggest that BF is a more sensitive perimetric index than SF. We think that this last hypothesis is very interesting and needs to be evaluated with the support of more data.

References

1 Flammer J, Drance SM, Zulauf M: Differential light threshold: short- and long-term fluctuation in patients with glaucoma, normal controls and patients with suspected glaucoma. Arch Ophthalmol 102:704-706, 1984

2. Gramer E, De Natale R, Leydhecker W: Training effect and fluctuation in long-term follow-up of glaucomatous visual field defects calculated with program Delta of the Octopus perimeter 201 XXV International Congress of Ophthalmology, Glaucoma Society Meeting, Turin 11-14 May 1986. Proceedings, Part I. Rome: CIC Ed Int. New Trends Ophthalmol 1:219-228, 1986

3 Cruz AM: The effect of the number of threshold determinations on short-term fluctuation. In: Mills RP, Heijl A (eds) Perimetry Update 1990/1991, p 209. Amsterdam: Kugler Publ 1991

4. Mattioli R, Capris P, Gandolfo F, Morescalchi F, Zingirian M: La fluttuazione di "bracketing". Comunicazione all' II Congresso Società Italiana di Perimetria. Taormina, 8-9 November 1991

5 Gandolfo E, Morescalchi F, Capris P: Confronto e correlazione tra fluttuazione a breve termine e fluttuazione di bracketing nel glaucoma Communicazione all' VIII Riunione Associazione Italiana per lo Studio del Glaucoma. Rapallo, 14-15 March 1992

A visual field index for nerve fiber bundle defects

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Abstract

The perimetric analysis system PERIDATA provides a visual field index for nerve fiber bundle defects calculating loss variance of the whole central field divided by loss variance in 21 nerve fiber bundle zones The authors applied this index to the Octopus G1 normative database (n=836 fields), to 128 fields of eyes with chronic glaucoma and to 75 eyes with ocular hypertension. The index was normal in 96% of healthy and 95% of ocular hypertensive eyes; 49% of all glaucomatous fields (including those without clinically apparent nerve fiber bundle defects) and 80% of glaucomatous fields with clinically apparent nerve fiber pattern were abnormal. The auc-values of ROC curves for the separation of glaucomatous from healthy eyes was 0.7 for the nerve fiber index and 0.96 for MD. We conclude from our results, that (a) the nerve fiber index is able to identify nerve fiber bundle defects; (b) the nerve fiber index is less sensitive than MD in the detection of pathological visual fields among a heterogenous population of glaucomatous eyes with visual field defects of different configuration; and thus (c) the nerve fiber bundle index alone is not useful for screening purposes but may facilitate in the differentiation of central and peripheral alterations

Purpose

Visual field indices are commonly used for the interpretation of visual fields. Most of these indices (*e.g.*, MD, CLV) represent global changes in sensitivity values across the visual field[1]. For the most part, the topographical arrangement of visual field defects is not considered.

In this study, we used a new index for nerve fiber bundle defects derived from specific topographical alterations of the visual field. We determined the specificity and sensitivity of this parameter in patients with chronic glaucoma, ocular hypertension and normal findings.

Material and methods

Weber and Ulrich[3] developed a computer program (PERIDATA) to facilitate in the interpretation of visual fields providing new indices for visual field defects in various locations.

One of these indices is the nerve fiber bundle index which detects visual field depression in 21 nerve fiber bundle zones (Fig. 1). This index is calculated using the ratio of global loss variance and local loss variance in each of these zones. The maximum index of all 21 zones is used as the nerve fiber bundle index, thus representing the zone with the most localized visual field defect[3].

For this study we calculated global visual field indices and the nerve fiber bundle index for 836 visual fields of healthy eyes (G1 normal population), 128 eyes with chronic glaucoma and 75 eyes with ocular hypertension (all Octopus G1) using the PERIDATA analysis system. The inclusion criteria for glaucoma were an IOP higher than 21 mmHg and typical changes in the visual field and/or of the optic disc. The glaucoma population consisted predominantly of patients with mild or moderate visual field defects (MD = 7.1±4.36, CLV = 36.7±37.5). Ocular hypertension was defined as an IOP higher than 21 mmHg, a vertical C/D ratio not exceeding

The program PERIDATA was provided by J. Weber, MD The authors have no financial affiliation with the companies which produce the instruments and programs used in this study

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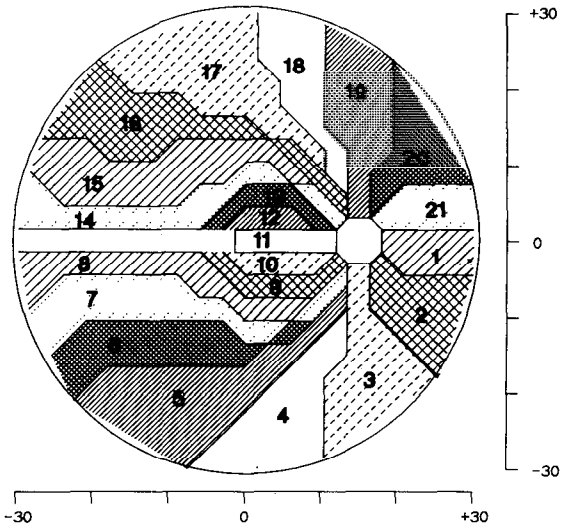

Fig. 1. The visual field, divided into 21 nerve fiber bundle zones, as described by Weber and Ulrich[3].

0.7 and a normal visual field.

For the calculation of sensitivities and specificities, the cut-off value was fixed at 1.15. ROC curves for the separation of glaucomatous visual fields from normal findings were calculated as previously described[4].

For further differentiation the visual fields were clinically classified by one of us (FD) in visual fields with (n=51) or without (n=77) nerve fiber bundle defects. These subgroups were tested separately regarding their sensitivity, specificity and ROC values.

Results

The results of this study are summarized in Table 1.

Table 1. Nerve fiber index and MD in different populations, descriptive data, sensitivities and ROC values

Population	*No.*	*Nerve fiber index mean value and SD*	*Min*	*Max*	*Positive*	*ROC auc*	*ROC(MD) auc*
Normal	836	1.04±0.061	0.93	1.36	37/836	-	-
Glaucoma (all)	128	1.28±0.35	0.97	2.89	63/128	0.70	0.96
Glaucoma (nf)	51	1.40±0.35	0.99	2.48	41/51	0.92	0.99
Glaucoma (nnf)	77	1 20±0.32	0.97	2.89	24/77	-	-
Ocular hypertension	75	1.06±0.069	0.95	1.42	4/75	0.56	0.58

all: all glaucoma patients; nf: patients with clinical nerve fiber defects; nnf: patients with clinical visual field alterations other than nerve fiber defect; auc: area under ROC curve; positive = rate of pathological results, ROC(MD): auc-values calculated for MD in the same populations

In the normal population, the rate of false positive results was shown to be 37/836, equivalent to a specificity of 96%. The results for patients with ocular hypertension were equivalent to a 95% specificity and were therefore within the same range. For all glaucoma patients, the nerve fiber bundle index showed a low sensitivity of 49% and was thus not much different from findings in normal patients.

From 51 patients with clinically apparent nerve fiber bundle defects, 41 were correctly classified by the index as being affected (sensitivity of 80%). Patients with glaucoma and visual field changes other than nerve fiber bundle defects had a markedly lower nerve fiber index

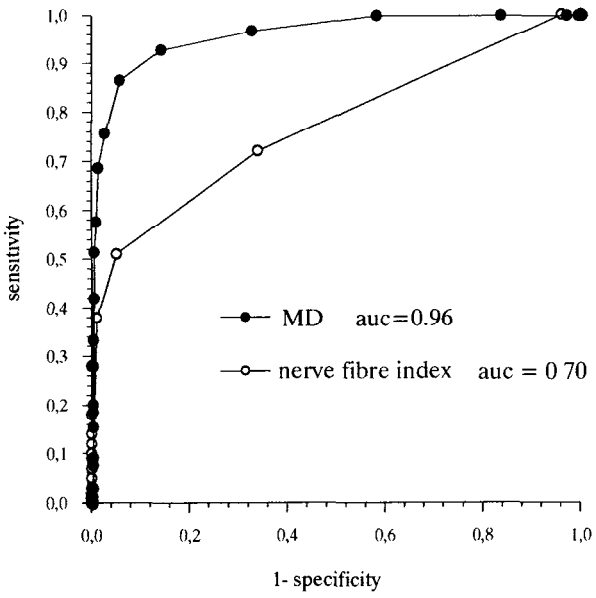

Fig. 2. ROC curves of the nerve fiber bundle index and MD, calculated for all glaucoma patients

(sensitivity 31%).

Separation of affected and unaffected fields (Fig. 2) turned out to be superior for MD (area under ROC curve (auc) = 0.96) compared to the nerve fiber index (auc=0.70).

Limiting the calculation to patients with obvious nerve fiber configuration improved the auc-value to 0.92, while selecting patients with alterations other than nerve fiber bundle defects led to an auc-value of 0.68, near the auc-minimum of 0.5.

Comparing the auc-values of the nerve fiber index and MD calculated for patients with clinically obvious nerve fiber bundle defects, we could demonstrate that, even in those patients, MD had a slightly higher auc-value than the nerve fiber index.

Discussion

Global visual field indices are commonly used for the detection of pathological findings and their follow-up in computer perimetry[1,5]. For calculation of these indices, the topographical arrangement of visual field defects is not taken into consideration.

Recently, attempts have been made to develop new indices, reflecting the topographical arrangement of visual field defects[3,6,7]. Mandava *et al.*[7] and Weber and Ulrich[3] developed indices representing localized visual field defects with nerve fiber configurations. Mandava *et al.* reported a sensitivity and specificity of 88% for the detection of glaucomatous visual field defects using their nerve fiber index.

In the present study, we could demonstrate a lower sensitivity of 49% for the nerve fiber index. These results correspond with those reported by Weber and Ulrich who used the Humphrey perimeter programs 30-2 and 30-S for their study[3]. The difference from the results of Mandava *et al.*[7] might be partially explained by the composition of the glaucoma population. The definition of glaucoma and the extent of visual field defects within the population can seriously affect the results. For our study, we mainly used patients with mild to moderate visual field defects representing patients with early glaucoma. Visual fields with diffuse loss were not excluded from our population.

Due to the wide variety of visual field defects in early glaucoma, the nerve fiber index, detecting only one single feature of glaucomatous visual field damage, could classify about one half of the glaucomatous visual fields correctly. Limiting the calculation to those patients with clinically obvious nerve fiber bundle defects, the sensitivity increased to 80%, demon-

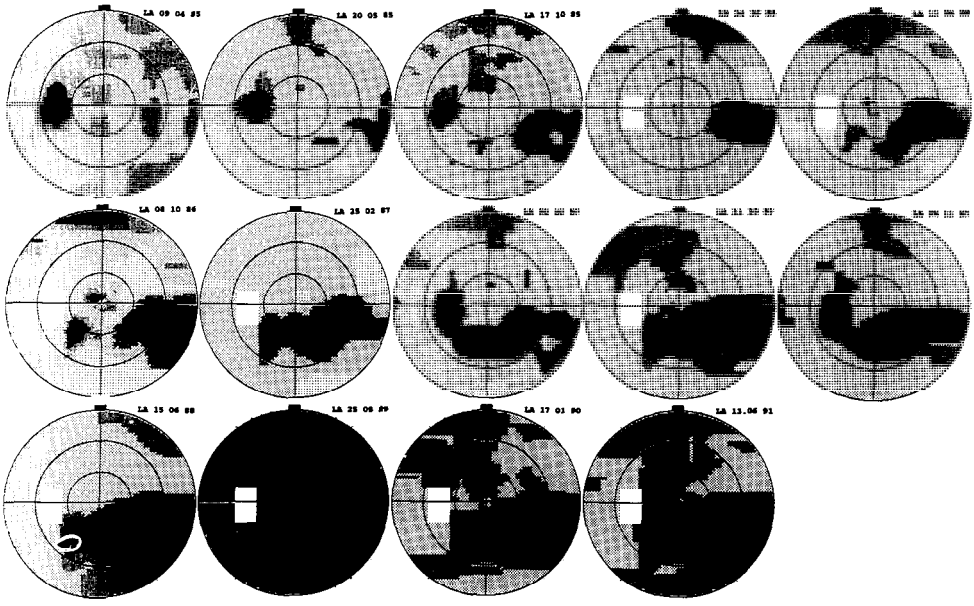

Fig. 3a.

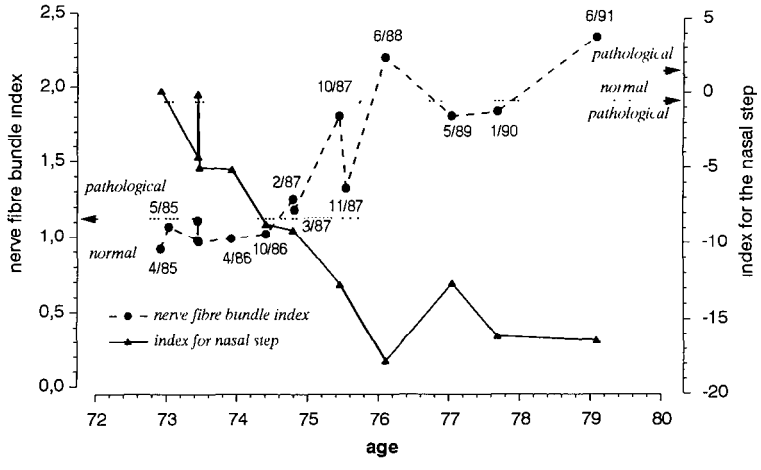

Fig. 3b.

Fig. 3. a. Patient FE: progression of visual field defects from 1985 to 1991 due to chronic glaucoma. *b.* Patient FE: nerve fiber bundle index and index for the nasal step from 1985 to 1991.

strating that this index is, indeed, able to identify this type of defect. The clinical judgement of visual fields, however, does not provide an absolutely correct standard for the calculation of sensitivities.

Due to the high number of zones compared to a scattered distribution of 59 stimuli in program G1, in some of these nerve fiber bundle zones only two stimulus locations are used for the calculation of the nerve fiber bundle index. Therefore, a reduction in the number of nerve fiber zones might further increase the sensitivity of this index.

Calculating an index for nasal step[4] upon those glaucomatous visual fields which were classified by the nerve fiber index as being normal, we found that 43% had a pathological nasal step index. Thus, a combination of nerve fiber index and the index for nasal step could improve the overall sensitivity to 71%. This example demonstrates that a combination of different in-

dices, each representing a single characteristic of glaucomatous visual fields, could be one way of improving sensitivity without deterioration of specificity.

In a population of eyes with lesions of the central visual pathway[8], the nerve fiber bundle index appeared to be affected as frequently as in the glaucoma population. A further precise differentiation was possible in these eyes with a special index for hemianoptic alterations

An example of the progression of visual field defects in glaucoma with corresponding indices for nerve fiber bundle defects and the nasal step is shown in Fig. 3a and b. In this case, a visual field defect first appeared in the nasal region at the horizontal meridian. The index for the nasal step became slightly abnormal. With extension of the defect into the Bjerrum region, the nerve fiber bundle configuration becomes more evident and the nerve fiber bundle index becomes increasingly affected.

We conclude from our results that the index for nerve fiber bundle defects, as introduced by Weber and Ulrich, allows the recognition of nerve fiber patterns. Due to the variety of different types of visual field defects in glaucoma, the sensitivity of this index for detecting early visual field defects in glaucoma is lower compared to the global index MD. Therefore, the nerve fiber bundle index alone is not useful for screening purposes. Its screening capabilities could be improved by combination with other topographical indices, such as the index for the nasal step.

References

1. Flammer J: The concept of visual field indices Graefe's Arch Clin Exp Ophthalmol 224:389-392, 1986
2. Brusini P, Nicosia S, Weber J: Automated visual field management in glaucoma with the Peridata program. In: Heijl A, Mills RP (eds) Perimetry Update 1990/91. Amsterdam: Kugler Publ 1991
3. Weber J, Ulrich H: A perimetric nerve fiber bundle map Int Ophthalmol 15:193-200, 1990
4. Damms T, Dannheim F, Dannheim D: Visual field indices for the nasal step: different calculation procedures and their correlation with the clinical classification of visual field defects. Eur J Ophthalmol 3:21-25, 1993
5 Heijl A, Lindgren G, Lindgren A, Olson J, Asman P, Myers S, Patella M: Extended empirical statistical package for evaluation of single and multiple fields in glaucoma: STATPAC 2 In: Heijl A, Mills RP (eds) Perimetry Update 1990/91 Amsterdam: Kugler Publ 1991
6 Åsman P: Computer-assisted interpretation of visual fields in glaucoma Acta Ophthalmol (Suppl) 70:206, 1992
7 Mandava S, Caprioli J, Zulauf M: A visual field index for nerve fiber bundle defects in glaucoma J Glaucoma 1:178-183, 1992
8. Dannheim F, Damms T, Wessel S: Visual field indices for lesions of the central visual pathways. This Volume, pp 233-238

"Pericecal index" in early glaucoma automated visual fields

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Abstract

The aim of this study was to discover whether a group of test points from a widely used threshold standard program (30-2 Humphrey Field Analyzer) could be employed to create a clinically useful "pericecal index" (PI). The mean sensitivity of 11 test points around the blind spot was calculated in 70 glaucomatous patients with very slight visual field damage, and in 55 age-matched normal subjects, taking into account one eye only. The difference was statistically significant ($p<0.001$) The authors also compared PI with the mean sensitivity of 11 control points, located in the lower field at the same eccentricity, in glaucoma patients and in the normal group. Moreover, the mean sensitivity of these points in glaucomatous and normal eyes was compared The difference between PI and the control points was only statistically significant in glaucomatous patients. On the other hand, the authors found a significant difference between normal and glaucoma control points, probably due to a scattered sensitivity depression in the Bjerrum area.

Introduction

The interest in differential light examination of the pericecal area in early glaucoma has already been shown[1-5]. All previous studies, however, are based on results obtained using special custom programs, with a thick net of test points. Although useful in showing a significant sensitivity depression in about one-third of eyes with very early glaucoma, these tests cannot be used in routine visual field examination, because they are too time-consuming. For this reason, we recently proposed using some test points from a standard threshold program to create a pericecal index[6].

The purpose of the present study is to evaluate the usefulness of a modified pericecal index in clinical practice.

Subjects and methods

This study is based on a pool of visual field data regarding 70 patients aged 34 to 70 years (mean 57.4) with early open-angle glaucoma and subtle visual field defects. As a control group, we examined 55 normal subjects, aged 41 to 77 years (mean 57.3) All subjects were tested with the Humphrey Field Analyzer program 30-2 (Zeiss-Humphrey, San Leandro, CA), which measures the differential light sensitivity at 76 points, within 30°. Only one eye per subject was considered. The following exclusion criteria were adopted for the control group:

1. poor cooperation (>25% fixation losses; >33% false negative and/or false positive answers);
2. history of ocular disease;
3. best corrected visual acuity lower than 20/25 or refractive error higher than four diopters;
4. intraocular pressure greater than 21 mmHg; and
5. peripapillary atrophy or any optic disc anomaly.

Patients with characteristics listed under 1, 3 and 5 were excluded from the glaucoma group (apart from the glaucomatous disc cupping), together with those with advanced visual field

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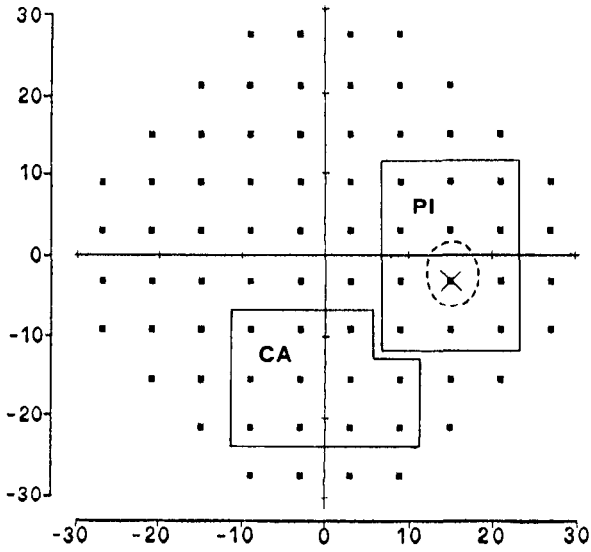

Fig 1 Test points from HFA 30-2 program used to calculate the "pericecal index" (PI) and the control area (CA)

defects (MD >-4 dB; PSD >4 dB; SF >3 dB; CPSD >3.5 dB).

We selected 12 test points located in the pericecal area, disregarding the point under the horizontal meridian at 15° of eccentricity, which usually coincides with the blind spot absolute scotoma. Pericecal index (PI) was defined as the mean value of the remaining 11 points.

Furthermore, we calculated the mean value of another group of 11 test points, located at the same eccentricity in the lower field, and used this as the control area (CA) (Fig. 1).

We compared PI values against CA values in the glaucoma and control groups and the PI and CA values between glaucomatous patients and normal subjects.

We divided the normal subjects into three age groups (<50 years, 15 subjects; 50-60 years, 20 subjects; >60 years, 20 subjects), calculating the values of PI and CA and the prediction limits for normality ($p<5\%$) in each group. Student's t test was used for statistical analysis.

Results

The mean PI was 27.2 dB ± 1.7 in the glaucoma group and 28.7 dB ± 2.2 in the control group. The difference was statistically significant ($p<0.001$). The mean CA value was 28.4 dB ± 1.7 in glaucomatous patients and 29.3 dB ± 2.1 in normals ($p<0.001$). The difference between PI and CA values in the normal group was not statistically significant, whereas in the glaucoma group this difference was highly significant ($p<0.001$).

Grouping the glaucomatous patients by age, the PI was significantly abnormal ($p<5\%$) in nine eyes (12.9%), whereas the CA value was below this level of significance in four cases (5.7%). In the same group, MD was significantly abnormal in eight cases (11.4%), PSD in three cases (4.3%), SF and CPSD in nine cases (12.9%). In 57 eyes with normal global indices, an abnormal PI was found in seven cases (12. 3%).

Discussion

The blind spot and the pericecal area are usually disregarded in most automated visual field tests and statistical programs. The main reason for this is the intra- and interindividual threshold variability, generally considered to be very large in this area.

Our previous studies[7,8] do not support this point of view, and show that short-term fluctuation in the pericecal area is not much higher than the global SF found with the HFA 30-2 program.

Thus, this area can regain the importance which it had in the past, when the enlargement of the blind spot was commonly considered an early sign of perimetric glaucomatous damage.

The present study seems to confirm that a depression in differential light sensitivity can often be found in early glaucoma around the blind spot absolute scotoma, also with standard test programs.

Similar results were found by Jonas *et al.*[9], using manual kinetic perimetry: these authors found significant correlations between the blind spot size and the total area of the optic disc, the peripapillary scleral ring, and parapapillary chorioretinal atrophy.

In our study, this finding does not seem to be related to a papillary crescent of choroidal atrophy, even if, according some authors[10], some degree of peripapillary chorioretinal atrophy is present in all patients with glaucoma. On the other hand, Masukagami *et al.*[11], using fundus photo-perimetry, did not find any relation between the pericecal depression and the conus or angioscotoma. In short, a satisfactory explanation for this finding is not available at present.

We also considered another area (CA) with the same number of test points, located at the same eccentricity in the inferior visual field. In normal subjects there were no significant differences between mean sensitivity in the pericecal area and in this group of points, whereas a statistically significant difference was found in glaucomatous patients. Mean sensitivity in the CA of the glaucoma group, however, was significantly lower than that of the control group.

These findings, in our opinion, mean that in early glaucoma patients there is a sensitivity depression not only around the blind spot, but also in other regions of the Bjerrum area. This scattered depression is often not sufficient to significantly alter the global indices, in particular the MD, which is sensitive to large field defects.

In conclusion, a pericecal index, together with other visual field indices, either global (MD, PSD, etc.) or topographical (*e.g.*, nasal index), could be useful for a more accurate automated visual field test interpretation in early glaucoma.

The various possible causes of an aspecific depression of sensitivity in the pericecal area, such as myopia, peripapillary atrophy, etc., should of course be taken into consideration, in order to avoid any misinterpretation.

References

1. Brusini P, Della Mea G, Tosoni C: Pericecal light sensitivity in suspected glaucoma and in early primary open-angle glaucoma. New Trends Ophthalmol 1:235-240, 1986
2. Brusini P, Della Mea G, Tosoni C: Analisi perimetrica computerizzata dell'area pericecale nell'otticopatia glaucomatosa iniziale. Atti 67° Congr SOI, pp 273-278. Bologna: Nuova Casa Ed L Cappelli, 1988
3. Gandolfo E, Capris P, Zingirian M: Perimetria computerizzata dell'area pericecale. Atti X Conv SOSi 163-169, 1985
4. Inoue Y, Inoue T: Analysis of the Mariotte blind spot in glaucomatous eyes using a CP bracket (Octopus). Jpn J Clin Ophthalmol 37:597-602, 1983
5. Zingirian M, Gandolfo E, Capris P: Computerized assessment of pericecal perimetry for detection of early glaucoma. In: Second International Conference of Ophthalmology, Odessa, pp 191-192, 1981
6. Brusini P, Della Mea G, Miani F, Tosoni C: L' "indice pericecale" nella diagnosi precoce di glaucoma ad angolo aperto. Minerva Oftalmol 32:59-62, 1990
7. Brusini P, Della Mea G, Tosoni C, Miani F: Studio della fluttuazione a breve termine nell'area pericecale di soggetti normali. Boll Ocul 68(Suppl 6):101-106, 1989
8. Brusini P, Della Mea G, Tosoni C: Short-term fluctuation in the pericecal area. Glaucoma. 13:18-20, 1991
9. Jonas JB, Gusek GC, Fernandez MG: Correlation of the blind spot size to the area of the optic disk and parapapillary atrophy. Am J Ophthalmol 111:559-565, 1991
10. Heijl A, Samander C: Peripapillary atrophy and glaucomatous visual field defects. Doc Ophthalmol Proc Ser 42:403-407, 1985
11. Masukagami H, Furuno F, Matsuo H: Blind spots of normal and high myopic eyes measured by fundus photo-perimetry. Doc Ophthalmol Proc Ser 49:489-493, 1987

Sensitivity and specificity of visual field indices

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Abstract

The present study investigates the sensitivity and specificity of visual field indices to determine empirically the best cutoff values for such indices. A test data set with one Program G1 Octopus visual field of 75 normal and 75 glaucomatous subjects was created. Subjects without experience with the test and visual fields with high rates of false negative (>5%) or positive responses (>15%) were excluded. The diagnostic precision of the glaucoma pattern index, loss variance, corrected loss variance was better than for the indices mean defect and short-term fluctuation. The proposed values for the glaucoma pattern index (2.9 dB^2), loss variance (5 3 dB^2) and corrected loss variance (2.2 dB^2) result in an increased sensitivity but only moderately reduced specificity. The proposed values for mean defect and short-term fluctuation (0.6 and 1.5 dB, respectively) give a considerably improved diagnostic precision compared with values based on the current normal values of 2.0 dB and differ markedly from current normal values. The results may help practitioners better to evaluate early visual field defects, at least in patients experienced with the test who give reliable responses. The reduced specificity of the proposed cutoff values calls for a careful examination of the optic disc and optical media to avoid a false diagnosis.

Introduction

Automated perimetry provides practitioners with an easy and reliable method to test visual fields, but the interpretation of these results remains a challenge. Various graphical[1-5] and numerical presentations[6,7] of the results help to interpret visual fields. Most perimeters provide the user with a set of global visual field indices[6,8-11]. Several new indices have been proposed recently[12-20]. Each of these summarizes the visual field differently and may be used to diagnose visual field change[21,22]. However, the value of global visual field indices has been questioned[23,24].

The perimetric results are compared with values based on multicenter studies of normal subjects. Clinicians generally accept the fifth percentile found in the normal value data base as a cutoff value to separate normal from defective visual fields[6,11,25]. The present study revisits this concept and investigates the sensitivity and specificity of visual field indices with receiver operating characteristics (ROC) curves[26].

Material and methods

Glaucomatous visual fields were selected from the database of 4996 Octopus (Octopus model 201) G1 visual fields. By an algorithm, the fields were categorized by "stringent", "moderate",

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or "liberal" criteria for loss (Table 1)[17]. Only reliable visual fields were chosen from experienced subjects with a false positive error rate of <15% and a false negative error rate of <5%. All three phases of program G1 were measured. In addition, only visual fields that satisfied the "liberal" or "moderate" criteria for loss were chosen. Seventy-five visual fields of 75 open-angle glaucoma patients were thus selected.

Table 1. Criteria for categorization of abnormalities for Octopus program G1 fields to select the visual fields for this test data set

Stringent - one or more of the following:
6 adjacent test locations of >5 dB loss each
4 adjacent test locations of >10 dB loss each
Difference of >10 dB loss across the nasal horizontal meridian at 3 adjacent test locations
Moderate - one or more of the following:
4-5 adjacent test locations of >5 dB loss each
2-3 adjacent test locations of >10 dB loss each
Difference of >10 dB loss across the nasal horizontal meridian at 2 adjacent test locations
Liberal - one or more of the following:
2-3 adjacent test locations of >5 dB loss each
1 test location of >10 dB
Difference of 5 dB loss across the nasal horizontal meridian at 2 adjacent test locations

Normal visual fields were selected similarly from the 824 visual fields of the normal database of Octopus program G1[11,25]. All subjects had at least one previous visual field and the same criteria for reliability were chosen. They had to satisfy the "liberal" criteria for loss or show no loss. A total of 75 normal visual fields were age-matched with the 75 glaucomatous visual fields. These 150 visual fields constitute the present test data set.

To validate clinically the inclusion and exclusion criteria mentioned above, two experienced Octopus users (MZ and TZ) subjectively evaluated the 150 fields of the present test data set evaluating all visual field presentations offered by Octosoft (including Bebié curves). A visual field was defined as "borderline" if the two experts agreed it was difficult to judge if the visual field was pathological or normal.

The glaucoma pattern index (GPI), loss variance based on the results of the first phase only (LV), corrected loss variance (CLV), mean defect (MD), and short-term fluctuation (SF) were calculated for the 75 normal and 75 glaucomatous visual fields of the test data set[9,10,17]. Sensitivity and specificity, as well as diagnostic precision, were calculated at incrementing cutoff values for each index. The precision of each index was tested by plotting these data in receiver operating characteristic (ROC) curves. From these curves, cutoff values optimal for discriminating normal from glaucomatous visual fields can be found by identifying the point on the curve closest to the specificity and sensitivity of 100%. Areas under the ROC curves (AUC), separate indicators of test precision, were calculated to further assess the value of each index to discriminate between normal and glaucoma[26]. AUC takes into account the entire range of cutoff values: a perfect index has an AUC of 1, and an AUC of 0.5 indicates an index without any diagnostic value.

Results

Descriptive statistics for the glaucoma and normal groups in the test data set are given in Table 2. Although visual fields of normal subjects had mostly random, localized defects characterized by low values for GPI, CLV and LV, eight of the normal patients qualified for having loss by the "liberal" criteria. The two observers categorized 20.7% or 31 of the 150 visual fields as "borderline". The differences in visual field indices between the two groups were all statistically significant ($p<0.005$) Sensitivity and specificity at the current normal values and the optimal cutoff value as well as the diagnostic precision (proportion of patients correctly diagnosed as being normal or glaucomatous) for each index is given in Tables 4 and 5, respectively The ROC curves have been published elsewhere[17].

Table 2. Background statistics (*t* tests)

Variable	*Normals*	*Glaucoma*	*p value*
Age (years)	58.4	57 9	0 689
False negative responses	0.093	0 120	0 600
False negative catch trials	24.3	25 4	0 020
False positive responses	0.653	0.827	0.296
False positive catch trials	30.0	31 7	0.000
Stimuli presented	503.0	527 1	0.000

Table 3. Clinical assessment of visual fields by two experienced Octopus users with Octosoft

	Normal		*Glaucoma*	
Normal	58	77%	2	3%
Borderline	16	21%	15	20%
Moderately defected	1	1%	28	37%
Obvious defect			30	40%
Total	75	100%	75	100%
Artifacts:				
Blind spot			2	3%
Lens rim artifact	3	4%	2	3%
Prolonged learning effect			2	3%
Lid scotoma	1	1%		
"Pathological" central point	1	1%		
Total	5	6%	6	9%

Table 4. Proposed cutoff values optimized for a high diagnostic precision

Index	*Specificity*	*Sensitivity*	*Diagnostic precision*	*AUC*	*Cutoff value*
GPI	66/88%	66/88.0%	88.0%	0.94	2.9 dB^2
LV	64/85.3%	65/86.7%	86.0%	0.93	5.3 dB^2
MD	58/77 3%	67/88.3%	83.3%	0.90	0.6 dB
CLV	60/80.0%	64/85.3%	82.6%	0.89	2.2 dB^2
SF	52/69.3%	65/86.7%	78.0%	0.82	1.5 dB

AUC: area under the receiver operating characteristics curve, see text; GPI: glaucoma pattern index; LV: loss variance calculated on the results of the first phase only; MD: mean defect calculated on both phases; CLV: corrected loss variance; SF: short-term fluctuation

Table 5. Cutoff values based on the currently used normal values

Index	*Specificity*	*Sensitivity*	*Diagnostic precision*	*AUC*	*Cutoff value*
GPI	72/96.0%	60/80.0%	88.0%	0.94	4.0 dB^2
LV	67/88 3%	60/80.0%	84.7%	0.93	6.0 dB^2
MD	72/96.0%	38/50.7%	73.3%	0.90	>2.0 dB
CLV	71/94.7%	49/65.3%	80.0%	0.89	>4.0 dB^2
SF	68/90.7%	23/30.7%	60.7%	0.80	2.0 dB

See Table 4 for abbreviations

Discussion

The current normal values of program G1 are 2 dB for MD, 6 dB^2 for LV, 4 dB^2 for CLV and 2 dB for SF. In contrast, the frequency distributions given in the publication on the G1 normal value data set for the indices MD, CLV and SF suggest values above 1.5 dB, 3 dB^2 and 1.75 dB may be abnormal even though they are above the fifth percentile[11]. Results of a study[27] with Program JO of the Octopus 201 perimeter suggest optimal diagnostic precision for a CLV value of 1.4 dB^2. However, these results cannot be adopted to programs with different test grids and

re-test algorithms. Therefore, the present study investigates the sensitivity and specificity of visual field indices.

The results (Table 5) reveal low sensitivities if the fifth percentile of the normal population is used as cutoff value setting the specificity to 95%[23,24]. The proposed cutoff values for GPI, LV, and CLV (2.9, 5.3, 2.2 dB^2, respectively) result in a similar diagnostic precision, *i.e.*, the number of cases correctly diagnosed as normal or glaucomatous remained approximately the same. The proposed cutoff values for MD and SF (0.6 and 1.5 dB, respectively) improve the diagnostic precision by 10% and 14%, respectively, compared with values based on the current normal values of 2.0 dB. The current normal values differ considerably from the proposed values and have reasonable sensitivities and specificities.

For all indices, the proposed values result in an equal number of wrongly diagnosed normal subjects and glaucomatous subjects. The results may help practitioners to better evaluate early visual field defects, at least in patients experienced with the test who give reliable responses. However, the reduced specificity of the proposed cutoff values calls for a careful examination of the optic disc and optical media to avoid a false diagnosis.

References

1. Bebié, H, Flammer J, Bebié T: The cumulative defect curve: separation of local and diffuse components of visual field damage Graefe's Arch Clin Exp Ophthalmol 227:9-12, 1989
2. Fankhauser F: Problems related to the design of automatic perimeters. III. The display and interpretation of perimetric results by automated methods. Doc Ophthalmol 47:113-121, 1979
3. Papoulis C, Weber J: A graphical bar to visualize the quantitative development of visual fields. This Volume, pp 49-52
4. Weber J, Geiger R: Gray scale display of perimetric results: the influence of different interpolation procedures. In: A Heijl (ed) Perimetry Update 1988/1989, pp 447-454. Amsterdam: Kugler Publ 1989
5. Weber J, Krieglstein GK: Graphical analysis of topographical trends (GATT) in automated perimetry. Int Ophthalmol 13:351-356, 1989
6. Heijl A, Lindgren G, Olsson J: A package for the statistical analysis of visual fields. Doc Ophthalmol Proc Ser 49:153-168, 1987
7 Wu DC, Schwartz B, Nagi P: Trend analysis of automated visual fields. Doc Ophthalmol Proc Ser 49:175-189, 1987
8. Åsman P, Heijl A: Weighted versus non-weighted visual field indices in glaucoma. Presented at the Xth International Perimetric Society Meeting, Kyoto, Japan, October 20-23, 1992
9. Flammer J: The concepts of visual-field indices. Graefe's Arch Clin Exp Ophthalmol 224:389-392, 1986
10 Flammer J, Drance SM, Augustiny L, Funkhouser A: Quantification of glaucomatous visual field defects with automated perimetry. Invest Ophthalmol Vis Sci 26:176-181, 1985
11. Zulauf M, LeBlanc RP, Flammer J: Normal visual fields measured with Octopus Program G1: I. Global visual-field indices. Graefe's Arch Clin Exp Ophthalmol 1993 (submitted for publication)
12. Åsman P, Heijl A: Glaucoma hemifield test: automated visual field evaluation Arch Ophthalmol 110:812-819, 1992
13. Brusini P, Della Mea G, Miani F, Tosoni C: "Pericecal index" in early glaucoma automated visual fields. This Volume, pp 15-17
14. Damms T, Dannheim F, Ahlers S: A visual field index for nerve fiber bundle defects. This Volume, pp 9-13
15 Dannheim F, Damms T, Wessel S: Visual field indices for lesions of the central visual pathways. This Volume, pp 233-238
16. DeNatale R, Romeo G, Fama F: Short-term fluctuation versus bracketing fluctuation in normals, hypertension and glaucomatous eyes. This Volume, pp 7-8
17. Mandava S, Caprioli J, Zulauf M: Glaucoma pattern index to quantify glaucomatous visual field loss. J Glaucoma 1:178-181, 1992
18. Mandava S, Zulauf M, Hoffman D, Caprioli J: A visual field index for nerve fiber bundle defects in glaucoma. Invest Ophthalmol Vis Sci (Suppl) 32:1105, 1991
19. Weber J: The quantification of congruence between the right and left visual field. This Volume 1993
20 Zingirian M, Mattioli R, Capris P, Gandolfo E, Morescalchi F: Intra-bracketing fluctuation: a new perimetric index. This Volume, pp 3-5
21 Zulauf M, Caprioli J: Fluctuations of the visual field in glaucoma. Ophthalmic Clin N Am 4:671-697, 1991
22. Zulauf J, Caprioli J: What constitutes progression of glaucomatous visual field defects? Sem Ophthalmol 7:130-146, 1992

23. Chauhan BC, Drance SM, Douglas GR: The use of visual-field indices in detecting changes in the visual-field in glaucoma. Invest Ophthalmol Vis Sci 31:512-520, 1990
24. Seamone C, LeBlanc R, Rubillowicz M, Mann C, Orr A: The value of indices in the central and peripheral visual fields for the detection of glaucoma Am J Ophthalmol 106:180-185, 1988
25. Zulauf M, Flammer J, LeBlanc RP: Normal visual fields measured with Octopus Program G1: I The differential light sensitivity at individual test locations Graefe's Arch Clin Exp Ophthalmol 1993 (submitted for publication)
26. Murphy JM, Berwick D, Weinstein M: Performance of screening and diagnostic tests: application of receiver operating characteristic analysis. Arch Gen Psychiat 44:350-355, 1984
27. Liao P, Gollamudi SR, Hirsch J: Evaluation of corrected loss variance as a visual-field index I CLV exceeds RMS in discriminating between glaucoma-suspect patients with no loss of visual sensitivity and normal observers. Ophthalmologica 197:136-143, 1988

Reaction time in automatic perimetry: its evaluation in normals, hypertensives and glaucomatous patients

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Abstract

In automated perimetry, the "reaction time" is the mean interval between stimulus presentation and patient response Such a parameter is always recorded in all perimetric tests carried out by the Perikon PCL90. The authors studied the "reaction time" during threshold perimetric examination performed in 146 eyes of three groups of subjects: normals, hypertensives and glaucoma patients. All subjects were well trained and homogeneous for age, refractive error and reliability. The mean "reaction time" was 505±38 msec in normals, 526±53 msec in hypertensives and 540±51 msec in glaucoma patients Significant differences (ANOVA test) were present between the first and second groups (normals *versus* hypertensives; $p = 0.006$) and between the first and third groups (normals *versus* glaucoma patients; $p = 0.0008$). No statistical significant difference was detected between hypertensives and glaucoma patients. The studied parameter was not age-related, and therefore it probably represents an index of visual system disease.

Introduction

Automatic perimetry makes it possible to extract more information from a normal examination than that obtained from traditional manual perimetry: modern instruments are able to integrate the topographic light sensitivity values with perimetric indices and with many parameters which indicates the patient's test reliability.

For each examination the Perikon PCL90 perimeter (Optikon, Rome, Italy)[1] provided traditional perimetric indices according to Flammer[2] and Heijl *et al.*[3], the kinetic indices[4], as well as several other parameters, such as reaction time.

In static perimetric examination, reaction time is the time interval between the presentation of each stimulus and the subject's response (pressing the push-button). There are only a few contributions in the literature dedicated to reaction time in perimetry.

In 1982 Greve *et al.*[5] found the reaction time in normal subjects, measured during static supraliminal examination with the LED perimeter PERITEST (Rodenstock), to be 350 to 600 msec. Rouland[6,7] recently studied this parameter by means of the "moniteur ophtalmologique", utilizing a supraliminal threshold related and eccentricity compensated strategy in 76 points inside 30°, and found an average reaction time of 477 msec in normal subjects, without significant differences due to age, but which was significantly increased (708 msec) in a group of glaucomatous patients. The availability of this extra parameter provided automatically by the Perikon PCL90[1] for each examination of current use in clinical practice, without prolonging its duration, has induced us to measure reaction time first of all in a group of normal subjects and to compare these data with those obtained from another two groups of subjects: glaucomatous and borderline.

Material and methods

The Perikon PCL90 perimeter[1], designed by Optikon in collaboration with the Perimetric Group from the University of Genoa Eye Clinic, is a computerized projection instrument which makes it possible to carry out static, kinetic and mixed examinations.

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We used program DS 30-II which explores, by threshold strategy with a III Goldmann-size stimulus (200 msec exposure time), 80 points (placed along orthogonal axes analogously to the 32 Octopus and Central 30-2 Humphrey programs) inside the central 30° for a total averaging 474±65 presentations for each normal examination. The DS 30-II program, as with all Perikon programs, provides the average reaction time and the interval between each stimulus in msec during the examination: the latter is constantly and automatically adapted according to the average value of the former obtained from the last eight presentations.

We examined 146 eyes of subjects aged 30 to 70 years (average 54 years) without systemic disease or therapeutic treatment which could influence cooperation, divided into two age groups of 30-50 years and 50-70 years, respectively. The subjects were then further divided into three groups as follows:

- Group 1: normal subjects: 56 eyes of normal subjects, 32 belonging to the 30-50 year age group and 24 to the 50-70 year age group;
- Group 2: hypertensive subjects: 58 eyes of subjects affected by ocular hypertension (IOP ≥23 mmHg without visual field defects or optic disc changes typical of glaucoma), 38 belonging to the 30-50 year age group and 20 to the 50-70 year age group;
- Group 3: glaucomatous patients: 32 eyes with typical glaucomatous visual field defects and optic disc changes, 12 belonging to the 30-50 year age group and 20 to the 50-70 year age group.

None of the eyes examined had other ocular diseases able to influence perimetric performance, and they had a corrected visual acuity of ≥0.9. About 50% of the subjects in each group had had previous experience of perimetric examination. For statistical correlations, we used the analysis of variance (ANOVA).

Results

The results of the groups studied are summarized in Table 1. Reaction time in normal subjects was 505 msec (±38). Statistical analysis showed a highly significant difference between normal and glaucomatous subjects ($p = 0.00077$) and between normal and hypertensive subjects ($p = 0.006$), and no significant difference between glaucomatous and hypertensive patients. (The statistical difference was maintained when comparing the three groups within each age group, except when comparing normal and hypertensive subjects in the 30-50 year age group.)

Table 1. Average reaction time (± SD) in msec in the three groups studied

Subjects	*Age (years)*		
	30-50	*50-70*	*30-70*
Normal	505±42	506±33	505±38
Hypertensive	526±53	532±36	528±48
Glaucomatous	540±51	548±49	544±48

However, no statistical difference was found between the different age groups, and statistical analysis of correlation between reaction time and age confirmed the complete independence of these two parameters.

Conclusions

Our results showed the reaction time in normal subjects to be 505±38 msec and confirmed that this parameter, in automatic perimetry, is significantly increased in glaucomatous and ocular hypertensive subjects compared to normal ones; furthermore, reaction time is completely independent of age.

The finding of an increased reaction time in a visual field examination, which was otherwise normal, can certainly not be interpreted singularly as a useful sign for clinical diagnosis. This finding can, however, together with other signs (short-term fluctuation, bracketing fluctuation), constitute evidence of initial functional defect at a stage where differential light sensitivity,

commonly measured by perimetry, has not yet been affected.

The Perikon PCL90 perimeter together with its software, thus provides an extra parameter which can enrich perimetric analysis without prolonging the examination time.

References

1. Zingirian M, Gandolfo E, Capris P, Mattioli R: "Perikon PCL90": a new automatic perimeter. In: Mills RP, Heijl A (eds) Perimetry Update 1990/91, pp 403-407. Amsterdam: Kugler Publ 1991
2. Flammer J: The concept of visual field indices. Graefe's Arch Clin Exp Ophthalmol 224:389-392, 1986
3. Heijl A, Lindgren G, Olsson J: A package for the statistical analysis of the visual fields. Doc Ophthalmol Proc Ser 49:153-168, 1986
4. Capris P, Gandolfo E, Camoriano GP, Zingirian M: Kinetic visual field indices In: Heijl A (ed) Perimetry Update 1988/89, pp 223-227. Amsterdam: Kugler Publ 1989
5. Greve EL, Dannheim F, Bakher A: The Peritest, a new automatic and semi-automatic perimeter Int Ophthalmol 5:201-214, 1982
6. Rouland JF: Analyse du temps de réponse du patient en function de la topographie au cours du champ visuel. Ophtalmologie 5:147-148, 1991
7. Rouland JF, Hache JC: Variations du temps normal de réponse du patient pendant la mesure du champ visuel. Ophtalmologie 5:48-52, 1991

An evaluation of clusters in the visual field

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Abstract

The authors used a statistical cluster analysis to analyze patterns of loss in 76 visual fields with typical glaucomatous defects to identify "natural groupings" of test locations in the visual field. Eleven clusters in the Octopus program G1 visual field were thus defined. In a separate population of 70 early glaucomatous and 70 age-matched normal visual fields, the local mean defects within these clusters and the global mean defect were calculated to assess their relative abilities to distinguish between the two groups. The 11 local mean defects collectively had a sensitivity of 90% and a specificity of 93%; the global mean defect had a sensitivity of 83% and a specificity of 87%. In addition, the authors examined the long-term fluctuation of clusters compared to individual test locations. Four hundred and ten visual fields of 93 clinically stable eyes of 67 glaucoma patients, as well as 210 visual fields of 105 eyes of 105 normal subjects, were studied. In the stable glaucoma group, mean fluctuation of clusters was 3.5 dB^2, and mean fluctuation of individual test locations was 7 0 dB^2 In the normal group, the respective values were 0.6 dB^2 and 1.8 dB^2. Cluster analysis was effective in detecting localized loss and in dampening long-term fluctuation. The authors discuss the use of clusters in distinguishing normal from glaucomatous as well as stable from deteriorating visual fields.

Introduction

Automated perimetry, although a crucial measure for the detection and therapeutic plan in glaucoma, has presented some still unresolved challenges. Detection of glaucoma, for example, has been insufficient with commonly employed global visual field indices, such as MD and CLV, because they are insensitive to the early defects typical of glaucoma. A second problem has been the distinction of visual field deterioration from long-term fluctuation, defined as unexplained, reversible variance in repeated threshold measurements over time. Allowable limits of fluctuation are necessary for detecting real loss, but they have been difficult to set due to the high fluctuation of single threshold sensitivities[1]. This problem is compounded by the further increase of fluctuation shown in stable, intermediate glaucomatous defects, previously demonstrated by several investigators[2,3].

In our study, clusters are defined as contiguous groups of test locations that are considered together and may provide advantages in the evaluation of visual field data. First, they can be used to calculate local rather than global indices, which are expected to be more sensitive to localized loss, if the clusters are carefully defined to reflect typical patterns of loss. Furthermore, the consideration of clusters instead of single test locations may dampen long-term fluctuation in the visual field by averaging out random changes. Previous work in clusters has shown promising results in these two areas[4,5], although no one study has presented clusters with the consideration of both local indices and long-term fluctuation.

The purpose of this study was to define clusters and evaluate their utility in the interpretation of visual fields. The ability of local mean defects within the defined clusters was compared to that of the global mean defect in detecting glaucoma. In addition, the effect of the clusters on long-term fluctuation was explored in stable glaucoma patients and normal subjects.

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Methods

The development of clusters of test locations

Glaucomatous visual fields were selected from the Yale Glaucoma Service Octopus Perimetry database, which includes visual fields measured with the Octopus 201 Perimeter Program G1 since 1985 at the Yale Eye Center. The following selection criteria were satisfied:

1. a diagnosis of open angle glaucoma;
2. experience in perimetry;
3. satisfactory reliability, defined as both a false positive and false negative error rate below 15%;
4. mean defect (MD) below 5.0 dB; and
5. reproducible, typical glaucomatous defects, as defined by the criteria in Table 1.

One visual field was randomly chosen if a patient had more than one eligible visual field, leaving a total of 170 selected glaucomatous visual fields.

Table 1 Criteria for typical glaucomatous defects

Any one of the following:	
1.	Two or more contiguous points with a 10-dB loss or greater in the superior or inferior Bjerrum areas, compared with perimeter-defined age-matched controls
2	Three or more contiguous points with a 5-dB loss or greater in the superior or inferior Bjerrum areas
3.	A 10-dB difference across the nasal horizontal midline in two or more adjacent locations

In order to identify related test locations in the visual field, 100 visual fields were randomly selected from the population described above. To further select well-localized defects, only visual fields with a corrected loss variance (CLV) over 10 dB^2 were chosen for the analysis. These 76 remaining visual fields were converted to "defect" visual fields by calculating the difference between the mean measured sensitivity and the expected sensitivity in age-matched normals for each test location. Normal values were calculated as follows:

$$z_i(\text{Age}) = z_i(20) - (0.065)(\text{Age}-20)$$

where $z_i(\text{Age})$ is the expected sensitivity at test location i for a subject at that age in years, and $z_i(20)$ is the corresponding sensitivity in a normal 20-year-old, as stored in Octopus Program G1. Considering all these "defect" visual fields together, Pearson correlations were calculated for each possible pair of the 59 test locations. The resulting similarity matrix contained 1711 elements, with each element being a correlation coefficient of two test locations that reflects the strength of the relationship between them. Using a statistical software package (SYSTAT; Systat Inc., Evanston, IL), a nearest neighbor cluster analysis was performed on the similarity matrix. This method is used to find natural groups, or clusters, of related test locations. The results were represented by a hierarchical tree diagram of test locations, which is useful for defining clusters of variable size and strength depending on the distance along the tree. Test locations that did not fall clearly in one cluster were either grouped together to form a new cluster or were assigned to the nearest cluster.

Comparison of local and global mean defects

A database of glaucomatous and normal visual fields was formed to test the diagnostic precision of the local mean defects and the global mean defect. The test glaucoma set of visual fields was comprised of the 70 remaining visual fields from the previously mentioned 170 glaucomatous visual fields less the 100 used to describe the clusters. The test normal set of 70 age-matched visual fields was a subset of a large normal database of Octopus Program G1 fields recently obtained for a study of normal limits. The normal subjects were volunteers from various centers with no history of eye or systemic disease and a normal ocular examination. In addition, visual fields were eliminated for any of the following:

1. any intraocular pressure above 21 mmHg;
2. satisfaction of the criteria for typical glaucomatous loss (Table 1);
3. poor reliability, defined as a false positive error rate greater than 15% or a false negative error rate greater than 5%; or
4. poor visual acuity, defined as worse than 20/25 for subjects below the age of 60 years or worse than 20/30 for subjects above the age of 60 years.

Local mean defects, or MD1 through MD11, were calculated simply as the average of the defects of the test locations within each previously defined cluster. A discriminant analysis of the 11 local mean defects was performed using the statistical package mentioned above, and the discriminant function was used on the test dataset to classify normal and glaucomatous visual fields. The sensitivity and specificity of this discriminant function was compared to those for the global mean defect.

Evaluation of long-term fluctuation in clusters

We examined fluctuation in stable glaucomatous as well as normal visual fields. Serial, stable glaucomatous visual fields were chosen from the Yale Glaucoma Service Octopus database for a previous study of long-term fluctuation at individual test locations[1]. Four hundred and ten visual fields of 93 clinically stable eyes of 67 patients were selected by the following criteria:
1. a diagnosis of primary open angle glaucoma, pigmentary glaucoma, or pseudo-exfoliation with glaucoma;
2. at least three visual fields spanning a period of at least one year;
3. a pupil diameter greater than 2 mm at each perimetry session;
4. a pupil diameter change from test to test of less than a factor of two;
5. a visual acuity better than 20/50 before each perimetry session;
6. distance refractive error between -5 and +5 diopters spherical equivalent with not more than 1.5 diopters of cylinder;
7. no cataract extraction during the study interval; and
8. previous experience with perimetry.

In addition, stable glaucomatous visual fields were chosen by excluding eyes for the following criteria over the study interval:
1. a change in optic nerve head appearance by examination of serial stereoscopic photographs;
2. an increase in dosage or number of ocular medications; or
3. any type of glaucoma or cataract surgical procedure.

Serial normal visual fields of at least two visual fields were chosen from the previously mentioned normal database. The exclusion criteria included:
1. poor reliability, defined as a false positive error rate greater than 15% or a false negative error rate greater than 5%;
2. satisfaction of the criteria for typical glaucomatous loss (Table 1); or
3. no prior perimetry experience.

In each examination, program G1 visual fields have two phases and therefore two threshold measurements for each test location. The average of the two thresholds was taken as the sensitivity for each test location. The average of all the sensitivities within a previously defined cluster was taken as the mean cluster sensitivity. Fluctuation by test location was calculated as the variance (in dB^2) of serial sensitivities at that test location. Mean fluctuation by test location over the entire field was calculated as the average of these 59 variances. Analogously, a cluster fluctuation was taken as the variance of the serial mean cluster sensitivities; mean fluctuation by clusters was calculated as the average of all the cluster fluctuations. Mean cluster fluctuation was compared to mean fluctuation by test location in the stable glaucoma and normal groups by the statistical Student's *t* test. Individual cluster fluctuations were plotted to examine the spatial distribution of fluctuation over the visual field.

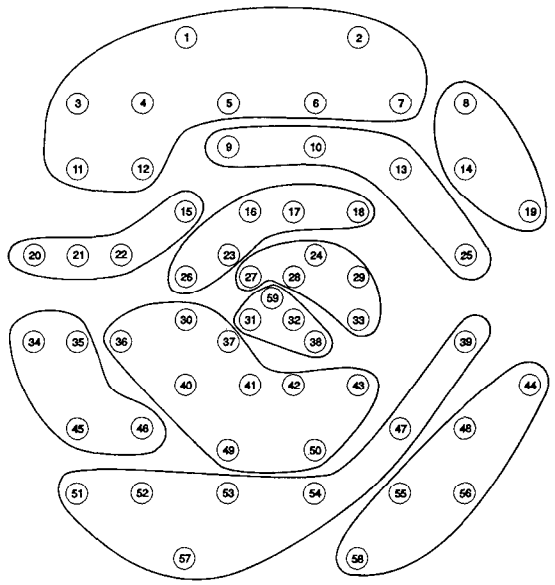

Fig. 1. Octopus program G1 visual field with test locations grouped by cluster analysis into 11 clusters.

Results

Fig. 1 displays the 11 empirically defined clusters of test locations. Table 2 compares the diagnostic precision of the cluster mean defects to that of the global mean defects. Table 3 compares the long-term fluctuation within clusters *versus* by test location in the normal and stable glaucoma groups.

Table 2. Diagnostic precision of local and global mean defect

	Global MD (dB)	*Local MD (dB)*
Sensitivity	83%	90%
Specificity	87%	93%
Diagnostic precision	85%	92%

Table 3. Comparison of long-term fluctuation by test location and within clusters in normals and stable glaucoma

	Long-term fluctuation (dB^2)	
	by test location	*within clusters*
Normals	1.8	0.6
Stable glaucoma	7.0	3.5

Discussion

The use of clusters of test locations to evaluate the visual field has been proposed by several researchers. Most studies have defined clusters by attempting to approximate the known nerve fiber architecture of the retina[4,6-8]. One group has proposed clusters defined from an empiric perimetric retinal map but has not published uses for the clusters[9].

Our clusters are also based on experimental patterns of visual field loss, rather than arbitrary divisions. The clusters reflect the nerve fiber bundle pattern, but are not symmetric across the

horizontal meridian, as are the previously defined non-empiric clusters. In addition, clustered test locations do not span the nasal horizontal meridian.

One potential drawback of clusters for local indices is that defects must fall within a single cluster to be fully accounted. Our method of cluster definition was employed to minimize this problem by forming clinically relevant clusters reflecting typical glaucomatous defects, and the comparison of local and global indices is one measure of our success. The 11 local mean defects, when considered together by a discriminant analysis, were superior to the global mean defect alone in discriminating glaucomatous from normal visual fields.

Long-term fluctuation within the clusters was less than by individual test location in both the normal and the stable glaucoma groups. Our data also reflect the increased variability of visual fields in glaucoma. Allowable limits of long-term fluctuation were difficult to set when calculated by test location[1]; within clusters, the difference in long-term fluctuation between the normal and stable glaucoma groups is widened by over 50%, suggesting more easily set guidelines for detecting true, progressive visual field loss.

One might expect that any grouping of test locations in the visual field will decrease long-term fluctuation. However, there are several characteristics which make the clusters reported here useful. One characteristic is the empiric definition of the clusters based on typical glaucomatous visual field defects. Another is the confidence in the boundaries of the clusters, enforced by not only clinical experience but also by the effectiveness of the local cluster indices. Further studies will include the use of these clusters in the long-term follow-up of visual fields.

References

1 Boeglin RJ, Caprioli J, Zulauf M: Long-term fluctuation of the visual field in glaucoma. Am J Ophthalmol 113:396-400, 1992
2. Flammer J, Drance SM, Zulauf M: Short- and long-term fluctuation in patients with glaucoma, normal controls, and patients with suspected glaucoma. Arch Ophthalmol 102:704, 1984
3. Werner EB, Drance SM: Early visual field disturbances in glaucoma. Arch Ophthalmol 35:1173, 1977
4. Werner EB, Petrig B, Krupin T, Bishop K: Variability of automated visual fields in clinically stable glaucoma patients. Invest Ophthalmol Vis Sci 30:1083, 1989
5. Chauhan BC, Drance SM, Douglas GR: The use of visual field indices in detecting changes in the visual field in glaucoma. Invest Ophthalmol Vis Sci 31:512-520, 1990
6 Wirtschafter JD, Becker WL, Howe JB, Younge BR: Glaucoma visual field analysis by computed profile of nerve fiber function in optic disc sectors. Am Acad Ophthalmol 89:255-267, 1982
7. Sommer A, Enger C, Witt K: Screening for glaucomatous visual field loss with automated threshold perimetry. Am J Ophthalmol 103:681-684, 1987
8. Åsman P, Heijl A: Glaucoma hemifield test: automated visual field evaluation. Arch Ophthalmol 110:812-819, 1992
9. Weber J, Ulrich H: A perimetric nerve fiber bundle map Int Ophthalmol 15:193-200, 1991

Sectorization of visual field in glaucoma

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Abstract

In order to sectorize the central visual field of glaucoma more objectively, 103 visual fields of the Humphrey Field Analyzer program 30-2 obtained from 103 primary open angle glaucoma (POAG) patients at an early to moderately advanced stage, were analyzed by the VARCLUS procedure, a new clustering algorithm developed by SAS Institute Inc. Based on the deviation of the measured threshold value from the age-corrected normal reference value, the total deviation (TD) given by STATPAC, test points of the 30-2 program were mathematically clustered and the whole central visual field was divided into 15 sectors using a mathematical optimization strategy. The distribution of sectors was compatible with the projection of nerve fiber layers and there was no sector extending over the horizontal meridian, but the sector pattern was not completely symmetrical around it.

Introduction

Automated perimeters enable us to perform routine measurements of differential light threshold values in the visual fields of patients, but a large volume of numerical data produced by automated perimeters needs adequate treatment with mathematical statistics. Point-wise analyses, such as the paired *t* test, have been reported to be unsuitable[1] for detecting the time course of change in the visual field defect, mainly because of the considerable inter-test variation of the measured threshold values[1-4].

The sectoring method has been reported by several investigators[5-11]. With this method, the visual field is divided into several sectors and the sum or average of the threshold values of clustered test points in each sector are used for judgment of visual field change. By using the sum or the average of the values obtained from several test points, inter-test variability can be reduced and the detection of changes in the visual field can be facilitated[6]. Sector patterns reported in the previous studies were all based on the assumed retinal nerve fiber layer anatomy[5-11], but they differ from each other. By applying a suitable clustering procedure to the results of automated perimetry obtained from glaucoma patients, it would be possible to obtain a mathematically optimal clustering of test points, *i.e.,* the most objective sectoring pattern of the visual field.

In the present study, we applied the VARCLUS procedure, a new clustering algorithm developed by Warren Sarle at the SAS Institutes Inc.[12], to the visual fields obtained from primary open angle glaucoma (POAG) patients using the 30-2 program of the Humphrey Field Analyzer (Allergan-Humphrey, San Leandro, CA), and attempted to construct a sector pattern of the central visual field of POAG.

Material and methods

Subjects

Visual field data obtained from 103 POAG eyes of 103 patients using the 30-2 program of the Humphrey Field Analyzer were included in the present study. All the eyes were diagnosed as POAG by the measurement of intraocular pressures, optic nerve findings, visual fields test,

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and other ophthalmologic and systemic examinations. The entry criteria of subjects' eyes were as follows:

1. visual acuity equal to or better than 0.5;
2. refractive error of less than 5 diopters;
3. the patients had experienced at least two perimetric examinations using the 30-2 program before the test of which results were used in the present study;
4. a rate of fixation loss, false positive and false negative given by STATPAC of less than 33%, and a pupil diameter of more than 3 mm;
5. a mean deviation (MD) given by STATPAC of above -15 dB.

If both eyes of a patient met the above criteria, only one randomly chosen eye was included in the study. The data of left eyes were converted into mirror images of themselves. Characteristics of subjects and subject eyes are summarized in Table 1.

Table 1. Characteristics of subjects and subjects' eyes (mean ± SD)

Visual acuity	1.02 ± 0.23
Age (year)	61.00 ± 12.4
Refraction (diopter)	-0.85 ± 1.9
Fixation loss (%)	8.10 ± 7 5
Mean deviation (dB)	-7.55 ± 4.00
No. of right eyes	56
No. of left eyes	47

Method of analyses

Total deviation (TD) value given by STATPAC, *i.e.*, the deviation of differential threshold value from the age-corrected reference value at each test point, were used. The value of TD at the i-th test point was subtracted by the mean TD of the whole visual field and a vector $\mathbf{x}_i$ with 103 (the number of subject eyes) elements ($x_{i,1}$, $x_{i,2}$, $x_{i,3}$, .., x_{ij}, ...$x_{i,103}$) corresponding to the i-th test point was constructed. Letting y_{ij} be a standardized x_{ij} with variance 1 and mean 0, then VARCLUS tries to minimize:

$$RSS = \sum_{i}^{74} \sum_{j}^{103} (y_{ij} - a_i m_{N(i)j})^2 \qquad (1)$$

where $m_{N(i)j}$ is the j-th coordinate of the representative vector of the $N_{(i)}$-th cluster ($\mathbf{m}_{N(i)}$) to which vector $\mathbf{y}_i$ is allocated[12]. In the above equation, unknown factors are coefficient a's, allocation of vector y's and representative vector m's. VARCLUS starts from an initial allocation and looks for a local optimal allocation by changing the allocation of each y and checks whether the "least squares" criterion decreases. VARCLUS continues this process of re-allocation of each y until the decrease in the value of RSS ceases to occur. The number of clusters (k), *i.e.*, number of sectors in the visual field, was determined according to the following criteria:

1. each cluster consists of at least three test points;
2. the proportion of the variation explained by the representative vectors, which is calculated as 1 - RSS / {(103-1)-74}, is highest.

The output of the procedure gives the standardized scoring coefficient (c_i) of $\mathbf{y}_i$ for each cluster. If $\mathbf{y}_i$ is allocated to the N-th cluster, c_i is equal to the value of a_i divided by the eigenvalue of the principal component of the N-th cluster and represents the contribution of the i-th point to the representative vector ($\mathbf{m}_N$) for the N-th cluster. By using the standardized scoring coefficients (c_i), the j-th standardized coordinate of the representative vectors of the N-th cluster (m_{Nj}) can be calculated as follows:

$$m_{Nj} = \sum_{i} c_i y_{ij} \qquad (2)$$

where the summation is taken over $\mathbf{y}_i$ which belongs to the N-th cluster.

Results

A visual field was divided into 15 sectors (Fig. 1). Fig. 2 shows the standardized scoring coefficients (c_i) with which the representative vectors can be calculated. The proportion of the variation explained by the representative vectors was 0.751. There were no sectors extending over both upper and lower hemifields and the sector patterns in the upper hemifield and those in the lower hemifield were roughly symmetrical. However, some differences in sector pattern were found between upper and lower hemifields (sectors 6, 7, 8, 12, 13, 14). Table 2 shows the correlation coefficients among each representative vector (**m**), which represent the correlations among each sector. The correlation coefficients were high between neighboring sectors in the same hemifield, but very low or negative between those in the upper and lower hemifields.

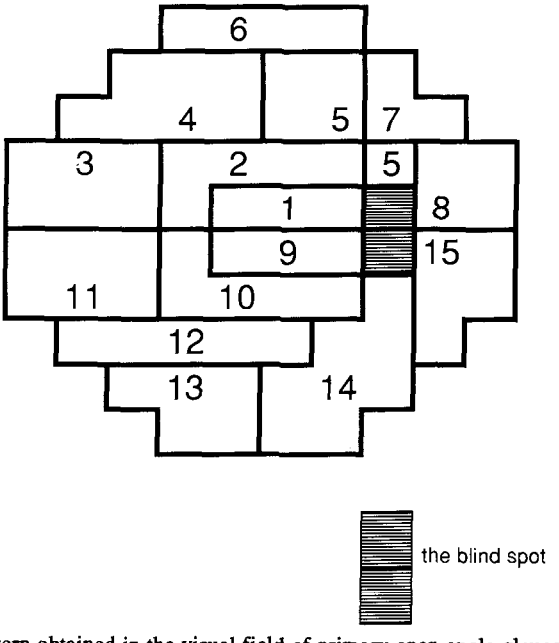

Fig. 1. The sector pattern obtained in the visual field of primary open angle glaucoma patients. All the test points in the visual field are divided into 15 sectors. The distribution of sectors seems to reflect the projection of the nerve fiber layers.

			0 273	0 293	0 291	0 278			
		0 154	0 164	0 157	0 225	0 226	0 381		
	0 154	0 162	0 170	0 160	0 223	0 238	0 373	0 359	
0 186	0 194	0 186	0 220	0 246	0 225	0 212	0 278	0 280	0 284
0 178	0 200	0 180	0 237	0 361	0 381	0 436		0 289	0 271
0 183	0 198	0 184	0 238	0 387	0 412	0 400		0 215	0 233
0 187	0 197	0 194	0 221	0 234	0 227	0 213	0 138	0 240	0 234
	0 223	0 228	0 237	0 228	0 212	0 141	0 139	0 214	
		0 222	0 225	0 232	0 142	0 144	0 142		
			0 220	0 219	0 140	0 151			

the blind spot

Fig. 2. The standardized sorting coefficient (c_i) of each test point. The representative vectors can be calculated using those values.

Table 2. Inter-sector correlations (sector numbers shown correspond to the numbers in Fig. 1)

sector / sector	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
1	1.000	0.417*	0.252	0.047	-0.062	-0.155	-0.050	0.053	0.023	-0.215	-0.227	-0.222	-0.321*	-0.250	-0.027
2	0.417*	1.000	0.749*	0.630*	0.419*	0.253	0.143	-0.341*	-0.325*	-0.519*	-0.574*	-0.656*	-0.651*	-0.615*	-0.489*
3	0.252	0.749*	1.000	0.676*	0.233	0.182	-0.017	-0.362*	-0.306	-0.546*	-0.423*	-0.609*	-0.584*	-0.632*	-0.469*
4	0.047	0.630*	0.676*	1.000	0.699*	0.601*	0.421	-0.095	-0.566*	-0.683*	-0.632*	-0.742*	-0.716*	-0.679*	-0.500*
5	-0.062	0.419*	0.233	6.999*	1.000	0.686*	0.758*	0.097	-0.448*	-0.506*	-0.591*	-0.671*	-0.639*	-0.505*	-0.411*
6	-0.155	0.253	0.182	0.601*	0.686*	1.000	0.562*	0.025	-0.395*	-0.563*	-0.515*	-0.535*	-0.435*	-0.380*	-0.266
7	-0.050	0.143	-0.017	0.421*	0.758*	0.562*	1.000	0.446*	-0.231	-0.430*	-0.495*	-0.550*	-0.463*	-0.302	-0.140
8	0.053	-0.341*	-0.362*	-0.095	0.097	0.025	0.446*	1.000	0.177	-0.109	-0.195	-0.159	-0.034	0.196	0.499*
9	0.023	-0.325*	-0.306	-0.566*	-0.448*	-0.395*	-0.231	0.177	1.000	0.447*	0.138	0.247	0.192	0.397*	0.447*
10	-0.215	-0.519*	-0.546*	-0.683*	-0.506*	-0.563*	-0.430*	-0.109	0.447*	1.000	0.676*	0.645*	0.388*	0.343*	0.168
11	-0.227	-0.574*	-0.423*	-0.623*	-0.591*	-0.515*	-0.495*	-0.195	0.138	0.676*	1.000	0.754*	0.494*	0.189	0.053
12	-0.222	-0.656*	-0.609*	-0.742*	-0.671*	-0.535*	-0.550*	-0.159	0.247	0.645*	0.754*	1.000	0.791*	0.481*	0.147
13	-0.321*	-0.651*	-0.584*	-0.716*	-0.639*	-0.435*	-0.463*	-0.034	0.192	0.388*	0.494*	0.791*	0.000	0.685*	0.356*
14	-0.250	-0.615*	-0.632*	-0.679*	-0.505*	-0.380*	-0.302	0.196	0.397*	0.343*	0.189	0.481*	0.685*	1.000	0.611*
15	-0.027	-0.489*	-0.469*	-0.500*	-0.411*	-0.266	-0.140	0.499*	0.447*	0.168	0.053	0.147	0.356*	0.611*	1.000

*highly significant ($p<0.001$)

Discussion

In the present study, we divided the visual field into sectors by directly analyzing the results of visual field tests obtained from POAG patients. Werner *et al.*[5,6], Wirtshafter *et al.*[7] and Sommer *et al.*[8,9] divided the visual field into some sectors based on the assumed projection of the retinal nerve fiber layers[13-16] and examined the possibility of using those sectors for diagnosis or follow-up of glaucoma[5-11]. A new version of STATPAC (STATPAC 2) includes a new program using the sectoring method (hemifield test)[11]. However, there were differences in the described sector pattern. Therefore, the sector pattern obtained in this study is thought to be very informative because it was mathematically determined by the visual field data of the 30-2 program in early to moderately advanced POAG eyes without any underlying presumptions, such as nerve fiber layer anatomy.

Generally, factor analyses or hierarchical clustering procedures have been widely used for clustering variables (in this study, test points in the visual field)[17]. However, conventional orthogonal factor analyses are not suitable for the clustering test points in the glaucomatous visual field because they assume independent common factors. Application of oblique factor analyses with numerous options in factor-extraction and factor-rotation has not gained wide acceptance[17] and the results of hierarchical clustering procedures are sensitive to the methods adopted, because of their strict requirements of geometrical structure. Although the basic idea of the VARCLUS procedure[12] comes from traditional oblique factor analyses, it aims at direct clustering of variables and allows non-zero correlation between clusters. Furthermore, VARCLUS provides the representative vectors corresponding to each cluster, with which the results of visual field tests can be summarized, into fewer representative values without losing their relevant information. For the above reasons, we employed this method for clustering test points in the visual field of glaucoma.

The sector pattern obtained seems to reflect the assumed retinal nerve fiber layer and generally extends along arcs originating from the blind spot. There was no sector extending over both the upper and lower hemifields. In those points, the sector pattern obtained here was similar to those previously reported[5-11]. However, the sector pattern was not completely symmetrical around the horizontal meridian (sectors 6, 7, 8, 12, 13, 14), which may reflect the fact that the nerve fiber distribution pattern is not completely symmetrical across the horizontal meridian[18].

By utilizing the sector pattern obtained, it would be possible to anticipate where the next visual field defect will most likely develop in clinical situations, because the depression tends to cluster in the same sector. In addition, the sector pattern may be used in follow-up of the visual field damage in glaucoma and for assessment of reliability of the visual field defect; if the depression of sensitivity is seen at some points in the same sector, the probability that the recorded depression is not a false negative will he higher. Furthermore, the sensitivities obtained in the sectors 1-3 and those obtained in the sectors 9-11 may be compared for early detection of glaucoma, since they are mirror image sectors across the horizontal meridian.

With regard to the correlation coefficients between sectors, those between neighboring sectors in the same hemifield tended to be significantly positive and those between the sectors in the upper hemifield and sectors in the lower hemifield were negative. Considering that in early to moderately advanced glaucoma, the visual field defects were usually confined to either the superior or inferior hemifield[19,20], this result is reasonable and supports the methods used to diagnose early glaucoma by comparing the extent of the sensitivity depression of a sector in the upper hemifield with that of its mirror image sector in the lower hemifield[8,9,11].

References

1. Hills JF, Johnson CA: Evaluation of the t test as a method of detecting visual field changes. Ophthalmology 95:261-266, 1988
2. Flammer J, Drance SM, Zulauf M: Differential light threshold short- and long-term fluctuation in patients with glaucoma, normal controls, and patients with suspected glaucoma. Arch Ophthalmol 102:704-706, 1984
3. Wilensky JT, Joondeph SC: Variation in visual field measurements with an automated perimeter. Am J Ophthalmol 97:328-331, 1984

4. Heijl A, Lindgren A, Lindgren G: Test-retest variability in glaucomatous visual fields. Am J Ophthalmol 108:130-135, 1989
5. Werner EB, Bishop KI, Koelle J et al: A comparison of experienced clinical observers and statistical tests in detection of progressive visual field loss in glaucoma using automated perimetry. Arch Ophthalmol 106:619-623, 1988
6 Werner EB, Petrig B, Krupin T et al: Variability of automated visual fields in clinically stable glaucoma. In: Heijl A (ed) Perimetry Update 1988/89. Amsterdam: Kugler Publ 1989
7. Wirtschafter JD, Becker WL, Howe JD et al: Glaucoma visual field analysis by computed profile of nerve fiber function in optic disc sectors. Ophthalmology 89:255-267, 1982
8. Sommer A, Duggan C, Auer C et al: Analytic approaches to the interpretation of automated threshold perimetric data for the diagnosis of early glaucoma. Trans Am Ophthalmol Soc 83:250-267, 1985
9 Sommer A, Enger C, Witt K: Screening for glaucomatous visual field loss with automated threshold perimetry. Am J Ophthalmol 103:681-684, 1987
10. Heijl A, Lindgren A, Lindgren G: Interpoint correlations of deviations of threshold values in normal and glaucomatous visual fields. In: Heijl A (ed) Perimetry Update 1988/89 Amsterdam: Kugler Publ 1989
11. Introducing STATPAC 2: New Release for the Humphrey Field Analyzer. San Leandro CA: Allergan-Humphrey 1989
12. SAS/STAT™ User's Guide, Release 6 03 edn Cary: SAS Institute Inc 1989
13 Aulhorn E, Harms H: Early visual field defects in glaucoma. In: Leydhecker (ed) Glaucoma Symposium. Tutzing Castle. Basel: Karger 1966
14. Aulhorn E, Karmeyer H: Frequency distribution in early glaucomatous visual field defects. Doc Ophthalmol Proc Ser 14:75-83, 1976
15. Furuno F, Matsuo H: Early stage progression in glaucomatous visual field changes. Doc Ophthalmol Proc Ser 19:247-253, 1979
16. Drance SM: Glaucomatous visual field defect In: Ritch R, Shields MB, Krupin T (eds) Glaucomas. St Louis: CV Mosby 1989
17. Kendal M: Multivariate Analysis. 2nd edn. London: Charles Griffin & Co Ltd 1980
18. Minckler DS, Ogden T: Primate arcuate nerve fiber bundle anatomy. In: Heijl A (ed) Perimetry Update 1988/89. Amsterdam: Kugler Publ 1989
19. Hart WM, Becker B: The onset and evolution of glaucomatous visual field defects. Ophthalmology 89:268-279, 1982
20. Mikelberg FS, Drance SM: The mode of progression of visual field defects in glaucoma. Am J Ophthalmol 98:443-445, 1984

Pointwise analysis of serial visual fields in normals

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Abstract

This study investigated learning effects in normals, initially using conventional analysis of the global indices as calculated by the Humphrey Field Analyzer 630 An alternative new index (LP) is proposed, and its ability to detect learning effects in normal subjects is compared with conventional methods. LP is the ratio of the number of locations that have increased in sensitivity between field test n and (n+1) to the total number of locations which have changed in sensitivity. This proportion is not influenced by locations showing extreme changes in sensitivity, unlike the global indices mean sensitivity (MS) and mean deviation (MD). Thirty normal novice subjects (aged 19 to 33 years, mean 24.5 years) attended for three visits on separate days. At each visit each subject underwent two 30-2 programs on one eye, selected at random, giving a total of six fields. Simple statistical models combined with graphical analysis of MD and MS illustrate the learning effect, but a significant pattern was not observed. Furthermore, plots for individual subjects illustrate the inter-subject variability. LP, however, demonstrated a statistically significant improvement in sensitivity between tests 1 and 2 only ($p<0$ 01). Spatial analysis of field locations (test 1 to test 2) is presented. This technique exposed the spatial configuration of the learning to be mainly in the superior field, and to increase with eccentricity. However, using a simple filter process the peripheral learning is shown to be partly a function of the extreme values which occur in these regions of the field. LP and filtered spatial representations of serial fields can reduce the "noise" within these data, which may be useful in detecting changes in glaucomatous visual fields.

Introduction

Many methods of analysis have been applied to data obtained from static automated perimetry. Typically, such methods involve simple statistical analysis of the global indices, mean deviation (MD), mean sensitivity (MS) and short-term fluctuation (SF). Spatial representation of the visual field and probability maps[1-5] help identify those locations showing changes in sensitivity. A difficulty with any form of analysis is that the data are subject to great inter- and intra-individual variability, which calls into question the use of normal age-corrected visual field data for comparison purposes. Variability tends to be greater in pathological fields[6-14]. It is now accepted that an increase in the variability of a patient's visual field may precede actual sensitivity loss[13-15]. The reliability indices (fixation losses, false positives and false negatives) serve to identify a reliable field, and, in conjunction with SF, help to distinguish between variability and actual changes in sensitivity.

The primary aim of this study was to compare the ability of an alternative form of analysis to detect a learning process in normal subjects with the usual analysis of the global indices MS and MD as calculated by STATPAC of the Humphrey Field Analyzer 630. An image processing filter was applied to the visual field data to reduce the effect of inherent variability[16]. Spatial representations of the learning process are presented, both before and after the use of the filter process.

The presence of a learning process with subjects new to automated perimetry is well established[17-19]. It is usually demonstrated as an improvement in the mean sensitivity, mean deviation, and both short- and long-term fluctuations. A number of investigators believe most of the

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learning to be complete after the performance of the first or second field tests[7,9,20]. However, learning has been shown to continue beyond the first two field tests in some subjects, particularly if their initial test thresholds are low[20,21].

A few other studies have either failed to demonstrate a learning process[22], or consider any improvement in sensitivity to be counterbalanced by a decrease in sensitivity associated with a fatigue effect, resulting from the duration of the examination[12,23].

The learning effect has been shown to vary with location, becoming greater with increasing eccentricity, particularly beyond 30° and in the superior region of the field, in both normal subjects[4,19,24] and glaucoma suspects[21].

Wild *et al.*[21] have shown a transfer of learning from the first to the second eye tested, demonstrated by an increase in mean sensitivity of both the complete field and of the superior quadrant.

A secondary aim of this study, not discussed further here, was to establish the optimum protocol for a subsequent investigation which will examine the sensitivity of the central field in myopia, using a grid resolution of 4.2 degrees. This resolution is obtained by combining the 30-2 and 30-1 central programs of the Humphrey Field Analyzer. The study method to be described below was designed with this follow-up investigation in mind.

Material and methods

The sample consisted of 30 volunteers (aged 19 to 33 years, mean 24.5 years) new to automated perimetry and free from any ophthalmological abnormality. Each subject attended for three visits on separate days. At each visit the subject underwent two 30-2 programs on one eye, selected at random, using the Humphrey Field Analyzer 630. A rest period of ten to 15 minutes was given between fields. Thus, a total of six fields was obtained for each subject. Only one eye was tested to avoid the confounding effects of a transfer of learning from one eye to the other[21].

Statistical analysis

Typical approach

Typically, the effect of learning on sensitivity is observed as an improvement in MD or MS with successive field tests. A sample mean for MD and MS is calculated for each field test. The significance of differences between fields is investigated using hypothesis testing, and temporal trends are illustrated diagrammatically[2,19-21,25-27]. A two-way ANOVA for both MD and MS with subjects and field test as the main factors, was adopted as a starting point for this study.

Alternative approach

Consider one subject and their field data from test n and test (n+1). The threshold value at each location in test n is subtracted from the corresponding value in test (n+1). The difference at each location is then identified as:

- positive {an increase in sensitivity from test n to test (n+1)},
- negative {a decrease in sensitivity from test n to test (n+1)}, or
- no change

This process is repeated for all locations, excluding the two blind spot locations. The index LP (the learning proportion) is defined as the ratio of the number of locations which have increased in sensitivity between tests n and (n+1) to the total number of locations that have changed in sensitivity. This index can be calculated for field tests 1 to 2, 2 to 3, 3 to 4, etc.

In the absence of learning, it would be expected that half those locations showing a change in sensitivity would increase, and half would decrease, from one test to the next. Thus, LP should equal 0.5. If a greater proportion of points increase in sensitivity from one test to the next (a learning effect) the value of LP would increase, thus LP would be greater than 0.5.

A sample mean LP and a 95% confidence interval were constructed for each test from all 30 subjects. These values were plotted and compared with the null hypothesis, LP = 0.5.

Results

A plot of the sample means of MD is given in Fig. 1. This shows some of the characteristics of the typical learning curve obtained from subjects new to automated perimetry. MD improves, as expected, from the first to the second field test. However, an apparently greater improvement in sensitivity occurs between tests 3 and 4.

However, such plots are limited in their ability to describe fully the variability of subjects' responses. For example, it should be noted that the error bars do not encompass all the observations obtained. The inadequacy of such plots to fully describe the variability is discussed in detail by Matthews *et al.*[28]. Further to illustrate the diversity of individual responses, typical examples from nine subjects are presented in Fig. 2.

It is difficult to draw firm conclusions from the results shown in Fig. 1. The appropriateness of the statistical methods typically used to compare the sample means is questionable. To

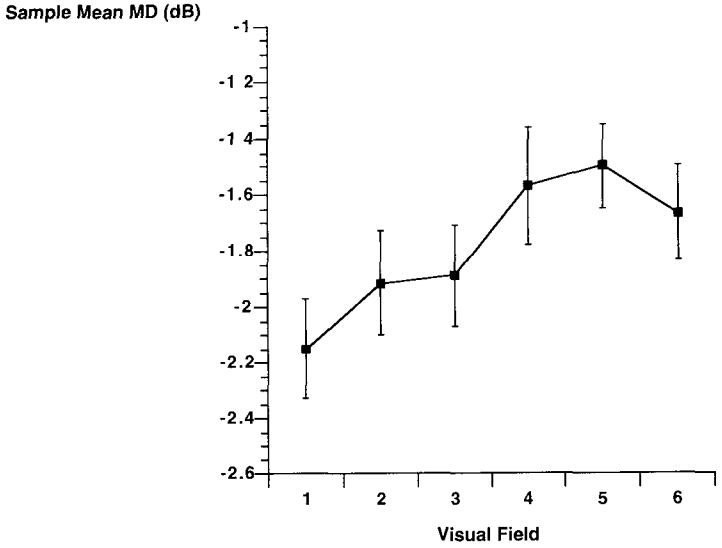


Fig. 1. Sample mean of the mean defect, MD (± SE), for 30 subjects plotted against successive field tests.

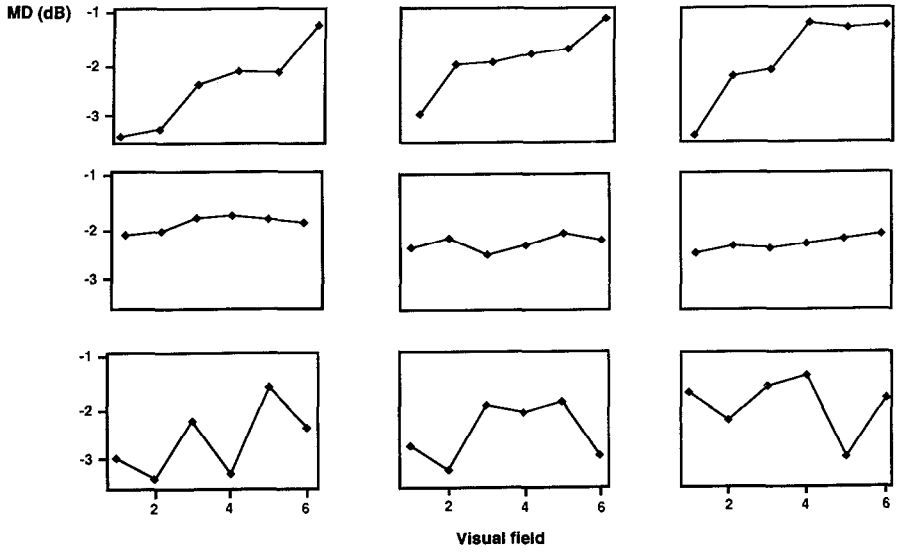


Fig. 2. Mean defect, MD, plotted against successive field tests for nine subjects.

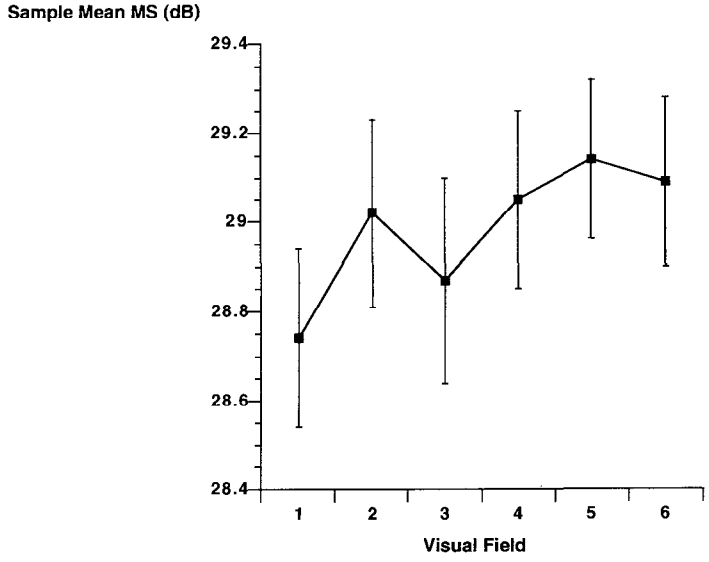


Fig. 3 Sample mean of the mean sensitivity, MS (± SE), for 30 subjects plotted against successive field tests

compare each mean as if from an independent sample is certainly invalid. A paired *t* test is also inappropriate because of the multiple comparisons involved. A two-way ANOVA, with subjects and test as the main factors, is an acceptable and robust method, but the assumptions, including a constant within sample variance, are often overlooked. There were no significant differences between the sample means (F-test; p=0.14). A tentative conclusion would be that, based on an analysis of MD, there is no clear evidence of a learning effect.

Any arithmetic mean, such as MD, is adversely affected by extreme values. Intuitively there are likely to be several influential outliers (values which are incompatible with the rest of the data set) in a field from an inexperienced subject. Therefore, MD may not be the optimum index to describe the general improvement in sensitivity associated with the learning phenomenon.

Similar results were obtained using MS (Fig. 3). Again there were no statistically significant differences between the sample means. Analysis of MS is subject to the same criticisms as MD.

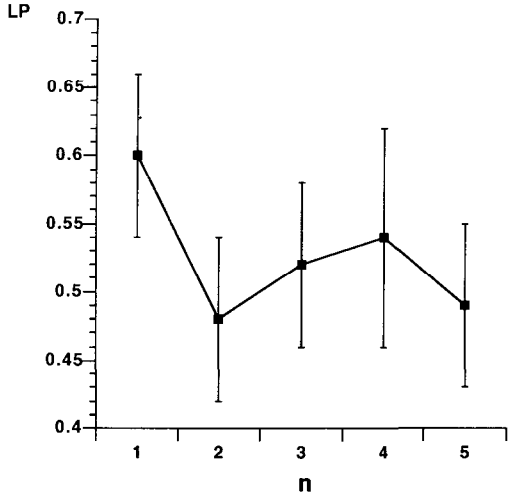
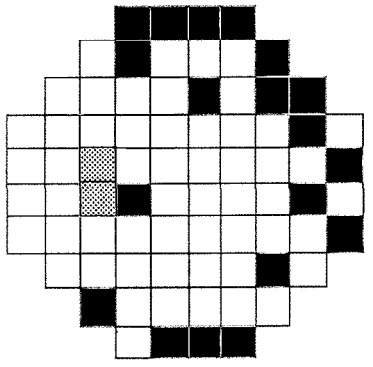


Fig. 4. Sample mean of learning proportion, LP, with 95% confidence intervals, for 30 subjects plotted for field tests n to n+1, where n = 1 to 5.



■ = Top 25% of locations with largest increase in sensitivity

▒ = Blind spot

Fig. 5. Spatial representation of the increases in threshold sensitivity between field tests 1 and 2, for 30 subjects.

A plot of LP for our sample is shown in Fig. 4. The space between the bar representing the 95% confidence interval for LP (1 to 2) and the expected value of 0.5 implies that the ratio is significantly larger than 0.5 between tests 1 and 2 (p=0.01). There are no other significant differences since the expected value is encompassed by the 95% confidence intervals for the remaining cases. This suggests, in agreement with previous studies[20,21], a learning effect between tests 1 and 2 only.

Spatial representations

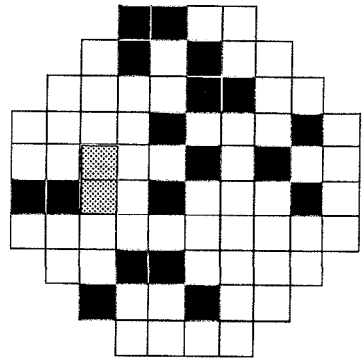
Considering field tests 1 and 2 only, a spatial representation of the learning was constructed. At each location the change in sensitivity (positive or negative) in dB between field test 1 and 2 was determined for each subject. The mean change per location for all 30 subjects was cal-

X1	X2	X3
X8	Y	X4
X7	X6	X5

- **Di = absolute {middle value - average of neighbouring points}**

- $Di = \left| y_i - \frac{\sum x_j}{n} \right|$ where i = 1 to 74

Fig. 6. Nine locations from a visual field plot.



= Top 25% of locations with largest increase in sensitivity

= Blind spot

Fig 7 Spatial representation of the increases in threshold sensitivity between field tests 1 and 2, for 30 subjects, after the spatial filter was applied.

culated. Fig. 5 shows the 25% (upper quartile) of locations with the greatest increases in sensitivity. These tend to be predominantly in the periphery of the central field program, particularly in the superior field. This is in agreement with previous studies on learning[4,19,21,29]. One possible explanation that has been suggested for the greater learning in these regions of the field is that the patient may learn to consciously raise the upper lid.

The variability of threshold responses tends to be greater in these peripheral regions of the field[12,30-32]. This presents difficulties when attempting to distinguish true change from intra-test (short-term fluctuation), inter-test (long-term fluctuation) or inter-individual variations. An attempt was made to describe this variability by using a spatial filter process, to remove possible erroneous results (outliers) from the data set. An image (spatial) processing filter can be used to enhance or smooth the data. The filter employed is illustrated in Fig. 6 which shows a location with threshold sensitivity y, surrounded by eight neighboring points. The mean threshold sensitivity of the surrounding eight locations is calculated and subtracted from y, taking the absolute value of this difference to be D_i. This process was repeated for all locations in the 30-2 program for tests 1 and 2 only. This filter is a simple version of a technique employed in image analysis[16]. For locations at the edges of the field there will be fewer, albeit sufficient, contiguous locations making a contribution.

The frequency distribution for D_i was plotted. An arbitrary cut-off point was taken to exclude the upper 10% of values for D_i. For values of D_i within this zone, the original value of y is replaced by the mean of the surrounding locations. The resulting filtered data were analyzed as above to determine the 25% (upper quartile) of locations now showing the greatest increases in sensitivity (Fig. 7). These are observed to be more randomly distributed over the central field. The filtered version has de-emphasized the increases occurring towards the periphery of the central field, allowing locations situated more centrally to become apparent.

Discussion

In many analyses of visual field data some form of data reduction is used. MD and MS are examples of data reduction which quantify and summarize the state of the field. They are widely understood and are considered statistically robust, but have limitations and disadvantages as described above. The alternative approaches suggested here are clearly not definitive, however, development of these ideas could enhance the analysis of serial visual fields.

The advantage of LP, when compared with MD and MS, is that it is not influenced by extreme values. On the other hand, LP joins with MD and MS as a further example of data reduction, and as such must inevitably lead to some loss of information. Also values of LP were normally

distributed about the mean value. Conversion of the data into a proportion described by a yield parameter allows the use of other statistical methods, unconsidered before, to model the temporal progression of a visual field.

The proportion of unchanged locations between visual field tests correlated well with both the Reliability Indices and Questions Asked, and may provide an alternative method of assessing reliability. If such a correlation were confirmed, test time could be reduced by eliminating the need for false positive and false negative catch trials.

A known phenomenon, namely the spatial configuration of the learning effect, was used to demonstrate the methodology of a filter process. The peripheral learning, and in particular that in the superior region, was shown to be partly a function of the extreme values (outliers) which tend to occur in these regions of the field. This technique of utilizing the dependence which exists between adjacent locations has potential in detecting or removing the variability present in visual field data.

The learning proportion (LP) and filtered spatial representations of serial visual fields may, with further development, be used for the long-term follow-up of pathological visual fields, but the decline in sensitivity with age must be taken into consideration. This could facilitate the extraction of true progression from the "noise" within serial glaucomatous visual fields.

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References

1 Werner EB, Bishop KI, Koelle J, Douglas GR, Le Blanc KP, Mills RP, Schwartz B, Whalen WR, Wilensky JT: A comparison of experienced clinical observers and statistical tests in detection of progressive visual field loss in glaucoma using automated perimetry. Arch Ophthalmol 106:619-623, 1988
2. Werner EB, Adelson A, Krupin T: Effect of patient experience on the results of automated perimetry in clinically stable glaucoma patients. Ophthalmology 95:764-767, 1988
3. Heijl A, Lindgren G, Olsson NJ: A package for the statistical analysis of visual fields. Doc Ophthalmol Proc Ser 49:153-168, 1987
4. Heijl A, Lindgren G, Olsson J, Åsman P: Visual field interpretation with empirical probability maps Arch Ophthalmol 107:204-208, 1989
5. Heijl A, Åsman P: Clinical study of perimetric probability maps. Arch Ophthalmol 107:199-203, 1989
6. Holmin C, Krakau CET: Variability of glaucomatous visual field defects in computerised perimetry Graefe's Arch Klin Exp Ophthalmol 210:235-250, 1979
7. Flammer J, Drance SM, Zulauf M: Differential light threshold. Short- and long-term fluctuations in patients with glaucoma, normal controls and patients with suspected glaucoma Arch Ophthalmol 102:704-706, 1984
8 Flammer J, Drance SM, Fankhauser F, Augustiny L: Differential light threshold in automatic threshold perimetry: factors influencing the short-term fluctuation. Arch Ophthalmol 102:876-879, 1984
9. Wilensky J, Joondeph B: Variation in visual field measurements with an automated perimeter. Am J Ophthalmol 107:328-331, 1984
10. Parish RK, Schiffmann J, Anderson DR: Static and kinetic visual field testing: reproducibility in normal volunteers. Arch Ophthalmol 102:1497-1502, 1984
11. Lewis RA, Johnson CA, Keltner JL, Labermeier PK: Variability of quantitative automated perimetry in normal observers. Ophthalmology 93:878-881, 1986
12. Katz J, Sommer A: Asymmetry and variation in the normal hill of vision. Arch Ophthalmol 104:65-68, 1986
13 Hoskins HD, Magee SD, Drake MV, Kidd MN: A system for the analysis of visual fields using the Humphrey Visual Field Analyzer Doc Ophthalmol Proc Ser 49:145-151, 1987
14. Werner EB, Bishop KI, Davis P, Krupin T, Petrig B, Sherman C: Visual field variability in stable glaucoma patients Doc Ophthalmol Proc Ser 49:77-83, 1987
15. Heijl A: A simple routine for demonstrating increased threshold scatter by comparing stored computer fields. Doc Ophthalmol Proc Ser 42:35-38, 1985
16. Fitzke FW, Kemp CM: Probing visual function with psychophysics and photochemistry. Eye 3:84-89, 1989
17. Greve EL: Single and multiple stimulus static perimetry in glaucoma; the two phases of the visual field examination. Doc Ophthalmol 36:1-355, 1973

18. Heijl A, Krakau CET: An automatic perimeter, design and pilot study. Acta Ophthalmol 53:293-310, 1975
19. Wood JM, Wild JM, Hussey M, Crews SS: Serial examination of the normal visual field using Octopus projection perimetry: evidence of a learning effect. Acta Ophthalmol 65:326-333, 1987
20. Heijl A, Lindgren G, Olsson J: The effect of perimetric experience in normal subjects. Arch Ophthalmol 107:81-86, 1989
21. Wild JM, Dengler-Harles M, Searle AET, O'Neill EC, Crews SJ: The influence of the learning effect on automated perimetry in patients with suspected glaucoma. Acta Ophthalmol 67:537-545, 1989
22. Kosoko O, Sommer A, Auer C: Duration of automated suprathreshold vs quantitative threshold field examination: impact of age and ocular status. Arch Ophthalmol 104:398-401, 1986
23 Brenton RS, Phelps CD, Rojas P, Woolson RF: Interocular differences of the visual field in normal subjects. Invest Ophthalmol Vis Sci 27:799-805, 1986
25. Heijl A, Lindgren G, Olsson J: Reliability parameters in computerised perimetry. Doc Ophthalmol Proc Ser 49:593-600, 1987
25. Wild JM, Searle AET, Dengler-Harles M, O'Neill EC: Long-term follow-up of baseline learning and fatigue effects in the automated perimetry of glaucoma and ocular hypertensive patients. Acta Ophthalmol 69:210-216, 1991
26. Werner EB, Krupin T, Adelson A, Feitl ME: Effect of patient experience on the results of automated perimetry in glaucoma suspect patients Ophthalmology 97:44-48, 1990
27 Autzen T, Work F: The effect of learning and age on short-term fluctuation and mean sensitivity of automated static perimetry. Acta Ophthalmol 68:327-330, 1990
28. Matthews JNS, Altman DG, Campbell MJ, Royston JP: Analysis of serial measurements in medical research Br Med J 300:230-235, 1990
29. Adelson AJ, Werner EB, Krupin T: Learning effects in automated perimetry in ocular hypertensive and early glaucoma patients. Invest Ophthalmol Vis Sci (Suppl) 29:356, 1988
30. Heijl A, Lindgren A, Lindgren G: Test-retest variability in glaucomatous visual fields. Am J Ophthamol 108:130-135, 1989
31 Heijl A, Lindgren G, Olsson J: Normal variability of static perimetric threshold values across the central visual field. Arch Ophthalmol 105:1544-1549, 1987
32. Brenton RS, Phelps CD: The normal visual field on the Humphrey Field Analyzer. Ophthalmologica 193:56-74, 1986

A graphic bar to visualize the quantitative development of visual fields

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Abstract

The quantitative distribution of sensitivity values in automated perimetry can be shown by the cumulative curve (Bebié) or box plots. Cumulative curves are not very suitable for the follow-up of a series of fields because they need too much space. Box plots are graphical, but usually only show five percentiles: 0, 15, 50, 85 and 100. Changes of segments between them are invisible. The new graphical bar is a stack histogram which shows the portion of each defect class on the whole field. There are eight defect classes. The graphical pattern is similar to the gray-scale used for topographical field representations The visualization of series of fields by series of graphical bars appears to be more precise and illustrative than alternative representations.

Introduction

The numerical distribution of one-dimensional sensitivity values is an important aspect in evaluating the general state of a visual field. The cumulative curve of Bebié[1] shows every single value and is, therefore, superior to all other types of one-dimensional representations of a single field. However, a series of fields cannot be viewed at a glance. For this purpose, diagrams of mean defect (MD)[2] or box plots[3] were suggested and implemented into perimetric data analysis programs. The MD is only a single value, the box plot represents only five points of sensitivity

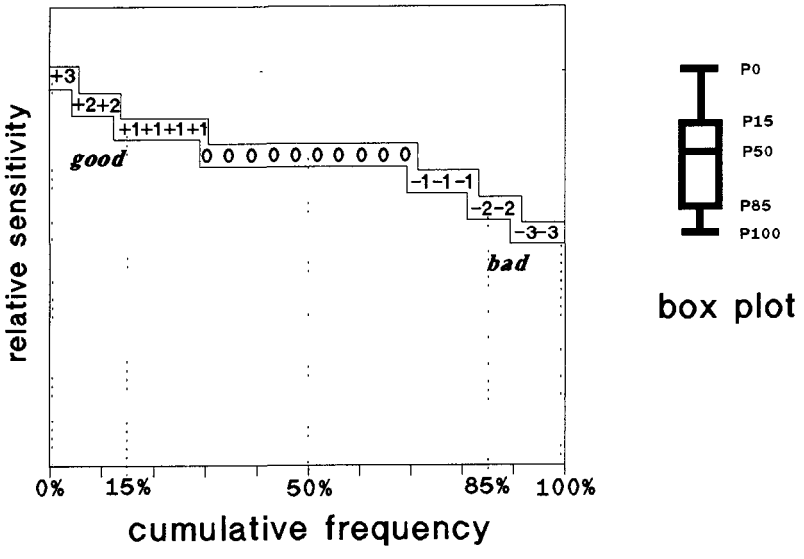

Fig. 1. Relation between cumulative frequency curve (left) and box plot (right). The box plot represents five different values of the cumulative curve.

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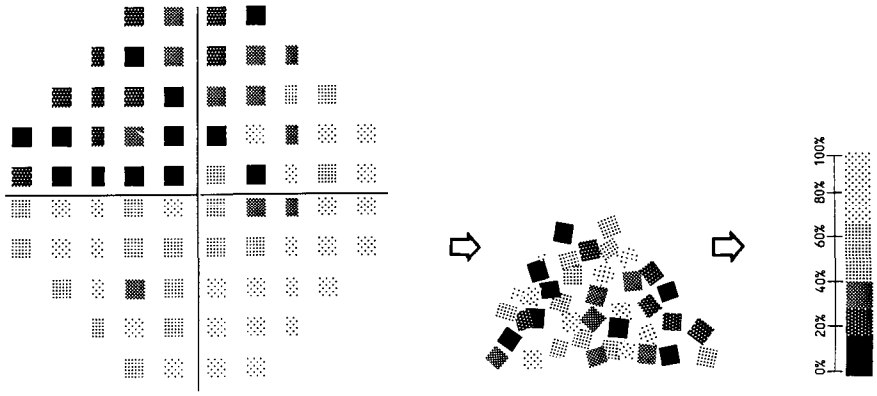

Fig. 2. Creation of the graphical bar: gray-scale symbols (left) are dissolved from their spatial information (middle) and rearranged in a stack histogram (right).

distribution (Fig. 1). Our purpose was the development of a new manner of representation which would furnish more information in the same space.

Method

In the new representation, each sensitivity value is represented by a gray-scale square. The scale is equivalent to the common gray-scale representation[4]. These data are delivered from their spatial information and put into a column in the order of value (Fig. 2). The lowest sensitivity class is at the bottom and the highest is at the top. The portion of each class is expressed by its extent. In statistical terminology, this type of representation is called a "stack histogram". We labelled it a "graphical bar"[5].

Results

The basis for the gray-scale is relative, norm-related sensitivity. Therefore, sensitivity classes in the graphical bar are defect classes. According to the norm-related gray-scale of PeriData, we defined eight classes of 5 dB in size. The examples in Fig. 3. show that the percentage of each defect class can easily be read from the graphical bar.

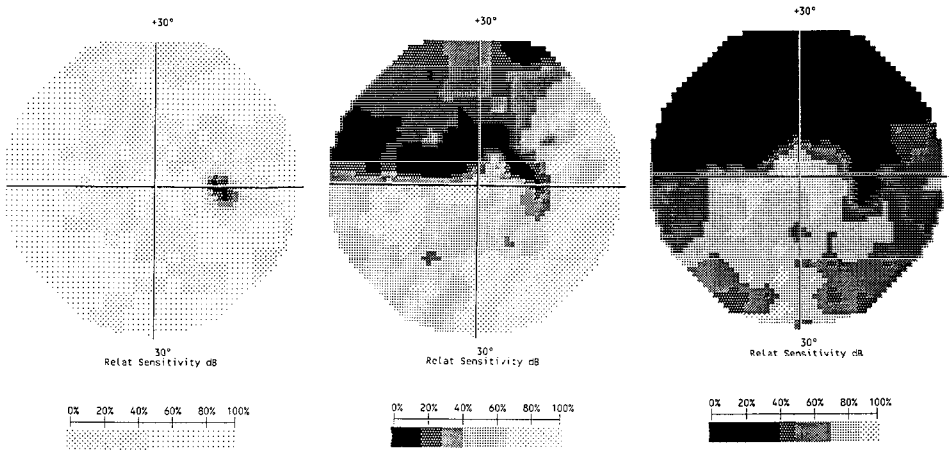

Fig 3 Visual fields with no damage (left), partial damage (middle) and severe damage (right). The graphical bar visualizes the size of defect classes.

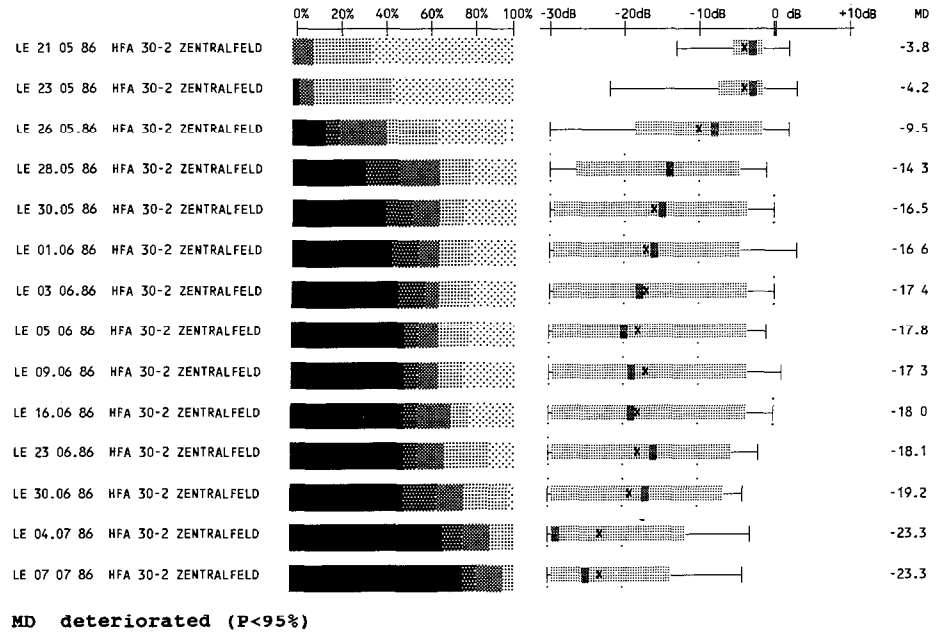

Fig. 4. A series of 14 fields of a case with progressive retinitis. These were printed with PeriData using the print-out type "overview". The graphical bar (left) clearly shows that the progression is caused by a downshift of the whole field, indicated by an increase in the lowest defect class and a decrease in the highest class. The box plot (right) demonstrates the progression as well, but the portion of absolute defects cannot be seen.

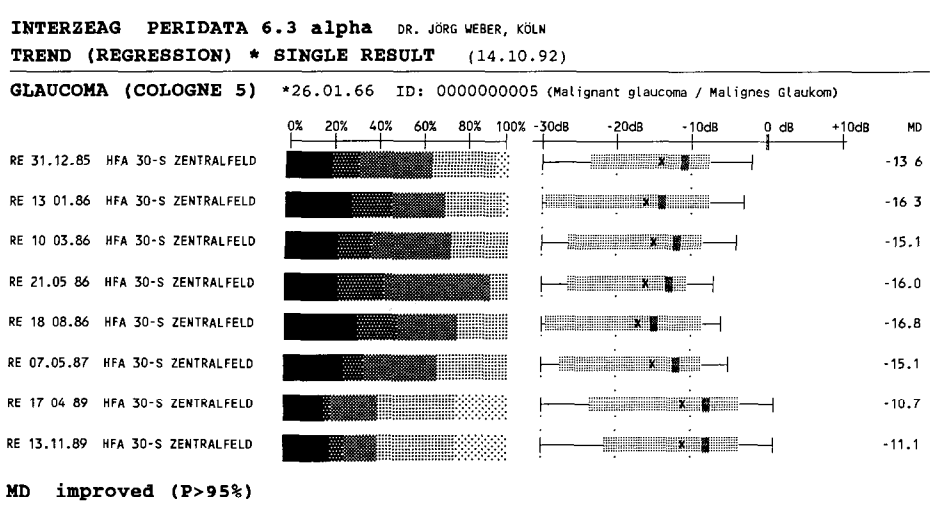

Fig. 5. A series of eight fields in a glaucoma case. Trend analysis (linear regression) shows that the MD improved significantly. The box plot (right) shifted upwards with the upper arm and the box. The graphical bar (left) shows that the improvement is limited to the better portion of the field. The portion of absolute defects fluctuates around 20% without any trend.

Fig. 4 demonstrates a series of 14 fields of a case with progressive retinitis. They were printed with PeriData using the print-out type "overview". The graphical bar clearly shows that the progression is caused by a downshift of the whole field, indicated by an increase in the lowest defect class and a decrease in the highest class. Between fields 4 and 11, there was a stable phase, in which 40% of the points were absolute defects. The box plot demonstrates the progression as well, but the portion of absolute defects cannot be seen. It can be assumed somewhere between 15%and 50%, because the 15% border is down and the median is still good. Moreover, the upper border fluctuates during the stable phase because it is based only on one measurement.

Fig. 5 shows a series of eight fields in a glaucoma case. Trend analysis (linear regression) shows that the MD improved significantly. The box plot shifted upwards with the upper arm and the box. The graphical bar, however, shows that the improvement is limited to the better portion of the field. The portion of absolute defects fluctuates around 20% without any trend being seen.

Conclusions

1. The graphical bar represents a series of visual fields on minimum space. Fifteen fields can be seen simultaneously on the screen. Thirty fields are printed on one sheet of paper.
2. The graphical bar is easy to read. Experience with the gray-scale in topographical representations allows intuitive access to the information given by the column.
3. The graphical bar is precise. The quantity of eight sensitivity classes is represented graphically. In comparison, the box plot shows five values of the distribution, of which two (the upper and lower end) are dependent on a single measurement.
4. The graphical bar is less precise in showing the linearity or non-linearity of a visual field trend.
5. In summary, the graphical bar is an advantageous acquisition for graphical representations of the visual field, especially with regard to follow-up.

References

1. Bebié H, Flammer J, Bebié T: The cumulative defect curve: separation of local and diffuse components of visual field damage. Graefe's Arch Clin Exp Ophthalmol 227:9-12, 1989
2. Bebié H, Fankhauser F: Statistical program for the analysis of perimetric data. In: Greve EL, Verriest G (eds) Proceedings of the Fourth International Visual Field Symposium, Bristol 1980, pp 9-10. The Hague: Dr Junk Publ 1981
3. Heijl A, Lindgren G, Olsson J: A package for the statistical analysis of computerized fields. In: Greve EL, Heijl A (eds) Proceedings of the Seventh International Visual Field Symposium, Amsterdam 1986, pp 153-168. Dordrecht: Nijhoff/Dr Junk 1987
4. Weber B, Spahr J: Zur Automatisierung der Perimetrie: Darstellungsmethoden perimetrischer Untersuchungsergebnisse. Acta Ophthalmol 54:349-362, 1976
5. Weber J: Die "Peridata-Grafikzeile": ein neues Verfahren zur Visualisierung des zeitlichen Gesichtsfeldverlaufs. Sitzungsbericht der 153. Versammlung des Vereins Rheinisch-Westfälischer Augenärzte. Balve: Zimmermann-Druck 1992

Perikon PCL90: a statistical program

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Abstract

In order to collect a normal data base for the Perikon PCL90 automatic perimeter, a large study was carried out in four Italian cities (Genova, Messina, Udine and Verona). Several parameters were taken into account: age, cultural level, geographical origin, etc. The visual fields of more than 350 normal people were analyzed using static and kinetic tests. All age classes were included in the study. A severe inclusion protocol concerning pupil size, IOP, media transparency, C/D ratio, etc. was adopted. All data collected were interpolated by optimized mathematical models utilizing multi-variable equations (age, meridian, eccentricity, luminance, etc.). This mathematical process provided the authors with the normal static and kinetic thresholds for all tested points and different ages. Such a statistical program is able to provide: *1.* global static perimetry indices (according to both Heijl's and Flammer's methods); *2.* global kinetic indices; *3.* mean reaction time; *4.* perimetric maps (numeric, symbolic, and differential); *5.* probability maps; *6.* follow-up maps.

Introduction

In the past, the visual fields (VF) of normal subjects have been the object of numerous studies, carried out both with the Goldmann perimeter[1-3] and with computerized perimeters[4-10].

With the recent introduction of the static-kinetic perimeter Perikon PCL90 and its more advanced characteristics[11-13], we thought it necessary to carry out a new series of tests, both static and kinetic and both on the central and the peripheral VF, in normal subjects.

The aim of this study was to make an up-to-date model which, exploiting the Perikon computer's capacities, would permit a comparison with a static test carried out with any pattern, including custom, and with static-kinetic programs such as DS/K, taking into account all those parameters which would be shown to be particularly significant for the threshold.

Material and methods

We collected data by carrying out static central DS 30-II and peripheral DS 30/60-II programs and a mixed program with central static and two isopter kinetics DS/K on over 400 eyes, in order to create a significant normality model for the Perikon.

The four University Eye Clinics in Genova, Messina, Udine and Verona, each with a Perikon, took part in the study, enlisting normal subjects according to the following protocol:

1. Number: at least 50 subjects and 100 eyes at each center;
2. Sex: immaterial;
3. Age: evenly distributed in the following groups:
   - I : 10-20 years
   - II : 21-30 years
   - III : 31-40 years
   - IV : 41-50 years

Ing. R. Mattioli is employed as a research engineer by Optikon SpA. The other authors have no commercial involvement with the company

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- V : 51-60 years
- VI : 61-70 years
- VII : over 70 years

4. Education: evenly distributed in each age group, except for group I, among primary, secondary, higher education, and university;
5. Inclusion criteria:
   - Refraction: ±3 D (spherical equivalent), with less than 1 D astigmatism;
   - Pupil: ≥2.5 mm diameter at the time of examination;
   - Cup/disc ratio: <0.5;
   - IOP: <22 mmHg and >8 mmHg;
   - No generalized and/or ocular disease;
   - No therapy influencing threshold or attention;
   - Corrected visual acuity in bowl ≥0.8.
6. Examinations: 30-II and 30/60-II alternatively on right eye and left eye (50% of subjects); DS/K alternatively on right eye and left eye (50% of subjects), repeating the first test on 20% of subjects after one week (to assess the learning effect).
7. Physical parameters of test and fixation target: standard;
8. Correction: long distance correction within 30°, only if positive with spherical equivalent for astigmatism, in subjects <40 years; correction for long distance adding another +3 D with spherical equivalent for astigmatism, in subjects >40 years.
9. Historical indications: experience in automated perimetry, education, smoking, alcohol consumption, area and altitude of residence, habitual physical activity, IOP and cup/disc ratio were recorded.

Results

At the end of the study, which lasted about one year, the number of subjects examined is that shown in Fig. 1. Note that excluding some of the tests of subjects in the older age groups has considerably reduced the number of these tests, but still leaves a significant number of them.

Thus, the total number of central static VF (DS 30-II and static part of DS/K) was 425, plus 112 peripheral (30/60-II) and 117 kinetic (kinetic part of DS/K) VF. A further 15% of these tests was excluded on the basis of reliability indices (false positives or negatives over 20%; high incidence of fixation losses; etc.). We preferred not to exclude other tests on the basis of average threshold or variance in order not to create a "super-normal" sample which would reduce the specificity of the analysis.

Figs. 2 and 3 give an indication of the average global VF of all ages (average 38 years). Standard deviations are considerably less if the results are subdivided into the seven age groups.

The trend of average threshold with age is better represented by a second order interpolated

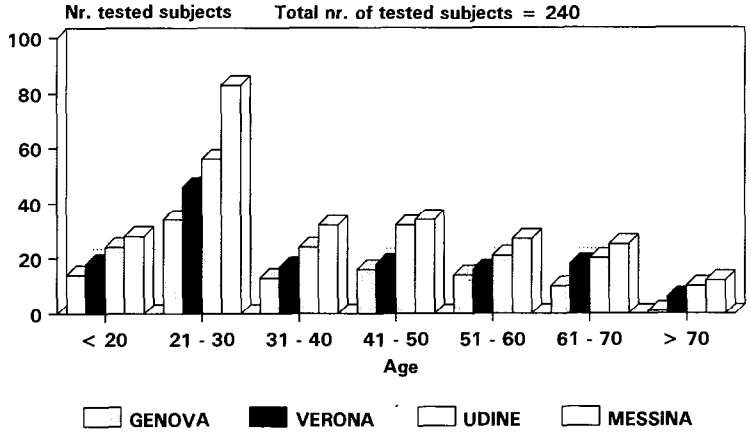

Fig. 1. Number of tests performed.

			27.3 ±3.3	27.4 ±2.9	26.5 ±3.1	26.4 ±3.3			
		28.2 ±2.8	28.8 ±2.8	29.1 ±2.9	28.2 ±2.9	28.6 ±2.6	27.9 ±3.0		
	28.2 ±3.2	29.3 ±3.1	29.8 ±2.5	30.1 ±2.6	29.4 ±2.8	29.6 ±2.9	29.1 ±3.0	28.6 ±2.8	
27.2 ±5.1	29.2 ±3.3	30.3 ±2.6	31.1 ±2.2	31.5 ±2.4	30.9 ±2.5	30.0 ±2.3	29.7 ±4.1	29.4 ±2.7	29.2 ±2.7
27.9 ±4.2	29.7 ±3.5	31.3 ±2.6	32.1 ±2.2.	32.6 ±2.4	32.5 ±2.5	31.3 ±2.3	27.8 ±4.1	29.8 ±2.7	29.4 ±2.7
				34.5					
27.4 ±4.6	29.8 ±3.5	31.6 ±2.6	32.0 ±2.3	32.6 ±2.4	32.7 ±2.4	31.8 ±2.4	10.7 ±%12	29.8 ±2.7	29.9 ±2.6
27.2 ±4.6	29.1 ±3.9	30.7 ±2.3	31.5 ±2.3.	31.8 ±2.4	31.9 ±2.2	31.3 ±2.4	30.3 ±2.6	30.2 ±2.4	29.7 ±2.4
	28.3 ±4.5	29.6 ±3.0	30.4 ±2.4	30.7 ±2.3	30.7 ±2.3	30.8 ±2.4	30.7 ±2.5	29.8 ±2.5	
		28.2 ±3.8	29.3 ±2.5	29.6 ±2.8	30.4 ±2.4	30.2 ±2.5	29.9 ±2.4		
			27.7 ±3.7	28.2 ±3.1	29.3 ±2.4	29.1 ±2.7			

PROGRAM : DS 30 - II
AGE BETWEEN : 0 and 99 years
NUMBER OF TESTS : 376

Fig. 2. Average threshold in all tested eyes (central 30°).

			2.8 ±5.1	9.2 ±8.2	9.4 ±8.7	11.7 ±9.0			
	4.7 ±6.7	14.3 ±8.3	20.2 ±6.2	22.4 ±5.8	21.0 ±6.2	21.8 ±5.7	20.8 ±6.3	17.8 ±7.5	
	16.2 ±8.4	23.6 ±5.4	26.0 ±3.8	27.4 ±3.0	26.6 ±2.7	26.4 ±2.7	25.4 ±4.5	23.1 ±5.3	
11.9 ±8.7	21.8 ±6.0	26.3 ±4.0					27.9 ±2.6	26.4 ±2.9	24.1 ±4.5
14.9 ±8.6	22.5 ±7.4	26.6 ±5.0					29.7 ±2.6	28.0 ±4.0	25.1 ±6.0
13.0 ±9.1	22.4 ±7.6	26.4 ±5.5					30.2 ±2.3	27.8 ±5.5	26.0 ±6.2
5.4 ±8.0	20.5 ±8.1	25.1 ±6.3					30.2 ±2.3	27.8 ±5.9	26.0 ±5.8
	8.1 ±9.5	21.8 ±8.1	25.6 ±6.3	27.2 ±4.8	28.5 ±5.4	27.9 ±5.2	26.9 ±5.8	25.5 ±5.8	
	0.9 ±3.8	11.2 ±9.7	21.2 ±7.7	23.1 ±7.3	24.6 ±7.1	24.1 ±8.1	23.3 ±8.0	23.5 ±5.6	
			17.5 ±5.9	19.2 ±5.8	20.4 ±6.5	21.4 ±7.0			

PROGRAM : DS 30/60 - II
AGE BETWEEN : 0 and 99 years
NUMBER OF TESTS : 92

Fig. 3. Average threshold in all tested eyes (central 30-60° area).

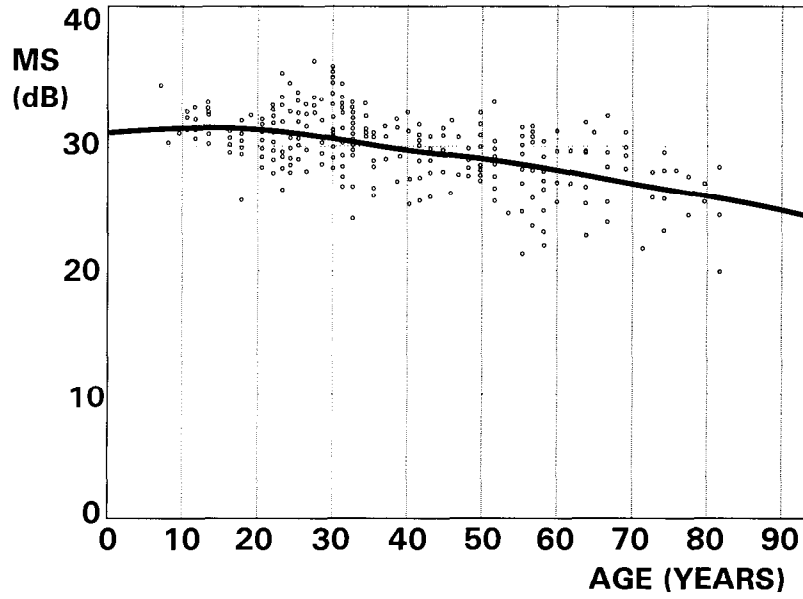

Fig. 4. Interpolated curve of average sensitivity.

curve, with a gradient which increases with age (Fig. 4), rather than by linear regression. Inter-individual variations are considerable in any case. Fig. 5 shows Pearson's correlation indices, and their level of significance between various parameters in a group of DS 30-II and DS/K examinations.

Noteworthy among the most significant correlations are age with average threshold (MS: mean sensitivity, CREF: central reference, and FT: foveal threshold), as has already been reported[1-8,14] and bracketing fluctuation (BF) with the short-term threshold fluctuation (SF) measured in ten sample points[15-18].

There is poor dependence of threshold on pupil diameter and perimetric experience, of average reaction time on age[19], and between static fluctuations and kinetic fluctuations.

Living habits seem to correlate poorly with threshold factors, even when smoking and alcohol always tend to reduce sensitivity while extra-urban or mountain residences and a less sedentary lifestyle increase it: none of these variations reach statistical significance.

Education seems to be a factor which influences more thresholds, particularly FT. FT, being the first point measured in the examination, makes us believe that this increase is due to the faster understanding of the test procedures by subjects with a higher level of education. A more accurate assessment of these parameters, with methods appropriate to their non-gaussian distribution and which reduce their inevitable dependence on the primary factor age, will be the subject of further study.

Data interpolation

In order to permit the computer to establish how much the results of a perimetric examination differ from normal, and at what level of significance, it is necessary for the data collected in this way to be synthesized in a model of normal VF.

Such a model could be made up of several maps, such as those in Figs. 2 and 3, one for each age group. This model, however, would still include the influence of the differences in threshold existing between the various points examined, which are several degrees of eccentricity away from one another. It is also influenced by inevitable differences between adjacent age groups and by the limited number of examined individuals, despite the large size of the sample. Furthermore, it would only permit comparison between examinations carried out with the same programs used in the study (DS 30-II, DS/K and DS 30/60-II).

	AGE	REA	KSFL	SFL	BFL	MS	CREF	FT	MD	LV	CLV	PD	C/D	IOP	ACTV	ALTD	RESI	ALCO	SMOK	SCHO	EXPE
REA	022																				
	N S																				
KSFL	084	.198																			
	N S	018																			
SFL	.115	125	- 017																		
	03	0182	N S																		
BFL	249	.062	097	396																	
	<<	N S	N S	<<<																	
MS	- 425	009	- 140	-.222	- 187																
	<<<	N S	N S	<	0003																
CREF	- 306	- 049	- 048	- 023	- 146	.402															
	<<<	N S	N S	N S.	0054	<<<															
FT	- 554	-.224	- 183	- 337	- 342	654	409														
	<<<	<	0292	<<	<<<	<<<	<<														
MD	276	189	- 000	360	431	-.463	-.220	-.862													
	0001	0091	N S	<<<	<<<	<<<	0027	<<<													
LV	196	141	-.102	288	261	- 159	- 040	- 472	451												
	0001	0059	N S	<<<	<<	.002	N S	<<<	<<<												
CLV	165	117	- 086	- 001	163	-.093	-.038	- 377	347	954											
	0013	023	N S	N S	0016	N S	N S	<<	<<	<<<											
PD	- 228	- 041	- 084	038	- 092	- 008	070	035	048	036	011										
	<	N S	N S.	N S	N S	N S	N S	N S	N S	N S	N S										
C/D	.107	- 057	- 114	- 014	-.000	-.14	- 213	- 155	- 086	017	003	280									
	0464	N S	N S	N S	N S	0093	0001	0039	N S	N S	N S	<<<									
IOP	.397	004	- 056	- 03	.082	-.081	- 203	- 087	- 026	- 147	- 148	- 172	138								
	<<<	N S	N S	N S	N S	N S	0001	N S	N S.	0059	0056	0012	0102								
ACTV	- 316	065	- 029	.108	- 024	.112	.071	107	013	- 099	- 130	088	-.085	- 259							
	<<<	N S	N.S	047	N S	035	N S	.0434	N S	N.S	0141	N S	N S	<<							
ALTD	- 044	06	184	122	- 057	.058	.133	-.018	- 008	.026	- 015	019	- 003	-.175	081						
	N S	N S	0289	0248	N S	N S	0131	N S	N S	N S	N S	N.S	N.S	0011	N S.						
RESI	037	158	220	089	042	026	141	- 035	143	151	126	- 047	- 312	- 031	- 084	244					
	N S	0029	0088	N S	N S	N S	0086	N S	N S	0044	0178	N S	<<<	N S	N S	<<					
ALCO	237	099	- 108	136	026	- 045	009	- 106	086	115	057	023	004	-.038	132	.113	036				
	<<	N S	N S	01	N S	N.S.	N S	0387	N S	0251	N S	N S.	N S	N S	0125	0327	N S				
SMOK	052	013	- 125	136	075	- 079	.095	- 078	124	070	028	- 022	038	- 045	063	242	- 035	302			
	N S	N S	N.S	0101	N S	N S	N.S	N S	N S	N S	N S	N S	N S	N S	N S	<<	N S	<<<			
SCHO	- 382	- 109	- 253	- 122	- 147	.234	131	269	- 104	- 038	-.008	017	- 021	- 271	169	- 043	- 287	- 008	015		
	<<<	0341	0023	0204	0046	<	0118	<<<	N S	N S.	N S	N S	N S	<<<	0014	N S	<<	N S	N S		
EXPE	.016	.013	- 001	-.046	- 046	.136	- 016	123	- 188	- 037	.002	- 188	- 095	073	- 023	- 045	- 138	- 083	- 004	223	
	N S.	N S	N S	N S	N S	0081	N S.	0165	0098	N S	N S	0002	N S.	N.S	N S	N S	0093	N S	N S	<	
	AGE	REA	KSFL	SFL	BFL	MS	CREF	FT	MD	LV	CLV	PD	C/D	IOP	ACTV	ALTD	RESI	ALCO	SMOK	SCHO	EXPE

Top value = r (Pearson correlation)
Bottom value = p (significativity): N S = > 05 < = <.00005 << = < 000005 <<< = < 0000005)

AGE = Patient's age (Years)
REA = Mean reaction time (msec)
KSFL= Kinetic fluctuation (dB)
SFL = Short term 10 pt fluctuation (dB)
BFL = Bracketing fluctuation (dB)
MS = Mean sensitivity (dB)
CREF= Central reference (dB)
FT = Foveal threshold (dB)
MD = Mean defect (dB)
LV = Loss variance (dB^2)

PD = Pupil diameter (mm)
C/D = Cup to disk ratio
IOP = Intra ocular pressure (mmHg)
ACTV = Phisical activity (1=Sedentary 2=Moderate 3=Intense)
ALTD = Altitude (1=Sea level 2= >500mt)
RESI = Residence (1=Urban 2=Rural)
ALCO = Alcohol consumption (wine :0=No 1=<½lt/day 2=>½lt/day)
SMOK = Smoking (Cigarettes or eq : 0=No 1=<10 2=10-20 3=>20)
SCHO = Education level (0=None 1=elem 2=midd 3=high 4=univ.)

Fig. 5. Pearson's correlation indices

For the computerized perimeter Perikon PCL90, we preferred to use the following mathematical model:

$$
\begin{aligned}
T = {} & X0 + [X11 + X12*\cos(ME) + X13*\sin(ME) + \\
& + X14*\cos(ME*2) + X15*\sin(ME*2)..... \\
& ....+ X1m*\sin(ME*m/2)] * EC + ... \\
& + [X21 + X22*\cos(ME) + X23*\sin(ME) + \\
& + X24*\cos(ME*2) + X25*\sin(ME*2)..... \\
& ....+ X2m*\sin(ME*m/2)] * EC^2 + ... \\
& ..... \\
& + [Xn1 + Xn2*\cos(ME) + Xn3*\sin(ME) + \\
& + Xn4*\cos(ME*2) + Xn5*\sin(ME*2)..... \\
& .....+ Xnm*\sin(ME*m/2)] * EC^n \qquad (1)
\end{aligned}
$$

The normal threshold "T" is a continuous function of sensitivity in dB of the variables eccentricity (EC), meridian (ME), apart from age.

In this model the meridian hemisections of VF are polynomes of "Nth" order bound to

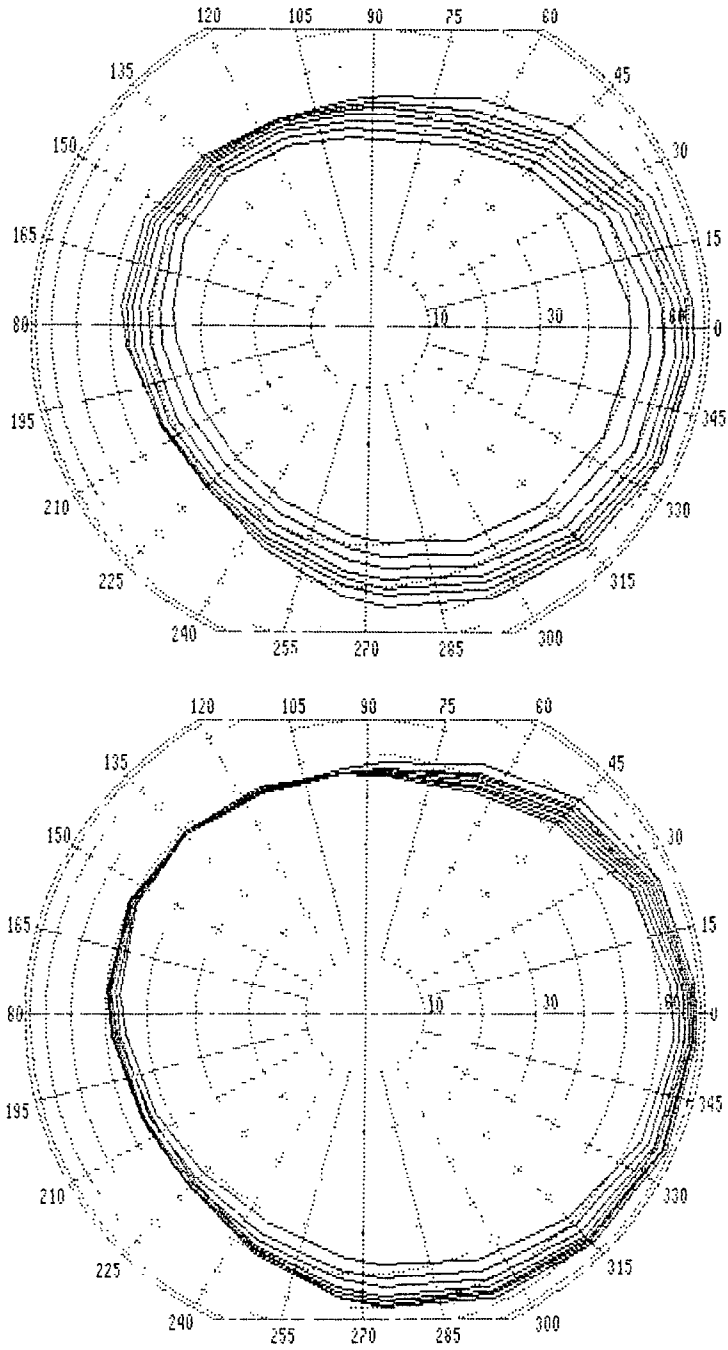

Fig. 6. Normal isopters (20 and 25 dB) in the different age groups.

"EC=0" for foveal threshold "X0", the coefficients of which in "EC, EC^2....EC^n" are themselves a periodic function of the meridian "ME", factorized in terms of a series of Fourier up to the "M/2-th" harmonic component.

The "N*M+1" coefficients of this equation were defined by the minimal squares method. This method consists of making minimal the sum "S" of the squared differences between aver-

age experimental sensitivities and theoretical ones, calculated with equation (1) in all points "np", apart from the points located in the blind spot:

$$S = \sum_{i=1}^{np} 1/\sigma i^2 \, [T(EC,ME)-Ti] \qquad (2)$$

where σi are the standard deviations in points i.

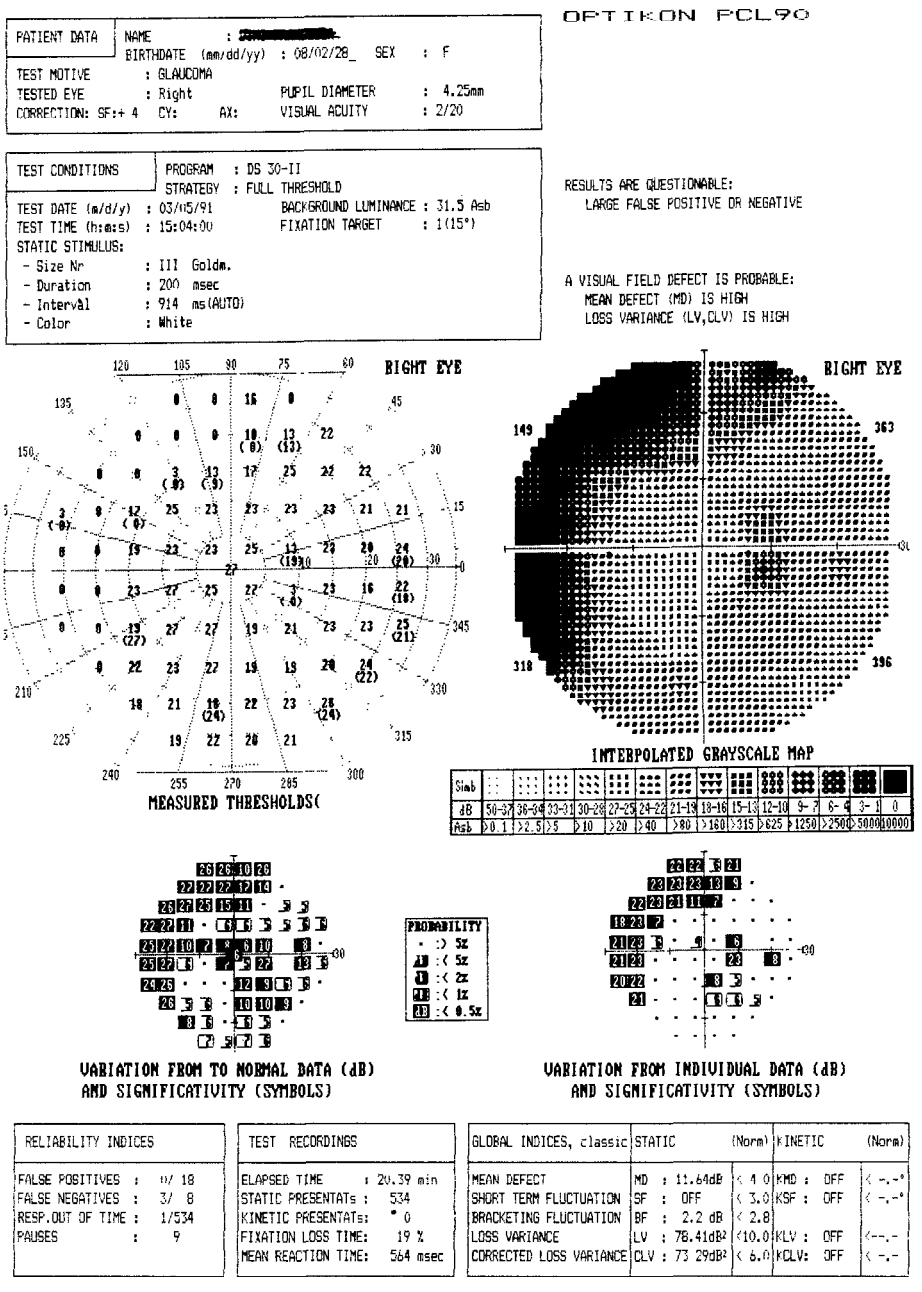

Fig. 7. Print of a visual field analyzed with the new statistical software.

Equation (2) should be analytically minimized with respect to the variables "N*M+1", making the partial derivatives "N*M+1" equal to zero with respect to them. The linear system of "N*M+1" order obtained in this way is therefore resolved for each age group.

The coefficients, weighed for the number of subjects in each age group, are thus interpolated with polynomes of "P"order as a function of age. In a similar way, one can also interpolate percentile threshold values with various probabilities and the normal isopters.

For the isopters, equation (1) should be modified inserting luminance of the targets in place of eccentricity, and eccentricity "EC" of the isopter on the given meridian "ME" in place of threshold "T".

Order "N=7", "M=3", "P≥2" for static and "N=9","M=2", "P≥2" for isopters measured at 20 and 25 dB were found to be optimal.

Fig. 6 shows how the normal isopters at 20 and 25 dB (with target III) vary with age, calculated on the kinetic model.

Application of the statistical model

In order to bring the Perikon up-to-date with the statistical software, a package containing an auto-installing diskette and a "statkey" to insert into the appropriate slot at the back of the computer are available. When the key is taken out, the classic representations of the test are carried out; when it is placed in the slot, the tests which preceded the upgrade are also analyzed statistically, as long as they were carried out under standard physical conditions.

Fig. 7 shows the print of a VF with the Perikon PCL90 statistical software. The defects are given by the numbers in dB, and the different markings of these numbers signal their statistical significance, with decreasing "P" values[20,21].

In the map of variations with respect to the individual model, the possible generalized decrease in sensitivity is eliminated before local analysis is carried out, and this favors the distinction of localized defects with respect to, for example, those due to preretinal alterations[20,21].

Both static and kinetic classic global indices are reported on the printout to Flammer (SF, MD, LV, CLV)[17]. Those weighed according to Heijl also appear on the monitor[4]. Bracketing fluctuation (BF) was added to these[18], which substitutes classic SF in calculating CLV, when SF has not been measured, with a significant reduction in test duration.

When one of the global and/or reliability indices falls outside the normal prefixed ranges, a corresponding note also appears on the top of the paper. Furthermore, it is possible to print a follow-up of the tests, also carried out with mixed programs such as DS/K, together with the graphs of the main global indices.

Conclusions

In comparison with other perimetric statistical programs, the "Perikon" strategy of results analysis offers the following advantages:

- it supplies both weighted and non-weighted perimetric indices;
- it supplies the new index "BF";
- it also supplies kinetic indices;
- it enables the statistical evaluation of all threshold tests including custom, kinetic and mixed static-kinetic ones.

References

1. Drance SM, Berry V, Hughes A: Studies on the effects of age on the central and peripheral isopters of the visual field in normal subjects. Am J Ophthalmol 63:1667-1672, 1967
2. Egge K: The visual field in normal subjects. Acta Ophthalmol (Suppl 169) 62:1-69, 1984
3. Zehnder-Albrecht S: Zur Standardisierung der Perimetrie. Ophthalmologica 120:255-270, 1950
4. Heijl A, Lindgren G, Olsson J: A package for the statistical analysis of visual field. Doc Ophthalmol Proc Ser 49:154-168, 1987

5. Katz J, Sommer A: A longitudinal study of age-adjusted variability of automated visual fields. Arch Ophthalmol 105:1083-1086, 1987
6. Katz J, Sommer A: Asymmetry and variation in the normal hill of vision Arch Ophthalmol 104:65-60, 1986
7. Flammer J, Drance SM, Fankhauser F, Augustiny L: Differential light threshold in automated static perimetry: factors influencing short-term fluctuation Arch Ophthalmol 102:876-879, 1984
8. Rutishauser C, Flammer J, Haas A: The distribution of normal values in automated perimetry. Graefe's Arch Clin Exp Ophthalmol 227:513-517, 1989
9. Béchetoille A, Dykman P, Muratet JY: Une banque de données pour l'analyse du champ visuel normal avec le programme central 30/1 du périmètre automatisé de Humphrey. J Fr Ophtalmol 9:837-841, 1986
10. Bebié H, Fankhauser F: Statistical program for the analysis of perimetric data. Doc Ophthalmol Proc Ser 26:9-10, 1981
11. Mattioli R : Sviluppi attuali nella perimetria computerizzata Minerva Oftalmol 32:137-140, 1990
12. Zingirian M, Gandolfo E, Capris P, Mattioli R: Perikon PCL90: a new automatic perimeter. In: Mills RP, Heijl A (eds) Perimetry Update 1990/1991, pp 403-407. Amsterdam: Kugler Publ 1991
13. Zingirian M , Gandolfo E, Capris P: Perimetria, stato attuale. Monograph. Società Oftalmologica Italiana, No 2, pp 1-104. Rome: Esam Futura 1990
14. Brenton RS, Phelps CD: The normal visual field on the Humphrey Field Analyzer. Ophthalmologica 193:56-74, 1986
15. Hirsch J: Statistical analysis in computerized perimetry In: Whalen WR, Spaeth GL (eds) Computerized Visual Fields: What They Are and How to Use Them, pp 309-344. Thorofare: Slack Publ 1985
16. Funkhouser AT, Fankhauser F: A comparison of unweighted and fluctuation-weighted indices (within the central 28° of glaucomatous visual fields measured with the Octopus automated perimeter). Int Ophthalmol 15:347-351, 1991
17. Flammer J: The concept of visual field indices. Graefe's Arch Clin Exp Ophthalmol 224:389-392, 1986
18. Mattioli R, Capris P, Gandolfo E, Morescalchi F, Zingirian M: La fluttuazione di "bracketing". Second Congress of the Italian Perimetric Society, Taormina, November 8-9, 1991
19. Rouland JF: Comparison des mesures du champ visuel sur écran cathodique et sur coupule: à propos de 600 cas des glaucomes. Ophthalmologie 5:182-183, 1991
20. Heijl A, Åsman P: A clinical study of perimetric probability maps. Arch Ophthalmol 107:199-203, 1989
21. Heijl A, Lindgren G, Olsson J, Åsman P: Visual field interpretation with empiric probability maps. Arch Ophthalmol 107:204-208, 1989

Comparing long-term variability using the Humphrey Field Analyzer and the Ring Perimeter in glaucoma patients and normal subjects

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Introduction

Automated differential light threshold (DLT) perimetry is accepted as the current perimetric standard for the detection of glaucomatous optic nerve damage and its progression as the disease worsens[1]. Deciding whether progression of damage is present is a very important part of the glaucoma patient's management with major clinical implications. Unfortunately this decision is made difficult for the clinician by the long-term fluctuations of sensitivity which occur in the field[2,3]. Long-term variability is known to be worse in more peripheral field locations and in areas of glaucomatous damage when the DLT method is used. This fluctuation occasions considerable disagreement amongst even very experienced clinicians when they are asked to grade the same set of fields for progression[4].

Resolution perimetry as developed by Frisén[5] uses a novel stimulus to assess the visual field. The stimulus consists of a bright ring with darker borders which has "vanishing optotype" qualities[6]. The ring size is varied to assess the sensitivity of the field at a given location while the ring luminance and contrast are held constant. This unusual target results in a field which does not show an increase in variability in the periphery in normals measured twice[7], or five times[8]. Comparison of DLT and resolution variability in normals using a small number of highly defined points confirms that variability increases as sensitivity decreases using DLT, whilst in the resolution field it does not[9].

This fundamental difference between the two methods may allow for easier definition of disease progression if the confounding influence of increasing variability with worsening damage is removed.

This study was undertaken to examine variability found with each method in normals and stable glaucoma patients measured five times.

Subjects and methods

Subjects

Twenty-one glaucoma patients and 14 normals were recruited for the study. The patients came from the Royal Perth Hospital Glaucoma Clinic and had previously documented intraocular pressures over 22 mmHg, glaucomatous optic nerve head changes or nerve fiber layer changes and confirmed mild to moderate field defects on the Humphrey Field Analyzer (HFA) 24-2 program. The field defect had to consist of at least three contiguous points significant at the 1% level on the STATPAC I program, but with no more than four contiguous points with zero sensitivity in two or more quadrants. Severely damaged cases were avoided as variability is known to fall as the limits of the dynamic range of the instrument are reached[2]. All patients were considered clinically stable during the trial period. Normals were recruited from hospital and university staff. All had intraocular pressures less than or equal to 21 mmHg with normal slit-lamp and undilated optic disc and fundus examination. All subjects had a recent refraction giving a visual acuity of 6/9 or better. The refraction had a spherical equivalent of plus or minus

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5 diopters or less and a cylindrical component of plus or minus 2 diopters or less[10,11]. Any general medical conditions likely to affect the field such as diabetic retinopathy, multiple sclerosis or cerebrovascular accident, also resulted in exclusion. If both eyes qualified on these criteria, one was chosen randomly for the study. No subjects were excluded on the basis of their reliability indices. After an explanation had been given of the study, informed consent was obtained from all subjects. The study was approved by the Royal Perth Hospital ethics committee.

Methods

Visual fields were obtained following the manufacturer's directions. Careful attention was paid to the instruction and positioning of the subjects who were constantly supervised until they showed their ability to perform the visual field test. Supervision was then intermittent at a rate determined by the field technician's assessment of the patient's ability to perform the task. Six pairs of fields were performed at approximately one week to one month intervals. Both fields were performed at the same session with a five-minute break between them. The order of machines was alternated to minimize uneven fatigue effects. The first pair of fields was discarded to reduce any learning effect[7,12]. Pupil size was not modified unless it was less than 2 mm and miotics were not introduced during the study for any glaucoma patients. All threshold results were entered into a mainframe version of SAS (SAS Institute Inc., Cary, NC) for further analysis.

A direct comparison of the variability found with the two machines is not possible because of the different psycho-physical methods used. To overcome this difficulty, the results from both machines were analyzed in several different ways which aimed to show how variability changed in relation to sensitivity and location for each group within each method.

A multi-linear regression technique was used which regressed the mean sensitivity of a location against the variance over the five measurements at that location for a given subject. Subject results were pooled into normals and glaucoma patients and the regression was corrected for distance from fixation and upper and lower hemifield locations.

To look further at the effect of eccentricity, the field was divided into inner, middle and outer zones and the same regression was performed with results separated into each zone. The relationship between variability and mean sensitivity was also examined by pooling data from all locations with similar mean sensitivities and taking the mean and SD of the variances found.

Results

Subjects' mean ages on commencing the study were 69.4 (±12.05 SD) years for the glaucoma group and 49.0 (±9.43 SD) years for the normals. The glaucoma group had an average mean defect HFA score of -4.86 (±2.53 SD) dB with the normal group showing -0.79 dB (±0.98 SD) dB. The modest MD scores in the glaucoma groups reflect our selection bias against cases with severe damage.

Mean sensitivity and the variance across the five replicates for each location are plotted for each machine and subject group in Fig. 1 (A-D). The x axis scale is reversed on the Ring Perimeter figures to assist in interpretation of the regression lines shown. This is needed because, with the Ring machine, retinal sensitivity worsens as ring size increases, whilst the HFA scale shows improving sensitivity with increasing dB score. All plots have a large number of hidden points where several measurements have fallen on exactly the same location. The regression lines are plotted as a dotted line if the line's slope is not significantly different from

Fig. 1. Scatterplots of mean sensitivity and variance over the five replicates for each location by subject group. Many points plotted represent more than one reading with identical values. Least squares regression lines with slopes which are significantly different from zero are drawn as a solid line, dotted if non-significant. Scales are reversed on the Ring Perimeter plots to aid interpretation (see text). *A.* Normal subjects on HFA: variance = -2.05 × mean sensitivity + 64.3; $r^2 = 0.20$, $p<0.0001$. *B.* Normal subjects on Ring Perimeter: Variance = -0.23 × mean sensitivity + 1.80; $r^2 = 0.10$, $p<0.0001$. *C.* Glaucomatous subjects on HFA: variance = -1.63 × mean sensitivity + 49.7; $r^2 = 0.16$, $p<0.0001$. *D.* Glaucomatous subjects on Ring Perimeter: variance = +0.056 × mean sensitivity + 0.83; $r^2 = 0.003$, $p = 0.09$.

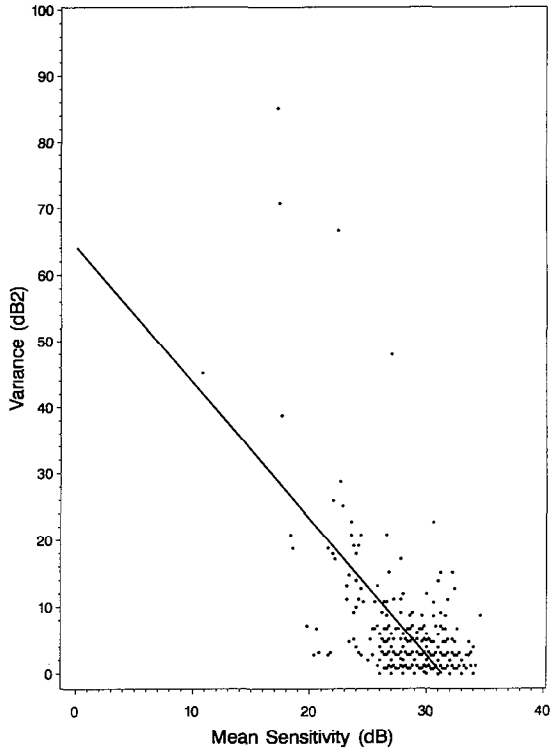

Fig. 1A. Humphrey Perimeter: variance by mean sensitivity, normal subjects.

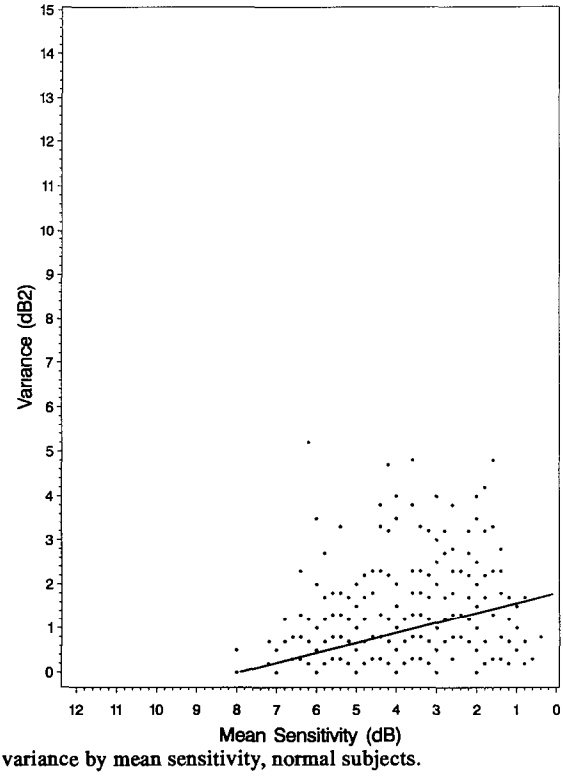

Fig. 1B. Ring Perimeter: variance by mean sensitivity, normal subjects.

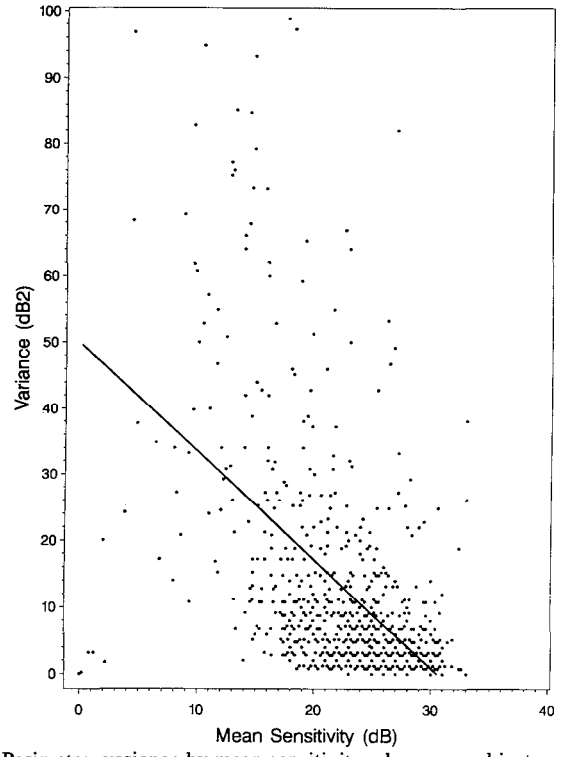

Fig. 1C Humphrey Perimeter: variance by mean sensitivity, glaucoma subjects.

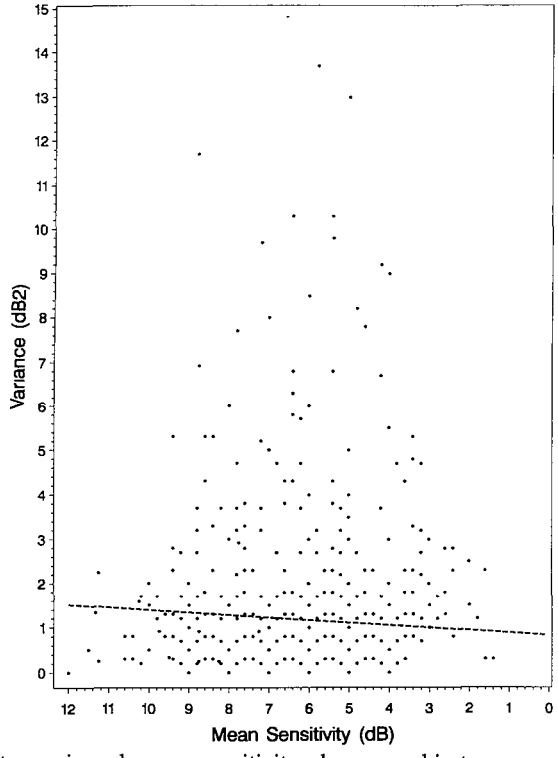

Fig. 1D. Ring Perimeter: variance by mean sensitivity, glaucoma subjects

zero, or a solid line when the slope differs significantly from zero. The equations for these least squares regression lines show that the variability found with the HFA machine increases significantly as sensitivity falls for glaucoma subjects and normals. The Ring Perimeter shows no significant slope of the regression line for glaucoma subjects although with normals a small increase in variability is found as sensitivity increases.

These regression lines were also corrected for distance from fixation and for upper and lower hemifield point location to assess the importance of these variables. These results are given in Table 1 and show distance from fixation was not significant on the Ring machine for normals or glaucoma subjects. The HFA machine showed variance increased with distance from fixation in normals but the effect was lost in the glaucoma group.

Table 1. Multi-linear regression of variance (VAR) on mean sensitivity (mean) corrected for distance from fixation and upper and lower hemifield point location (using SAS general linear models procedure)

Normal subjects	
HFA	VAR = -3.39 × mean + 104
	r^2 = 0 29 p<0.0001
	Distance p<0 0001
	Hemifield p<0 0001
Ring Perimeter	VAR = -0.20 × mean + 1 19
	r^2 = 0.21 p<0.001
	Distance p = 0 57
	Hemifield p = 0.95
Glaucoma patients	
HFA	VAR = -1.93 × mean + 41 89
	r^2 = 0.34 p<0.001
	Distance p = 0.69
	Hemifield p = 0.93
Ring Perimeter	VAR = 0 09 × mean + 0.45
	r^2 = 0.45 p = 0 05
	Distance p = 0.37
	Hemifield p = 0.05

To examine further the effect of location and the variability found, the field was divided into three zones. The HFA locations were divided into 0-8 degrees, 8-16 degrees, 16-24 degrees, while the non-regular Frisén group was divided using three zones defined in previous studies[7,8]. Resulting regression lines found for each zone are given in Table 2. These results are similar to the pooled results and show a significant increase in variability with decreasing sensitivity for glaucoma patients on the HFA in all zones, with no significant effect on the ring machine. The normal subjects on the HFA show a significant increase in variance with poorer thresholds for the outer two zones, whilst for the Ring machine the opposite effect occurred.

Table 2. Multi-linear regression of variance (VAR) on mean sensitivity (mean) with field locations grouped into inner, middle and outer zones (using SAS general linear models procedure)

	Zone		
	Inner	*Middle*	*Outer*
Normal subjects			
HFA			
	VAR = 0.08 × mean - 1.01	VAR = -0 63 × mean + 20.2	VAR = -3.43 × mean + 100.3
	r^2 = 0.25 p = NS	r^2 = 0.24 p<0.0001	r^2 = 0.29 p<0.0001
Ring Perimeter			
	VAR = -0 30 × mean + 1 46	VAR = -0 36 × mean + 1 69	VAR = -0.11 × mean + 0.08
	r^2 = 0.28 p<0.01	r^2 = 0.30 p<0 0001	r^2 = 0.23 p = NS
Glaucoma patients			
HFA			
	VAR = -1.76 × mean + 45.2	VAR = -1 34 × mean + 32 8	VAR = -2.33 × mean + 46.1
	r^2 = 0.69 p<0.0001	r^2 = 0.33 p<0.0001	r^2 = 0.34 p<0.0001
Ring Perimeter			
	VAR = 0.02 × mean + 0.28	VAR = 0.09 × mean - 0.02	VAR = 0.03 × mean + 0 67
	r^2 = 0.52 p = NS	r^2 = 0.51 p = NS	r^2 = 0.41 p = NS

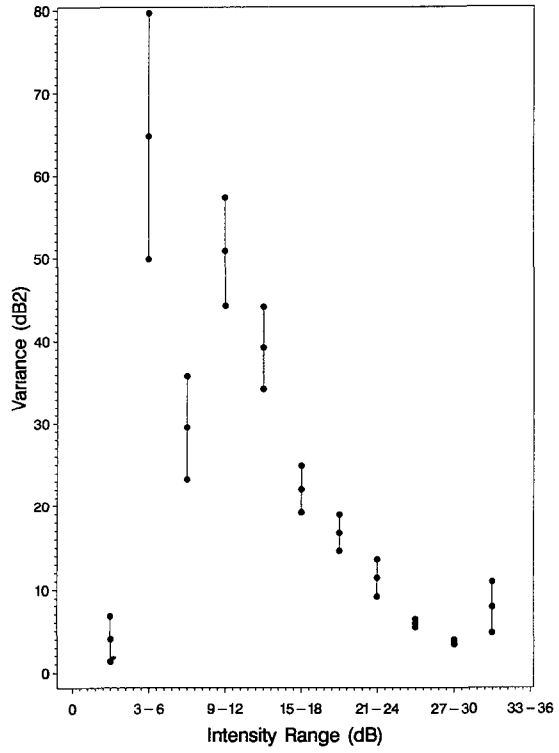

Fig. 2A. Humphrey Perimeter: glaucoma subjects

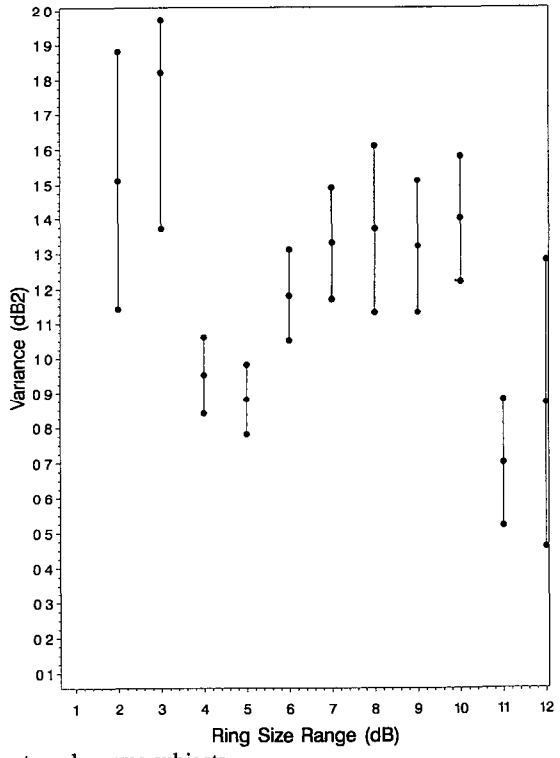

Fig. 2B. Ring Perimeter: glaucoma subjects.

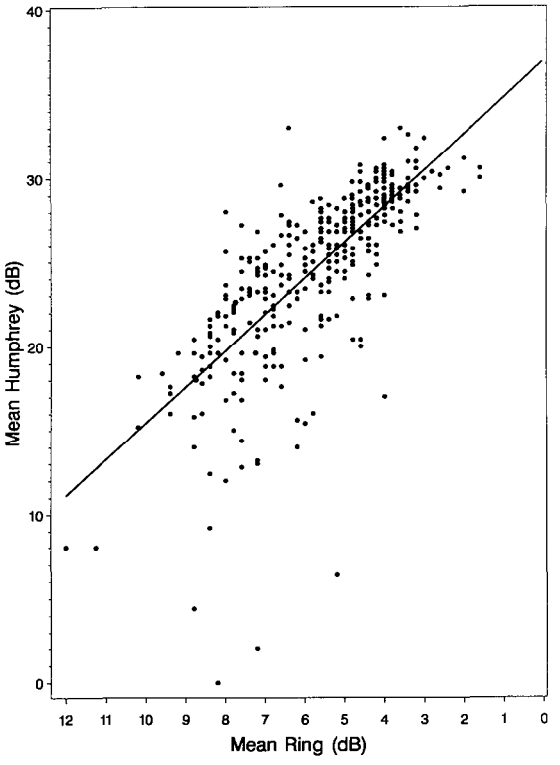

Fig 3. Mean Ring sensitivity plotted against mean HFA sensitivity for the 17 locations with similar XY coordinates for the two machines for the glaucoma subjects Mean HFA sensitivity = -2.15 × mean Ring sensitivity + 36.9; $r^2 = 0.56$ $p<0$ 0001.

Variance may be expected to fall in any perimetric method where sensitivity has fallen beyond the dynamic range of the instrument. This problem was minimized by patient selection where glaucoma cases with confluent areas of zero scores on the HFA were rejected from the study. However, to look further for this effect, pointwise mean sensitivities were grouped into suitable ranges (3 dB steps for the HFA, 1 dB for the Ring). The mean variance for each range of similar values was then plotted against the mid range value. (Fig 2, A and B). The expected rise in variance with worsening sensitivity is shown for the HFA in its mid range, with less variance for the upper and lower ends of the dynamic range. Although the elegant curve shown by Boeglin *et al.*[2] has not been achieved with this small group of patients a similar trend is demonstrated. By contrast, no clear relationship is shown for the Ring perimeter between sensitivity and variance, supporting the result achieved with other approaches outlined above.

To assess the relationship between the mean sensitivity over the five fields at a given location on the two machines, the location patterns for the two machines were examined. Because of the differing patterns no points coincided exactly, but 17 points were found with XY coordinates matching within 1° on the X and Y axes. All but one of these points were located with the central 15 degrees of the field. The scatter plot between the scores found on the two machines at these locations for the glaucoma subjects is shown in Fig. 3. The correlation is highly significant with an r^2 of 0.56, $p<0.0001$.

Fig. 2. Mean sensitivity plotted against variance found when scores are grouped by mean sensitivity into 12 levels for each machine. Error bars represent ± one standard error of the mean. *A.* Humphrey Perimeter, glaucoma subjects. *B.* Ring Perimeter, glaucoma subjects

Discussion

Automated perimetry has minimized the operator-induced component of variation in the visual field but the variation which remains using the differential light threshold method makes the clinical definition of disease progression difficult. Well-trained observers frequently disagree on the presence of progression in a series of visual fields[4]. When one considers that a midperipheral location with a defect depth of 6 dB may be found to fluctuate across the dynamic range of the instrument at the next examination, without the sensitivity of the point having changed, this difficulty in defining progression is not surprising[13]. This high degree of variability may be due to a worsening of the signal to noise ratio as the DLT spot falls on a retinal area with a falling neural channel density[14]. The ring target enlarges with falling retinal sensitivity and covers a similar number of neural channels to reach threshold in normals, regardless of eccentricity[15]. This prevents the increase in variability with increasing eccentricity in normals found with DLT[9]. This study shows the same trend in glaucomatous subjects.

The scalloped pattern seen when variance is regressed on mean sensitivity for the Ring machine (Fig. 1, B and D) is due to the slight rise in variability which occurs when the true retinal sensitivity of a location falls between the available ring sizes. This is an unusually graphic demonstration of how highly repeatable the threshold measurement is with this machine which, to our knowledge, has not previously been shown.

The present study has shown in normals and glaucoma patients that the DLT method results in an increase in variability as sensitivity falls. The effect is present when the field is considered in total, or when divided into three zones. In contrast, the Ring Perimeter does not show an increase in variability with falling sensitivity when similarly analyzed. This underlines the fundamental difference between the methods which may be of importance when following glaucoma patients for disease progression. However, the possibility of this difference being artifactual must be considered because the two approaches are so different. Two possible explanations need to be considered. The first is the difference in the number of steps across the dynamic range of the instrument. If the HFA had only 15 luminosity steps covering the 0-45 dB range, the numeric values found for the variance would be different but the direction of the slope of the regression line of variance on mean sensitivity would not. The second possible explanation might be that the Ring Perimeter is actually measuring a smaller range of sensitivity with the available Ring sizes. This seems unlikely because Ring size and DLT threshold at 15° and 30° eccentricity in normals are highly correlated[9]. Our data also show a weaker correlation between mean sensitivity over the five fields for each method. The scatterplot shown (Fig. 3) covers most of the dynamic range for both machines and demonstrates that the Ring Perimeter has a similar range. Smaller sensitivity range is therefore not the reason for the difference found.

The clinical importance of the differences found has not been addressed in this study. Direct numeric comparison of the variances is not possible but relating the variance found to the instrument's own dynamic range intuitively seems one possible manner in which to compare the machines. Using Figs. 1C and D or 2A and B, and taking the square root of the variance to convert the units to dB for comparison with the instrument's dynamic range, the HFA variance seems larger below 21 dB.

This study shows that variability increases as sensitivity decreases for the HFA but not for the Ring Perimeter. Although comparisons between the methods are made difficult by the dissimilar psycho-physical testing modalities, the difference appears to be important when judged against each instrument's own dynamic range. A long-term prospective study testing for disease progression, preferably using a non-perimetric gold standard, will be required to clarify the clinical importance of the differences found.

References

1. Wilensky JT: Automated perimetry: how do we interpret the results? Arch Ophthalmol 107:185-186, 1989
2. Boeglin RJ, Caprioli J, Zulauf M: Long-term fluctuations of the visual field in glaucoma. Am J Ophthalmol 113:396-400, 1992
3. Heijl A, Lindgren A, Lindgren G: Test-retest variability in glaucomatous visual fields. Am J Ophthalmol 108:130-135, 1989

4. Werner EB, Bishop KI, Koelle J et al: A comparison of experienced clinical observers and statistical tests in detection of progressive visual field loss in glaucoma using automated perimetry. Arch Ophthalmol 106:619-623, 1988
5. Frisén L: A computer-graphics visual field screener using high-pass spatial frequency resolution targets and multiple feedback devices. Doc Ophthalmol Proc Ser 49:441-446, 1987
6. Frisén L: Vanishing optotypes: a new type of acuity test letters Arch Ophthalmol 104:1194-1198, 1986
7. House P, Schulzer M, Drance S, Douglas G: Characteristics of the normal central visual field measured with resolution perimetry. Graefe's Arch Clin Exp Ophthalmol 229:8-12, 1991
8. Douglas GR, Drance SM, Mikelberg F et al: Variability of the Frisén Ring Perimeter In: Heijl A (ed) Perimetry Update 1988/89, pp 197-198. Amsterdam: Kugler Publ 1989
9. Chauhan BC, House PH: Intra-test variability in conventional and high-pass resolution perimetry. Ophthalmology 98:79-83, 1991
10. Heuer DK, Anderson DR, Feuer WJ, Gressel MG: The influence of refraction accuracy on automated perimetric threshold measurements Ophthalmology 94:1550-1553, 1987
11. House PH, Drance SM, Schulzer M, Wijsman K: The effect of refractive blur on the visual field using the Ring Perimeter Acta Ophthalmol 68:87-90, 1990
12. Heijl A, Lindgren G, Olsson J: The effect of perimetric experience in normal subjects Arch Ophthalmol 107:81-86, 1989
13. Heijl A, Lindgren A, Lindgren G: Inter-test variability of computer-measured individual differential light threshold values in glaucomatous visual fields. In: Heijl A (ed) Perimetry Update 1988/89, p 165 Amsterdam: Kugler Publ 1989
14. Heijl A, Lindgren G, Olsson J: Normal variability of static perimetric threshold values across the central visual field. Arch Ophthalmol 105:1544-1549, 1987
15. Frisén L: Acuity perimetry: estimation of neural channels. Int Ophthalmol 12:169-174, 1988

Comparative study of visual field defects between normal tension glaucoma and high tension glaucoma

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Introduction

Normal tension glaucoma (NTG) is diagnosed when typical glaucomatous optic nerve head damage and visual field defect are present in the apparent absence of abnormally elevated intraocular pressure (IOP). Although a recent epidemiological study showed that prevalence of NTG may be much higher than previously thought[1], considerable controversy on the pathogenesis of NTG remains[2-6]. Differences in the pattern of visual field defects between NTG and high tension glaucoma (HTG) are also under question and the results of previous studies are conflicting[7-12]. These previous reports, however, differed in the method of visual field measurement, definition of scotoma, or stage of the disease of the subjects.

In the present study, we attempted to re-examine this problem by comparison of raw data obtained with the Humphrey 30-2 program between the two diseases. The Humphrey 30-2 program, which incorporates a grid pattern similar to that of the Octopus 32 program and a statistical analysis package (STATPAC)[13], is one of the most widely used test programs for following the visual field. Thus, any differences between the two groups could have direct clinical significance.

Materials and methods

Subjects

Sixty-four eyes of 64 cases of NTG and 60 eyes of 60 cases of HTG were analyzed. The mean deviation (MD)[13] of all subjects was -10 dB or more, and the refractive error was -6 diopter or more. Moreover, eyes with tilted discs were excluded from the study.

Inclusion criteria of NTG were: (1) visual field defect corresponding to glaucomatous optic disc change; (2) normal open angle; (3) an IOP of 21 mmHg or less including a 24 hour IOP determination; (4) no rhinological or neurosurgical disorder; (5) no history of shock or hemodynamic crisis. In the present study, primary open-angle glaucoma eyes showing a maximum IOP of 25 mmHg or higher were included as HTG eyes.

There were no significant differences between the two diseases, except for maximum IOP and corrected pattern standard deviation (CPSD)[13] (Table 1). In addition, there were no significant between-group differences in distribution of age, MD or refractive error (Fig. 1).

Table 1. Background of the subjects

	NTG (n=64)	*HTG (n=60)*	*p**
Age (years)	54.5 ±10.5	54.2 ±13.5	NS
Refraction (D)	-1.9 ± 2.3	-1.8 ± 2.2	NS
MD (dB)	-5.10± 2.24	-4.78± 2.83	NS
CPSD (dB)	7.65± 3.58	5.58± 3.25	0.02
Max IOP (mmHg)	18.4 ± 2.0	28.8 ± 5.0	<0.001

*: unpaired *t* test; NS: not significant

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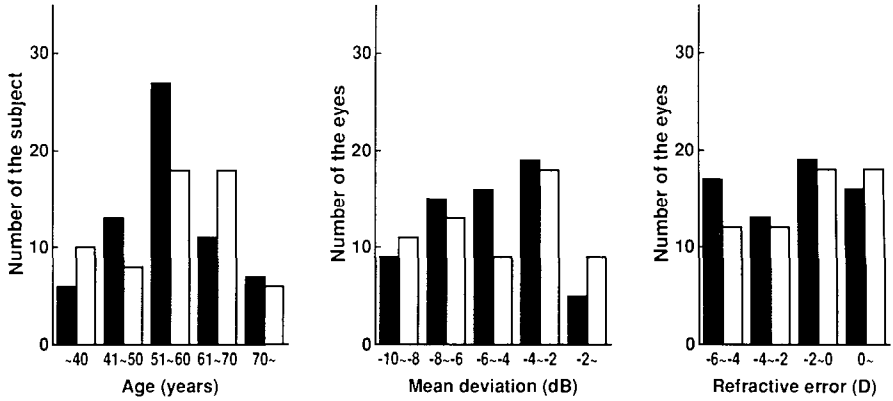

Fig. 1. Distribution of age, MD and refractive error in NTG and HTG. Solid bars indicate NTG, open bars HTG.

Method of analyses

Total deviation (TD) is a numeric value representing the difference in decibels between the patient's threshold and the age-corrected normal reference values at each test point of the Humphrey 30-2 program (STATPAC)[13]. In the present study, we used TD as a parameter for between-group comparisons. Further, we introduced two other parameters for comparison between NTG and HTG. The first is [TD - mean TD], where mean TD is given by averaging 70 test points of the Humphrey 30-2 program excluding the uppermost four points due to uncertainty of results. [TD - mean TD] indicates how the result obtained at the questioned test point deviates from the overall status of the central 30 degree visual field. As the second parameter, we introduced [TD / mean TD], to normalize the TD by the extent of overall visual field damage, as an index of disease stage.

Results

Mean of TD at each test point is shown in Fig. 2. A Wilcoxon rank-sum test revealed significant differences between NTG and HTG at several points ($p<0.05$). Figs. 3 and 4 show means of [TD - mean TD] and medians of [TD / mean TD] in NTG and HTG, respectively. Since the values of [TD / mean TD] significantly deviated from normal distribution, medians were adopted for this parameter. Subsequent Wilcoxon rank-sum tests found significant differences

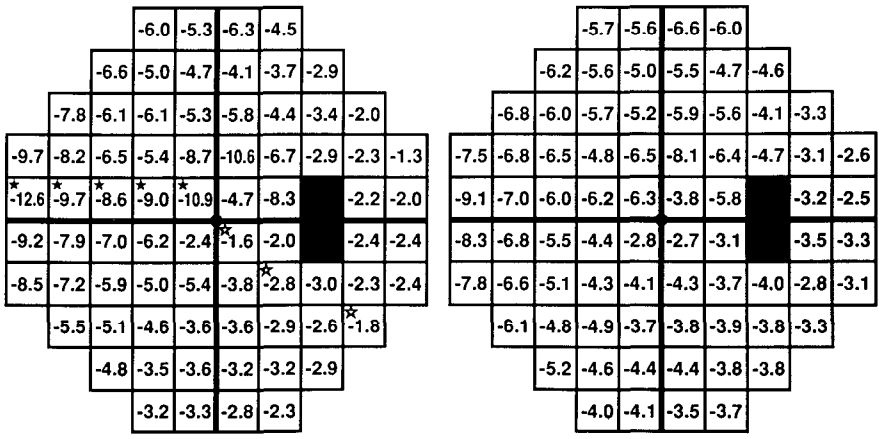

Fig. 2. Mean of TD (dB) at each points (left: NTG, right: HTG). ★ indicates more depressed and ☆ less depressed, respectively ($p<0.05$).

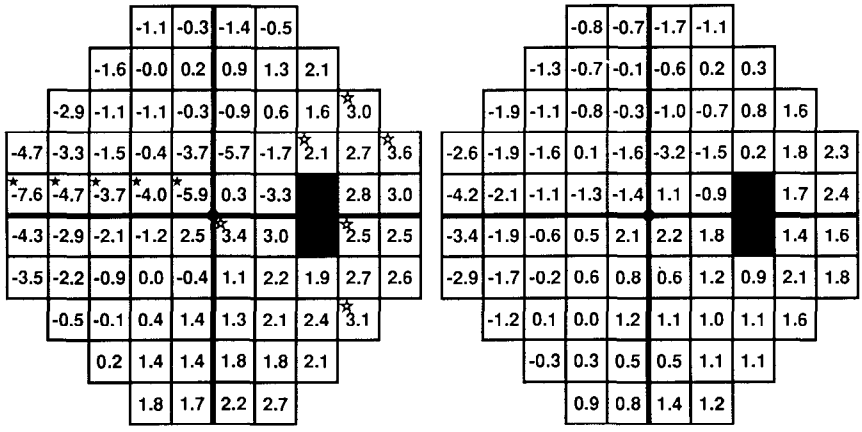

Fig. 3. Mean of [TD - mean TD] (dB) at each point (left: NTG, right: HTG) ★ indicates more depressed and ☆ less depressed, respectively ($p<0.05$)

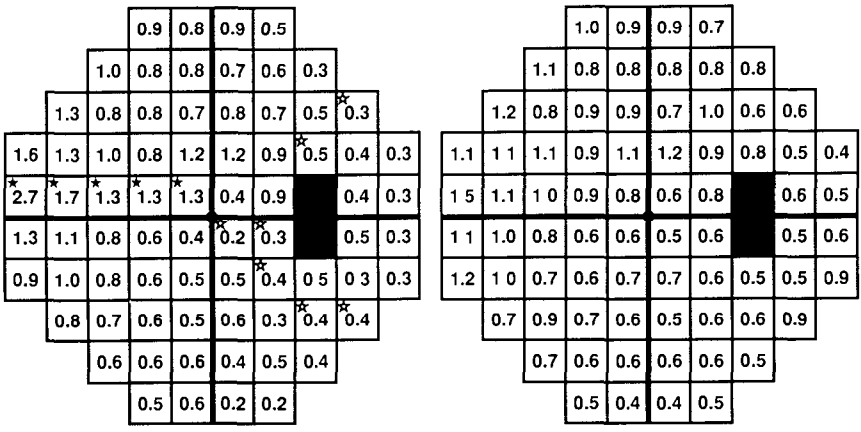

Fig. 4. Mean of [TD / mean TD] at each point (left: NTG, right: HTG). ★ indicates more depressed and ☆ less depressed, respectively ($p<0.05$).

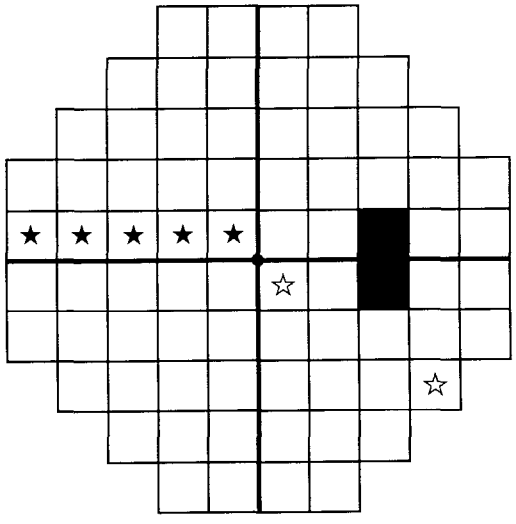

Fig. 5. Test points commonly determined as more depressed ★ and less depressed ☆ by all parameters in NTG eyes ($p<0.05$).

between NTG and HTG at several points ($p<0.05$). Fig. 5 shows test points where all parameters showed significant between-group differences. In NTG, an area just above the horizontal meridian and extending from the fixation to the nasal periphery was found to be significantly more depressed, while a point temporal inferior to the blind spot was less depressed.

Discussion

In studying possible differences in the pattern of visual field damage between NTG and HTG, it is of primary importance to match the disease stage. We first confirmed the absence of significant differences in the mean or distribution of MD between the two patient groups. Further, we introduced the parameter [TD / mean TD], which provides a normalized distribution of TD by incorporating the mean value of overall visual field damage, which is an index of disease stage. Thus, comparisons between the two diseases can be carried out excluding the influence of stage of disease as much as possible.

In the present study, differences in the visual field were noted between NTG and HTG. Specifically, an area just above the horizontal meridian and extending from the fixation to the nasal periphery was found to be significantly more depressed in NTG. This result is compatible with previous descriptions of differences: scotoma in NTG is more localized, closer to fixation and has a steeper slope. Retinal nerve fibers from an area close to the horizontal meridian run closer to the choroid and the peripheral portion of the optic nerve head, while nerve fibers from an area near to the optic nerve head run closer to the vitreous and a more central portion of it[14]. Thus, the present study may suggest that there is a difference in the process of damage to the optic nerve head between NTG and HTG. In fact, taken together with findings of several recent studies suggesting differences in the appearance of the optic nerve head between the two diseases, the present results may support the hypothesis that the pathogenesis of NTG differs from that of HTG[4-6]. The clinical implications of the present findings are clear. Since the present findings were obtained on the grid pattern routinely used in clinical practice, they can be directly applied in following NTG eyes. In particular, a point just nasal superior to the fixation needs special attention, because its involvement may significantly affect central visual acuity.

Meanwhile, the parameter [TD - mean TD] gives an indication of whether the visual field is diffusely damaged or not. If diffuse damage is present, the value of [TD - mean TD] will be close to 0 at all test points, and *vice versa*. The number of such points was significantly greater in HTG eyes than in NTG eyes (χ^2 test, $p<0.01$). This result is compatible with the higher CPSD value found in the present NTG eyes and confirms previous findings showing that high IOP causes more diffuse damage in the visual field[3,15].

In summary, the present study demonstrated that the pattern of visual field damage differs between NTG and HTG. Further, the present study specified the test points on the Humphrey 30-2 program where damage is likely to be more severe in NTG eyes. This result will be of significant clinical use in following the patient.

References

1. Shiose Y, Kitazawa Y, Tsukahara S et al: Epidemiology of glaucoma in Japan: A nationwide glaucoma survey. Jpn J Ophthalmol 35:133-155, 1991
2. Yamazaki Y, Lakowski R, Drance SM: A comparison of the blue color mechanism in high- and low-tension glaucoma. Ophthalmology 96:12-15, 1989
3. Chauhan BC, Drance SM: The influence of intraocular pressure on visual field damage in patients with normal-tension and high-tension glaucoma. Invest Ophthalmol Vis Sci 31:2367-2373, 1990
4 Caprioli J, Spaeth GL: Comparison of the optic nerve head in high and low tension glaucoma. Arch Ophthalmol 103:1145-1149, 1985
5 Gramer E, Bassler M, Leydhecker W: Cup/disk ratio, excavation volume, neuroretinal rim area of the optic disk in correlation to computer-perimetric quantification of visual field defects in glaucoma with and without pressure. Doc Ophthalmol Proc Ser 49:329-348, 1986
6. Yamagami J. Araie M, Shirato S: A comparative study of optic nerve head in low- and high-tension glaucoma Graefe's Arch Clin Exp Ophthalmol 230:446-450, 1992
7. Motolko M, Drance SM, Douglas GR: Visual field defects in low-tension glaucoma: comparison of defects seen in low-tension glaucoma and chronic open angle glaucoma Arch Ophthalmol 100:1074-1077, 1982

8. Phelps CD, Hayreh S, Montague PR: Visual fields in low-tension glaucoma, primary open angle glaucoma and anterior ischemic optic neuropathy. Doc Ophthalmol Proc Ser 35:113-124, 1983
9. King D, Drance SM, Douglas G, Schulzer M, Wijsman K: Comparison of visual field defects seen in normal-tension glaucoma and high-tension glaucoma. Am J Ophthalmol 101:204-207, 1986
10. Hitchings RA, Anderton SA: A comparative study of visual field defects seen in patients with low-tension glaucoma and chronic simple glaucoma Br J Ophthalmol 67:818-821, 1983
11. Caprioli J, Spaeth GL: Comparison of visual field defects in the low-tension glaucomas with those in the high-tension glaucomas Am J Ophthalmol 97:730-737, 1984
12. Drance SM, Douglas GR, Airaksinen PJ, Schulzer M, Hitchings RA: Diffuse visual field loss in chronic open-angle glaucoma Am J Ophthalmol 104:577-580, 1987
13. STATPAC User's Guide: Humphrey Instruments Ltd-SKB: San Leandro, CA, USA, 1986
14. Shields MB: Textbook of Glaucoma, 3rd edn 90 Baltimore: Williams & Wilkins, 1992
15. Caprioli J, Sears M, Miller JM: Patterns of early visual field loss in open-angle glaucoma Am J Ophthalmol 103:512-517, 1987

MONITORING GLAUCOMA PROGRESSION

Are visual field defects in the lower hemifield a risk factor in POAG?

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Abstract

The authors examined the influence of the location of scotomas and of systolic blood pressure on deterioration of the visual field in primary open angle glaucoma (POAG). In earlier studies, they found a low systolic blood pressure and visual field defects in the lower hemifield more frequently in low tension glaucoma than in POAG. Do visual field defects in POAG affecting mostly the lower hemifield point to an insufficient perfusion of the optic nerve head due to a low blood pressure? The visual fields of 153 eyes (153 patients) with POAG and regulated IOP were examined with the Octopus program 31 The loss per test point in the upper and lower hemifields was calculated. The systolic blood pressure was known and a long-term follow-up (three to 19 visual field examinations during a period of one to eight years) was available in all patients. With the Delta program, the authors decided in every case whether or not the visual field showed a tendency to deteriorate: *1.* In patients with a systolic blood pressure of less than 140 mmHg, they found a tendency for visual field defects to deteriorate four times more frequently than in patients with a systolic blood pressure above 140 mmHg. 2. Location of visual field defects in the upper and lower hemifields correlates significantly to systolic blood pressure (Spearman Rank Correlation, Rho=0.202, $p<0.05$): the lower the systolic blood pressure, the more severe the visual field defect in the lower compared to the upper hemifield. *3.* In patients with predominant visual field defects in the lower hemifield, the authors found a tendency for visual field defects to deteriorate two times more frequent than in patients with visual field defects predominantly in the upper hemifield.

Introduction

In glaucoma, intraocular pressure (IOP) is not the only villain we have to deal with. In primary open angle glaucoma (POAG) there are IOP-related and IOP-independent risk factors[1]. These IOP-independent risk factors are particularly striking in low tension glaucoma (LTG), but are also involved in POAG[2-7]. IOP-independent risk factors are a reason for further visual field deterioration after regulation of the intraocular pressure[8].

The aim of this study is therefore the quantitative evaluation with computer perimetric long-term observation of three possible risk factors in patients with POAG after IOP regulation.

1. Low systolic blood pressure: What is the prognosis of visual field stability in patients with low and high systolic blood pressure?
2. Scotomas more frequently in the lower visual field: Do patients with visual field defects more frequently in the lower hemifield have a lower systolic blood pressure? Is deterioration more frequent in patients with scotomas in the lower hemifield?
3. Does pre-existing visual field damage influence the prognosis of the visual field?

Methods

We reviewed the files of 153 patients with POAG who fulfilled the following including criteria, in order to examine the influence of the following risk factors on deterioration of the visual field: systolic blood pressure; location of scotomas in the lower hemifield, pre-existing visual field damage.

Inclusion criteria for the study were:

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1. POAG already with visual field defects at the beginning of the observation period;
2. a visual acuity of 0.8 or better;
3. refraction of ± 3 dpt;
4. long-term observation with threshold determining perimetry (Octopus perimeter 201, programs 31 or 33) twice a year;
5. an IOP of less than 22 mmHg during the follow-up period. Only the period in which IOP was regulated was evaluated;
6. information available on maximum IOP;
7. systolic blood pressure measured at the glaucoma department at the time of visual field examination. From several blood pressure recordings during the observation time with regulated IOP, we calculated and recorded the mean systolic blood pressure;
8. a minimum follow-up of one year with an IOP of less than 22 mmHg with a total observation time of one to eight years.

One hundred and fifty-three patients had a follow-up of three to 19 visual field examinations performed with programs 31 or 33 during an observation period of one to eight years with an IOP of 21 mmHg or less after medical therapy or operation.

Quantification of the size and depth of the scotoma

For quantification of scotomas in the upper and lower hemifields, we calculated the loss per test point for each visual field examination with program Delta, mode Series. These values are printed out with program Delta for the quadrants of the visual field (Fig. 1). The visual field at the beginning of the observation time with regulated IOP was selected for quantification of scotomas in the upper and lower hemifields. In order to define the location of scotomas in each patient, we calculated a quotient dividing the loss per test point in the upper hemifield by the loss per test point in the lower hemifield.

Definition of deterioration

With program Delta, mode Change, we decided whether the visual field showed a tendency to deteriorate or not. To reduce long-term variations, a calculated mean visual field at the beginning (if possible from three visual fields) was compared with a mean visual field at the end of the evaluation period with controlled IOP for calculation of any significant change (Fig. 2). Program Delta uses the *t* test. It is important to know that a tendency to deteriorate defined

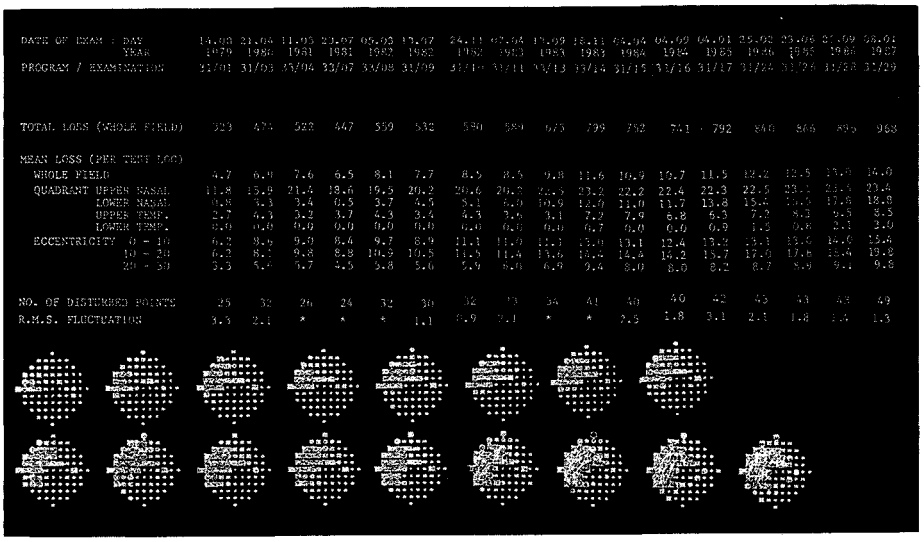

Fig. 1. Long-term follow-up of visual fields and mean loss per test point in the quadrants printed out with program Delta (mode Series).

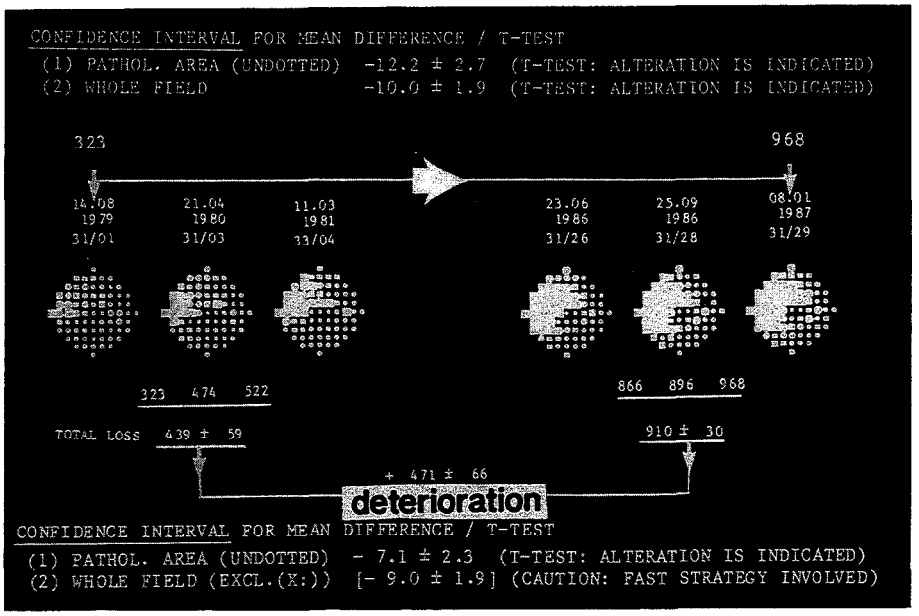

Fig. 2. Deterioration of visual field defects, calculated with program Delta (mode Change).

by program Delta often does not mean a clinically significant change for the worse in the visual field defect. This is because program Delta provides a test that is too sensitive and not specific enough to differentiate between long-term fluctuations and real changes in the visual field. Therefore, we define the results of program Delta as a "tendency" to deteriorate. The advantages and limitations of program Delta have been published elsewhere[5,7,9-11]. In this study we also used the χ^2-test and the Mann-Whitney U test.

Results

Risk factor: Low systolic blood pressure

1. Do patients with visual field defects located mainly in the lower hemifield have a lower systolic blood pressure than patients whose visual field defects affect mainly the upper hemifield?
   Table 1 shows the data of 71 of 153 patients showing an extreme asymmetry in the location of visual field defects; 50 patients had a two times greater loss per test point in the upper than in the lower hemifield (Table 1, left). The mean systolic blood pressure in this group was 158±37 mmHg. Twenty-one patients showed the opposite asymmetry (Table 1, right).

Table 1. Asymmetric visual field defects in the upper and lower hemifields and systolic blood pressure (n=71)

	In the upper hemifield twice or more visual field loss than in the lower hemifield (n=50)		*In the lower hemifield twice or more visual field loss than in the upper hemifield (n=21)*
Systolic blood pressure (mmHg)	158 ± 37	p<0.05	137 ± 27
Total loss (dB)	374 ±331	n.s.	379 ±358
Age (years)	65.1±12.5	n.s.	66.7±17.3
Maximum IOP (mmHg)	32.0± 6.4	n.s.	32.3± 6.3
Scotoma depth (dB/pp)	11.2± 4.6	n.s.	11.5± 3.6

They had a two times greater loss per test point in the lower than in the upper hemifield. The mean systolic blood pressure in this group was significantly lower (137±27 mmHg). Both groups are comparable because there is no significant difference in the mean total loss, which means that, in both groups, the stage of the disease is about the same. Nor is there a significant difference between either group regarding age, maximum IOP and mean scotoma depth.
Conclusion 1: Patients with scotomas mainly in the lower hemifield have a significantly lower mean systolic blood pressure than patients with visual field defects mainly in the upper hemifield.

2. Is there a correlation between systolic blood pressure and location of scotomas as a general rule?
To define the location of scotomas in each patient, we divided the loss per test point in the upper hemifield (total loss in program Delta in the upper quadrants, Fig. 1) by the loss per test point in the lower hemifield. For example, a quotient 2 means that the loss per test point in the upper hemifield is two times as large as the loss per test point in the lower hemifield. In all 153 patients this quotient, describing the location of visual field defects, correlates significantly with the mean systolic blood pressure (Spearman Rank Correlation, Rho=0.202, $p<0.05$).
Conclusion 2: The lower the systolic blood pressure, the more severe the visual field defect in the lower hemifield.

3. Are visual fields in patients with low systolic blood pressure more likely to undergo further damage?
Table 2 shows the frequency of deterioration in patients with POAG with systolic blood pressure above and below 140 mmHg. All 153 patients were divided into two groups. One group contained 87 patients with a systolic blood pressure above 140 mmHg (Table 2, right hand column). Among these, the visual field defect of 9.2% (eight patients) showed a tendency to deteriorate. The other group contained 66 patients with a systolic blood pressure up to 140 mmHg. In 34.9% (23 patients) the visual field defect showed a tendency to deteriorate. Both groups are comparable because there is no significant difference in mean total loss, age, maximum IOP, and scotoma depth (Table 2).
Conclusion 3: In this study the risk of further visual field damage was four times higher in patients with a systolic blood pressure of 140 mmHg or less than in patients with a systolic blood pressure above 140 mmHg.

Table 2. Risk factor: low systolic blood pressure. Frequency of deterioration in POAG with systolic blood pressure above and below 140 mmHg (n=153)

	Blood pressure ≤140 mmHg		*Blood pressure >140 mmHg*
Visual field: deteriorates	34.9% (23)		9.2% (8)
Visual field: remains stable	65.1% (43)		90.8% (79)
	100.0% (66)		100.0% (87)
		χ^2 = 15 29, p<0.001	
Systolic blood pressure (mmHg)	124.0± 14.7	p<0.001	170.0± 20.9
Total loss (dB)	641.8±548.6	n.s.	496.8±416.6
Age (years)	62.5± 14.0	p<0.001	69.5± 10.7
Maximum IOP (mmHg)	32.7± 8.1	n.s.	32.3± 6.6
Scotoma depth (dB/pp)	13.4± 6.1	n.s.	11.7± 4.8

Risk factor: location of scotomas found more frequently in the lower hemifield

4. Are visual field defects more likely to undergo further deterioration if they are located mainly in the lower hemifield?
Table 3 shows the frequency of deterioration in POAG with predominantly visual field defects in the upper or lower hemifield. In 98 patients the visual field defect (*i.e.*, the loss per

test point) was more severe in the upper than in the lower hemifield (Table 3, left side). Among these a visual field defect of 15.3% (15 patents) showed a tendency to deteriorate. In the remaining 55 patients (Table 3, right side) the visual field defect was located mainly in the lower hemifield. In this group we found that visual field defects tended to deteriorate in 29.1% (16 patients) (Table 3).

Conclusion 4: In patients with scotomas located mainly in the lower hemifield, deterioration of scotomas is twice as frequent as in patients with scotomas mainly in the upper hemifield.

Table 3. Risk factor: localization of scotomas. Frequency of deterioration in POAG with predominantly visual field defects in the upper and lower hemifields (n=153)

	Predominantly visual field defects in the upper hemifield		*Predominantly visual field defects in the lower hemifield*
Visual field: deteriorates	15.3% (15)		29 1% (16)
Visual field: remains stable	84.7% (83)		70.9% (39)
	100.0% (98)		100.0% (55)
		$\chi^2 = 4.14$, $p<0.05$	
Systolic blood pressure (mmHg)	154.8± 29.6	p<0.05	143.8± 27 9
Total loss (dB)	504.9±403 3	n.s.	647 0±580 7
Age (years)	67.1± 11.4	n.s.	65.5± 14.4
Maximum IOP (mmHg)	32.4± 7.3	n.s.	32.6± 7.2
Scotoma depth (dB/pp)	11.7± 4.8	n.s.	13.6± 6.1

Risk factor: pre-existing visual field damage

5. Is the amount of visual field loss a risk factor for further deterioration of the visual field? Table 4 shows the frequency of visual field deterioration in 153 patients with POAG with mild or severe visual field defects. We compared 92 patients with a total loss of up to 600 dB (Table 4, left side) with 61 patients with a total loss of more than 601 dB (Table 4, right side). In the group with mild visual field loss, the rate of further visual field deterioration was 13% (12 of 92 patients), compared to 31% (19 of 61) in the group with a more severe visual field loss. There were no differences in mean systolic blood pressure. The pre-existing visual field damage and low systolic blood pressure seem to be independent risk factors. The mean age, mean intraocular pressure and mean scotoma depth were not different between either group.

Conclusion 5. Patients with mild visual field damage have a significantly lower risk of further deterioration than patients with moderate or severe visual field damage.

Table 4. Risk factor: pre-existing visual field damage. Frequency of deterioration in POAG with mild and severe visual field defects (n=153)

	Total loss <600 dB		*Total loss >600 dB*
Visual field: deteriorates	13.0% (12)		31.2% (19)
Visual field: remains stable	87.0% (80)		68.8% (42)
	100.0% (92)		100.0% (61)
		$\chi^2 = 7.44$, $p<0.01$	
Systolic blood pressure (mmHg)	151.4± 27.9	n.s.	149.5± 31.8
Total loss (dB)	235.9±167.2	p<0.001	1071.3±352.9
Age (years)	66.2± 12.9	n.s.	67.1± 12.3
Maximum IOP (mmHg)	32.3± 5.5	n.s.	32.9± 9.4
Scotoma depth (dB/pp)	9.0± 2.7	p<0.001	17.8± 4.1

Discussion

The results of this study show that patients with POAG and low systolic blood pressure seem to be more vulnerable in the lower hemifield and have a higher risk of visual field deterioration. This is of clinical relevance. Location of scotomas in relation to blood pressure in POAG has not been evaluated until now, as far as we know.

It is of interest why we should wonder whether or not scotomas in the lower hemifield are a risk factor for visual field deterioration and why there should be a relation to low systemic blood pressure in patients with POAG.

In an earlier study, we found in LTG (stage II) that visual field defects were more frequent in the lower than in the upper hemifield, compared to POAG[12]. The frequency distribution of the test points of program 31 with absolute scotomas showed that, in POAG (stage II), absolute scotomas are more frequent in the upper hemifield and in LTG (stage II) they are more frequent in the lower hemifield. In anterior ischemic optic neuropathy (AION), scotomas are more frequent in the lower hemifield[5,7,12].

Phelps *et al.*[13] found similar results with Goldmann perimetry. In a previous study, we re-evaluated this difference in topography of visual field defects again in LTG, POAG and pigmentary glaucoma under quantitative conditions with program Delta, comparing the mean loss per test point in the upper and lower hemifield[7]. We again found the same result. In POAG (stage II), in the lower hemifield we found 82% as much damage as in the upper hemifield. In LTG (stage II) there was 162% as much damage in the lower hemifield as in the upper hemifield[5,7].

In another earlier study, we found hypotension in LTG in 59.3% compared to POAG in 11.6%. One hundred and twenty-five glaucoma patients with visual field defects stage II (*i.e.*, all patients were at the same stage of the disease) underwent a standardized complete medical diagnostic examination in internal medicine for that study[4]. It is of clinical and scientific interest that, in POAG as well, a low systolic blood pressure is a risk factor. The lower the systolic blood pressure, the more severe the visual field loss in the lower hemifield (*cf.* Table 1) and the more frequent the visual field deterioration (*cf.* Table 2). On the basis of quantitative computer perimetric evaluations, we could demonstrate and prove statistically the clinical observation that low systolic blood pressure is also an important risk factor in POAG.

The clinical observation that low systemic blood pressure is a risk factor has already been published. Lobstein and Herr[14] found that in patients with POAG a high systemic blood pressure delays the appearance of visual field defects. Sachsenweger[15] found that in POAG low systemic blood pressure accelerates, while high blood pressure slows down, the development of visual field defects.

Peräsalo and Raitta[16] found that in geriatric patients with POAG those with low systemic blood pressure (less than 120 mmHg) compared to patients with high blood pressure (more than 160 mmHg) had a worse visual acuity and more often showed a further deterioration of the visual field defects. Hayreh[17] carried out a 24-hour blood pressure recording and found that patients with LTG had very low blood pressure in the second half of the night. In POAG with further deterioration despite regulated IOP, we may find similar results with 24-hour blood pressure recording (*e.g.*, with the new "Spacelab" system).

Our results show that, in individual cases, the borderline of an IOP of 21 is arbitrary for separation of IOP-related and IOP-independent risk factors. For clinical studies comparing groups of patients, this definition is still valid.

In former studies[3,9], we demonstrated that severe pre-existing visual field damage is an important risk factor in LTG and POAG, and the results presented here confirm our findings.

In medical glaucoma therapy, compliance of the patient is a further risk factor which cannot be excluded from a study which determines the frequency of visual field deterioration[18]. Drug treatment should take this into account[19].

The inherent nature of scientific "discoveries" is that something is always incomplete and this will be realized at the end of the study. Therefore, we have to re-evaluate the diastolic blood pressure from the files and we have to calculate the mean blood pressure. With reference to diurnal variation, we should also have carried out several blood pressure measurements per day. This is not practical in a clinical routine. We are now starting a multi-center prospective study in 50 private practices in Germany with Humphrey perimeters (STATPAC program) and standardized blood pressure measurements, as well as standardized recording of topical and systemic medication at every eye examination over a period of five to seven years in patients

with ocular hypertension and POAG stage I. We think that the results of this pilot study are interesting enough to be reported. POAG patients with

- low systolic blood pressure
- predominant visual field defects in the lower hemifield, and
- severe pre-existing visual field damage,

have a poorer prognosis even with IOP at a normal level.

References

1. Gramer E, Althaus C: Bedeutung des erhöhten intraokularen Drucks für den glaukomatösen Gesichtsfeldschaden. Klin Mbl Augenheilk 197:218-224, 1990
2. Drance SM, Sweeney VP, Morgan RW, Feldman F: Studies of factors involved in the production of low tension glaucoma. Arch Ophthalmol 89:457-465, 1973
3. Gramer E, Althaus G: Risikofaktoren bei Niederdruckglaukom: klinische Studie zur Quantifizierung der Gesichtsfeldverschlechterung bei Glaukom ohne Hochdruck und Glaucoma simplex mit reguliertem intraokularen Druck mit dem Programm Delta des Octopus-Perimeters 201. Z Prakt Augenheilk 8:388-399, 1987
4. Gramer E, Leydhecker W: Glaukom ohne Hochdruck: Eine klinische Studie. Klin Mbl Augenheilk 186:262-267, 1985
5. Gramer E, Althaus G: Quantifizierung und Progredienz des Gesichtsfeldschadens bei Glaukom ohne Hochdruck, Glaucoma simplex und Pigmentglaukom. Klin Mbl Augenheilk 191:184-198, 1987
6. Goldberg I, Hollows FC, Kass MA, Becker B: Systemic factors in patients with low tension glaucoma. Br J Ophthalmol 65:56, 1982
7. Gramer E, Althaus G, Leydhecker W: Topography and progression of visual field damage in glaucoma, low tension glaucoma and pigmentary glaucoma with program Delta of Octopus perimeter 201. In: Greve EL, Heijl A (eds) Seventh International Visual Field Symposium, pp 329-348. Dordrecht: Dr Junk Publ 1987
8. Leydhecker W, Gramer E: Long-term studies of visual field changes by means of computerized perimetry (Octopus 201) in eyes with glaucomatous field defects after normalization of the intraocular pressure. Int Ophthalmol 13:113-117, 1989
9. Gramer E, Althaus G: Zur Progredienz des glaukomatösen Gesichtsfeldschadens: eine klinische Studie mit dem Programm Delta des Octopus-Perimeters 201 zum Einfluss des Vorschadens auf die Gesichtsfeldverschlechterung beim Glaucoma simplex. Fortschr Ophthalmol 85:620-625, 1988
10. Gramer E: Gesichtsfeldveränderungen bei Glaukom In: Krieglstein GK (ed) Das chronische Glaukom: Zeitgemässe Diagnostik und Therapie, pp 19-60. Ratingen: Augenspiegel-Verlag 1987
11. Gramer E, Althaus G: Einfluss des systolischen Blutdrucks auf die Lage der Gesichtsfeldausfälle bei Patienten mit Glaucoma chronicum simplex Ophthalmologie 1992
12. Gramer E, Mohamed J, Krieglstein GK:, Der Ort von Gesichtsfeldausfällen bei Glaucoma simplex, Glaukom ohne Hochdruck und ischämischer Neuropathie. In: Krieglstein GK, Leydhecker W (eds) Medikamentöse Glaukomtherapie, pp 59-72. München: Bergmann 1982
13. Phelps CD, Hayreh SS, Montague PR: Visual fields in low-tension glaucoma, primary open-angle glaucoma, and anterior ischemic neuropathy. In: Greve EL, Heijl A (eds) Fifth International Visual Field Symposium, pp 113-124. The Hague: Dr Junk Publ 1983
14. Lobstein A, Herr FJ: L'ophtalmodynamétrie dans le glaucome. Ann Ocul 199:38-69, 1962
15. Sachsenweger R: Der Einfluss des Bluthochdruckes auf die Prognose des Glaukoms. Klin Mbl Augenheilk 142:625-633, 1963
16. Peräsalo R, Raitta C: Low blood pressure: a risk factor for nerve fibre loss in institutionalized geriatric glaucoma patients. Acta Ophthalmol (Suppl) 195:65-67, 1990
17. Hayreh SS: Vascular factors in glaucomatous optic nerve damage. In: Drance SM (ed) Proceedings International Symposium on Glaucoma, Ocular Blood Flow and Drug Treatment. (in press)
18. Noack E: Patienten-Compliance bei langdauernder Glaukomtherapie Z Prakt Augenheilk 12:223-228, 1991
19. Gramer E: Neue Kombinationspräparate mit nur zwei Applikationen täglich als Bestandteil einer medikamentösen Drei- oder Vierkomponententherapie des Glaukoms. In: Gramer E, Kampik A (eds) Pharmakotherapie am Auge, pp 134-157. Heidelberg: Springer Verlag 1992

Forecasting progression of glaucomatous visual field loss

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Abstract

A model has been developed, based upon polynomial and multiple regression, which describes the sensitivity at each stimulus location in terms of the respective stimulus coordinates and in terms of the sensitivity at each of the previous t, t-1, t-2, etc., examinations. The aim of the study was to utilize the model to forecast the sensitivity at each stimulus location of the subsequent, t+1, examination. Comparison of the forecasted values with the recorded values might indicate departures from the expected trend over time. The model was developed from the fields (Humphrey Field Analyzer program 30-2 and 24-2) of a cohort of 49 patients (mean age 57.1 years, SD 13 4) attending a glaucoma clinic The mean period of follow-up was 37.6 months (SD 10.2 months) and the mean number of previous examinations 7 4 (SD 2.2). The effectiveness of the forecasting procedure was evaluated in terms of the pointwise error between the forecasted and the measured field. The precision was high in areas of high sensitivity and in areas of deep loss. Increased error was present at the edges of focal loss. Stimulus locations manifesting the greatest error over several visits frequently exhibited a subsequent sustained reduction in sensitivity

Introduction

The identification of visual field loss and the delineation of visual field progression is becoming increasingly dependent upon the use of statistical procedures. Progression of glaucomatous visual field loss is frequently evaluated in terms of the slope derived from the linear regression of the visual field index against examination date. The index may represent either the complete field or a given region of the field and the technique can also be applied to individual stimulus locations[1-3]. Increasing clinical opinion and research findings suggest that the visual field indices do not provide a sufficiently sensitive method for detecting the earliest change in the progression of glaucomatous field loss[4]. This may arise from several factors: the indices may be inappropriate for the description of glaucomatous field loss or the data reduction procedure, itself, may ignore potentially useful information on the pointwise distribution of sensitivity.

Clearly there is a need to develop an alternative statistical procedure for evaluation of serial visual fields in glaucoma. We have recently developed a mathematical model to describe the measured pointwise distribution of sensitivity at any given examination[5]. The model incorporates two elements. The first component utilizes a polynomial function that describes the sensitivity at any given stimulus location for any given examination in terms of the respective stimulus coordinates. This component of the model provides a topographical analysis of the visual field and reflects the uniformity or regularity of the distribution of sensitivity between adjacent stimulus locations. The second component utilizes multiple linear regression to describe the sensitivity at any given stimulus location for any given examination in terms of the sensitivity at that location determined on previous examinations and provides a longitudinal analysis of the visual field. The precision of the joint topographical and longitudinal model is

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a function of the regularity of the data over time and increases as a function of the number of previous examinations. The variation is governed by the quality of the data collected at any given examination and by the type of progression of the disease process.

The aim of the study was to evaluate the suitability of the model for forecasting visual field progression in glaucoma, *i.e.*, the sensitivity at each stimulus location of the subsequent, N+1, examination. It was hypothesized that a comparison of the predicted pointwise distribution of sensitivity with the measured distribution might provide additional information on change within the visual field. Agreement between the forecasted and measured fields would confirm the reliability of the measurement whilst departures from the randomly occurring errors would indicate an episodic change from the predicted sensitivity.

Methods

The model was derived from the Humphrey Field Analyzer program 30-2 and 24-2 fields of 49 patients (mean age 57.1 years, SD 13.4) attending a glaucoma clinic. The mean period of follow-up was 37.6 months (SD 10.2 months) and the mean number of prior examinations 7.4 (SD 2.2). The joint model can be described mathematically:

$$z_t = + A_1z_1 + A_2z_2 + \ldots\ldots A_{t-1}z_{t-1} + B_{00} + B_{10}x + B_{01}y + B_{11}xy + B_{21}x^2y + \ldots\ldots$$

$$= \sum_{i=1}^{t-1} A_iz_i + \sum_{i=0}^{n}\sum_{j=0}^{n} B_{ij}x^iy^j + u$$

where z_t is the sensitivity at any general stimulus location (x,y) at any examination t, where $t \geq 2$, and where A and B are coefficients.

The model can be fitted to the data using least squares.

If $\hat{A}_1, \hat{A}_2, \ldots\ldots \hat{A}_{t-1}$ and $\hat{B}_1, \hat{B}_2, \ldots\ldots \hat{B}_{t-1}$ are the parameter estimates, then z_{t+1} can be forecast using the equation:

$${}_fz_{t+1} = \hat{A}_1z_2 + \hat{A}_2z_3 + \ldots\ldots \hat{A}_{t-1}z_t + \sum_i \sum_j \hat{B}_{ij}x^iy^j$$

$$= \sum_{i=1}^{t-1} \hat{A}_iz_{i+1} + \sum_i \sum_j \hat{B}_{ij}x^iy^j .$$

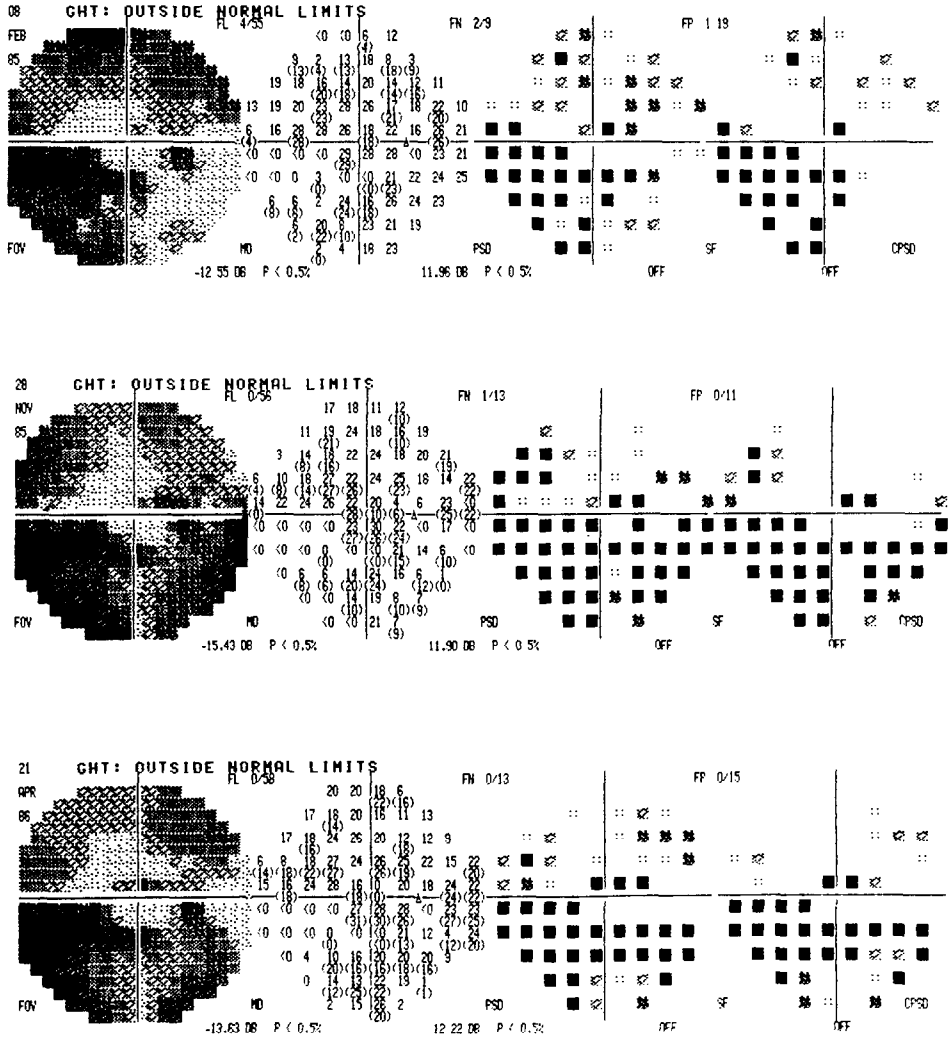
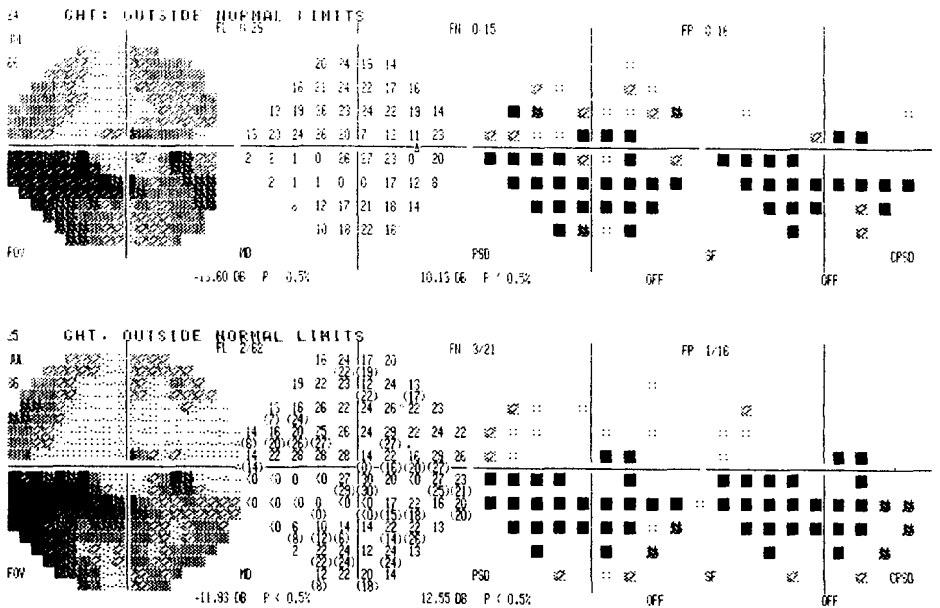


Fig. 1a. The initial three measured right eye fields of a 72-year-old with advanced primary open angle glaucoma.



			+2	-1	-2	+10		
		+4	+5	-2	+2	+9	+6	
	+5	+4	0	-3	0	+6	+3	+10
+1	+2	+4	+2	+8	+7	+7	+7	+5
-2	-2	-1	0	+2	+3	-3	0	+6
	-2	-1	-1	0	0	-1	+8	+8
		-1	-1	-7	-7	0	+10	
			+12	+6	-10	+8		

Fig. 1b-1. Left: the forecasted program 24-2 (above) and measured program 30-2 (below) fourth right eye fields of the case illustrated in Fig. 1a. Right: the associated pointwise difference (dB) between the forecasted and measured fields (the positive sign represents an underestimate of the forecasted sensitivity relative to the measured sensitivity (*i.e.*, an improvement) and the negative sign an overestimate *i.e.* a deterioration). Note the underestimation of sensitivity at the edges of the temporal hemifield is due to the variability of the initial three measured fields (Fig. 1a).

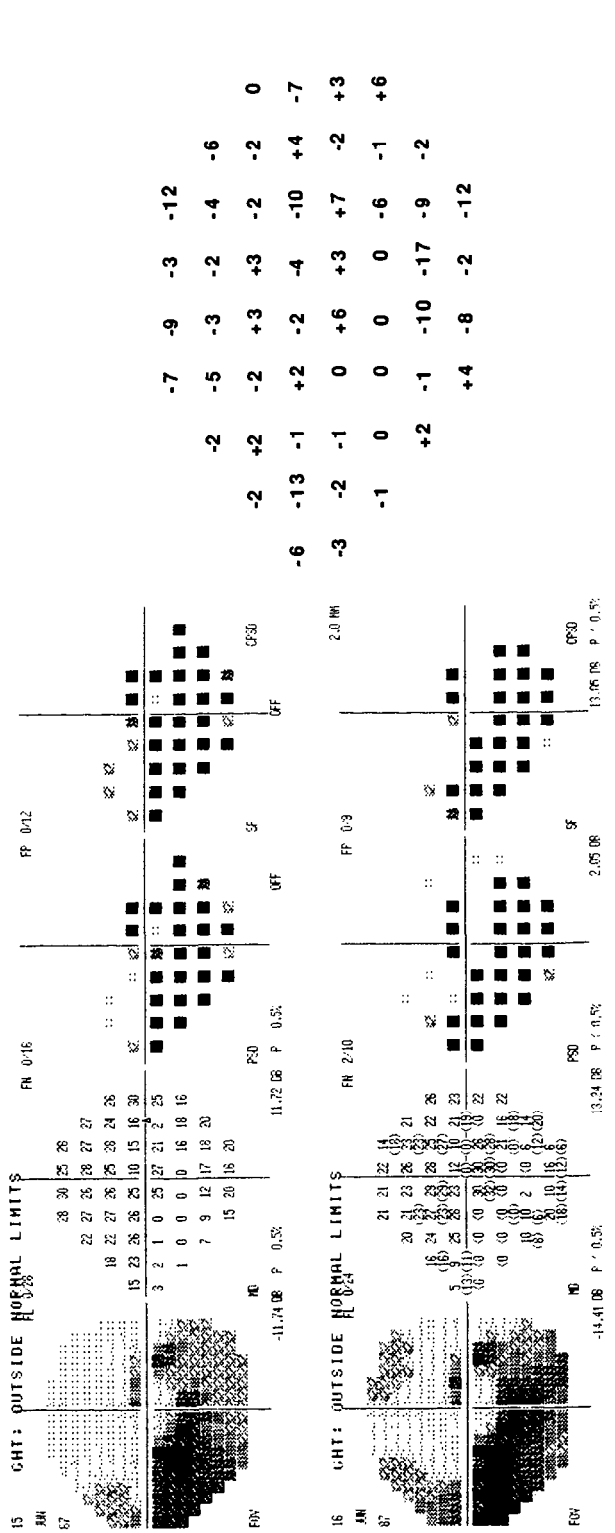


Fig. 1b-2. The corresponding forecasted (above) and measured (below) fifth right eye fields. Note the indication of deterioration in sensitivity at stimulus locations -27,3; -21,3; 9,3; which is sustained at the sixth examination.

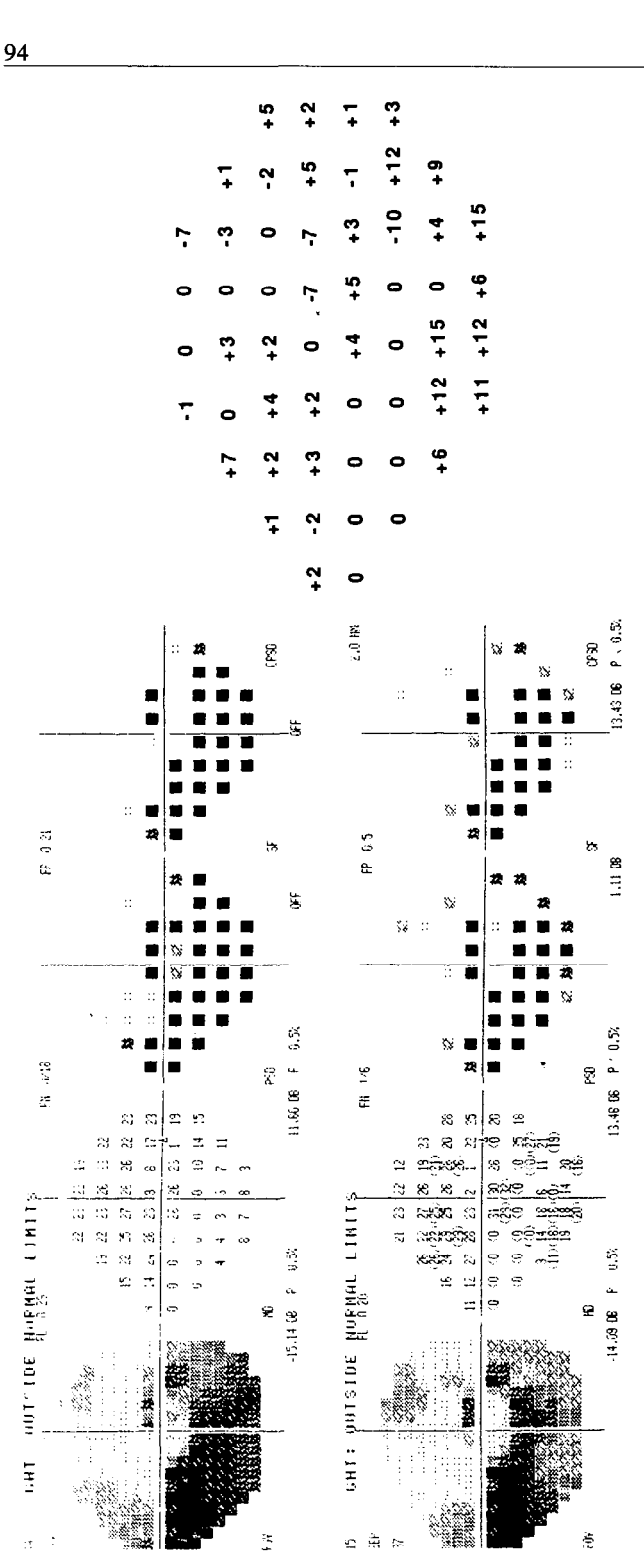


Fig. 1c. Top: the corresponding forecasted (above) and measured (below) sixth right eye field. Note the (erroneous) forecasted underestimate of sensitivity at the extremities of the inferior field. Bottom: the forecasted seventh field.

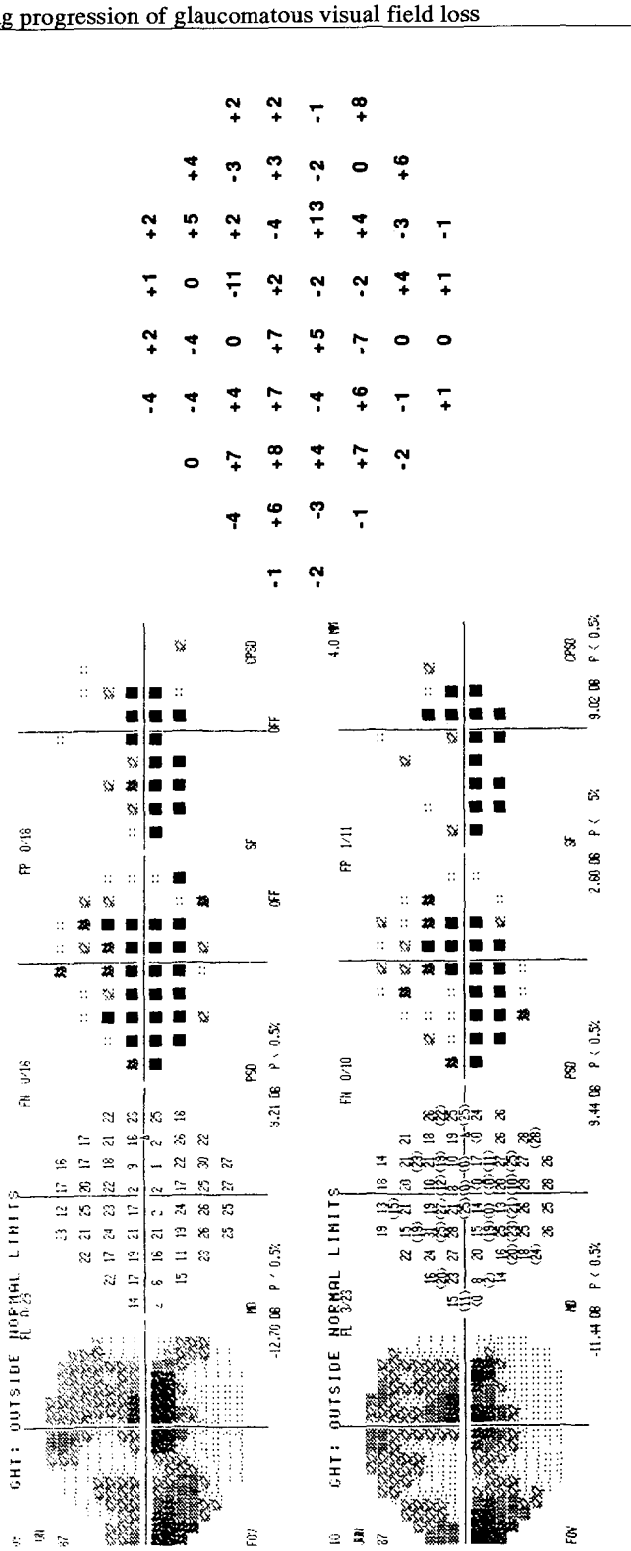
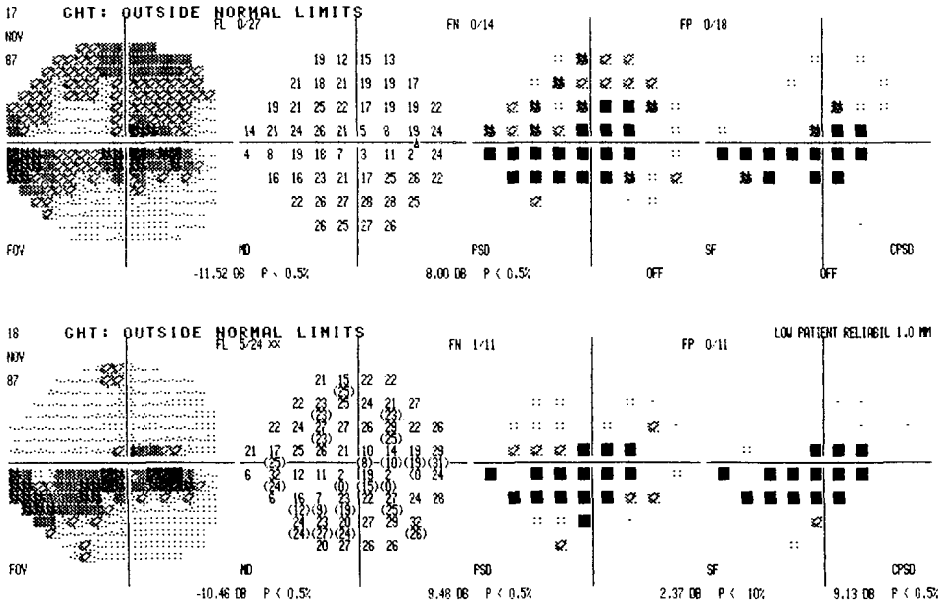


Fig. 2a-1. The forecasted (above) and measured (below) fourth right eye fields (left) and the associated pointwise difference (dB) between the forecasted and measured fields (right) of a 47-year-old with primary open angle glaucoma.



			+2	+8	+7	+9		
		+1	+5	+4	+5	+3	+10	
	+3	+3	0	+5	+9	+8	+3	+4
+7	+3	+1	0	0	+4	+4	0	+6
+2	+20	-7	-7	-6	+14	-9	-2	0
	-10	-2	-15	0	+5	+1	+2	+6
		+2	-1	-5	-1	+1	+4	
			-6	+2	-1	0		

Fig. 2a-2. The corresponding forecasted (above) and measured (below) fifth fields. Note the fifth measured field is of low reliability and exhibits an apparent improvement in the superior field.

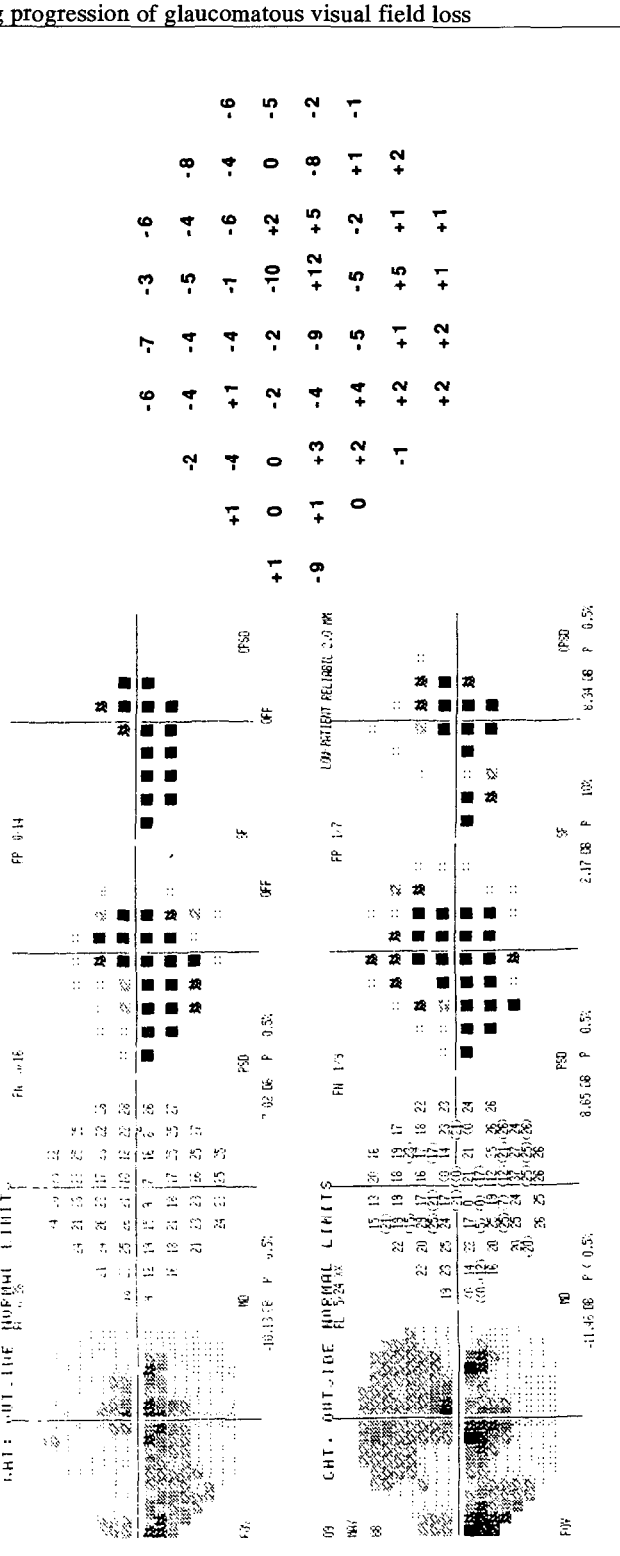


Fig. 2b-1. The corresponding forecasted (above) and measured (below) sixth right eye fields and difference plot. Note the overestimate of the forecasted sensitivity of the sixth field compared to the forecasted fourth and fifth fields which results from the influence of the unreliable measured fifth field.

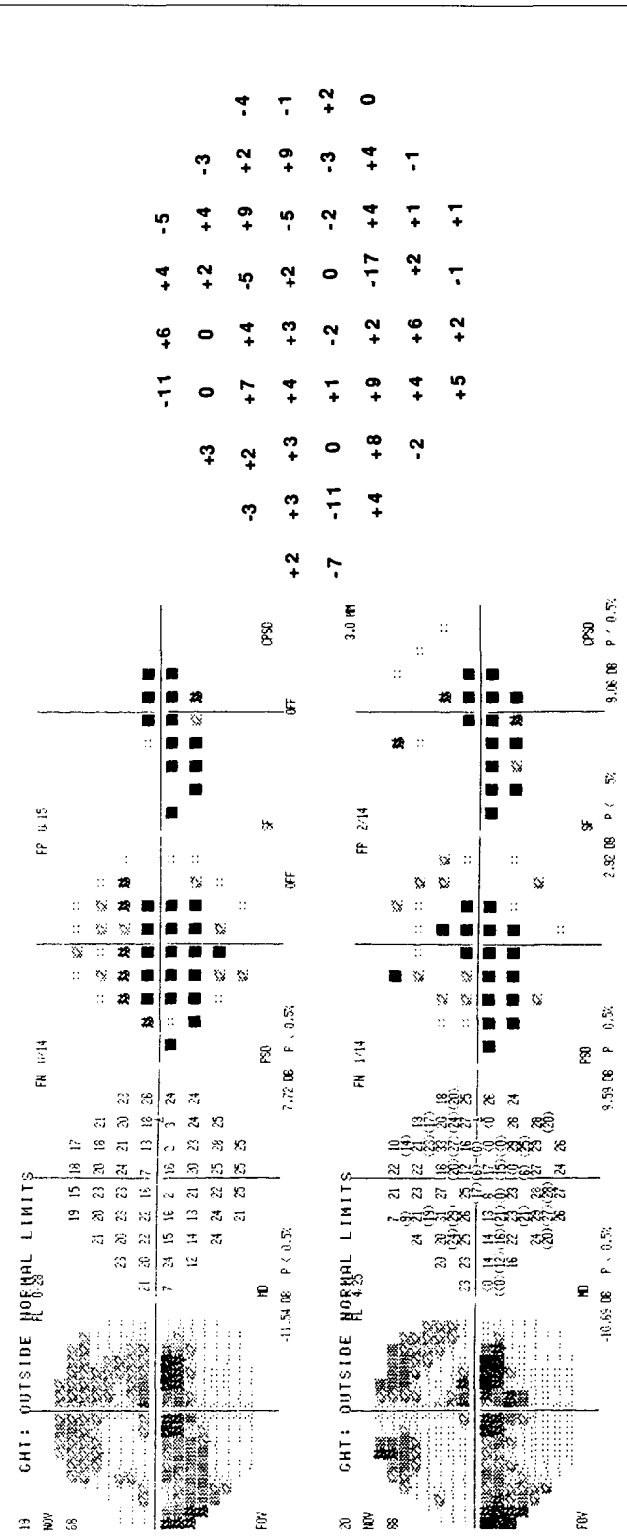


Fig. 2b-2. The corresponding forecasted (above) and measured (below) seventh right eye fields.

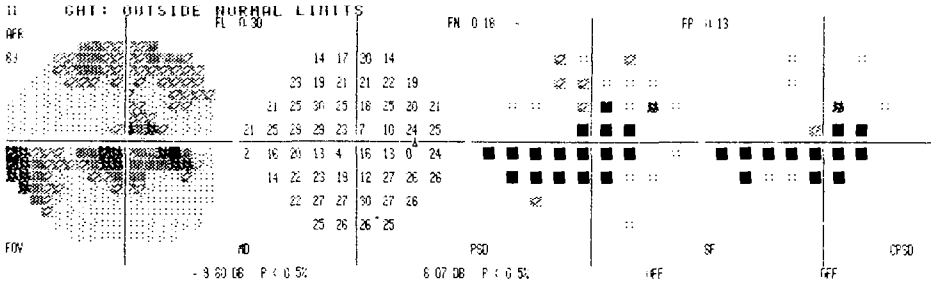


Fig. 2c The corresponding forecasted eighth field

Results

In stable fields or in those that show a regular linear decline in sensitivity, the pointwise error between the forecasted and measured field is small in areas of normal sensitivity and in areas of deep loss. The error increases with increase in eccentricity and is more variable at the edges of focal loss (Fig. 1).

The precision of the forecasting is governed by the quality of the prior data. The forecasted t+1 field can be adversely affected if the last measured field (*i.e.*, at time t) is of low reliability (Fig. 2).

Episodic progression of the visual field can be identified from the discrepancy between the forecasted and measured fields. Such discrepancies can be quite marked (Fig. 3).

Stimulus locations which exhibited the greatest variation in forecasting error over several visits were frequently found to be those that subsequently exhibit a sustained reduction in sensitivity.

Discussion

The multivariate model described here is a more powerful approach with much greater predictive power than the univariate model. Composite predictions are possible from a minimum of two visual field examinations since the information from all 76 stimulus locations is used to generate the sensitivity at a given stimulus location. The information derived by the univariate model from two separate examinations is rudimentary and experience would suggest that at least ten examinations would be necessary to obtain a reasonable fit. The estimation error for the multivariate model is generated for the complete field as a whole, whilst in the extreme case of the univariate model, *i.e.*, 76 individual equations, an estimation error is present at each location and is compounded when the field is considered as a whole. It must be realized, however, that the two techniques are not equivalent since the former uses time as a single continuous variable and the latter time in an ordinal capacity.

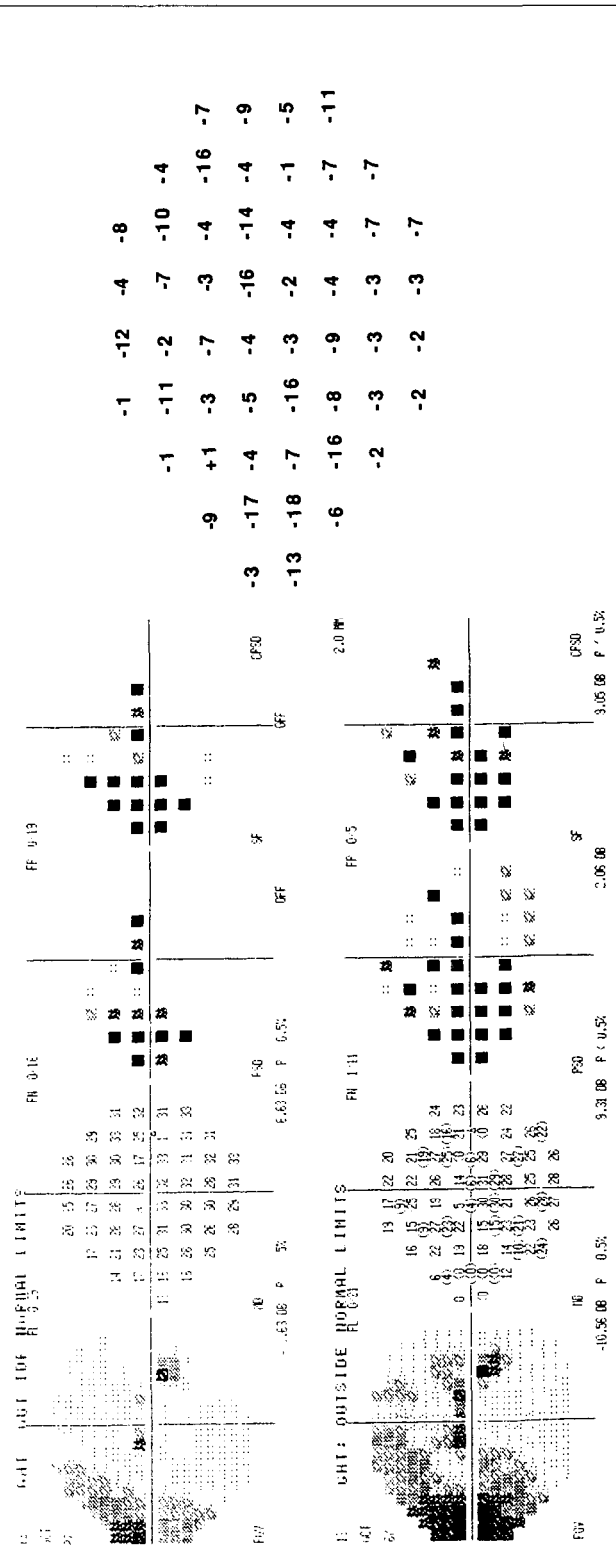


Fig. 3a-1. The forecasted (above) and measured (below) seventh right eye fields (left) and the associated pointwise difference (dB) between the forecasted and measured fields (right) of a 49-year-old with primary open angle glaucoma.

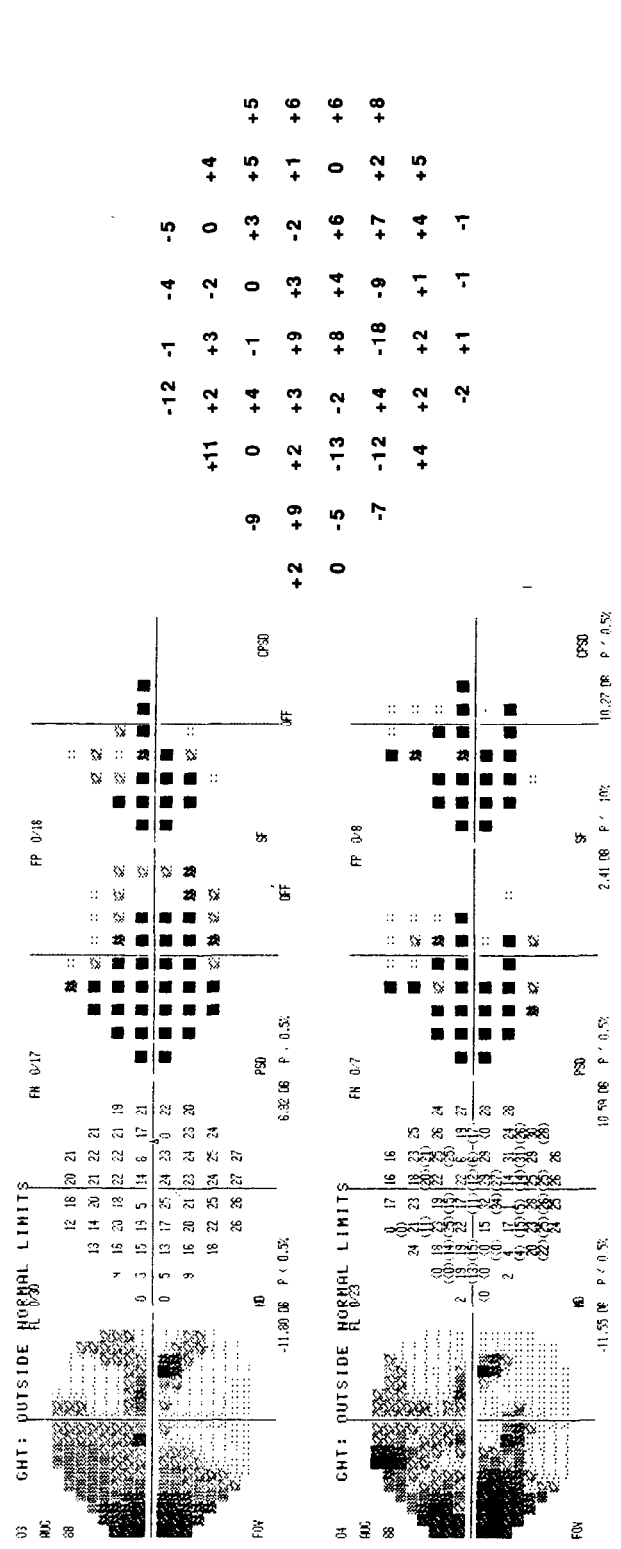


Fig. 3a-2. The corresponding forecasted (above) and measured (below) eighth fields. Note the marked difference between the forecasted and measured fields indicating episodic change.

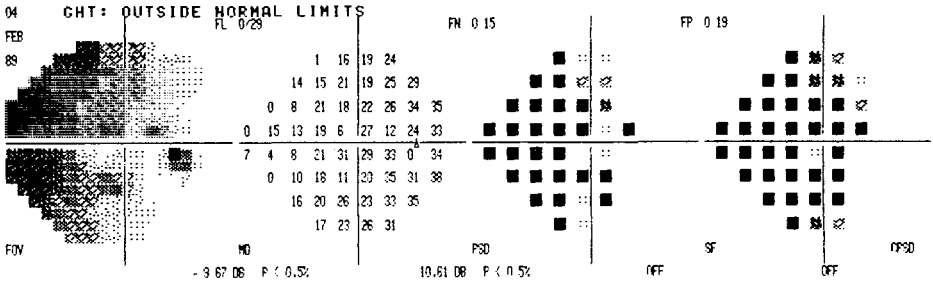


Fig. 3b. The corresponding forecasted ninth field.

References

1 Holmin C, Krakau CET: Visual field decay in normal subjects and in cases of chronic glaucoma. Graefe's Arch Clin Exp Ophthalmol 213:291-298, 1980
2. O'Brien C, Schwartz B: The visual field in chronic open angle glaucoma: the rate of change in different regions of the field. Eye 4:557-562, 1990
3 O'Brien C, Schwartz B, Takamoto T, Wu DC: Intraocular pressure and the rate of visual field loss in chronic open angle glaucoma. Am J Ophthalmol 111:491-500, 1991
4. Chauhan BC, Drance SM, Douglas GR: The use of visual field indices in detecting changes in the visual field in glaucoma Invest Ophthalmol Vis Sci 31:512-530, 1991
5. Wild JM, Hussey MK, Flanagan JG, Trope GE: Pointwise topographical and longitudinal modelling of the visual field in glaucoma. Invest Ophthalmol Vis Sci (in press)

Progression of chromatic and achromatic sensitivity loss in early glaucoma

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Abstract

In this study, the authors carried out prospective longitudinal measurements of spectral increment thresholds of the central field with a Maxwellian view optical system over five years, to clarify the time course of chromatic and achromatic luminance sensitivity in patients with early glaucoma. Twelve glaucoma patients and 20 age-matched normal controls were studied by means of spectral increment threshold measurements at the fovea with a 1-degree spectral test target flashed at either 1 Hz (200 msec duration) or at 25 Hz (10 msec duration) on a 1000 photopic troland white background. As a result, spectral increment threshold measurements showed that progressive loss of sensitivity of 1 Hz, especially in the range of the short wavelength, and 25 Hz stimulation was detected These results suggest that the progressive impairment of chromatic channels, especially in the short wavelength and luminance channels may occur in patients with early glaucoma

Introduction

In has been known that color vision changes occur early in the time course of glaucoma. Some studies[1,2] showed that as high as 80% of glaucoma patients have disturbed color discrimination, usually described as "blue-yellow" defects. Lakowski and Drance[3] also showed that about 20% of ocular hypertensive patients show severe color vision defects; they consider losses in color vision to be an important risk factor in the transition of ocular hypertension to chronic simple glaucoma, and color vision defects may be apparent before visual field defects.

The detection of flicker of a spectral light on an intense white background is mediated by chromatic pathways for low flicker rates and by achromatic pathways for high alternation rates[4,5].

In this study, we carried out prospective longitudinal measurements of spectral increment thresholds of the central field with a Maxwellian view optical system over five years to clarify the time course of chromatic and achromatic luminance sensitivity in patients with early glaucoma.

Methods

A three-channel Maxwellian view optical system with a 500 W xenon arc as a light source was used in this study (Fig. 1). A circular test light of 1-degree diameter was superimposed on the center of a 5-degree white background field of 1000 photopic trolands. For the test light,

Table 1. Stimulus conditions to test chromatic channel and achromatic (luminance) channel

	Chromatic channel	*Achromatic (luminance) channel*
Channel	Red-green channel	V (λ)
	Blue-yellow channel	V′ (λ)
Ganglion cells	Tonic	Phasic
	Sustained	Transient
Stimulus duration	Long (200 msec)	Short (10 msec)
Stimulus frequency	Low (1 Hz)	High (25 Hz)
Temporal resolution	Poor	Good

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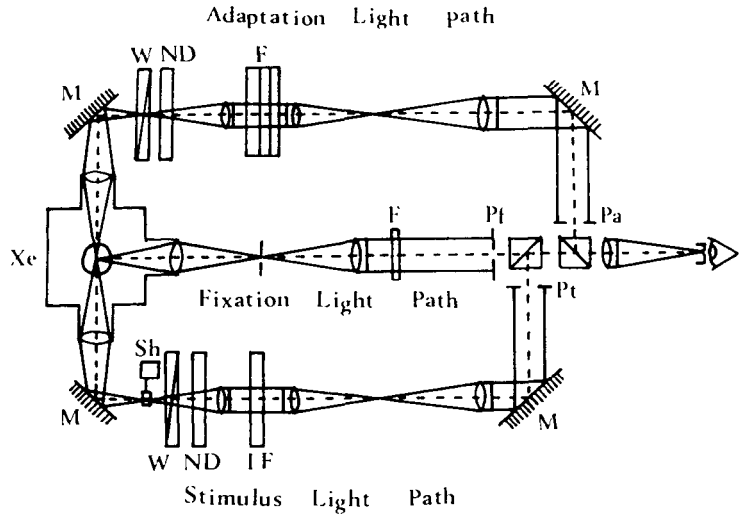

Fig 1. Block diagram of a three-channel Maxwellian view optical system. Xe: xenon lamp; ND: neutral density filter; W: optical wedge; M: mirror; Sh: shutter; IF: interference filter; Pt: stimulus pattern; Pa: adaptation pattern: PF: fixation pattern

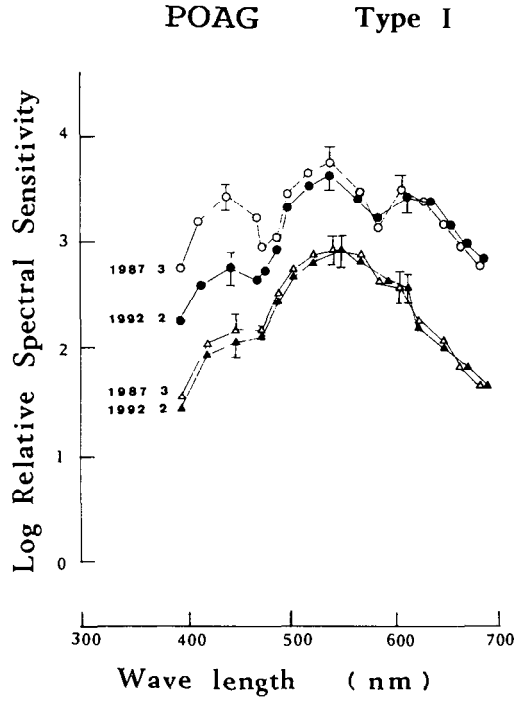

Fig. 2. Spectral sensitivity curves in a patient with early glaucoma. A selective reduction of chromatic sensitivity in the short wavelength over five years can be seen. The stimulus duration and frequency of the upper two curves were 200 msec and 1 Hz, and those of the lower curves 10 msec and 25 Hz, respectively. The luminance of white background was 1000 photopic trolands.

interference filters with dominant wavelengths of between 380 and 701 nm with 8 to 18 nm half-band widths were used. Two kinds of stimulus were used (Table 1). The stimulus duration and frequency of the first experiment were 200 msec and 1 Hz and of the second experiment 10 msec and 25 Hz. After viewing a 5-degree white background for five minutes, the subject was asked to detect a centrally fixated spectral test spot. The radiance of the test spot was decreased until the spot no longer flickered.

Twelve early glaucoma patients (age range 36 to 56 years, mean age 48.2) and 20 normal subjects (age range 35 to 57 years, mean age 47.3) were studied by means of spectral increment threshold measurements at the fovea with a 1-degree spectral test target flashed at either 1 or 25 Hz on a bright white background and with the source filaments focused into the plane of the observer's pupil. Annual examination of spectral increment threshold measurements was made for all subjects during the five years. The visual field was examined with a Goldmann perimeter and a Humphrey Field Analyzer every six months. Simultaneous stereo-fundus photography was also carried out every six months.

Results

Compared to an age-matched group of normals (n=20, mean age 47.3), chromatic and achromatic spectral sensitivity functions for early glaucoma (n=12, mean age 48.2) showed a marked progressive sensitivity loss in chromatic processing especially in the range of short wavelengths and also progressive sensitivity loss in luminance processing.

In 12 early glaucoma patients, all having a visual acuity better than 20/20, we have found two types of reduction in sensitivity for chromatic (1 Hz flicker) sensitivity and achromatic (25 Hz flicker) sensitivity. In the first group of five patients with early glaucoma or glaucoma

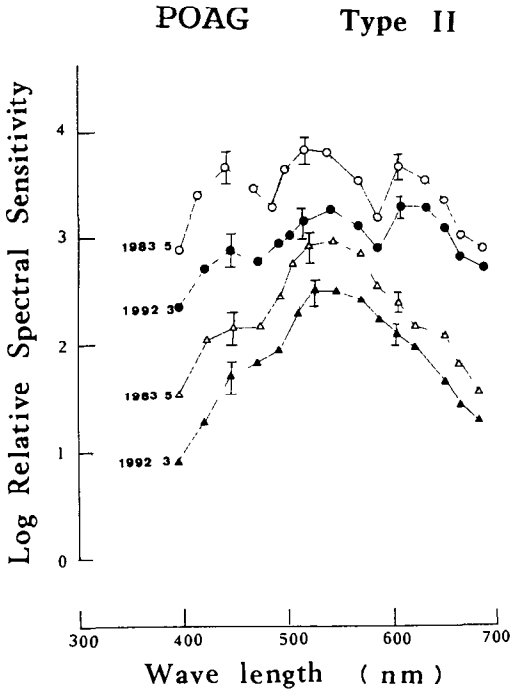

Fig. 3. Spectral sensitivity curves in a patient with early glaucoma. An overall reduction in chromatic sensitivity for all wavelengths together with a loss in achromatic sensitivity over nine years can be seen. The stimulus duration and frequency of the upper two curves were 200 msec and 1 Hz, and those of the lower curves 10 msec and 25 Hz, respectively. The luminance of white background was 1000 photopic trolands.

suspects (mean deviation with Humphrey Field Analyzer ≤5 dB), we found a selective reduction of chromatic sensitivity in the short wavelengths without any loss in luminosity function or chromatic sensitivity in middle and long wavelengths (Fig. 2). In the second group of seven patients with early glaucoma (mean deviation with Humphrey Field Analyzer ≤10 dB), we found an overall reduction in chromatic sensitivity for all wavelengths and also a loss of achromatic sensitivity (Fig. 3). Annual measurements of the spectral increment threshold during the five years showed progressive loss of both chromatic sensitivity for all wavelengths, especially the short wavelength, and achromatic sensitivity for all wavelengths, in ten of 12 early glaucoma patients (Fig. 3).

These results suggest that the progressive impairment of chromatic channels, especially in the short wavelength, and luminance channels may occur in patients with early glaucoma.

Discussion

It has been found that the spectral sensitivity curve for a low temporal frequency test flash on an intense white background shows three peaks which are at about 440 nm, 530 nm and 610 nm. The peak near 440 nm can be accounted for by the action of blue cones, while the narrowed peaks at about 500 nm has been attributed to linear subtractive interaction between the green and the red cones[6-8]. It has recently been proposed that the three peaks of the normal curve for low temporal frequency test flashes reflect the activity of the opponent-color system, whereas the single peak for high temporal frequency flicker detection is related to the luminance system[4,5].

Applying the spectral sensitivity measurements on a white background during the five years of the study, we have found that although there was a loss in sensitivity for both chromatic and achromatic systems, there was a progressive and most prominent loss of a chromatic sensitivity in the short wavelength region in most cases of early glaucoma. Consequently, it was felt that the blue cone system was much more vulnerable in most early glaucoma patients. But, it could be argued that some of the sensitivity loss observed at the short wavelength end of the spectrum may have resulted from an increase in the inert yellow pigments of the eye. These pigments are primarily the macular pigment and the pigmentation of the crystalline lens. But, our data argue against this possibility because the selective chromatic sensitivity loss in the short wavelength region was found without achromatic sensitivity loss in some early glaucoma cases. If a short wavelength attenuation occurred due to inert pigments, this should have been reflected in the achromatic sensitivity data at short wavelengths. The preceding observation of the progressive deterioration of sensitivity of 1 Hz stimulation in the range of short wavelengths may be interpreted in terms of a specific loss of the subject's opponent-color system and this could explain his poor color discrimination. Color vision changes are relatively early changes found in glaucoma. In this paper, we presented the results of a prospective longitudinal measurement of spectral increment thresholds of the central field with a Maxwellian view optical system over five years in early glaucoma patients, and we found that the blue-cone system was much more vulnerable in most early glaucoma patients.

There is considerable evidence for some separation of chromatic and achromatic information in the visual system[4,5,9-11]. Recently, De Monasterio and Gouras[12] have shown that there are two groups of ganglion cells in the rhesus monkey, (tonic) or X cells which are organized opponently for color information and (phasic) or Y cells which are non-opponent and organized to carry achromatic information.

The detection of flicker of a spectral light on a white background appears to be mediated by chromatic pathways for low flicker rates and by achromatic pathways for high flicker rates[5]. Inasmuch as chromatic and achromatic activity are carried by two different populations of ganglion cells, our results suggest that most early glaucoma patients have a selective loss of integrity of the pathways served by the tonic ganglion fibers at first and then a loss of integrity of the pathways served by both types of ganglion cells.

Acknowledgements

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References

1. Fishman GA, Krill A, Fishman M: Acquired color defects in patients with open-angle glaucoma and ocular hypertension Mod Probl Ophthalmol 13:335-338, 1974
2. Lakowski R, Bryett J, Drance SM: A study of colour vision in ocular hypertensives. Can J Ophthalmol 7:86-95, 1972
3. Lakowski R, Drance SM: Acquired dyschromatopsias: the early functional losses in glaucoma. Doc Ophthalmol Proc Ser 19:159-165, 1979
4. King-Smith PE: Visual detection analyzed in terms of luminance and chromatic signals. Nature 225:69-70, 1975
5. King-Smith PE, Kranda K, Wood ICJ: An acquired color defect of the opponent color system Invest Ophthalmol Vis Sci 15:584-587, 1976
6. Krande K, King-Smith PE: Detection of coloured stimuli by independent linear system. Vision Res 9:733-745, 1979
7. Sperling HG, Harwerth RS: Red-green cone interactions in the increment-threshold spectral sensitivity of primates. Science 172:180-184, 1971
8. Thornton JE, Pugh EN Jr: Red/green color opponency at detection threshold. Science 219:191-193, 1983
9. De Valois RL, Abramov I, Jacobs GH: Analysis of response patterns of LGN cells. J Ophthalmol Soc Am 56:966-977, 1966
10. Wiesel TN, Hubel DH: Spatial and chromatic interactions in the lateral geniculate body of the rhesus monkey. J Neurophysiol 29:1115-1156, 1966
11. Gouras P: Identification of cone mechanisms in monkey ganglion cells. J Physiol 199:533-547, 1968
12. De Monasterio FM, Gouras P: Responses of macaque ganglion cells to far violet lights. Vision Res 17:1147-1156, 1977
13. Anthony JA, Frank Z, Rosemary R, John CC: Chromaticity and luminosity changes in glaucoma and diabetes. Doc Ophthalmol Proc Ser 33:413-418 1982
14. Anthony JA, Rosemary R, Roger H, Robert S: Spectral sensitivity and color discrimination changes in glaucoma and glaucoma-suspect patients. Invest Ophthalmol Vis Sci 23:516-524, 1982

Discrimination between progression and non-progression visual field loss in low tension glaucoma using MDT

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Abstract

Low tension glaucoma patients who had good sensitivity in at least one portion of the visual field measured by the Humphrey Field Analyzer were followed over a period between 1986 and 1992 Motion detection thresholds (MDT) were measured in the more normal part of the visual field and visual field progression was analyzed by pointwise linear regression analysis using Progressor software. The patients were divided into those with initially normal MDT (22 patients) and those with initially abnormal MDT (40 patients). Significant progression was found after four years in 10/22 (45%) with initially normal MDT while 30/40 (75%) with initially abnormal MDT showed significant progression. MDT and pointwise linear regression analysis may be helpful in following these patients.

Introduction

Despite advances in quantitative measurements of the visual field, the optic nerve head and the nerve fiber layer, these cannot always provide an early assessment of progression or non-progression of visual field loss in glaucoma patients[1-4]. We have previously shown that motion detection thresholds (MDT) may be abnormal in ocular hypertension, in patients with large disc cup ratios, early glaucoma and normal fellow eyes of low tension glaucoma patients even when their computerized visual fields were considered normal[5-8]. This may be related to preferential losses of large ganglion cells in glaucoma[9] and their role in magnocellular function which is thought to underlie motion detection[10]. The mode of progression of visual field defects in high tension glaucoma has been studied by various methods, but little is known about the progression of visual field defects in low tension glaucoma[11,12]. The aim of this study was to test the hypothesis that MDT may predict early visual field progression in a group of low tension glaucoma patients. In this study we investigated how visual field progression in low tension glaucoma is related to MDT in patients with asymmetrical hemifield defects.

Material and methods

Low tension glaucoma patients with hemifield defects attending the glaucoma unit at Moorfields Eye Hospital were selected from our visual field database. The criteria for the diagnosis of low tension glaucoma (LTG) were:

1. mean IOP of less than 21 mmHg and maximal IOP less than 24 mmHg on two-hourly in-hospital 24-hour intraocular pressure curves;
2. glaucomatous optic disc cupping and nerve fiber loss;
3. open angle by gonioscopy;
4. absence of any other ocular or neurological pathology, and
5. visual field defects.

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Visual fields measured by program 30-2 or 24-2 of the Humphrey Field Analyzer (HFA) were considered to be abnormal if there was one location or more with a dB loss from the corrected pattern standard deviation (CPSD) of 10 dB or more. A field was considered unreliable if 20% or more fixation losses or more than 30% false positive or false negative responses were recorded. In addition this patient group was selected for having good HFA visual field sensitivity in at least one hemifield. All patients had MDT measured in the better hemifield at 15 degrees eccentricity on either the 330- or 30-degree meridian just above or below the blind spot. The Progressor visual field statistical analysis package was used to determine whether there was statistically significant worsening at each visual field location[12].

One observer measured MDT without knowledge of patient status except that the testing location for MDT was chosen to be in an area of the Humphrey visual field where thresholds were within 10 dB of normal. The testing procedure has previously been described[5-8]. The cutoff for abnormal motion sensitivity was eight minutes of arc.

For each patient, clinical data recorded included age, visual acuity, IOP, cup disc ratio and MDT. All Humphrey results were analyzed by Progressor with a personal computer. The follow-up clinical data were collected from each patient's Humphrey visual field records. They all were experienced patients who had visual fields and routine eye examination at approximately four monthly intervals. The mean of the HFA values from the CPSD at the four locations surrounding the MDT test location were used as the measure of sensitivity for the MDT cluster.

The patient group included 62 low tension glaucoma patients of which 23 (37%) were male and 39 (63%) female with a mean age of 63.9±8.9 years (range 42-80). Neurological disease was ruled out in each case. No patient was undergoing any anti-glaucoma treatment. All had a visual acuity of 6/9 (20/30) or better and with no detectable lens opacity at the time of visual field testing. One eye per patient (26 right, 36 left) was used for further statistical analysis. All patients were experienced in automated static perimetry, had approximately three computerized fields per year and at least six fields over a mean follow-up period of 3.7 years (range 2-5 years). Twenty-two (36%) patients had normal MDT and 40 (64%) had abnormal MDT. The average of four locations from the MDT testing cluster was used to compare MDT with HFA sensitivity.

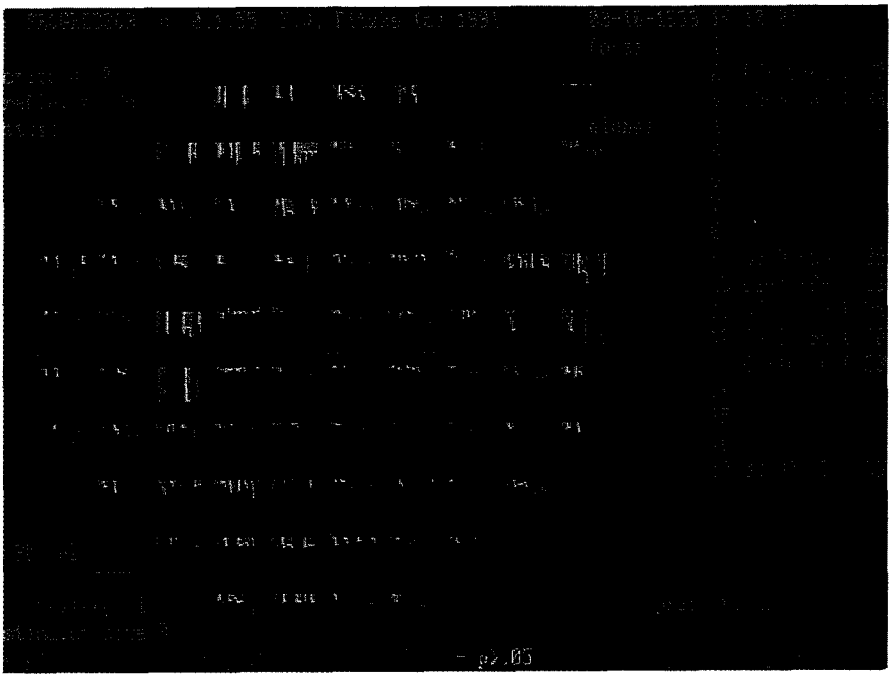

Fig. 1. Pointwise linear regression analysis from Progressor for one eye over a period from 1986 to 1992 with 17 visual fields The length of the bars represents dB loss (see calibration scale in figure) at each location over time. Significant progression determined by linear regression analysis is indicated by red (95%) or bright red (99%).

Criteria for visual field progression

The definition of progression of visual field loss was based on the following:

1. Three consecutive fields with progression in at least one location at $p<0.01$ defined by the Progressor histogram summary with no locations showing improvement at $p<0.01$ (*e.g.*, due to learning effects); or
2. Two or more locations showed significant losses in the better hemifield at $p<0.05$ on the last two fields by Progressor and there was at least one location of one field with progression with no locations showing improvement ($p<0.01$).

All other possibilities were considered to indicate a stable field.

The right eye was usually tested first for all the psychophysical tests including MDT and HFA. In order to limit any learning effects, the left eye was selected when patients had asymmetrical defects in both eyes. All clinical data were processed using a spreadsheet (Quattro 3.5). Data analysis included Cox proportional hazards survival analysis which was carried out using the Epidemiological Graphics, Estimation, and Testing software (EGRET Version 1.81).

Results

Fig. 1 shows the results of the Progressor pointwise analysis for one patient. This shows the results from the left eye of 17 visual fields measured between 1986 and 1992. This patient began with a superior visual defect but with many locations in the inferior hemifield initially

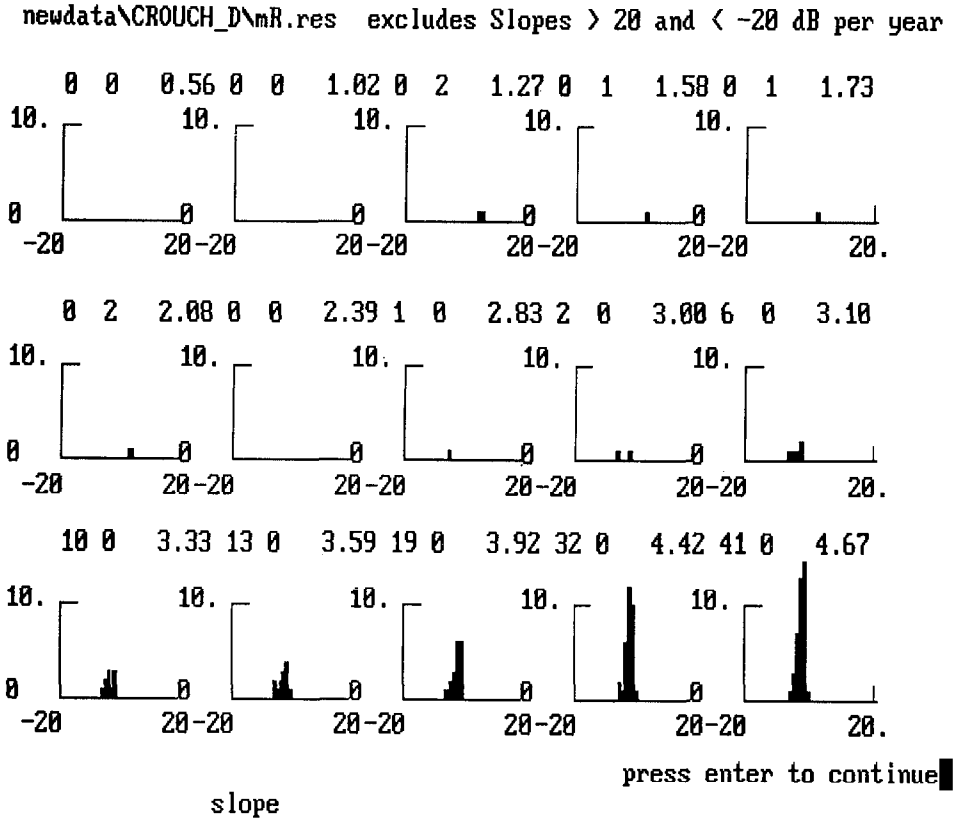

Fig. 2. Progressor histogram summary of number of locations showing significant change at the 99% level from another patient. Each panel represents the results for one visual field beginning with field number three. Green represents improvement and red worsening with the corresponding slopes for each on the abscissa.

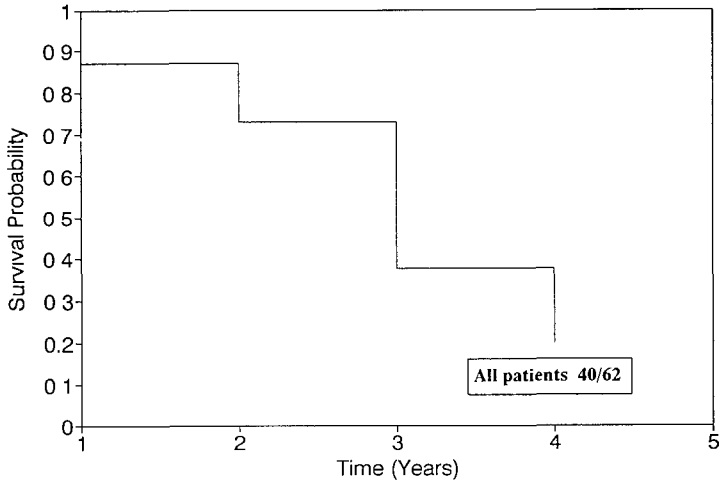

Fig. 3 Survival probability of visual fields plotted *versus* time in years.

within 10 dB of normal. MDT in the inferior hemifield was abnormal (9.66 minutes of arc). After a period of two to three years, significant worsening was found at several locations in both the superior and the initially normal inferior hemifields.

Fig. 2 shows the results of the Progressor histogram summary analysis showing the number of locations at each field beginning with the third field which shows significant losses. The number of locations showing significant progression increases over a period of two to three years.

There were no significant differences in age, sex, years of follow-up, or number of fields between the two groups, shown in Table 1. Twenty-two patients (35%) had initially normal and 40 (64%) abnormal MDT. Differences between the two groups for the MDT and for the mean sensitivity at the four locations surrounding the MDT test location were significant. Forty-seven eyes (75.8%) had better lower and 15 eyes (24.2%) had better upper hemifields.

Fig. 3 shows the overall survival analysis according to the Kaplan-Meier method. Both groups showed deterioration of visual fields, but those with normal MDT had longer survival compared to those with abnormal MDT. According to the Kaplan-Meier method, the one-year survival probability for all patients was estimated at 87.9% (confidence interval (CI) 75.9-93.3%), the two-year survival probability at 73% (CI 56-83%) and the four-year survival was 20% (CI 9.6-34%).

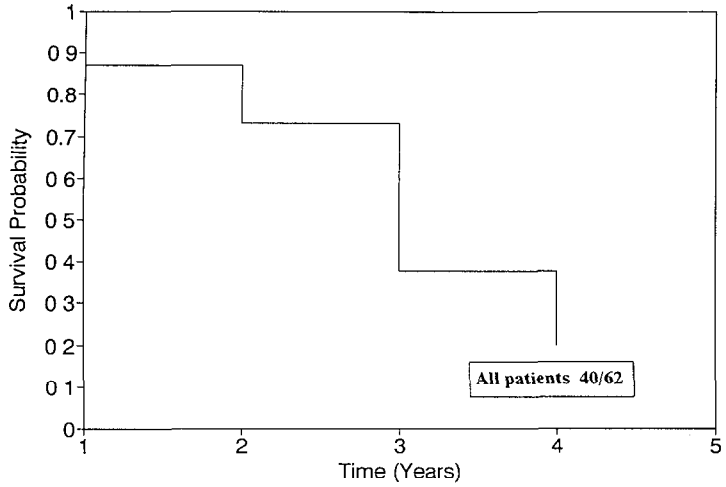

Fig. 4. Survival probability of visual fields plotted *versus* time in years for patients with initially normal MDT and initially abnormal MDT.

Table 1. Demographics of study population

		Normal MDT (n=22)	*Abnormal MDT (n=40)*	*P*
Age	Mean (SE)	63 9 (2 14)	66.2 (1.212)	0.377
Sex	No. (%)			
	Male	6 (27)	12 (36)	
	Female	16 (72)	28 (70)	0.828
Follow-up (months)		41 (3.28)	41 (2.7)	0.488
Number of fields		12.4 (0 84)	13.67 (0.73)	>0.1
		mean (SE)	*mean (SE)*	
dB in MDT cluster		1.67 (0.21)	3.825 (0.815)	0.000
MDT (minutes of arc)		6.428 (0.245)	10.37 (0 815)	0 000

Table 2. Kaplan-Meier Estimator by clinical group

Year	*Normal motion*		*Abnormal motion*	
	survival probability	*(95% CI)*	*survival probability*	*(95% CI)*
1	0.91	(0.68, 0.98)	0 85	(0.70, 0.93)
2	0 86	(0.63, 0.95)	0 66	(0 48, 0 78)
3	0 70	(0 45, 0.85)	0.18	(0.07, 0.33)
4	0.34	(0 14, 0 62	0.09	(0.02, 0.24)

Table 2 shows the Kaplan-Meier estimates of status of survival probability for patients with abnormal MDT and normal MDT. Patients with abnormal MDT were more likely to have progressive visual field loss than those with normal MDT (Fig. 4). The decrease of survival probability among patients with abnormal MDT compared with those with normal MDT was apparent by the third year of follow-up.

At the end of the study period, 10/22 patients with initially normal MDT showed HFA progression while 30/40 of those with initially abnormal MDT showed HFA progression.

Discussion

Visual field defects in low tension glaucoma patients are usually bilateral and sometimes both horizontal upper and lower hemifields are affected. The morphology and pathology of this condition is unclear as is the speed and the rate of visual field progression. Progression may continue for many years during a patient's life time. The early prediction of progression or survival of visual field is very important for glaucoma management but it is difficult to find the best method to measure field progression. Our data have shown that 90% of eyes in this study had no visual field progression in the first year. This did not mean that there was no deterioration since small changes are difficult to detect by standard methods. With the aid of motion sensitivity, we may improve our ability to predict which visual fields will progress. Our results have shown that eyes with normal MDT had a longer survival time than those with abnormal MDT.

References

1. Glicklich RE, Steinman WC, Spaeth GL: Visual field change in low-tension glaucoma over a five-year follow-up. Ophthalmology 96:316-320, 1989
2. Takamoto T, Schwartz B: Reproducibility of photogrametric optic disc measurements. Invest Ophthalmol Vis Sci 26:814, 1983
3. Peli E, Hedges TR, McInnes T, Hamlin J, Schwartz B: Nerve fiber layer photography: a comparative study. Acta Ophthalmol 65:71, 1987

4. Levene RZ: Low tension glaucoma: a critical review and new material. Surv Ophthalmol 24:621-664, 1980
5 Fitzke FW, Poinoosawmy D, Ernst W, Hitchings RA: Peripheral displacement thresholds in normals, ocular hypertensives and glaucoma. In: Greve EL, Heijl A (eds) Seventh International Visual Field Symposium, pp 447-452. Dordrecht: Nijhoff/Dr Junk 1987
6. Fitzke FW, Poinoosawmy D, Nagasubramanian S, Hitchings RA: Peripheral displacement thresholds in glaucoma and ocular hypertension. In: Heijl A (ed) Perimetry Update 1988/89, pp 399-405. Amsterdam: Kugler Publ 1989
7 Poinoosawmy D, Hitchings RA, Fitzke FW, Nagasubramanian S: Motion detection thresholds in early normal-tension glaucoma. In: Bechetoile A (ed) Normal Pressure Glaucoma, pp 248-251. Paris: Japprenard 1991
8 Poinoosawmy D, Fitzke FW, Wu JX, Hitchings RA: Motion detection threshold may be used to predict conventional visual field loss in low-tension glaucoma suspects. Invest Ophthalmol Vis Sci (Suppl) 33:1278, 1992
9. Quigley HA, Sanchez RM, Dunkeburger GR, Henaut NL, Baginski TA: Chronic glaucoma selectively damage large optic nerve fibers Invest Ophthalmol Vis Sci 28:913-918, 1987
10 Livingstone MS, Hubel DH: Psychophysical evidence for separate channels for perception of form, color, movement and depth J Neurosci 7:3416-3468, 1987
11 Gramer E, Althaus G: Quantifizierung und Progredienz des Gesichtsfeldschadens bei Glaukom ohne Hochdruck, Glaucoma simplex und Pigmentglaukom Klin Mbl Augenheilk 191:184-198, 1987
12. Noureddin BN, Poinoosawmy D, Fitzke FW, Hitchings RA: Regression analysis of visual field progression in low tension glaucoma. Br J Ophthalmol 75:495-495, 1991

Analysis of the progression of visual field changes in low tension glaucoma

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Abstract

Because not much is yet known about patients with low tension glaucoma who have progressive visual loss, the authors retrospectively examined the prevalence of progression of visual field defects, and the influence of intraocular pressure on progression, in patients with low tension glaucoma who had been followed in their clinic for at least two years With *t* test analysis, progression of visual field defects was found in 25 of 47 eyes (53 2%), while linear regression analysis revealed progression in 25 of 42 eyes (59.5%) There was no difference between those patients with progression and those without progression in terms of age, incidence of disc hemorrhage, and various intraocular pressure indices Furthermore, no statistically significant correlation was observed between the intraocular pressure indices and the regression slopes in those patients with progression as judged by linear regression analysis These results indicate that progression of visual field defects occurred in just over one-half of the patients, and suggest that intraocular pressure has little influence on such progression

Introduction

In 1857, Von Graefe noted that some patients had optic disc cupping and pallor despite normal intraocular pressures. Since then, many studies have reported the characteristics of visual field defects in low tension glaucoma (LTG)[1], as well as differences in visual field defects between LTG and high tension glaucoma[2-4]. However, not much is known about the prevalence of progression and the ocular characteristics of progression in patients with LTG[5-9].

In this study, we retrospectively analyzed visual fields measured by the Octopus 31 program or the Humphrey 30-2 program to determine the prevalence of progression of visual field defects in LTG and to study the effect of intraocular pressure on progression of visual field defects in this disease.

Patients and methods

We studied 47 eyes of 26 patients with LTG whose visual fields had been examined for more than two years. All patients had been treated with topical medical therapy for glaucoma but had not undergone any laser treatment or surgery. Patients were seen at three-monthly intervals in our outpatient department. At each visit, intraocular pressure was measured with the Goldmann tonometer and optic discs were assessed by slit-lamp biomicroscopy. Automated perimetry with the Octopus or the Humphrey analyzer was performed every six to 12 months.

Fulfillment of all of the following criteria was necessary for the diagnosis of LTG:

1. open angle;
2. intraocular pressure of 21 mmHg or less including diurnal variation;
3. glaucomatous disc cupping;
4. glaucomatous visual field defects; and
5. no other diseases affecting the visual fields.

Progression of visual field defects was identified by means of two different methods of analysis as follows.

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Method 1

Initial and final visual fields in patients who were examined using the Octopus 31 program were compared with the Delta program. Significant deterioration of the mean threshold of the whole field or of pathological areas was defined as progression.

For patients tested using the Humphrey 30-2 program, final visual fields were analyzed by mean defect (MD) change probability with STATPAC 2. Visual fields with significant deterioration in MD were also defined as progression.

Age, intraocular pressure indices (maximum, minimum, range, mean, and standard deviation), and incidence of disc hemorrhage in patients with progression were compared to those without progression (unpaired t test and χ^2 test).

Method 2

Out of 47 eyes of 26 patients, 42 eyes of 23 patients whose visual fields had been examined more than five times were subjected to linear regression analysis in order to estimate progression. Regression coefficients in patients who were examined by the Octopus 31 program were obtained from the mean threshold per test point in dB for each region (whole field, four quadrants, and three eccentricities in the series mode of the Delta program) *versus* time in months. Regression slopes were also calculated in the same manner in patients who were followed using the Humphrey 30-2 program.

Based on statistical significance of the regression slopes ($p<0.05$) in the whole field and in the seven defined regions, the trends in a sequence of visual fields were divided into three categories: whole field progression, regional progression, and no progression.

Various intraocular pressure indices were compared between the three categories. In addition, correlation between the regression slopes and intraocular pressure indices for whole field and regional progression categories were calculated in order to determine the influence of intraocular pressure on progression (correlation coefficient, p value)[9].

Results

Results with method 1

Forty-seven eyes of 26 patients (mean age 66.2 ± 11.7 years; range 35-81 years) were followed up for a mean of 49.0 ± 14.3 months. Progression of visual field defects was judged to have occurred in 25 of 47 eyes (53.2%); 14 of 23 eyes with the Delta program and 11 of 24 eyes with STATPAC 2. There was no difference between the groups with and without progression in terms of age, follow-up period, intraocular pressure indices, or incidence of disc hemorrhage (Table 1).

Table 1. Age, follow-up period, IOP indices, and incidence of disc hemorrhage in progression and no-progression groups

	Visual fields with progression (n=25)	*Visual fields with no progression (n=22)*
Age (years)	62.8±11.6	58.8±10.2
Follow-up (months)	49.6±14 5	48.7±14.4
IOP (mmHg)		
maximum	18.1± 2.0	17.3± 2 0
minimum	10.6± 1.7	10.4± 1.6
mean	14.0± 1.3	14.4± 1.4
range	7.5± 2.6	7.0± 1.4
SD	1.9± 0.4	1.8± 0.3
Disc hemorrhage (eyes)	5	10

Results with method 2

Forty-two eyes of 23 patients who underwent more than five consecutive visual field examinations during the follow-up period were subjected to linear regression analysis. Twenty-three eyes of 13 patients were followed up with the Octopus 31, and 19 eyes of ten patients with the Humphrey 30-2. Patients (mean age 61.3 ± 11.3 years) underwent a mean of 7.3 ± 2.1 visual field examinations and were followed up for a mean of 55.3 ± 14.9 months.

Regression analysis of the whole field revealed a statistically significant negative slope in seven eyes examined with the Octopus 31 and in three eyes examined with the Humphrey 30-2. The mean slope was -0.062 ± 0.032 dB/month, with a range of -0.016 to -0.148 dB/month, and those eyes were considered to have progressive LTG (labeled whole field progression). Fifteen eyes had statistically significant negative slopes in one or more of the seven regions but not in the whole field, and those eyes were also considered to have shown progression (labeled regional progression). Therefore, a total of 25 of 42 eyes (59.5%) showed some type of progression. Seventeen eyes did not have statistically significant negative slopes in either the seven regions or in the whole field, and were labeled no progression. Furthermore, five eyes showed statistically significant, although small, positive slopes in at least one of the seven regions, and those eyes were included in the no progression category.

Table 2 displays a comparison of the three categories in terms of age, number of visual field tests, follow-up period, incidence of disc hemorrhage, and various intraocular pressure indices.

Table 2. Age, number of visual field tests, follow-up period, IOP indices and incidence of disc hemorrhage in whole field progression, regional progression, and no-progression groups

	Whole field progression (n=10)	*Regional progression (n=15)*	*No progression (n=17)*
Age (years)	59.6±15 6	64.3± 8.5	60.3±10.7
No. of visual field measurements	8.9± 2.2	7.1± 2.2 *	6 6± 1.5
Follow-up (months)	63.2±13.9	56.0±16.9	49 9±11 9
IOP (mmHg)			
maximum	18 5± 2.6	18.1± 1.9	17.2± 1.8
minimum	10.8± 1.6	10.9± 1.8	10.0± 1.4
mean	14.4± 1.5	14.4± 1.4	13.6± 1.1
range	7.7± 2.7	7.1± 2.2	7.2± 1.9
SD	1 9± 0.4	1.8± 0.3	1.9± 0.4
Disc hemorrhage (eyes)	4	5	6

*$p<0.05$

Table 3. The mean regression slopes of the three categories in the whole field and in the seven regions

	Whole field progression (n=10)	*Regional progression (n=15)*	*No progression (n=17)*
Whole field	-0.061±0.036	-0.028±0.037 *	-0 001±0.049
Upper nasal	-0.045±0.044	-0.026±0.061 *	-0.010±0.080
Lower nasal	-0.077±0.059	-0.032±0.059	-0.002±0.087
Upper temporal	-0.061±0.038	-0.025±0.054 *	-0.005±0.032
Lower temporal	-0.050±0.054	-0.025±0.039 *	0.016±0.054
0~10°	-0.106±0.082	0.007±0.216 *	-0.024±0.080
10~20°	-0.071±0.046	-0.035±0.027 *	-0.015±0.060
20~30°	-0.047±0.033	-0.015±0.054	0.013±0.044

*$p<0.05$

The mean regression slopes in each region for the three categories are listed in Table 3. There was a difference in the number of field tests and the mean slopes but not in the intraocular pressure indices.

The correlation between the regression slopes of each region and the intraocular pressure indices were calculated to evaluate the effect of intraocular pressure on progression in the whole field progression and regional progression categories. We did not find a reasonable correlation in either (Table 4). There were statistically significant correlations between increasing intraocular pressure and visual field improvement in a few categories, however, we dismissed these as spurious results.

Table 4 The correlation coefficients and *p* values between regression slopes and intraocular pressure indices of whole field progression and regional progression groups. *P* values mean the level of significant from zero

		Maximum	*Minimum*	*Range*	*Mean*	*SD*
Whole field progression (n=10)						
Whole	r	-0.192	0.126	-0 262	0.089	-0.203
field	p	0 595	0.729	0.464	0.807	0.574
Upper	r	-0.048	0.091	-0.101	0.131	-0.220
nasal	p	0.896	0.803	0.782	0 719	0 542
Lower	r	-0.178	0 027	-0 189	0.086	-0.194
nasal	p	0.622	0.094	0 600	0.814	0 592
Upper	r	0.044	0 262	-0.114	0.225	0.095
temporal	p	0.905	0 465	0.754	0.532	0.795
Lower	r	-0 198	0.224	-0 326	0.046	-0 139
temporal	p	0.584	0 533	0.358	0.090	0.701
0~10°	r	-0.233	0.110	-0.292	0.065	-0.121
	p	0.517	0.763	0 413	0.866	0 739
10~20°	r	-0 043	0 186	-0.153	0.218	-0.066
	p	0.906	0.607	0.673	0.545	0.857
20~30°	r	-0.209	0.086	-0.254	0.035	-0.291
	p	0.563	0.813	0.478	0.923	0.415
Regional progression (n=15)						
Whole	r	0.327	0.386	-0 037	0.537	-0.230
field	p	0.234	0 156	0.897	0 039	0 410
Upper	r	0.002	0 174	-0.141	0.271	-0.315
nasal	p	0.993	0.535	0.616	0.330	0.253
Lower	r	0 167	0 171	0.002	0 258	-0 152
nasal	p	0.553	0.542	0.994	0.352	0.588
Upper	r	0.089	0.133	-0.033	0.149	-0.117
temporal	p	0 753	0.637	0.907	0 597	0.678
Lower	r	0.574	0.610	-0.010	0.727	-0.070
temporal	p	0.025	0.015	0.973	0.002	0.805
0~10°	r	0.127	0.095	0.031	0.126	0.035
	p	0.651	0 736	0.913	0.656	0.903
10~20°	r	0.198	0.085	0.100	0.239	0.068
	p	0.479	0.763	0.724	0.390	0 809
10~30°	r	0 289	0.369	-0.056	0.544	-0.273
	p	0 297	0.176	0.843	0.036	0.324

Discussion

It is often difficult to judge whether visual fields have shown progression or not over a period time, particularly in glaucoma patients. There are two ways in which to evaluate a change in visual field; one is by *t* test analysis and the other is by regression analysis. Analysis using the *t* test has disadvantages, including long-term fluctuation, which may result in different outcomes. In contrast, all perimetric data can be subjected to linear regression analysis, with the trend in a sequence of visual fields being deduced by examination of the regression slope. However, this method also has some disadvantages. More than five visual field tests are nec-

essary to determine an accurate trend, and long-term fluctuation can also affect the results.

In this study, the prevalence of progression in LTG was examined using both methods. *T* test analysis revealed progression in 25 of 47 eyes (53.2%). On the other hand, regression analysis revealed progression in ten eyes (23.8%) when the whole field was examined, and in 15 additional eyes (35.7%) when the seven regions were examined. Therefore, a total of 25 of 42 eyes (59.5%) analyzed by linear regression showed progression.

In comparison to our data, Chumbley and Brubaker[5] reported progression in 41% of 34 eyes with LTG, while Anderton *et al.*[6] observed progression in 40% of 56 patients using Goldmann perimetry. Glicklich *et al.*[7] reported progression in 53% of patients at a three-year follow-up and in 62% at a five-year follow-up using the Octopus. Nouredinn *et al.*[8] found progression in 37% of 168 eyes with LTG using the Humphrey analyzer. Each of these studies utilized different methods from the ones we used for estimating progression.

The influence of intraocular pressure on the progression of visual field defects in LTG has not been well delineated. Cartwright and Anderson[10] reported that intraocular pressures were higher in more seriously damaged eyes in patients with LTG whose eyes differed in degree of disease severity. Ito *et al.*[11] reported that intraocular pressure indices were higher in patients with LTG who showed progression compared to those who did not. In contrast, Glicklich *et al.*[7] and Nouredinn *et al.*[8] found no difference in intraocular pressure between progression and no-progression groups. We also found, in our study, that there was no difference in intraocular pressure indices between progressive LTG and no-progressive LTG. Furthermore, among patients with progression, no reasonable statistically significant correlation was observed between intraocular pressure indices and the regression slopes.

We conclude that, in our population of LTG patients, just over one-half showed progression of visual field defects over a two-year period when data were analyzed by two independent methods. Moreover, we found that progression of visual field changes in LTG did not correlate with intraocular pressure within the confines of the study.

References

1. Hitchings RA, Anderson SA: A comparative study of visual field defects seen in patients with low tension glaucoma. Br J Ophthalmol 67:818-821, 1983
2. Moltoko M, Drance SM, Douglas GR: Visual field defects in low tension glaucoma. Comparison of defects in low tension glaucoma and chronic open angle glaucoma. Arch Ophthalmol 97:730-737, 1984
3. Caporioli J, Spaeth DL: Comparison of visual field defects in low tension with those in high tension glaucoma Am J Ophthalmol 96:148-152, 1983
4. King D, Drance SM, Douglas GR, Schlzer M, Wigsman M, Hitchings RA: Comparison of visual field defects in normal tension glaucoma and high tension glaucoma. Am J Ophthalmol 101:204-207, 1986
5. Chumbley CC, Brubaker RF: Low tension glaucoma. Am J Ophthalmol 81:761-765, 1976
6. Anderton SA, Coakes RC, Poinoosawmy D, Clarke P, Hitchings RA: The nature of visual loss in low tension glaucoma. Doc Ophthalmol Proc Ser 42, 96:316-320, 1984
7. Glicklich RE, Steinman WC, Spaeth GL: Visual field change in low tension glaucoma over a five years follow up. Ophthalmology 96:316-320, 1989
8. Nouredinn BN, Poinoosawmy D, Fitzke FW, Hitchings RA: Regression analysis of visual field progression in low tension glaucoma. Br J Ophthalmol 75:493-495, 1991
9. O'Brien C, Schwartz B, Takamoto T, Wu DC: Intraocular pressure and the rate of visual field loss in chronic open angle glaucoma. Am J Ophthalmol 111:491-500, 1991
10. Cartwright MJ, Anderson DR: Correlation of asymmetric damage with asymmetric intraocular pressure in normal tension glaucoma. Arch Ophthalmol 106:898-900, 1988
11. Ito M, Sugiura T, Mizokami K: A comparative study on visual field defect in low tension glaucoma. Acta Soc Ophthalmol Jpn 95:790-794, 1991

Is diffuse visual field loss in low-tension glaucoma a prognostic indicator for progression?

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Abstract

Diffuse field loss may be a sign of intraocular pressure-dependent damage in glaucoma, and therefore a predictor of further progression in low tension glaucoma (LTG) patients. The authors studied the uninvolved hemifield (13 upper and 37 lower) in 50 LTG patients (mean age 65.1 years; Humphrey Field Analyzer, program 24-2) One masked observer retrospectively classified the uninvolved hemifield into four groups (normal (N) , localized loss (L), diffuse loss (D), combined diffuse and localized loss (DL)). Two different masked observers assessed the same hemifield after a follow-up of 50 9±14.3 months (range 25-75 months) using pointwise linear regression analysis to define progression. There was no statistical difference in the incidence of progression between the four groups (L=47.1%; D=46.2%; DL-50%; N=40% progressed). The diffuse component of visual field loss in the uninvolved hemifield did not allow prediction of further progression. The pressure dependence of diffuse loss in LTG remains questionable

Introduction

Low tension glaucoma (LTG) is defined as an optic neuropathy with typical glaucomatous visual field loss in the absence of increased intraocular pressure (IOP). Whereas the pathogenesis and morphology of glaucomatous disc changes may be different between LTG and primary open-angle glaucoma with increased IOP, *e.g.*, high tension glaucoma (HTG), the pattern of visual field loss in LTG is generally similar[1,2], although some differences in localization (preponderance of the upper hemifield), eccentricity or depth of scotomata may exist[3-6]. Two different types of visual field defects in HTG patients are characterized by automated static threshold perimetry, the localized and diffuse type. The nature of these two different types is unknown, but it is hypothesized that diffuse visual field damage is pressure dependent and localized pressure independent[1,7,8].

The mode of progression of visual field defects in HTG has been studied by various statistical methods, but little is known about the progression of visual field defects in untreated LTG patients[6,9].

The presence of diffuse visual field loss in LTG patients at the time of diagnosis may be a sign of intraocular pressure-dependent damage, and there for a strong predictor of further progression.

The aim of this study was to investigate this hypothesis.

Material and methods

Low tension glaucoma patients under the care of one of us (RAH) were selected from the visual field database of Moorfields Eye Hospital Glaucoma Unit. Our criteria for diagnosis of LTG were:

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1. a mean IOP of ≤21 mmHg and maximal IOP of ≤24 mmHg on two-hourly in-hospital 24-hour intraocular pressure curves;
2. glaucomatous optic disc cupping and nerve fiber loss;
3. open angle by gonioscopy;
4. absence of any other ocular or neurological pathology[9].

The average of the first two computerized visual fields (Humphrey Visual Field Analyzer programm 24-2) was used to select LTG patients with absolute or advanced relative arcuate scotoma in one horizontal hemifield and minimal visual field defects or normal visual fields in the other (uninvolved) hemifield.

One masked observer (JS) retrospectively classified the uninvolved hemifield into four different groups:

1. Localized defects only (L): (Fig. 1) A cluster of three or more but maximal six points depressed >5 dB, or two points depressed ≥10 dB, or a nasal step consisting of ≥2 points with ≥8 dB loss were present. In the cumulative defect curve[10], a typical drop at the right hand side had to be observed. The mean defect in the hemifield (MD) did not exceed -2 dB, if the points with localized defects were excluded.
2. Diffuse sensitivity loss (D): (Fig. 2) None of the above defined signs of localized loss were present. The MD was ≤-2 dB with standard deviation of (SD) ≥3.0 dB. The range between the point with minimal and maximal loss was <10 dB.
3. Combination of localized and diffuse loss (DL): (Fig. 3) Evidence for localized defects as defined above. The remaining points (those not defined as locally depressed) fulfilled the criteria for diffuse loss.
4. Normal hemifield (N): (Fig. 4) MD did not exceed -2.0 dB, and no evidence for localized visual field defects was present.

According to the hypothesis, those visual fields in the D and L groups were regarded as being at risk for further progression.

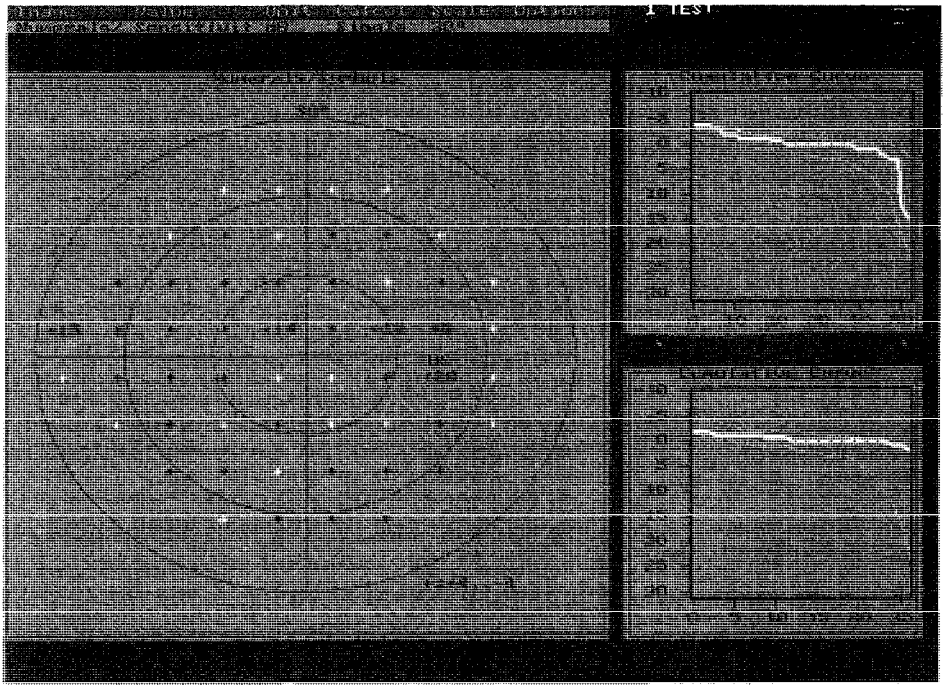

Fig. 1. Localized visual field loss: a 76-year-old female, right eye, lower hemifield: localized loss (nasal step), mean defect 1.2±1.0 dB. Top Bebié's curve shows an entire central field and lower curve shows an uninvolved hemifield

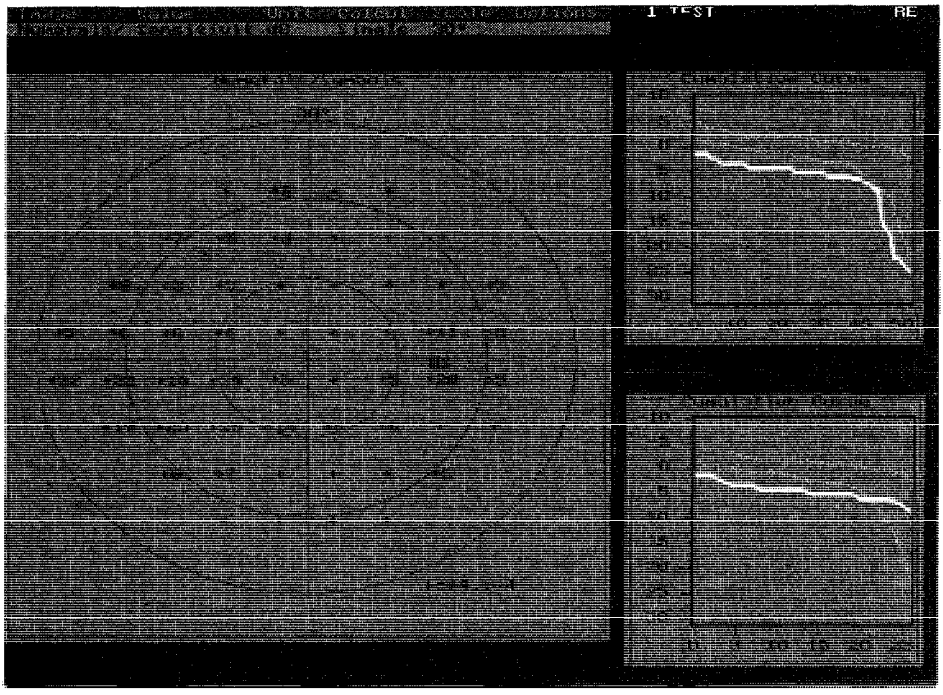

Fig. 2. Diffuse field loss: a 53-year-old female, right eye, upper hemifield: diffuse visual field loss, mean defect -4.5±1.7 dB. Top Bebié's curve shows the entire central field and lower curve shows the uninvolved hemifield.

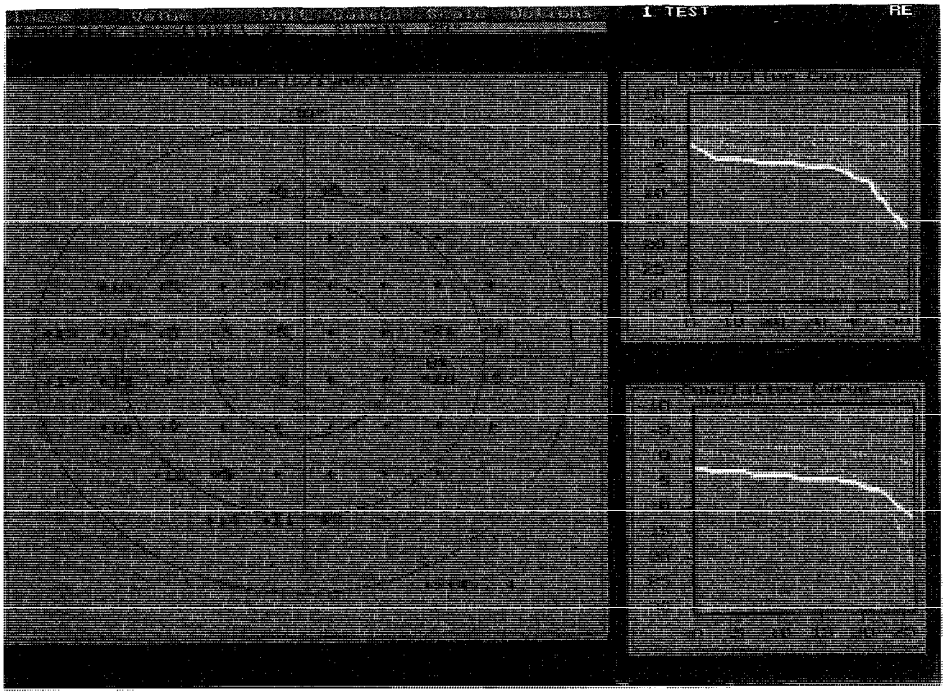

Fig. 3. Diffuse and localized field loss: a 71-year-old female, right eye, upper hemifield: diffuse visual field loss with nasal step, mean defect -4.5±1.4 dB. Top Bebié's curve shows the entire central field and lower curve shows the uninvolved hemifield.

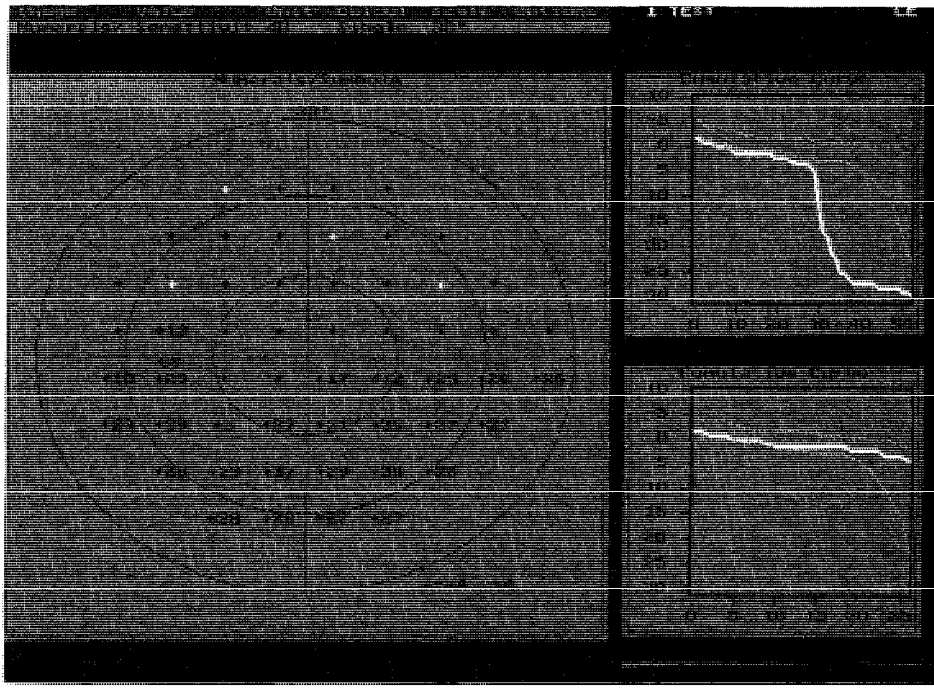

Fig. 4. Normal hemifield: a 45-year-old male, left eye, lower hemifield: normal hemifield, mean defect -0.7±1.4 dB. Top Bebié's curve shows the entire central field and lower curve shows the uninvolved hemifield

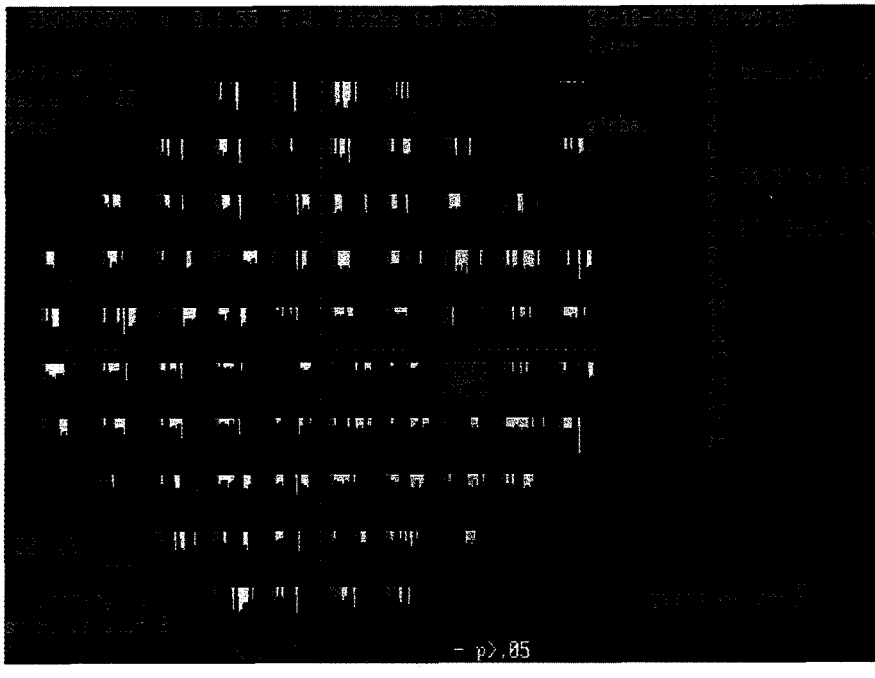

Fig. 5. Definition of progression. Pointwise linear regression analysis: more than two points in the hemifield show two consecutive significant negative slopes.

Two masked observers (RAH, COB) retrospectively assessed the same hemifield after a follow-up of at least two years to define progression using pointwise linear regression analysis[9]. Linear regression analysis was performed on each tested retinal location in the selected hemifield.

At and from the third field onwards the sensitivity of each point in decibels was compared with that of the previous field. A slope showing a change in sensitivity of less than 0.2 dB per month was considered to denote stability. On the other hand, a slope showing a decrease in sensitivity of more than 0.2 dB per month with a correlation coefficient of significance $p<0.05$, was considered to denote progression in that specific point.

For the purpose of this analysis, progression in a visual hemifield was considered to have occurred if at least the last two consecutive slopes of at least two tested locations were negative ($p<0.05$) (Fig. 5). All other possibilities, including a single negative regression slope, were considered to indicate a static field. The statistical analysis between the groups was performed using a Mann-Whitney U test.

Results

Fifty low tension glaucoma patients (37 female; 13 male) with a mean age 65.1±8.9 years (range 42-80) fulfilled the inclusion criteria. Neurological disease was ruled out in every case. No patient was on any antiglaucoma treatment. A visual acuity of 6/9 (20/30) or better was present in each eye, and no lens opacities existed at the time of visual field testing. Only one eye per patient (18 right, 32 left) was used for further statistical analysis. All patients were experienced in automated static perimetry and had at least eight computerized visual fields (mean 13.8±3.3; range 8-21) over a mean follow-up period of 50.9±14.4 (range 25-75) months. In the majority of the eyes (37, 74%) the lower, and in 13 patients the upper uninvolved hemifield was analyzed. Seventeen patients (34%) had localized defects only (L), 13 (26%) diffuse visual field loss (D) only, ten (20%) a combination of localized and diffuse loss (DL) and ten patients (20%) had a normal (N) uninvolved hemifield (Table 1). There were no statistical differences between the groups regarding patient age, number of visual field tests or length of follow-up. However, due to the definition of the groups, there were significantly ($p<0.0001$) larger mean defects (MD) in the groups with diffuse (D) and with combined diffuse and localized (DL) loss as compared to those with localized loss (L) and normal (N) hemifield. In addition, SD of the MD was significantly larger ($p<0.005$) in the group with combined diffuse and localized loss (DL) compared to the normal (N) and the localized loss (L) groups, but not to the group with diffuse loss (D).

Table 1. Pattern of visual field loss in the uninvolved hemifield in four different groups

Parameter	*Localized (L)*	*Diffuse (D)*	*Combined (DL)*	*Normal (N)*
n =	17	13	10	10
Patients' age	67.1 ± 8.2	63.4 ± 8.5	64.6 ± 6.1	64.3±12.8
No. of fields	13.6 ± 3.3	14.2 ± 4.3	13.2 ± 2.9	14.1± 2.7
Follow-up (months)	50.6 ±12.7	52.4 ±14.9	45.6 ±14.2	54.7±17.3
Mean defect (MD)	-0.39±1.11	-3.98±1.25	-4.02±0.95	0.15±1.54
SD of MD	1.45±0.36	1.66 ±0.46	1.92 ±0.40	1.40±0.24
% Progression	47.1	46.2	50.0	40.0

mean ± SD

Eight of 17 patients (47.1%) with localized defects only (L), 6/13 patients (46.2%) with diffuse visual field loss (D), 5/10 (50%) patients with combined diffuse and localized sensitivity reduction (DL) and 4/10 patients (40%) with normal (N) uninvolved hemifields showed two or more points with significant progression on linear regression analysis. These differences in the incidence of progression between the four groups were not statistically significant. If those 23 eyes which progressed were compared with those 27 which did not (Table 2), two significant differences were observed: the group with progression had on average more field tests ($p<0.05$) and the longer follow-up ($p<0.0001$). However, there was no difference in mean age or amount of visual field damage in the uninvolved hemifield at presentation.

Table 2. Progression *versus* non-progression in the uninvolved hemifield

Parameter	*Progression*	*Non-progression*	*Significance*
n =	23	27	NS
Patients' age	64 5 ± 8.0	65.5 ± 9.6	NS
No of fields	14.7 ± 3.0	12.9 ± 3.4	p<0.05
Follow-up (months)	59.1 ±12.5	43.9 ±12.3	p<0.0001
Mean defect (MD)	-1.97±2.26	-1.91±3 20	NS
SD of MD	1 56 ±0 34	1.62 ±0.47	NS

NS: not significant (p>0.1)

Discussion

Visual field defects in low tension glaucoma (LTG) patients at the time of diagnosis are usually bilateral and frequently advanced relative or absolute, often involving both horizontal hemifields. However, a substantial subgroup of LTG patients has at least one spared or "uninvolved" hemifield. We deliberately selected those patients from a large database of LTG visual fields to investigate retrospectively the predictive value of diffuse visual field loss.

In primary open-angle glaucoma with increased intraocular pressure, *i.e.,* high tension glaucoma (HTG), those patients with predominantly diffuse damage are reported to be significantly younger and to have a tendency for higher peak IOP than those with localized damage[7,8]. In HTG patients a direct correlation between the level IOP and the rate of visual field loss also exists[11].

If matched pairs of HTG and LTG patients are compared, eyes with HTG showed twice as much loss of sensitivity in the spared hemifield as compared to eyes with LTG[1]. However, this separation is not complete and between 1/4 to 1/3 of patients with LTG exhibit more diffuse damage than their matched HTG pair[12,13].

In this selected group of LTG patients, almost half the patients (23/50, 46%) had evidence of diffuse visual field loss in the uninvolved hemifield; 13/50 (26%) patients had pure diffuse loss of sensitivity, and another 10/50 (20%) a combination of diffuse and localized loss. This higher incidence may be due to patient selection. However, the overall rate of progression (23/50, 46%) in this group of untreated low tension glaucoma patients lies well within reported figures[2,9,14]. As also reported previously[14], a strong correlation between length of follow-up and incidence of progression exists. The diffuse component of visual field loss in the uninvolved hemifield did not allow prediction of further progression, as the same percentage of patients in each subgroup progressed. However, this does not indicate that diffuse visual field damage is not pressure dependent, as it is unlikely that localized and diffuse damage, as well as the mechanisms responsible for damage to the optic nerve in glaucoma are independent[13].

References

1. Drance SM, Douglas GR, Airaksinen PJ, Schulzer M, Hitchings RA: Diffuse visual field loss in chronic open-angle and low-tension glaucoma. Am J Ophthalmol 104:577-580, 1987
2. Levene RZ: Low tension glaucoma: a critical review and new material. Surv Ophthalmol 24:621-664, 1980
3 King DG, Drance SM, Douglas GR, Schulzer M, Wijsman K: Comparison of visual field defects in normal-tension glaucoma and high-tension glaucoma Am J Ophthalmol 101:204-207, 1986
4 Hitchings RA, Anderton SA: A comparative study of visual field defects seen in patients with low-tension glaucoma and chronic simple glaucoma. Br J Ophthalmol 67:818-821, 1983
5. Caprioli J, Spaeth GL: Comparison of visual field defects in the low-tension glaucomas with those in the high-tension glaucomas. Am J Ophthalmol 97:730-737, 1984
6. Gramer E, Althaus G: Quantifizierung und Progredienz des Gesichtsfeldschadens bei Glaukom ohne Hochdruck, Glaucoma simplex und Pigmentglaukom. Klin Mbl Augenheilk 191:184-198, 1987
7. Caprioli J, Sears M, Miller JM: Patterns of early visual field loss in open-angle glaucoma. Am J Ophthalmol 103:512-517, 1987
8. Glowazki A, Flammer J: Is there a difference between glaucoma patients with rather localized visual field damage and patients with more diffuse visual field damage? Doc Ophthalmol Proc Ser 49:317-320, 1987

9. Noureddin BN, Poinoosawmy D, Fitzke FW, Hitchings RA: Regression analysis of visual field progression in low tension glaucoma. Br J Ophthalmol 75:493-495, 1991
10. Bebié H, Flammer J, Bebié T: The cumulative defect curve: separation of local and diffuse components of visual field damage. Graefe's Arch Clin Exp Ophthalmol 227:9-12, 1989
11. O'Brien C, Schwartz B, Takamoto T, Wu DC: Intraocular pressure and the rate of visual field loss in chronic open-angle glaucoma Am J Ophthalmol 111:491-500, 1991
12 Chauhan BC, Drance SM, Douglas GR, Johnson CA: Visual field damage in normal-tension and high-tension glaucoma. Am J Ophthalmol 108:636-642, 1989
13 Chauhan BC, Drance SM: The influence of intraocular pressure on visual field damage in patients with normal-tension and high-tension glaucoma. Invest Ophthalmol Vis Sci 31:2367-2372, 1990
14. Glicklich RE, Steinmann WC, Spaeth GL: Visual field change in low-tension glaucoma over a five-year follow-up. Ophthalmology 96:316-320, 1989

Does glaucomatous visual field loss continue despite surgically subnormal IOP?

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Abstract

Intraocular pressures (IOPs) in the normal range of 11 to 21 mmHg are safe for humans without glaucoma. Several studies have shown that 40% or more of patients with glaucoma continue to lose visual field after trabeculectomy despite IOPs in this normal range. The published rates of loss appear to be lower if the average IOP is below 16 mmHg This suggests that subnormal IOPs (<11 mmHg) could be beneficial. Achievement of subnormal IOPs entails significant visual risk In order to evaluate the usefulness of attaining subnormal IOPs, visual fields were examined in 14 post-trabeculectomy eyes which had IOPs that never exceeded 12 mmHg for at least three years (and 85% of IOP readings were 10.5 mmHg or less) and had both reliable visual fields and stable visual acuity during the follow-up period. No eyes that met these conditions were excluded Eight of these eyes had advanced glaucoma (Aulhorn stage III or IV) and three others were diagnosed as having normal pressure (low tension) glaucoma. A retrospective analysis of visual fields was performed using six different sets of criteria for visual field loss. There were large discrepancies across the criteria, which appear to be due to failure to account adequately for test-retest variability. Considering all factors, 93% of eyes with stable subnormal IOPs (7 5 ± 1 4 mmHg) achieved stability of visual field at a mean follow-up of 46 ± 8 months

Introduction

It is known that some patients with glaucoma who have undergone "successful" filtration surgery continue to lose visual field despite intraocular pressures (IOPs) in the normal range of 11 to 21 mmHg. It is not clear why these patients progress. Recently, the American Academy of Ophthalmology, Glaucoma Panel[1], tabulated data from six studies of glaucoma filtering surgery, and noted that there appeared to be "a rough dose-response curve for the effect of IOP on stabilization of visual field defects". They concluded that prognosis for patients with advanced glaucoma could be improved by surgical achievement of subnormal pressures.

Results of a more complete review of the literature on IOP and field loss after glaucoma filtering surgery are shown in Fig. 1 and Table 1. We found 14 articles[2-15] between 1939 and 1991 which reported follow-up data on glaucoma surgery, giving both mean IOP at the end of the follow-up period and percentage of patients who had further progression of field defects after surgery (three studies reported data for more than one patient group, bringing the total number of data points to 19). Since most studies reported data from a small number of patients, the accuracy of the percentage estimates is generally low. Therefore, the 95% confidence limits for percentages based on the binomial distribution[16] are shown for each data point. Linear regression shows that IOP accounts for only 19% of the variance in the data, but there is a significant tendency for progression to be less at lower IOPs (r=0.44, p<0.05). This supports the idea that subnormal IOPs may prevent progression of field loss.

While results of the AAO tabulation[1] and our own literature review[2-15] are consistent, the high variability across studies means that the results are difficult to interpret. First, for many studies the criteria for field loss are not defined clearly, and for those with a clear definition it appears that some authors used quite strict criteria for field loss while others used much more lenient criteria. Second, for most of the studies, with the notable exception of Chandler's 1960 Gifford lecture[6], the pressure is simply reported as the IOP at the time of the final field in the

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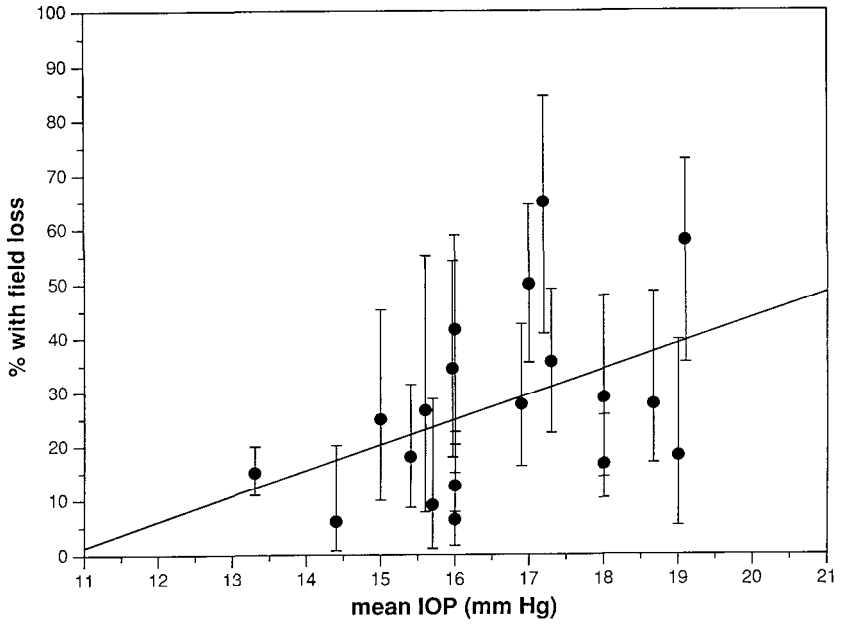

Fig. 1. Results of studies listed in Table 1 Percentage of patients with field loss after surgery is plotted as a function of mean IOP at the end of the follow-up period Error bars show the 95% confidence limits for the accuracy of the percentage estimate, based on the binomial distribution. The regression line has an x-intercept (where presumably no patients have visual field loss) at 10.7 mmHg, and the tendency to less loss at lower IOPs is significant (r=0.44, p<0 05)

follow-up period. Therefore, some patients must have had higher pressures than the mean for the group, and even for patients with low pressures at the end of the follow-up period there could have been periods of abnormally high pressure after surgery before the final pressure was obtained. Thus, the field loss could be due to pressures much higher than those indicated by the final IOPs.

Since subnormal IOPs are achieved at significant visual risk, it would be useful to know if subnormal IOPs are needed to prevent progression of field loss. A definitive answer to this

Table 1. Summary of literature on progression of field loss after trabeculectomy The first column gives the integer identifying the study in the list of references

Study No.	*No years of follow-up*	*No. of eyes*	*No. progressed*	*Mean IOP*	*% progressed*
2	5	252	38	13.3	15
3	5	33	2	14.4	6
4	3	24	6	15	25
5	5	50	9	15 4	18
6	26	15	4	15.6	27
7	4.4	22	2	15.7	9
8	3	62	4	16	7
9	4	95	12	16	13
9	20	29	10	16	35
10	3.5	24	10	16	42
11	5	54	15	16.9	28
12	5	48	24	17	50
13	?	20	13	17 2	65
14	4	42	15	17 3	36
9	5	102	17	18	17
15	5	31	9	18	29
8	20	36	10	18 7	28
9	5.5	22	4	19	18
3	5	19	11	19 1	58

question can only be obtained by a large prospective study. At this point we asked a simpler question: does achievement of subnormal IOP prevent progression of field loss? The answer to this question cannot determine whether subnormal IOPs are necessary to prevent progression of field loss, but can show if they are sufficient.

Methods

General

We examined charts of all patients (646 eyes) who had undergone trabeculectomy at the Glaucoma Associates of Texas in the years 1986 through 1989. Criteria for inclusion in the study were written down before the selection began. The first criterion was that once IOP was stabilized after surgery, it must have remained 12 mmHg or less for at least three years. The surgeon was allowed to manipulate IOP in the early postoperative period. Once IOP was stabilized, every subsequent IOP measurement was examined. Second, it was required that IOP remained 10.5 mmHg or less for at least 85% of the measurements. Third, during this period of stable subnormal IOP, there must have been two or more reliable fields spanning a period of at least three years, using the same program and machine. Fourth, for phakic eyes Snellen visual acuity must not have decreased by more than two lines during the course of the study. Patients who underwent uncomplicated cataract surgery during the follow-up period were included if IOP requirements were met. Fifth, the first postoperative visual field must have had a defect characteristic of glaucoma.

All kinetic fields were administered by a single highly trained perimetrist using a Goldmann perimeter. Standard isopters[17] were used until the separation between isopters exceeded 10°, then intermediate isopters were plotted using the a,b,c or d density filters with the base size and intensity of the outer isopter. Occasionally, negative comments regarding reliability or fixation loss were written on the field chart by the perimetrist. When these occurred, they served as the only basis for rejecting kinetic visual fields as unreliable. The absence of negative remarks has long signified this perimetrist's satisfaction with the patient's performance.

Kinetic isopters should ideally represent the line between zones in which a given test object is seen and zones in which the object is not seen. Because the location of the line is usually obvious from the data points which determine it, we choose to omit the line or else draw it with a fine-pointed pencil. This policy provides a better idea of the number and distribution of data points which define the isopter. This practice enabled us to include in our personal criteria the requirement that an isopter can be considered to have changed only if at least three data points in a single quadrant were displaced.

Kinetic isopters plotted by random presentations occasionally produce a single isopter shift of 5° or more which reverses itself on subsequent testing[18]. This fluctuation is much less frequent when the indentation is also present in the same quadrant on two more isopters. This personal requirement is not currently echoed in the literature, partly because most perimetrists are not required to produce isopters which are no more than 10° apart.

All static visual fields were obtained on the Humphrey Visual Field Analyzer, with either the 30-2 or 10-2 programs, and test object sizes either III or V. There were therefore four types of fields, using one of the two programs and one of the two test objects. When the standard monitors of fixation loss, false positives or false negatives resulted in a double x along with the standard warning about reliability, the field was rejected for the purposes of the study.

The records of fields for qualified patients were reviewed using six sets of criteria for visual field loss in three categories: kinetic and static, kinetic-only and static-only. Each category had two elements: an author-derived set of criteria and a literature-derived set of criteria. For each patient, the first and last fields from the period of stable subnormal IOP were compared, using as many sets of criteria as were applicable. All criteria were selected and written down before any fields were analyzed.

Kinetic and static category

Criteria set 1 (author-derived): This was based on the physician's notes during the period of stable subnormal pressure. If at any time the physician noted that there was a change in the field requiring a change in treatment, this was considered a progression of field defect.

Criteria set 2 (literature-derived): This was a much more lenient criterion, selected from the literature[11]: a field was considered to have progressed only if it had changed from one Aulhorn stage to a higher one. Aulhorn stages are described in detail elsewhere[19], and are listed briefly in Table 2.

Table 2. Aulhorn stages for glaucomatous visual fields (see reference[19] for detailed descriptions)

I	Relative defects of the Bjerrum area
II	Spot-like and arcuate absolute defects in the Bjerrum area, with no connection to the blind spot
III	Bjerrum scotomas (absolute arcuate scotomas connected to the blind spot) Sometimes with a band-like nasal breakthrough into the periphery
IV	Extensive ring-shaped or half ring-shaped absolute defects in the paracentral visual field area (up to 30°), leaving a central island of sensitivity
V	Central island collapsed, leaving only the remains of the temporal visual field

Kinetic-only category

Criteria set 3 (author-derived): A kinetic field was considered to have progressed if any one of four conditions was met:

a. An isopter surrounding visualized space had at least three points in a single quadrant which decreased by at least 5°, and this was confirmed on two or more other contiguous isopters (no more than one normal isopter between the three). For these confirmatory isopters, if they fell within 20° of fixation then a 3° change was confirmatory.
b. A new scotoma developed for which two isopters (separated by at least 5 dB or one standard size step) were plotted inside the scotoma.
c. A prior relative scotoma increased in depth, with the center deepening by at least 5 dB or one standard size step.
d. Any isopter used to plot a prior scotoma enlarged by at least 5° along any axis.

Criteria set 4 (literature-derived): The set of criteria[10] considered the field to have progressed if any one of four conditions was met:

a. deepening of a scotoma by 5 dB or more;
b. change of a scotoma from relative* (I-3-e or dimmer) to absolute (I-4-e or larger);
c. widening of a scotoma by 5° or more (same isopter for both fields);
d. widening of a nasal step or other peripheral defect at any spot by 5° or more in any standard isopter.

Static-only category

Criteria set 5 (author-derived): This set of criteria was designed to be applicable to all fields gathered with test objects III or V, using programs 30-2 or 10-2. In comparing any two fields, changes between tests were defined in terms of the mean RMS value for the two fields (the square root of the mean of the squares of the two short-term fluctuation values). Three criteria were used: 3, 4.5 or 6 RMS units. Since the field values are reported in dB units the change was always an integer, while the criteria often were not. Therefore, a given criterion was rounded to an integer using the following rule: if the remainder was 0.2 or less it was rounded down, otherwise it was rounded up. For the 30-2 program, points on the edge were excluded to avoid lens rim artifacts. The field was considered to have progressed if either of two conditions were met:

a. three or more points, each reduced by at least 3 RMS units, formed a cluster (*e.g.*, were contiguous vertically, horizontally or diagonally);
b. any single point was reduced by at least 4.5 RMS units on one of the two most recent fields, and the same location was also reduced by at least 3 RMS units on the other of the two most recent fields. If there were only two fields during the study period, then the individual data point must have been reduced by 6 RMS units in the final field.

*Reference 10 did not define "absolute scotoma" Aulhorn[19] defines absolute defects as not seeing test object I-4-e, arguing that larger objects will be too large to detect a small scotoma, and brighter objects will be too large due to scattered light. Using I-4-e as absolute, in order for a change from relative to absolute to be at least 5 dB, the relative scotoma could not be deeper than I-3-e.

Table 3. Patients with subnormal pressures in the current study

ID No.	*Eye*	*Age at surgery (years)*	*Highest pre-op IOP (mmHg)*	*Diagnosis*	*Stage*	*Field*	*Follow-up (months)*	*Post-op IOP mean ±1 SD (mmHg)*	*Set of criteria for evaluating progression*					
									1	*2*	*3*	*4*	*5*	*6*
1	OS	77	25	MXMG	IV	10-2/V	49	7±2	·	·			X	
3	OS	62	24.5	POAG	IV	10-2/III	37	8±2	·	·			·	
2	OS	64	25	CACG	IV	30-2/V	48	5±1	·	·			·	
4	OS	69	22	POAG	IV	30-2/V	38	9±1	·	·			·	
12	OS	72	24.5	POAG	III/IV	30-2/III	45	8±3	·	·			·	·
12	OD	71	29.5	POAG	III/IV	30-2/III	54	6±2	·	·			·	·
13	OD	75	21	NPG/MXMG	I	30-2/III	44	9±1	·	·			·	·
7	OD	60	24	MXMG	IV	kinetic	46	7±1	·	·	·	·		
11	OD	62	22	POAG	III	kinetic	36	9±1	·	·	·	X		
5	OD	81	28	POAG	II	kinetic	39	9±2	·	·	X	X		
6	OS	17	31	POAG	II	kinetic	43	5±2	·	·	X	X		
8	OD	54	22.5	NPG	II	kinetic	60	8±2	·	·	·	·		
9	OD	56	19.5	NPG	II	kinetic	53	7±2	·	·	·	X		
10	OD	81	17	CACG	II	kinetic	57	8±2	·	·	X	X		

POAG: primary open angle glaucoma; CACG: chronic angle closure glaucoma; NPG: normal pressure glaucoma; MXMG: mixed mechanism glaucoma. For the six sets of criteria, X indicates progression, a circle (·) indicates no progression. When there is no mark, the set of criteria was not applicable to the type of field with which the patient was tested

Criteria set 6 (literature-derived): For automated static perimetry, the only sets of criteria in the literature for the Humphrey Visual Field Analyzer that we were able to find were exclusively for the 30-2 program with spot size. Therefore, only three of the seven eyes tested with static perimetry could be evaluated with literature-derived criteria. Of the published criteria for automated static perimetry, we used the criterion of a cluster of three non-edge points which all had black triangles on the STATPAC 2 analysis[20].

Results

Out of the total of 646 eyes reviewed, only 14 eyes of 13 patients met all the qualifications. Characteristics of these eyes are listed in Table 3. Seven of these eyes had primary open angle glaucoma (POAG), three had normal pressure glaucoma (NPG), two had chronic angle closure glaucoma (CACG), and two had mixed mechanism glaucoma (MXMG). Only one eye (ID No. 12 OS) required glaucoma medications after surgery. For each eye, the first field in the series was classified according to the Aulhorn stages for degree of field damage[19], listed in Table 2. Four eyes had stage IV fields, two had fields intermediate between stages III and IV, two had stage III fields, five had stage II fields, and one had a stage I field. Five eyes had cataracts removed between the first and last fields in the series; for only one patient (ID No. 5) did acuity improve by more than two lines between the first and last fields. Seven eyes had been followed with manual kinetic perimetry (7 to 9 isopters, kinetic and static testing), and seven had been followed with automated static perimetry. The range of duration of the follow-up period was 36 to 60 months (mean ±1 SD = 46.3 ± 7.6), and 12 of 14 eyes have maintained stable subnormal IOPs to the present. The mean IOPs for each patient ranged from 5 to 9 mmHg (mean ±1 SD = 7.5 ± 1.4).

Results of applying the six sets of criteria are shown in Table 3. For none of the eyes did criteria Nos. 1 or 2 indicate progression. The two sets of criteria in the kinetic-only category *did* indicate progression, with three of seven fields scored as having progressed by the author-derived set (No. 3) and five of seven for the literature-derived set (No. 4). For the static-only category, the author-derived set (No. 5) scored one of seven eyes as having progressed, while the literature-derived set (ID No. 6) did not find progression in any of the three eyes to which it was applicable.

To determine the reasons for the discrepancies between the physicians' judgments as recorded in the chart (No. 1) and the judgments from the written sets of criteria (Nos. 3 to 6), each of three physicians (JRL, RLF and RJS) independently examined all fields from the charts for eyes for which discrepancies existed. In all but one eye (No. 6 OS), all three physicians concluded that the differences between the first and last fields fell within expected fluctuations for that patient. For that one eye, one of the three physicians felt that the change could not be accounted for by test-retest variability. In general, the discrepancies appear to be due to the fact that in the written criteria information on test-retest variability was not always obtained or sufficiently utilized.

Discussion

To our knowledge, this is the first report of post-trabeculectomy visual field changes in patients whose IOPs have remained subnormal during the entire follow-up period. This result is difficult to attain, and we were able to find only 14 eyes which had a period of at least 36 months in which IOP was stable and subnormal (never greater than 12 mmHg, and 10.5 mmHg or less for at least 85% of the measurements), and appropriate visual fields were both available and reliable. Ideally, visual fields should have been repeated more often, since many eyes which would otherwise have qualified did not have enough fields. Eleven of the 14 eyes had either severe field loss or normal-pressure glaucoma.

For all 14 eyes, review of the charts showed that at no point during the follow-up period did the physician note a field change requiring a change in treatment, and in our careful examination of all of the field data we only found evidence of progression in a single eye. These data suggest that achievement of stable subnormal pressures can prevent progression of visual field loss. With such a small sample, it is not possible to predict precisely the percentage of a larger

population with stable subnormal pressures which would be expected to have field loss. Statistical analysis of our small data set places confidence limits on the estimated percentage which will have loss[16]. Based on one of the 14 eyes progressing, there is a 5% chance that in a large population the percentage showing progression would be as high as 34% or as low as 0.2%. Therefore, it is possible that, in a larger sample of patients with stable subnormal IOPs, a significant fraction would show further visual field loss. Nonetheless, it is clear that in the large majority of cases progression was halted.

We attempted to use fixed written criteria to evaluate the percentage of eyes with field loss, but for kinetic fields found that this was less accurate than relying on the physician's judgment recorded in the charts. The primary problem was the lack of a well-defined method for including information about test-retest variability. The standard procedures for evaluating progression over a series of static fields could not be used for many patients, whose advanced glaucoma required use of spot size V and/or program 10-2. This necessitated development of author-derived criteria for evaluating these fields. For this small sample of fields the author-derived criteria were in good agreement with the clinical judgment, but these criteria have yet to be validated on a large patient population.

References

1 American Academy of Ophthalmology: Preferred Practice Pattern: Primary open-angle glaucoma, p 17, 1989
2. Lamping KA, Bellows AR, Hutchinson ST, Afran SI: Long-term evaluation of initial filtration surgery. Ophthalmology 93:91-101, 1986
3. Roth SM, Spaeth GL, Starita RJ, Birbillis EM, Steinmann WC: The effects of postoperative corticosteroids on trabeculectomy and the clinical course of glaucoma: five-year follow-up study Ophthalmic Surg 22:724-729, 1991
4. Jay JL, Murray SB: Early trabeculectomy versus conventional management in primary open angle glaucoma. Br J Ophthalmol 72:881-889, 1989
5 Kidd MN, O'Conner M: Progression of field loss after trabeculectomy: a five-year follow-up Br J Ophthalmol 69:827-831, 1985
6. Chandler PA: Long-term results in glaucoma therapy Am J Ophthalmol 49:221-246, 1960
7. Kolker AE: Visual prognosis in advanced glaucoma: a comparison of medical and surgical therapy for retention of vision in 101 eyes with advanced glaucoma. Trans Am Ophthalmol Soc 75:539-555, 1977
8. Watson PG, Jakeman C, Ozturk M, Barnett MF, Barnett F, Khaw KT: The complications of trabeculectomy (a 20-year follow-up). Eye 4:425-438, 1990
9. Jerndal T, Lundström M: 330 trabeculectomies: a long time study (3-5.5 years). Acta Ophthalmol 58:947-956, 1980
10. Werner EB, Drance SM, Schulzer M: Trabeculectomy and the progression of glaucomatous field loss Arch Ophthalmol 95:1374-1377, 1977
11. Popovic V, Sjöstrand J: Long-term outcome following trabeculectomy: II. Visual field survival. Acta Ophthalmol 69:305-309, 1991
12. Burke JW: Field changes after satisfactory filtration operations for glaucoma Trans Am Ophthalmol Soc 37:149-157, 1939
13. Holmin C, Storr-Paulsen A: The visual field after trabeculectomy: a follow-up study using computerized perimetry. Acta Ophthalmol 62:230-234, 1984
14. Greve EL, Dake CL: Four-year follow-up of a glaucoma operation. Prospective study of the double flap Scheie Int Ophthalmol 1:139-145, 1979
15. Rollins DF, Drance SM: Five-year follow-up of trabeculectomy in the management of chronic open angle glaucoma. In: Symposium on Glaucoma, Transactions of New Orleans Academy of Ophthalmology. St. Louis/Toronto/London: CV Mosby Co 1981
16. Rohlf FJ, Sokal RR: Statistical Tables, Second Edition, pp 157-162. New York: WH Freeman & Co 1981
17. Tate GW, Lynn JR: Principles of Quantitative Perimetry: Testing and Interpreting the Visual Field. New York/San Francisco/London: Grune & Stratton 1977
18. Parrish RK, Schiffman J, Anderson DR: Static and kinetic visual field testing: reproducibility in normal volunteers. Arch Ophthalmol 102:1497-1502, 1984
19. Aulhorn E: Visual field defects in chronic glaucoma In: Heilman K, Richardson KT (eds) Glaucoma, Conceptions of a Disease: Pathogenesis, Diagnosis, Therapy. Philadelphia/London: WB Saunders Co 1978
20. Morgan RK, Feuer WJ, Anderson MD: Statpac 2 glaucoma change probability. Arch Ophthalmol 109:1690-1692, 1991

Long-term visual field follow-up in betaxolol- and timolol-treated patients

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Introduction

The long-term influence of β-blocker treatment on visual function has not been well documented. The evidence that β-blockers may provide a favorable effect on visual field in glaucoma suspects is controversial[1-3], and the possibility that selective and non-selective β-blockers have different effects on vision has not been well explored. The three present studies were conducted to examine long-term effects of β-blockers on visual field. Two studies compared β-1 selective (betaxolol 0.5%) *versus* non-selective (timolol 0.5%) β-blocker treatment in glaucoma patients. These two studies are referred to here as the Basel Study and the Liège Study. The third study was designed to examine whether betaxolol has a favorable effect in preventing or delaying visual field loss in ocular hypertensive subjects; this study is referred to as the Paris Study. For the Basel and Liège studies, preliminary reports have been published[4-6].

Subjects and methods

Basel study

Patients who met the following criteria were enrolled:
a. IOP ≥24 mmHg;
b. early glaucomatous field defect; and
c. clinical evidence of glaucomatous optic nerve head damage.

Patients with systemic diseases or contraindications to β-blocker treatment were excluded. Patients were on no other local or systemic medication. All patients were from the outpatient glaucoma service of the University of Basel Eye Clinic, and gave informed consent. Forty patients were initially enrolled.

Examinations included slit-lamp biomicroscopy, ophthalmoscopy, IOP measurement with the Goldmann tonometer, blood pressure measurements in a sitting position, and perimetry with program G1 on an Octopus 201. All visual fields were performed by the same perimetrist on the same instrument under uniform conditions.

Patients who met the entry criteria underwent a two-week washout period, during which all previous glaucoma medication was discontinued. At the end of this two-week period, a baseline examination was performed. Patients were then randomly assigned, in a double-masked fashion, to bilateral BID treatment with either betaxolol 0.5% or timolol 0.5%. Follow-up examinations were performed three, six, 12, 18, 24, and 30 months after initiation of treatment.

Liège study

Primary open-angle glaucoma patients without concomitant ocular or systemic disease were enrolled. Patients underwent a 15-day washout period for any ocular hypotensive drugs, and were then randomly assigned to receive either betaxolol 0.5% or timolol 0.5% BID in both eyes. Both the patient and the observer were aware of the treatment assignment. All patients

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were from the glaucoma service of the University of Liège Eye Clinic, and gave informed consent. Twenty patients were initially enrolled.

Examinations included IOP measurement with a Goldmann applanation tonometer, and perimetry with program G1 of the Octopus 2000R instrument. All IOP measurements were made by the same observer, and all visual fields were performed by the same perimetrist on the same instrument. Examinations were performed at baseline (after the 15-day washout period), and at three, six, 12, 24, and 36 months after initiation of treatment.

Paris study

Patients with ocular hypertension (IOP ≥21 mmHg) and no glaucomatous visual field defect were eligible for enrollment. Patients were either currently untreated or washed off existing ocular hypotensive therapy before the start of the study. Patients with systemic diseases or contraindications to β-blocker treatment were excluded. Patients were on no other local or systemic medication. All patients were from the glaucoma service of Hôpital St. Joseph, Paris, and gave informed consent. One hundred and thirty patients were initially enrolled.

Examinations included slit-lamp biomicroscopy, ophthalmoscopy, IOP measurement with the Goldmann tonometer, blood pressure measurements in a sitting position, and perimetry with program G1 of an Octopus perimeter. All visual fields were performed by the same perimetrist.

After a baseline examination, patients were randomly assigned, in a double-masked fashion, to receive either betaxolol 0.5% or placebo (vehicle solution) BID in both eyes. Follow-up examinations were performed at six, 12, 18, 24, 30, 36, 42, 48, 54, and 60 months after initiation of double-masked treatment.

Results

Basel study

Patient demographics are shown in Table 1. Of the 40 patients initially enrolled, four patients discontinued treatment during the first 18 months of the study. Three patients discontinued from the timolol group, two for personal reasons and one because of a newly developed bronchial asthma. One patient in the betaxolol group discontinued treatment because of a stinging sensation upon eyedrop instillation. Seven other patients dropped out after the first 18 months of treatment. Of the five who discontinued from the timolol group, three showed a clear tendency toward deterioration of the visual field. Both the two dropouts from the betaxolol group were for personal reasons, and both had stabilized IOP and visual function.

Table 1. Patient demographics: Basel study

		Betaxolol-treated patients	*Timolol-treated patients*
No. of eyes		34	24
No of patients		17	12
Gender (M/F)		13/4	6/6
Age (years) ±SD		67.6±9.4	66.7±10.4
Baseline mean IOP			
(mmHg) ±SD	OD	21.4±5.0	22.4± 4.7
	OS	21.5±3.6	21.6± 4.0
Baseline mean MS			
(dB) ±SD	OD	24.5±3.4	23.7± 2.7
	OS	23.7±3.9	24.3± 2.2

Fig. 1 shows the mean IOP data for each treatment group during the 30-month follow-up period. The decrease in IOP was more pronounced in the timolol group during the time course of the study. The difference at 30 months was not statistically significant when compared with an unpaired *t* test.

Fig. 2 shows the averaged values of the visual field index mean sensitivity (MS) during the 30-month follow-up period. For both treatment groups, the visual fields improved during the

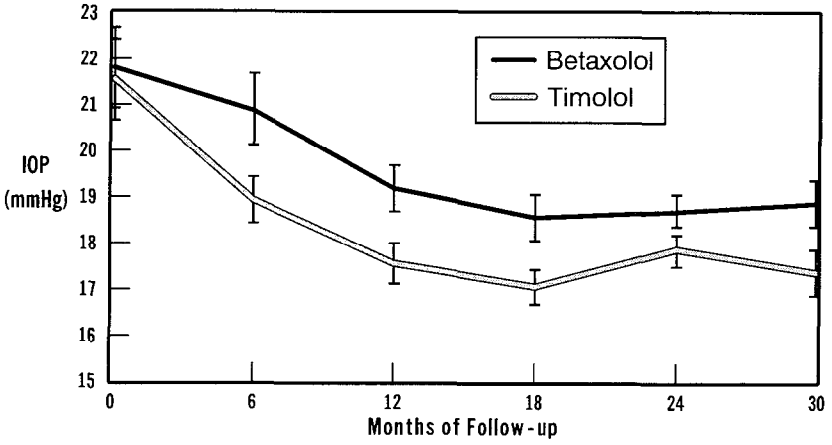

Fig. 1. Mean IOP (± SEM) during the 30-month follow-up period in glaucoma patients treated with betaxolol or timolol in the Basel study

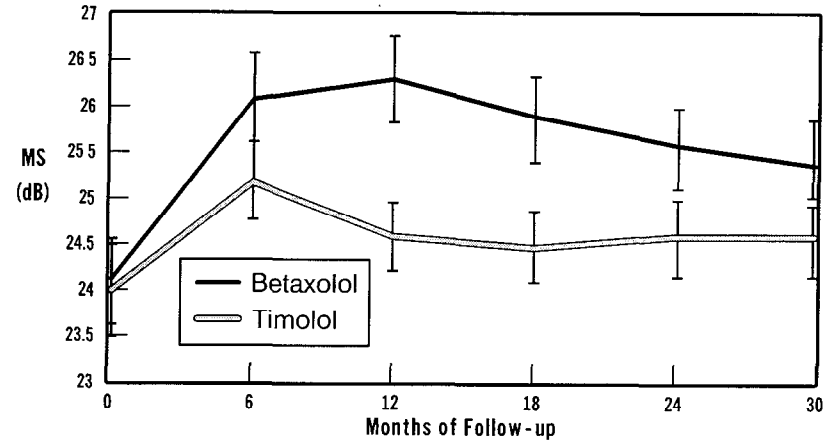

Fig. 2. Averaged values of visual field mean sensitivity (± SEM) during the 30-month follow-up period in glaucoma patients treated with betaxolol or timolol in the Basel study.

first six to 12 months and were then relatively stable during the remainder of the 30-month follow-up. The patients in the betaxolol group had a more pronounced improvement in the visual fields than did those in the timolol group.

Liège study

Patient demographics are shown in Table 2. Of the 20 patients initially enrolled, one dropped out for personal reasons. Nineteen patients were followed for 36 months.

Table 2. Patient demographics: Liège study

	Betaxolol-treated patients	*Timolol-treated patients*
No. of eyes	18	20
No. of patients	9	10
Age (years) ±SD	65 (57-75)	60 (49-70)
Baseline mean IOP (mmHg ±SD)	23.1±3.4	23.3±3.4
Baseline mean MS (dB) ±SD	25.2±4 1	25.1±3.1

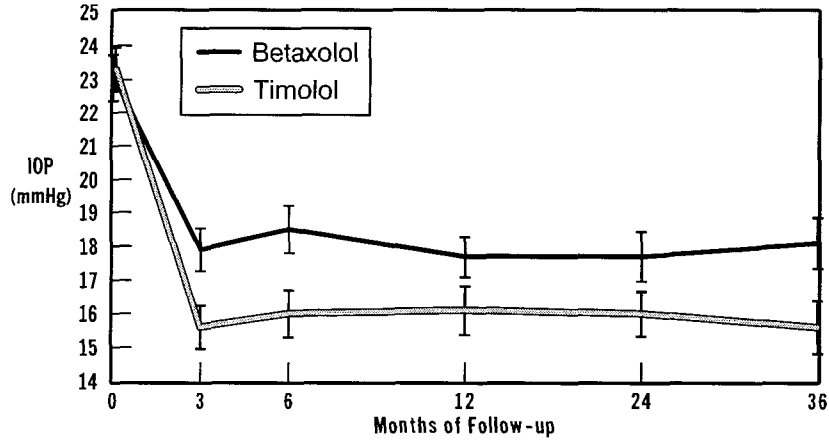

Fig. 3 Mean IOP (± SEM) during the 36-month follow-up period in glaucoma patients treated with betaxolol or timolol in the Liège study.

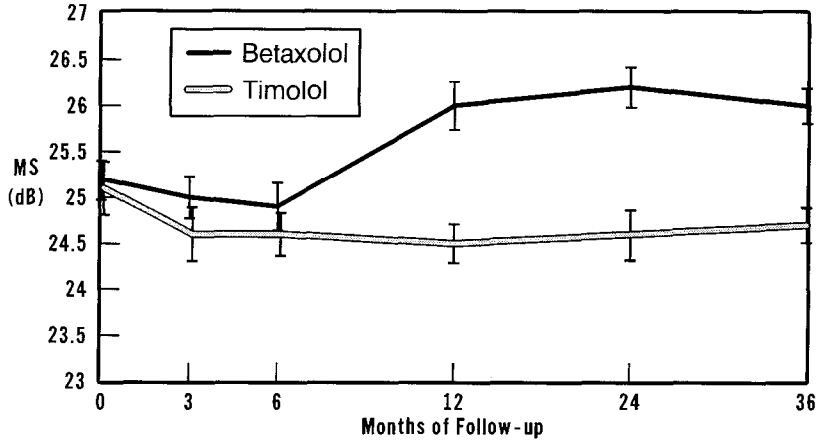

Fig. 4. Averaged values of visual field mean sensitivity (± SEM) during the 36-month follow-up period in glaucoma patients treated with betaxolol or timolol in the Liège study.

Fig. 3 shows the mean IOP data for each treatment group during the 36-month follow-up period. Throughout this period, the IOP decrease was approximately 2 mmHg greater with timolol treatment than with betaxolol treatment. This difference was not statistically significant.

Fig. 4 shows the averaged visual field values (MS) during the 36-month follow-up period. In the timolol group, MS decreased by approximately 0.5 dB at all examinations. In the betaxolol group, MS decreased by 0.2 and 0.3 dB at the three and six-month examinations, respectively. However, there was a statistically significant *increase* in MS in the betaxolol group at the 12, 24, and 36 month visits. The increases seen in the betaxolol group were statistically different from the decreases observed in the timolol group at the same time period.

Paris study

Patient demographics are shown in Table 3. Of the 130 initially enrolled, eight patients did not complete at least six months on the study regimen and were dropped from the evaluation. Additionally, 13 patients identified as having not met the entry criteria were dropped.

Fig. 5 shows the mean IOP data for each treatment group during the 60-month follow-up period. The mean IOP was always lower in the betaxolol group than the placebo group during the treatment period. The IOP difference between groups was statistically significant at months 12, 18, 24, 30, 42, 54, and 60.

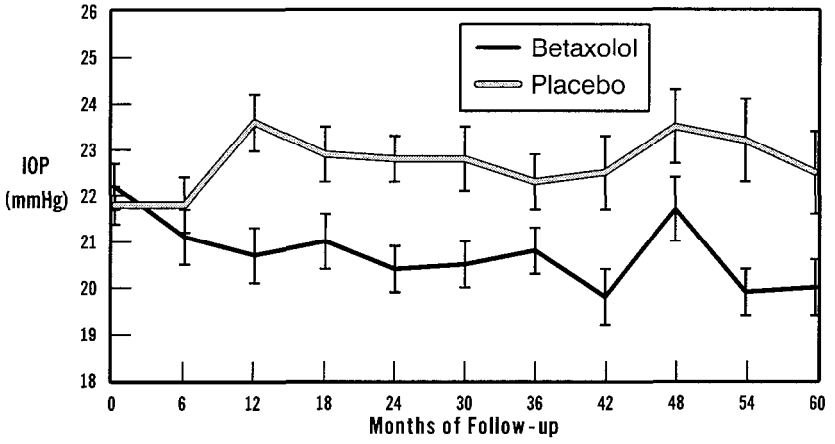

Fig. 5. Mean IOP (± SEM) during the 60-month follow-up period in ocular hypertensive patients treated with betaxolol or placebo in the Paris study.

Table 3. Patient demographics: Paris study

	Betaxolol-treated patients	*Placebo-treated patients*
No. of eyes	103	107
No. of patients	53	56
Gender (M/F)	26/27	23/33
Age (years) ±SD	52.3±12.8	55.4±10.1
Baseline mean IOP (mmHg) ±SD	22 2± 3.4	21.8± 3 2
Baseline mean MS (dB) ±SD	26.8± 1 4	26.3± 1.5

Fig. 6 shows the averaged visual field values (MS) during the 60-month follow-up period. Mean sensitivity was not statistically different at baseline for the two treatment groups. During the treatment period, there was a tendency for MS to decrease in the placebo group compared to the betaxolol group. This MS difference between groups became statistically significant at 36 months ($p<0.05$), and was statistically significant at 48 months ($p<0.01$), 54 months ($p<0.05$) and 60 months ($p<0.01$).

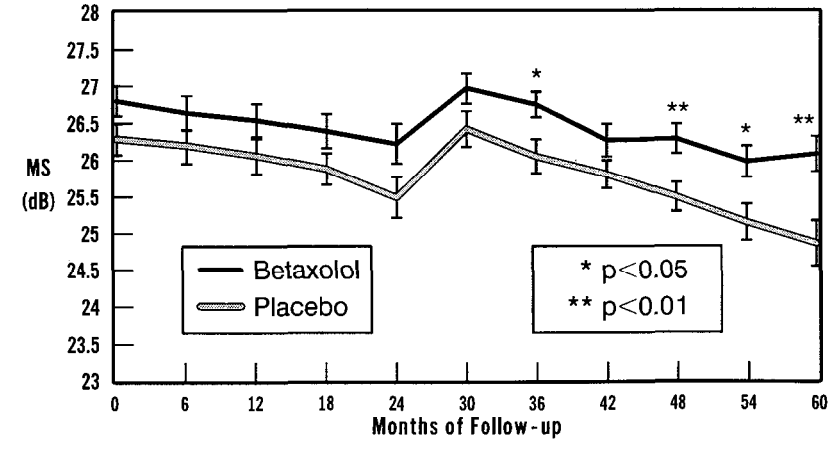

Fig. 6. Averaged values of visual field mean sensitivity (± SEM) during the 60-month follow-up period in ocular hypertensive patients treated with betaxolol or placebo in the Paris study.

Discussion

In both studies comparing selective *versus* non-selective β-blocker treatment in glaucoma patients, the effect on visual fields was better for betaxolol-treated patients than for timolol-treated patients. The more favorable visual field effect of betaxolol was seen despite better IOP control in timolol-treated patients.

In the Basel study the improvement in visual field mean sensitivity, which was significant through 18 months of treatment[4], was no longer statistically significant at 30 months. It should be noted, however, that three of the five dropouts in the timolol group showed a clear tendency toward visual field deterioration, whereas the dropouts in the betaxolol group all had stable visual function. We may therefore assume that the difference in visual function would have been larger had these dropouts been included.

The more favorable visual field effect seen with betaxolol, despite the more pronounced IOP reduction seen with timolol, indicates that factors other than IOP alone play a role in visual function preservation. While the mechanisms responsible for visual field survival cannot be explained by the present data, it is possible that a selective β-1 blocker such as betaxolol may have a better influence on the circulation of the optic nerve head than a non-selective β-blocker. Recent studies which measure what has been called ocular pulsatile blood flow[7,8] report that glaucoma patients tend to show decreases in this blood flow parameter while on timolol treatment but increases while on betaxolol treatment. Using another hemodynamic technique, Sponsel and his colleagues recently reported strong associations of better visual function with more rapid retinal leukocyte velocity in betaxolol-treated patients, but no such associations in timolol-treated patients[9].

The visual field data in the Paris study suggest that betaxolol treatment may provide a protective visual function effect in ocular hypertensive patients. The mean sensitivities significantly decreased in placebo-treated patients compared with betaxolol-treated patients, whose visual field sensitivities remained relatively stable throughout the 60-month period. Previous studies of the effect of timolol treatment in ocular hypertensives have reported conflicting results[1-3]. The advantage of the present investigation is that standard automated perimetry was used from the start of the study, allowing for more quantitative comparisons.

The studies reported here support the idea that a β-1 selective β-blocker such as betaxolol may have a more favorable effect on visual field preservation than non-selective β-blockers. Further work is underway to confirm these results, to explore the differences between selective and non-selective β-blocker effects on ocular blood flow, and to study the relation of ocular blood flow to visual function.

References

1. Schulzer M, Drance SM, Douglas GR: A comparison of treated and untreated glaucoma suspects. Ophthalmology 98:301-307, 1991
2. Epstein DL, Krug JH Jr, Hertzmark E, Remis LL, Edelstein DJ: A long-term clinical trial of timolol therapy versus no treatment in the management of glaucoma suspects. Ophthalmology 96:1460-1467, 1989
3. Kass MA, Gordon MO, Hoff MR, Parkinson JM, Kolker AE, Hart WM Jr, Becker B: Topical timolol administration reduces the incidence of glaucomatous damage in ocular hypertensive individuals. Arch Ophthalmol 107:1590-1598, 1989
4. Messmer C, Flammer J, Stümpfig D: Influence of betaxolol and timolol on the visual fields of patients with glaucoma. Am J Ophthalmol 112:678-681, 1991
5. Kaiser HJ, Flammer J, Messmer C, Stümpfig D, Hendrickson P: Thirty-month visual field follow-up of glaucoma patients treated with β-blockers. J Glaucoma 1:153-155, 1992
6. Collignon-Brach J: Long-term effect of ophthalmic β-adrenoceptor antagonists on intraocular pressure and retinal sensitivity in primary open-angle glaucoma. Curr Eye Res 11:1-3, 1992
7 Boles-Carenini B, Broglatti B, Boles-Carenini A, Sibour G: The actions of timolol and betaxolol on ocular pulsatile blood flow in glaucomatous eyes. In: International Symposium on Glaucoma, Ocular Blood Flow and Drug Treatment, 1991
8 Langham ME, Romeko WJ, T'omey K: The unfavorable action of a beta adrenoceptor blocker on ocular blood flow and vision in glaucomatous eyes Presentation at 4th Congress of the European Glaucoma Society, Amsterdam, The Netherlands, May 20-24, 1992
9. Shoemaker J, Sponsel W, Kaufman P, Blum F, Brady M, DePaul K, Zetlan S, Curran J: Correlation of the asymmetry of visual function and retinal leukocyte velocity in glaucoma; observed differences between timolol- and betaxolol-treated patients Invest Ophthalmol Vis Sci 33:4, 1992

A long-term visual field evaluation of glaucoma patients treated topically with timolol or carteolol

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Abstract

Eighty-seven eyes of patients with chronic open angle glaucoma treated with a topical non-selective β-blocker medication for from four to over ten years were examined in a retrospective study to evaluate the effectiveness of the therapeutic approach on visual field loss According to the topical medication received for lowering the IOP to a value of under 22 mmHg, the patients were assigned to one of two groups: 55 eyes received timolol monotherapy, 32 eyes received carteolol monotherapy Patients' visual fields were evaluated at the beginning and the end of the observation period (Octopus 201 Program 31 or Octopus 500 Program G1) and a yearly visual field loss in each quadrant was calculated. There was no significant difference in visual field deterioration between the two groups. Timolol and carteolol seem to be equally effective in the treatment of chronic open angle glaucoma.

Introduction

Adrenergic β-blocking agents are the most widely used topical anti-glaucomatous medication. They are differentiated according to selectivity, intrinsic sympathomimetic effect, potency, local anesthetic effect and pharmacokinetic characteristics[1]. Timolol maleate is a non-selective β_1- and β_2-adrenergic antagonist which lacks substantial intrinsic sympathomimetic activity and membrane stabilizing properties. Carteolol, another long-acting, non-selective β_1- and β_2-adrenergic antagonist, differs from timolol by its intrinsic sympathomimetic activity. According to previous studies both agents show an equal ability to reduce elevated intraocular pressure[2]. Various β-blockers differ in their ability to reduce intraocular pressure and their effect on visual field deterioration[3]. Long-term evaluations of glaucomatous visual field deterioration under topical timolol or carteolol medication are not available. We therefore decided to review our out-patient clinic data in order to find out whether there was a difference in the ability of timolol and carteolol to reduce intraocular pressure and whether they differ in their influence on visual field loss over a long-term follow-up period in patients with chronic open angle glaucoma.

Material and methods

The clinical charts of patients from our out-patient glaucoma department were evaluated retrospectively. Patients are regularly checked for diurnal intraocular pressure, visual acuity and visual field at least every six months. Our inclusion criteria were: (a) chronic open angle glaucoma treated with topical timolol 0.5% or carteolol 2% for at least four years without any additional therapeutic step necessary, (b) the maximum peak pressure of each diurnal intraocular pressure curve did not exceed 22 mmHg, (c) visual acuity was greater than 0.2, and (d) no other retinal or optic nerve disease was observed.

According to their medication two groups were created:

1. Fifty-five eyes treated with topical timolol 0.5%
2. Thirty-two eyes treated with topical carteolol 2%

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The following parameters were evaluated:

- Average intraocular pressure during the observation period, calculated from the diurnal intraocular pressure curves.
- Visual field loss. Perimetry was performed with an Octopus 201 perimeter using the program 31 or an Octopus 500 perimeter using the program G1. Visual field data from the beginning and the end of the observation period were compared, dividing the central 24° into four quadrants and excluding the center. A mean threshold sensitivity value was calculated for every quadrant. Visual field changes were compared as sensitivity changes per year.

Statistical analysis was carried out using the StatView 2.0 program version 1.01 on an Apple Mackintosh IIci computer. The Mann-Whitney U test was performed to compare the two groups.

Results

The average age of the patients in groups 1 and 2 was 69.1 (SD 10.4) years and 65.6 (SD 11.9) years, respectively, which was not significantly different. The mean follow-up time of the patients was 6.1 (SD 2.3) years and 5.6 (SD 1.7) years, respectively. The average intraocular pressure during the observation period was 17.0 (SD 1.5) mmHg and 17.4 (SD 1.9) mmHg, respectively. The mean yearly visual acuity loss was 2.8% (SD 2.7) and 2.0% (SD 2.3). There was no significant difference between the two groups regarding these parameters.

The mean threshold sensitivity of the visual field for the different medication groups at the beginning of the observation period was not significantly different: 21.0 dB (SD 5.8) and 21.8 dB (SD 4.6) for groups 1 and 2, respectively. The yearly sensitivity loss in the various quadrants overall and for the two medication groups separately was:

- Lower nasal quadrant 0.42 dB (SD 0.75), 0.38 dB(SD 0.77) and 0.50 dB (SD 0.70);
- Upper nasal quadrant 0.37 dB (SD 0.73), 0.40 dB (SD 0.70) and 0.32 dB (SD 0.79);
- Lower temporal quadrant 0.29 dB (SD 0.63), 0.21 dB (SD 0.60) and 0.44 dB (SD 0.67);
- Upper temporal quadrant 0.37 dB (SD 0.63), 0.35 dB (SD 0.61) and 0.42 dB (SD 0.67) overall and for groups 1 and 2, respectively.

Only the difference between the two medication groups in the lower temporal quadrant was statistically significant ($p<0.05$). The yearly sensitivity loss of the visual field as a whole was 1.32 dB (SD 2.27) and 1.69 dB (SD 2.62) in groups 1 and 2: this difference was not statistically significant.

Discussion

The visual field, regardless of whether it is normal or glaucomatous, deteriorates over time. One of the main advantages of automated perimetry is that it enables the observer to follow this deterioration closely and to perform statistical analysis of quantitative visual field data. As observed in previous reports[4-6], the data in this study, although showing no significant difference in deterioration between the various quadrants, underline a tendency that the nasal visual field might be more prone to damage. The nerve fibers of the temporal retina may be more susceptible to elevated intraocular pressure, as described by Jonas *et al.*[7].

The overall annual visual field loss was equal in both medication groups. Even though the annual visual field loss of the lower temporal quadrant was significantly slower ($p<0.05$) in the timolol group than the carteolol group, this was not enough to alter the overall results.

Investigators have reported contradictory data concerning correlation between visual field loss and mean intraocular pressure; some have found no correlation[8,9], while others demonstrated a significant correlation[10,11]. Recently, it was reported that betaxolol preserves the visual field better than timolol, even though timolol reduced the intraocular pressure more than betaxolol[3]. We did not find such a difference between timolol and carteolol. Timolol and carteolol in our study do not differ in their capability to reduce intraocular pressure, as reported by Scoville *et al.*[2], or in their effect on the patients' annual visual field deterioration.

References

1. Frischman WH, Teicher M. Beta-adrenergic blockade: an update. Cardiology 72:280-296, 1985
2. Scoville B, Mueller B, White BG, Kriegelstein GK: A double-masked comparison of carteolol and timolol in ocular hypertension Am J Ophthalmol 105:150-154, 1988
3 Messmer C, Flammer J, Stümpfig D: Influence of betaxolol and timolol on the visual fields of patients with glaucoma. Am J Ophthalmol 112:678-681, 1991
4. Drance SM, Bryett J, Schulzer M: The effect of surgical pressure reduction on the glaucomatous field. Doc Ophthalmol Proc Ser 14:153-158, 1977
5. Starrita RJ, Fellman RL, Lynn JR: Correlation of intraocular pressure in visual field after argon laser trabeculoplasty. Doc Ophthalmol Proc Ser 49:377-383, 1987
6. Crick RP, Vogel R, Newson RD, Shipley MJ, Blackmore H, Palmer A, Bulpitt CJ: The visual field in chronic simple glaucoma and ocular hypertension: its character, progress, relationship to the level of intraocular pressure and response to treatment Eye 3:536-546, 1989
7. Jonas JB, Nguyen NK, Strahwald H, Naumann GOH: Die retinale Nervenfaserschicht in Normal- und Glaukomaugen: Semiquantitative Daten von 398 Glaukomaugen. Klin Mbl Augenheilk 194:437-446, 1989
8. Holmin C, Krakau CE: Regression analysis of the central visual field in chronic glaucoma cases: a follow-up study using automated perimetry. Acta Ophthalmol 60:267-274, 1982
9 Krakau CET: Visual field decay in chronic glaucoma. In: Kriegelstein GK, Leydhecker W (eds) Glaucoma Update II. New York: Springer Verlag 1983
10. Mao LK, Stewart WC, Schields MB: Correlation between intraocular pressure control and progressive glaucomatous damage in primary open-angle glaucoma Am J Ophthalmol 111:51-55, 1991
11. Niesel P, Flammer J: Correlations between intraocular pressure, visual field and visual acuity, based on 11 years of observation of treated chronic glaucomas. Int Ophthalmol 3:31-35, 1980

The follow-up of glaucoma with a reduced set of test points

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Perimetry with reduced sets of test locations is an effective method of shortening the examination[1]. On the other hand, the amount of information gained is also reduced. With regard to the estimation of mean defect (MD) in glaucoma, we recently identified a ring-shaped pattern of test locations which was superior to 49 other patterns[2]. In a subsequent study, we compared the temporal variation of MD using the full set and the reduced set of points in a prospective study with four examinations at four-week intervals.

All fields were measured using a Humphrey Field Analyzer and program 30-2 or custom program REDUX. REDUX measures 14 points with a double bracketing strategy. The locations are identical to the test locations of program 30-2 between 15° and 20° eccentricity except for those in the area of the blind spot. In an earlier study[2], we proved the representation of this set of points in a data base of 424 fields of 257 patients with high tension glaucoma. The theoretical sample error (SE) with regard to the calculation of MD was calculated using the equation $SE=PSD/\sqrt{N}$ (PSD = pattern standard deviation, N = No. of points). SE of program 30-2 was 0.67 dB ($5.77/\sqrt{74}$), SE of program REDUX was 1.54 dB ($5.77/\sqrt{14}$). The theoretical partial sample error (PSE) of the subset *versus* the full set was 1.39 dB. True PSE was 1.33 dB. Thus, REDUX was representative of the whole field without any bias from spatial effects.

In this study, we examined 20 patients with POAG, LTG, pigmentary glaucoma or PEX glaucoma prospectively four times. The intervals were four weeks ±3 days. One eye was randomly selected for examination. Both programs were executed at each session. The order was randomly chosen at the beginning and kept unchanged during the whole study. Up until the present, 18 patients have completed the study. There were eight right and ten left eyes. Ten patients started with program 30-2, eight patients started with program REDUX.

We calculated the standard deviation of MD over all four examinations. This value is the long-term fluctuation of MD (LF-MD) or the homogeneous component of long-term fluctuation[3]. The mean LF-MD was 1.294 dB (SD ±0.852) for program 30-2 and 1.761 dB (SD ±0.936) for program REDUX. This is a ratio of 1:1.36 for standard deviation and 1:1.85 for variances. The long-term accuracy of program 30-2 was 1.85 times higher than program REDUX.

The mean examination time of program 30-2 was 15:25 minutes (SD ±2:15 minutes), the mean duration of program REDUX was 3:29 minutes (SD ±0.45 minutes). This is a ratio of 4.42:1. The examination time of program 30-2 was 4.42 longer.

The efficiency is benefit/cost or accuracy (1/variance) divided by examination time. The mean efficiency of program 30-2 was 0.0387, that of program REDUX 0.0924. Thus, the efficiency of program REDUX was 2.39 times higher than program 30-2.

The conclusions obtained were:

1. The ring area between 15° and 20° eccentricity is representative of the whole central field in glaucoma.
2. The long-term fluctuation of program REDUX is higher than program 30-2. The loss in accuracy is 1:1.85 compared to program 30-2.
3. The examination time of program REDUX is 4.42 times less than program 30-2.
4. The efficiency of program REDUX concerning long-term follow-up of index MD is 2.39 times higher than program 30-2. In practical terms, two examinations per year with REDUX are as accurate as one examination with 30-2, but the overall examination time is less than half.

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5. The only special feature of REDUX is the test point pattern. Therefore, it can be implemented with every automated perimeter which allows the definition of custom programs. The full article will be published elsewhere.

References

1. Funkhouser A, Fankhauser F, Hirsbrunner H: A comparison of three methods for abbreviating G1 examinations. Jpn J Ophthalmol 33:288-294, 1989
2. Weber J, Diestelhorst M: Perimetric follow-up in glaucoma with a reduced set of test points. Ger J Ophthalmol 1:409-414, 1992
3. Flammer J, Drance S, Zulauf M: Differential light threshold: short- and long-term fluctuation in patients with glaucoma, normal controls, and patients with suspected glaucoma. Arch Ophthalmol 102:704-706, 1984

Point by point linear regression analysis of automated visual fields in primary open angle glaucoma

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Abstract

The authors measured the rate of change of visual field threshold values over time (3.8 ± 1.3 years) at 48 test locations in the central 30 degree field (Octopus 2000R, program 31) of 40 primary open angle glaucoma patients (one eye per patient). All had a minimum of five with a mean of 12 visual field examinations and a minimum follow-up of 20 months. Twenty-five (63%) had a significant rate of loss of threshold values at one or more test points (mean number of deteriorating points 6.3) Fourteen of the 28 (50%) patients with stable overall fields showed a significant rate of loss at one or more test points (mean number of deteriorating points 3 4) The mean intraocular pressure in these 14 patients (17.2 ± 2.4 mmHg) was not significantly different from the 14 patients with stable fields without deteriorating test points (16.5 ± 3.1 mmHg) The use of global summary indices for longitudinal monitoring of the visual field in glaucoma may mask underlying changes occurring at individual test points. However, the clinical implication of these statistical results at individual test locations in the visual field needs to be clarified.

Introduction

Primary open angle glaucoma (POAG) is a chronic disease, leading to the accumulation of vast amounts of data on intraocular pressure and the visual field during the course of a patient's disease. The ability to numerically threshold the retinal sensitivity at different points in the visual field results in quantitative data which allows for statistical assessment. Number-crunching methods of reducing these data on the central 30 degree field to a single summary statistic have been used to present information on the visual field in a simple, easy to read fashion. These include methods presenting both diffuse and localized patterns of field loss in glaucoma, and also cluster analysis techniques[1-3].

The use of these global summary indices in a longitudinal fashion to evaluate change over time has been proposed as a means of monitoring the course of a patient's disease. Regression analysis of overall visual field performance *versus* time has been described by several authors[4-10]. More recently, this form of analysis has been applied to different regions[11] and individual test points of the central field[12-15]. In this report, we present our findings of a point by point regression analysis of retinal sensitivity using trend analysis[7] in 40 POAG patients followed over a period of 3.8 years.

Subjects and methods

The patients in this study satisfied the following inclusion criteria for POAG; intraocular pressure >21 mmHg at the time of diagnosis, characteristic optic nerve damage and visual field defects; open angles on slit-lamp biomicroscopy; best corrected visual acuity of 20/40 or better; previous perimetric experience; and a minimum follow-up of 20 months with a minimum of five visual field examinations. Forty patients met these criteria and were identified from the

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computerized database of patients under the care of the senior author (BS). The demographic and clinical data on these patients have previously been described in detail as part of a study on the relationship between ocular and systemic variables and the rate of change of the visual field in POAG[10]. One eye of each patient was randomly selected for the study.

The visual fields were tested with the Octopus 2000R automated perimeter using program 31. When a patient has performed five field examinations, a statistical software package is used to analyze change in threshold value over time (trend analysis)[7]. In this study, we excluded the 25 test points located on the periphery of the central 30 degree field. Therefore, the results we present refer to the remaining 48 test points of the central field. At each test point, the slope of the regression line of threshold values *versus* time was determined, and if significantly (Spearman $p<0.05$) different from zero, the slope is labelled as either negative (if threshold values are decreasing) or positive (if threshold values are increasing). The mean ± SD age of the group was 61.4 ± 12.2 years; the mean number of visual fields tests was 12 ± 5, and the mean follow-up period 45 ± 17 months. The mean intraocular pressure during the study was 16.7 ± 2.3 mmHg.

Results

Trend analysis of all 73 test points in the central field showed that ten patients had significant negative slopes (deteriorating fields), two had significant positive slopes (improving fields) and 28 had a non-significant rate of change in threshold values over time, *i.e.*, stable visual fields. The breakdown of the point by point regression analysis in each of these three groups is presented in Table 1.

Table 1. Overall field performance

	Stable (n=28)	*Deteriorating (n=10)*	*Improving (n=2)*
Number of patients with test point deterioration (mean number of deteriorating points)	14 (3 4)	10 (15.6)	1 (1)
Number of patients with test point improvement (mean number of improving points)	6 (1.8)	0	2 (7.5)

In the group of 28 with stable overall fields, 20 patients had at least one significant test point slope - 14 of whom had negative slopes (mean number of deteriorating points 3.4) - and six had positive slopes (mean number of improving points 1.8). Eight patients had no significant test point change; thus, none of the 28 patients had both a positive and a negative slope. All ten patients with deteriorating overall fields had a minimum of one negative test point (range four to 25, and a mean of 15.6). One of the two patients with overall field improvement had both a significant positive and negative test point occurring during the same time period. The mean number of improving test points in these two patients was 7.5.

Overall, 25 of the 40 patients (63%), and 14 of the 28 (50%) with stable central fields had a significant rate of loss at one or more test points. In the 28 patients with stable overall fields, there was no significant difference in the mean intraocular pressure between the 14 eyes with significant test point loss (17.2 ± 2.4 mmHg) and the 14 eyes without significant test point loss (16.5 ± 3.1 mmHg).

Discussion

The results presented here of point by point linear regression analysis in visual field loss agree with those presented by Hitchings *et al.* in POAG patients[12]. Hitchings' study found that between 57 to 65% of their patients had progression at one or more points in the visual field, depending on the type of treatment their patients had. The Moorfields group also found that 50% of patients (37% of eyes) with low tension glaucoma had significant progression at one or more test points[13]. We found that 63% (25 of 40) had a significant rate of decrease in threshold values at a minimum of one test location followed over 3.8 years.

The average number of deteriorating test points was 6.3 in the 25 patients showing progres-

sion at one or more test spots. This number of progressing points appears to be greater than that observed by Hitchings *et al.*[12], who found that between 2.75 and 3.85 points progressed depending on the form of treatment. As expected, when we subdivided our patients into those with stable overall fields (n = 28) and those with significant loss in the overall field (n = 10), there was a clear difference in the number of test points progressing in the two groups. Fourteen of the 28 with stable overall fields had significant deterioration in one or more test locations (mean number of progressing points 3.4). The mean number of progressing points in the ten patients with overall deterioration was 15.6.

The somewhat unexpected finding that 14 of the 28 patients with stable overall fields, had significant test point deterioration (one or more) is disturbing. This finding is emphasized by the relatively high (3.4) average number of deteriorating test points in these 14 patients - all the more so when five of the 14 deteriorated at only one point. It is clear that some of the 28 patients with stable overall fields show evidence of significant statistical and clinical deterioration at several test points which was masked by looking at the performance of the overall field.

In the group of 28 patients with stable overall fields, we observed that those with significant test point deterioration (n = 14) had a higher mean IOP (17.2 mmHg) than those (n = 14) without significant test point deterioration (16.5 mmHg), although this difference was not statistically significant. This suggests that even with well-controlled IOP during follow-up, it is not possible to guarantee immunity from further deterioration in the visual field. Hitchings *et al.* likewise found no difference in mean IOP between eyes with and without test point field progression in POAG[12], a feature also noted in LTG eyes by the Moorfields group[13].

We have previously presented the results on the average of all central test points[10] and the different regions of the field[11] using groups of test points which were clinically judged to behave as a functional unit. In the present study, we have used univariate linear regression analysis to measure change over time in the visual field in POAG, and applied it at individual test locations in the central field. Thus, we have not taken into account the fact that each test point does not behave as an independent unit. The mean number of data values used in the regression analysis, *i.e.*, the mean number of visual field examinations per patient, was 12. Thus, we can assume a reasonable fit for the data and the regression equations. We also feel that the use of the Spearman rank correlation coefficient to determine the statistical significance of the probability of the regression slopes being different from zero, *i.e.*, the null hypothesis, gives a conservative estimate of measuring change over time.

The clinical significance of individual test point deterioration is hard to determine. It is not entirely surprising that a test point immediately adjacent to a dense scotoma will show change over time. This may have no real bearing on the effectiveness of treatment at any one particular point in time as there will be a "time gap" between pathological insults to optic nerve fibers and the subsequent effect on visual function. Thus isolated test point deterioration may possibly be of only limited clinical relevance. The finding of two or more adjacent test locations deteriorating is of greater clinical importance, although again if this occurs at the boundary of a preexisting scotoma, it may simply reflect the "time gap" described above. For this reason, the appearance of one or more deteriorating test points in a part of the visual field previously unaffected assumes far greater clinical significance, as it may herald the unmasking of a new scotoma. While more sophisticated statistical approaches to regression analysis of automated perimetry will provide more reliable data, we, as clinicians, will still have to make a clinical judgment on the evidence provided. This should take into account the number and location of test point changes, and the extent and position of pre-existing scotomas. We should not rely too heavily on statistical results alone but should combine the statistical information and clinical picture before altering treatment.

References

1. Flammer J: The concept of visual field indices Graefe's Arch Clin Exp Ophthalmol 224:389-392, 1986
2. Heijl A, Lindgren G, Olssen J: A package for the statistical analysis of visual fields. Doc Ophthalmol Proc Ser 49:153-168, 1987
3. Chauhan BC, Drance SM, Lai C: A cluster analysis for threshold perimetry. Graefe's Arch Clin Exp Ophthalmol 227:216-220, 1989

4. Holmin C, Krakau CET: Visual field decay in normal subjects and in cases of chronic glaucoma. Graefe's Arch Clin Exp Ophthalmol 60:267-274, 1982
5. Holmin C, Krakau CET: Regression analysis of the central visual field in chronic glaucoma cases: a follow-up study using automated perimetry. Acta Ophthalmol 60:267-274, 1982
6. Spaeth GL: The effect of change in intraocular pressure on the natural history of glaucoma: lowering intraocular pressure in glaucoma can result in improvement of visual fields. Trans Ophthalmol Soc UK 104:256-262, 1985
7. Wu DC, Schwartz B, Nagin P: Trend analysis of automated visual fields. Doc Ophthalmol Proc Ser 49:175-189, 1987
8. Wild JM, Dengler-Harles M, Hussey MK et al: Regression techniques in the analysis of visual field loss. In: Heijl A (ed) Perimetry Update 1988/89, pp 207-216. Amsterdam: Kugler Publ 1989
9. Heijl A, Lindgren G, Lindgren A et al: Extended empirical statistical package for evaluation of single and multiple fields in glaucoma: Statpac 2. In: Mills RP, Heijl A (eds) Perimetry Update 1990/91, pp 305-315. Amsterdam: Kugler Publ 1991
10. O'Brien C, Schwartz B, Takamoto T, Wu DC: Intraocular pressure and the rate of visual field loss in chronic open angle glaucoma Am J Ophthalmol 111:491-500, 1990
11. O'Brien C, Schwartz B: The visual field in chronic open angle glaucoma; the rate of change in different regions of the field. Eye 4:557-562, 1990
12. Hitchings RA, Migdal CM, Fitzke F: Intraocular pressure control: does it protect the visual field. In: Krieglstein GK (ed) Glaucoma Update IV, pp 179-182. Berlin/Heidelberg: Springer Verlag 1991
13. Noureddin BN, Poinoosawmy D, Fietzke FW, Hitchings RA: Regression analysis of visual field progression in low tension glaucoma. Br J Ophthalmol 75:493-495, 1991
14. Cyrlin M, Rosensheim J, Cunningham S, Tressler C, Czedik C, Fazio R: New methods of analysis of serial visual fields. In: Mills RP, Heijl A (eds) Perimetry Update 1990/91, pp 257-271. Amsterdam: Kugler Publ 1991
15. Wild JM, Hussey MK, Flanagan JG, Trope GE: Pointwise topographical and longitudinal modelling of the visual field in glaucoma. Invest Ophthalmol Vis Sci

Perimetric studies on long-term hypotensive glaucoma after filtering surgery by intraoperative mitomycin application

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Abstract

Intraoperative application of mitomycin as a supplementary measure to enhance the filtering effect has been popularized in recent years. One of the most important characteristics of mitomycin application is long-term maintenance of an intraocular pressure below 12 mmHg postoperatively in most cases. The present study was carried out on 20 glaucomatous eyes to evaluate the visual field change with the Octopus 2000 in these glaucoma patients who have maintained a long-term low intraocular pressure of less than 12 mmHg throughout their postoperative course for more than six months. The reversible visual field defect and its implications will be discussed.

Introduction

Glaucomatous cup reversal in adult chronic open angle glaucoma was observed in early glaucoma by computerized disc analysis in 1990[1].

In 1982, intraoperative single application of mitomycin was reported as an effective adjunctive procedure for filtering operations in high risk glaucoma eyes[2]. Mitomycin is an antibiotic and antitumor agent isolated from *Streptomyces casespitosus*. It binds DNA and interrupts DNA synthesis by inhibiting cell mitosis. Mitomycin in eye drops was also used for prevention of recurrence after pterygium operations.

Recent follow-up studies for intraoperative application of mitomycin indicated that such an adjunctive procedure is not only effective in prolonging the filtering process, but can also maintain a rather lower intraocular pressure in the low teens in most cases postoperatively[3-6].

The present study was, therefore, undertaken to observe the long-term effect of the hypotensive status in these glaucoma patients of their visual fields.

Material and methods

Material

Thirteen eyes of 11 patients. including 11 eyes of primary open angle glaucoma patients and two eyes of post-iridectomy primary angle closure glaucoma patients, aged from 21 to 72 years. Eight males and three females were enrolled. Among these, five eyes were failures from previous filtering surgery while eight eyes were initial procedures. The surgical indication was an intraocular pressure elevation of more than 21 mmHg even with various topical hypotensive medications.

Surgery

Standard trabeculectomy and intraoperative application of 0.2 mg/ml mitomycin in gelform for three minutes was performed.

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Observations

Preoperative and postoperative follow-up of more than six months, including glaucoma routine such as intraocular pressure, optic disc, visual field analysis by Octopus 2000R or 500E using programs 32 and 38 were performed. The final judgement, however, was clinical. Subjective feeling of improvement in general vision was also analyzed.

Results

Perimetric analysis and postoperative long-term IOP level are summarized in Table 1. The IOP was kept at 8.2±3.7 mmHg for more than six months and mean sensitivity of the whole field raised from 12.44±4.82 to 15.37±6.17 dB. When the visual fields were analyzed individually by the Octopus Delta program, 12 of 13 eyes showed significant improvement. When a patient's subjective feelings about change of vision as a whole were determined, ten of 13 eyes improved, two eyes felt no difference, while one eye was worse than before the operation. Examination by ophthalmoscopy in all eyes revealed no difference pre- or postoperatively.

Table 1. Results of pre- and postoperative IOP and perimetric analysis

	No.	*Preoperatively*	*Postoperatively (6 months)*
IOP (mmHg)	13	29.0 ±8.2	8.2 ±3.7
MS (dB)	13	12.44±4.82	15.37±6.17
Total loss	13	1067 ±297	825 ±399

Discussion

Surgical intervention to reduce IOP to a safe range is important in glaucoma therapy. Recently, surgical procedures have been able to achieve a better maintenance of long-term lower IOP in most cases by supplementary application of mitomycin[2-4].

While progressive optic nerve damage associated with perimetric change in glaucoma is the rule, reversible disc cupping in chronic glaucoma has also been demonstrated after well-controlled IOP in patients by disc analysis in early glaucoma[6]. In connection with the improvements in automated perimetric studies, the results are rather variable. In this experiment, the mean IOP decreased from a preoperative level of 29.03±8.5 to 8.2±3.7 mmHg during a follow-up period of more than six months. Significant visual field improvement was observed in 12 of 13 eyes in this series.

Furthermore, most of the patients subjectively can report improvement of "vision" at two months postoperatively. Even though an improvement in perimetric studies associated with reversal in optic disc cupping by computerized analysis during a six months' follow-up was reported in 1992[7], it is conceivable that reversible visual function might precede detectable optic nerve improvement after a therapeutic approach in some cases.

Further perimetric studies in correlation with the stage of glaucoma, optic nerve damage, degree of field damage, and duration of IOP control as well as IOP fluctuation are desirable.

Conclusions

Maintenance of IOP in the low teens by adjunctive intraoperative application of mitomycin improved visual fields significantly as shown by the study of mean sensitivity using an Octopus perimeter postoperatively in 12 of 13 glaucomatous eyes during a follow-up of more than six months.

Most of the patients subjectively can report the improvement as early as two months postoperatively, associated with early visual field improvement in some cases. This result may imply that the visual function reversal precedes detectable optic nerve improvement.

References

1 Shin DH et al: Determinants of optic disc cup reversal in adult glaucoma patients. Invest Ophthalmol Vis Sci (Suppl) 31:457, 1990
2. Chen CW: Medical innovation in the effect of fistulizing operation. Chinese Med Assoc 30:15, 1982
3. Hung PT: Intraoperative topical use of mitomycin-c in the refractory glaucoma. Proceedings of the Ophthalmology Society of ROC (Suppl) p 20, 1989
4. Palmer SS: Mitomycin as adjunct chemotherapy with trabeculectomy. Ophthalmology 98:317, 1991
5. Kitazawa Y et al: Trabeculectomy with mitomycin: a comparative study with fluorouracil. Arch Ophthalmol 109:1693, 1991
6 Shin DH, Holec-Iwasko S, Shi DX, Hong YJ, Tsai CS, Briggs KS: Determination of optic disc cup reversal in adult glaucoma patients Invest Ophthalmol Vis Sci (Suppl) 31:457, 1990
7 Kai C, Cantor LB, Philips CA: Computerized optic disc change analysis and perimetric evaluation following glaucoma filtering operation. Invest Ophthalmol Vis Sci (Suppl) 33:882, 1992

OPHTHALMIC IMAGING

Correlation between optic disc changes and visual field loss in patients with unilateral glaucoma

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Abstract

The authors studied the visual field parameters and the optic disc structure in patients with unilateral or highly asymmetric glaucoma. Fifty-five patients were included in the study; 19 normal subjects served as a control group. Plotting the difference in neuroretinal rim area (y) of paired eyes of glaucoma patients *versus* the difference in mean sensitivity (x) leads to: $y = 0.01x + 0.32$ mm^2 From this finding, the authors conclude that, on average, the neuroretinal rim area may decrease by 0.3-0 4 mm^2 before a visual field defect occurs. A similar result was obtained for the cup/disc ratio ($y = -0.004x - 0\ 12$), whereas the normal controls showed only a diffuse spreading around x=0, y=0 These data confirm previous results showing that changes in the neuroretinal rim area are an early sign of ongoing glaucoma. Therefore, longitudinal disc monitoring is a proper strategy for early detection of glaucoma. However, accuracy and reproducibility of any technique used for longitudinal disc monitoring must be sufficient to assure changes in neuroretinal rim area smaller than 0.3 mm^2.

Introduction

It is widely accepted that changes in the optic disc structure, *i.e.*, enlargement of disc cupping, often occurs before a visual field defect can be measured[1-6]. Little information, however, exists on the quantitative amount of cup enlargement preceding visual field defects. The failure of a precise determination is often caused by the large inter-individual variation of disc and cup size[7,8]. Due to this large variation, only weak correlations were commonly found in studies concerning the relationship between disc parameters and visual field indices[3,9-18]. To reduce the influence of inter-individual variations, we evaluated the disc parameters and the visual fields of patients with unilateral or highly asymmetric glaucoma. Similar as recently published by Nanba *et al.*[19], the "normal" eye of each patient was used as a reference. The *intra*-individual difference in mean threshold sensitivity was correlated to the *intra*-individual difference in disc parameters.

Patients and methods

Glaucoma patients

Fifty-five patients with unilateral or highly asymmetric glaucoma were examined. Unilateral or highly asymmetric glaucoma was presumed if one of the following criteria were fulfilled:

1. intra-individual difference in mean threshold sensitivity >2 dB;
2. difference in intraocular pressure of >5 mmHg;
3. marked difference in disc cupping found by routine ophthalmoscopy.

Exclusion criteria were:

- ocular diseases other than glaucoma;
- inadequate pupil dilation;
- poor fundus image.

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Normal controls

Nineteen healthy volunteers acted as controls.

Disc analysis

The disc topography was determined using a Rodenstock Optic Nerve Head Analyzer. This computer automatically calculates the three-dimensional surface of the disc area. It has already been described in detail elsewhere[20]. The incorporated reliability factor ("unsuccessful correlations") was used to avoid artifacts caused by images of poor quality. In particular, pictures with unsuccessful correlations of ≥20% were excluded.

Visual field analysis

Visual fields were tested using the Octopus 2000R or the Octopus 1-2-3, program G1.

Results

The mean values in the glaucoma group were:
- age: 54 ± 15 years
- Δ rim area (right eye - left eye): 0.04 ± 0.44 mm²
- Δ rim area (unaffected - affected eye): 0.37 ± 0.23 mm²
- Δ cup/disc ratio (right eye - left eye): -0.02 ± 0.18
- Δ cup/disc ratio (unaffected - affected eye): -0.13 ± 0.13
- Δ disc area (right eye - left eye): -0.04 ± 0.37 mm²
- Δ disc area (unaffected - affected eye): 0.04 ± 0.31 mm²
- Δ mean sensitivity (right eye - left eye): -0.9 ± 8.4 dB
- Δ mean sensitivity (unaffected - affected eye): 5.64 ± 6.21 dB

The mean values in the control group were:
- age: 27 ± 6 years
- rim area: 1.68 ± 0.38 mm²
- cup/disc ratio: 0.4 ± 0.21

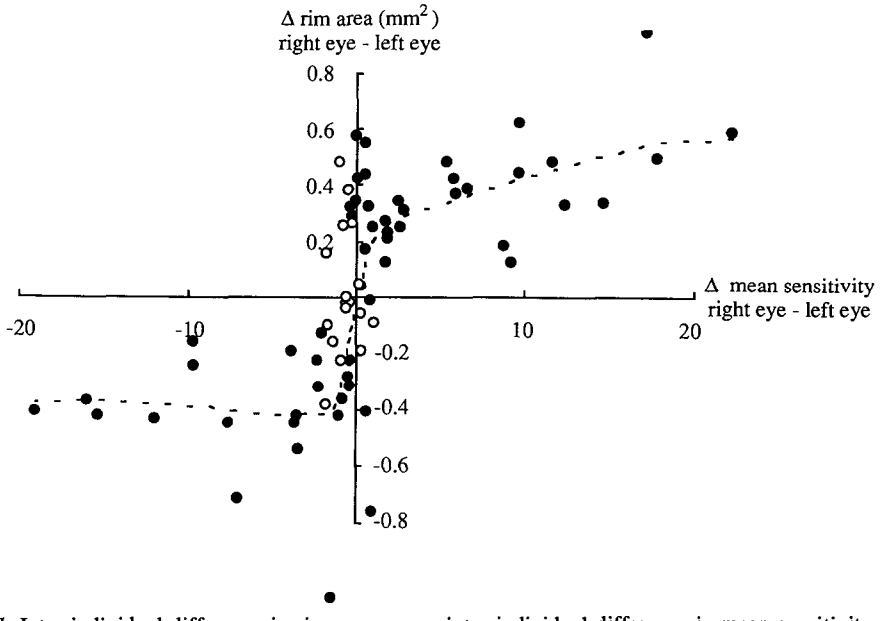

Fig. 1. Intra-individual difference in rim area *versus* intra-individual difference in mean sensitivity in patients with unilateral or highly asymmetric glaucoma (●) and normal controls (○).

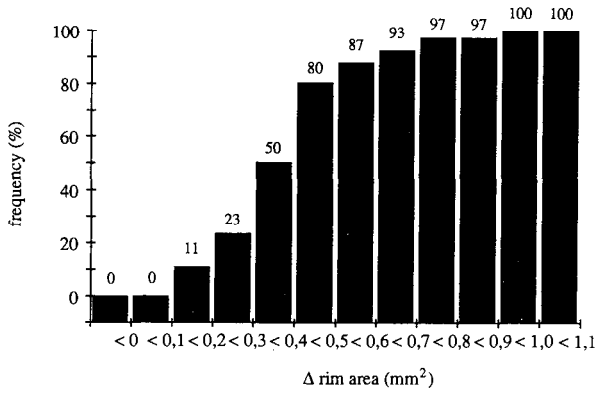

Fig. 2. Relative frequency of differences in rim area in patients with asymmetric fields, Δ mean sensitivity being >2 dB; n=30.

- Δ rim area (right eye - left eye): 0.01 ± 0.24 mm²
- Δ cup/disc ratio (right eye - left eye): 0.03 ± 0.1
- Δ mean sensitivity (right eye - left eye): 0.46 ± 0.8 dB

The correlation between Δ rim area (right eye - left eye) and Δ mean sensitivity (right eye - left eye) is shown in Fig. 1 (closed circles). Patients suffering from glaucoma in the right eye are represented bottom left, patients suffering from glaucoma in the left eye are represented top right. The values of the normal controls are given as open circles. The superposed dotted line gives a smoothed interpolation of the data points. Since the amount of visual field loss (Δ mean sensitivity) represents the stage of the glaucoma disease, Fig. 1 may be interpreted as follows:

- On average, Δ rim area = 0 and Δ mean sensitivity = 0, if both eyes are still normal, *i.e.*, before the onset of glaucoma.
- In the early stages of the disease, Δ rim area begins to increase, *i.e.*, the affected eye loses neuroretinal tissue. At this time, Δ mean sensitivity is still ~ 0.
- If Δ rim area reaches a critical amount, visual field defects can occur. At this advanced stage, the measurable loss of neuroretinal rim area is fairly completed. Δ rim area stays at a constant level while the visual field loss (Δ mean sensitivity) may increase more and more.

Fig. 2 shows the frequency distribution of Δ rim values in patients with Δ mean sensitivity of >2 dB, which is often used as a cut-off between normal and pathological fields. In these patients, the affected eye always had a smaller rim area than the unaffected eye, Δ rim being greater than 0.1 mm² in all cases, greater than 0.2 mm² in nearly 90% and greater than 0.3 mm² in 50%. Contrary to Fig. 2, Fig 3 shows the frequency distribution of Δ mean sensitivity values in patients with asymmetric discs (Δ rim area >0.2 mm²). The finding that 37% of patients with

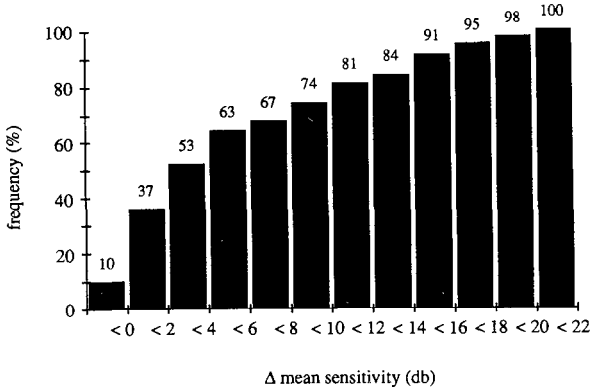

Fig. 3. Relative frequency of visual field changes in patients with asymmetric discs, Δ rim area being >0.2 mm²; n=27.

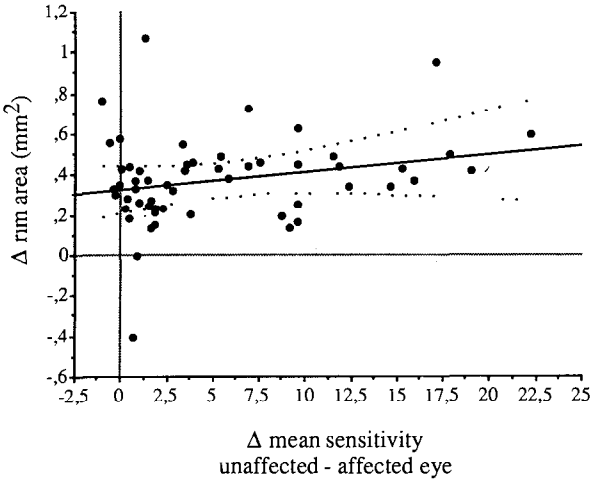

Fig. 4 Linear regression of Δ rim area (unaffected - affected eyes) as a function of Δ mean sensitivity (unaffected - affected eyes). The regression line is: y = 0.01x+0.32. Dotted lines: 99% confidence limits of the regression

asymmetric discs still have normal Δ mean sensitivity values (<2 dB) again confirms that visual field changes usually indicate an advanced stage of glaucoma.

To quantify the disc changes usually preceding the onset of visual field loss, Fig. 4 shows the differences (Δ rim area, Δ mean sensitivity) between unaffected and affected eyes. Linear regression (Fig. 4) yielded: y = 0.01x+0.32. From this equation we conclude that, on average, 0.32 mm² of neuroretinal tissue is lost before a visual field defect can be measured. A similar result was obtained when Δ cup/disc ratio was evaluated instead of Δ rim area (y = -0.004x-0.12).

Discussion

Our data confirm once more that changes in the disc structure usually precede the onset of visual field loss in glaucoma. On average, the neuroretinal rim area obviously may decrease by 0.3 to 0.4 mm² before a visual field defect is detectable by routine perimetry. This finding is in good agreement with the value found by Nanba *et al.*[19], who also calculated a linear regression between Δ rim area and Δ mean sensitivity in paired eyes of glaucoma patients. Therefore, the following conclusions can be drawn:

- Longitudinal monitoring of the disc structure is a valid strategy to detect early stages of glaucoma. Especially in ocular hypertensives without visual field defects, monitoring of the disc structure gives more information than monitoring of the visual field[21-24].
- Any device used for disc monitoring (Optic Nerve Head Analyzer, Imagenet, retinal analyzer, planimetry of fundus photographs, laser scanning tomography) must be sufficient to ensure a decrease in neuroretinal rim area of less than 0.3 mm². Up to now, this normally requires *more* than two or three examinations with any of these devices.
- If a glaucomatous visual field defect is present and the disc is already excavated, further changes of the disc structure are usually small and difficult to detect. At this stage, monitoring of the visual field gives more information than monitoring of the disc structure.

References

1. Armaly MF: The visual field defects and ocular pressure level in open angle glaucoma. Invest Ophthalmol Vis Sci 8:105-124, 1969
2. Betz P, Camps F, Collignon-Brach J, Lavergne G, Weekers R: Biometric study of the disc cup in open angle glaucoma. Graefe's Arch Clin Exp Ophthalmol 218:70-74, 1982

3. Funk J, Bornscheuer C, Grehn F: Neuroretinal rim area and visual field in glaucoma. Graefe's Arch Clin Exp Ophthalmol 226:431-434, 1988
4. Odberg T, Riise D: Early diagnosis of glaucoma. Acta Ophthalmol 63:257-263, 1985
5 Pederson JE, Anderson DR: The mode of progressive disc cupping in ocular hypertension and glaucoma. Arch Ophthalmol 98:490-495, 1980
6. Sommer A, Pollack I, Maumemee AE: Optic disc parameters and onset of glaucomatous field loss Arch Ophthalmol 97:1444-1448, 1979
7. Funk J, Dieringer T, Grehn F: Correlation between neuroretinal rim area and age in normal subjects Graefe's Arch Clin Exp Ophthalmol 227:544-548, 1988
8. Funk J, Dieringer T, Grehn F: Computergesteuerte Papillenanalyse mit dem Optic Nerve Head Analyzer: Normalwerte und Altersabhängigkeit verschiedener Papillenparameter. Klin Mbl Augenhlk 197:410-417, 1990
9. Airaksinen PJ, Drance SM, Douglas GR, Schulzer M: Neuroretinal rim areas and visual field indices in glaucoma. Am J Ophthalmol 99:107-110, 1985
10. Balazsi AG, Drance SM, Schulzer M, Douglas GR: Neuroretinal rim area in suspected glaucoma and early chronic open angle glaucoma: correlation with parameters of visual function. Arch Ophthalmol 102:1011-1014, 1984
11. Caprioli J, Miller JM: Optic disc rim area is related to disc size in normal subjects. Arch Ophthalmol 105:1683-1685, 1987
12. Caprioli J, Miller JM, Sears M: Quantitative evaluation of the optic nerve head in patients with unilateral visual field loss from primary open angle glaucoma. Ophthalmology 94:1484-1487, 1987
13. Dannheim F, Damms T, Obrecht S: Correlation of optic disc and visual field in glaucoma. In: Mills RP, Heijl A (eds) Perimetry Update 1990/91, pp 3-8. Amsterdam: Kugler Publ 1991
14. Drance SM, Balazsi G: Die neuroretinale Randzone beim frühen Glaukom. Klin Mbl Augenhlk 184:271-273, 1984
15. Guthauser U, Flammer J, Niesel P: The relationship between the visual field and the optic nerve head in glaucoma. Graefe's Arch Clin Exp Ophthalmol 225:129-132, 1987
16. Hart WM, Yablonski M, Kass MA, Becker B: Quantitative visual field and optic disc correlates early in glaucoma. Arch Ophthalmol 96:2209-2211, 1978
17. Quigley HA, Addicks EM: Quantitative studies of retinal nerve fiber layer defects. Arch Ophthalmol 100:807-814, 1982
18. Stürmer J, Schaer-Stoller F, Gloor B: Papillenausmessung mit Planimetrie und "Optic Nerve Head Analyzer" bei Glaukom und Glaukomverdacht II. Korrelation der Resultate der beiden Methoden mit Veränderungen des Gesichtsfeldes. Klin Mbl Augenhlk 196:132-142, 1989
19. Nanba K, Iwata K, Nagata K: Relationship between optic disc damage and visual field defects in glaucoma. In: Mills RP, Heijl A (eds) Perimetry Update 1990/91, pp 51-55. Amsterdam: Kugler Publ 1991
20. Klingbeil U: Fundus geometry measured with the analyzing stereo video ophthalmoscope. In: Masters BR (ed) Noninvasive Diagnostic Techniques in Ophthalmology. Berlin/Heidelberg/New York: Springer-Verlag 1990
21. Funk J: Detection of progressive glaucomatous disc damage. Invest Ophthalmol Vis Sci (Suppl) 32:1017, 1991
22. Funk J: Early detection of glaucoma by longitudinal monitoring of the optic disc structure Graefe's Arch Clin Exp Ophthalmol 229:57-61, 1991
23. Funk J: Nachweis progredienter glaukomatöser Papillenveränderungen vor dem Auftreten von Gesichtsfelddefekten. Klin Mbl Augenhlk 198:271-276, 1991
24. Funk J, Hakim R: Verlaufskontrollen glaukomverdächtiger Patienten mittels computergesteuerter Papillenanalyse. Fortschr Ophthalmol 88:308-313, 1991

Correlation of optic disc changes and visual field defects in glaucoma

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Abstract

Optic disc measurements with a computerized image analysis and Humphrey perimetry (program 30-2) were performed in 44 normal, 23 ocular hypertensive and 66 glaucomatous subjects with Aulhorn stages 1 to 5. Linear regression analyses revealed statistically significant correlations between optic disc parameters and visual field index MD (rim area r = 0.65, cup/disc ratio r = -0 55, cup volume r = -0.60). The change of optic disc parameters was considered to be curvilinear and seemed to accelerate up to an MD of around -5.0 to -10.0 dB which was equivalent to Aulhorn stages 2 to 3 and to decelerate after that. These results indicate that optic disc changes precede visual field defects up to MDs of around -5.0 to -10.0 dB and after that visual field defects develop more rapidly.

Introduction

Visual field defects and optic disc cupping are very important indices for the treatment of glaucoma. Quantitative optic disc measurements and automated static perimetry revealed a strong correlation between optic disc cupping and visual field defects[1-4]. Read and Spaeth[5] reported the concept that optic disc cupping initially preceded visual field defects, while visual field defects rapidly increased in later stages. Funk *et al.*[6] showed that visual field defects occurred only when the temporal rim area was smaller than 0.2 mm^2. We reported that optic disc changes preceded visual field defects up to a loss of 0.37 mm^2 in the rim area[7]. To find out up to what stage of glaucoma optic disc changes precede visual field defects, we analyzed the relationship between optic disc changes and visual field defects among normal subjects (NL), ocular hypertensives subjects (OH) and patients with chronic open-angle glaucoma (GL) with Aulhorn stages 1 to 5 visual field defects[8].

Material and methods

Patients were selected with disc areas from 1.99 to 2.89 mm^2 which represented the mean ± SD of the disc area in normals (NLs). Of 133 cases, there were 44 NLs, 23 OHs and 66 GLs including 12 cases of Aulhorn stage 1, 12 cases of stage 2, 13 cases of stage 3, 15 cases of stage 4 and 14 cases of stage 5. One eye of each patient was used. Seventy-one patients were male and 62 patients were female. The mean age was 46.1 years (range, 25-75 years). Mean refraction was -0.72 diopters (range, -6.0 ~+3.25 diopters).

Optic disc measurements were performed with computerized image analysis (Rodenstock Optic Nerve Head Analyzer) for the rim area, cup volume and cup/disc ratio. The definition of the cup and magnification correction for optic disc parameters were the same as reported previously[5].

Visual field examination was carried out with the Humphrey Visual Field Analyzer using program 30-2. Mean deviation (MD) was used as a visual field index. Optic disc measurements and visual field examination were performed within a month of each other.

For statistical analyses, one-way analysis of variance and the Mann-Whitney U test were used. Linear regression analysis was carried out for the correlation coefficient. Differences were considered statistically significant at $p<0.05$.

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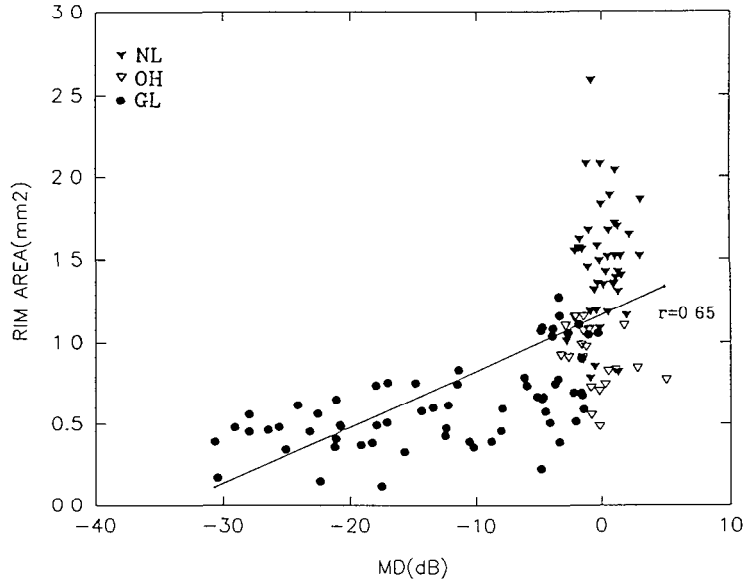

Fig. 1. Scatter diagram representing the relationship between rim area and visual field index MD in normal, ocular hypertensive and glaucomatous subjects. The solid line shows the linear regression

Results

There were no significant differences in age or refraction among the seven groups (*i.e.*, the groups from NL to GL with Aulhorn stage 5). The group of Aulhorn stage 2 showed a significantly larger disc area (2.53 ± 0.24 mm², mean ± SD), while no significant difference in disc area was observed among the other groups (2.32-2.49 mm²). Although linear regression analyses demonstrated significant correlation coefficients between optic disc parameters and MD (rim area r = 0.65, cup/disc ratio r = -0.55, cup volume r = -0.60), the pattern of change of

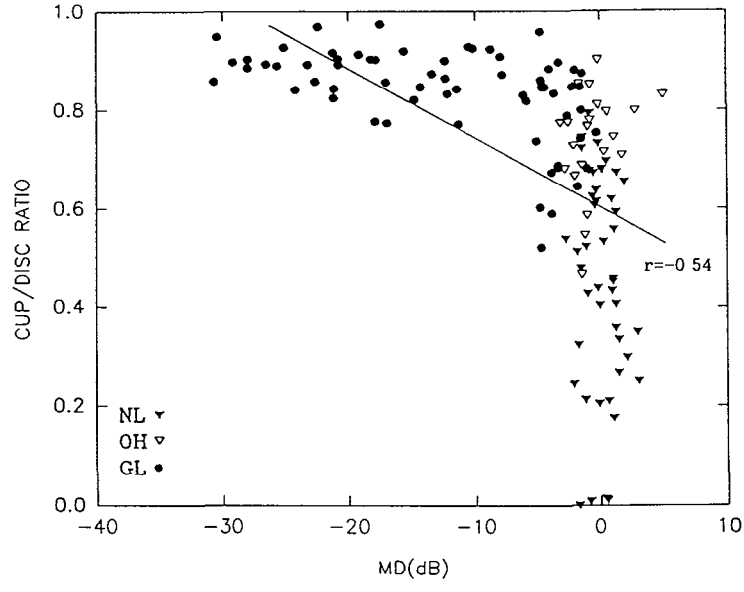

Fig. 2. Scatter diagram representing the relationship between cup/disc ratio and visual field index MD in normal, ocular hypertensive and glaucomatous subjects. The solid line shows the linear regression.

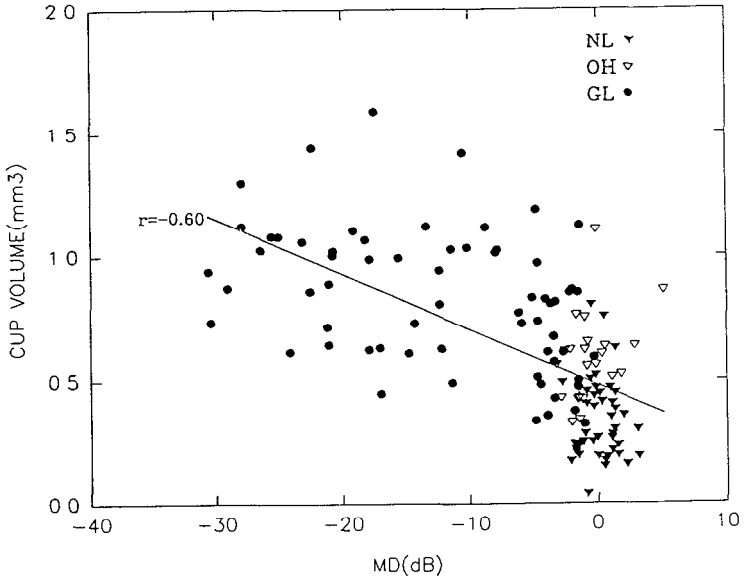

Fig 3. Scatter diagram representing the relationship between cup volume and visual field index MD in normal, ocular hypertensive and glaucomatous subjects The solid line shows the linear regression

optic disc parameters was curvilinear (Figs. 1, 2 and 3). The change of rim area as well as cup/disc ratio and cup volume seemed to accelerate rapidly up to an MD of around -5.0 to -10.0 dB and to decelerate after an MD of -10.0 dB (Figs. 1, 2 and 3). MDs of around -5.0 to -10.0 dB were almost equivalent to the MD of those with Aulhorn stages 2 to 3 (Fig. 4). There were significant differences in rim area as well as cup/disc ratio and cup volume between NL and OH and between Aulhorn stages 2 and 3 (Figs. 4 and 5). No significant difference in optic disc

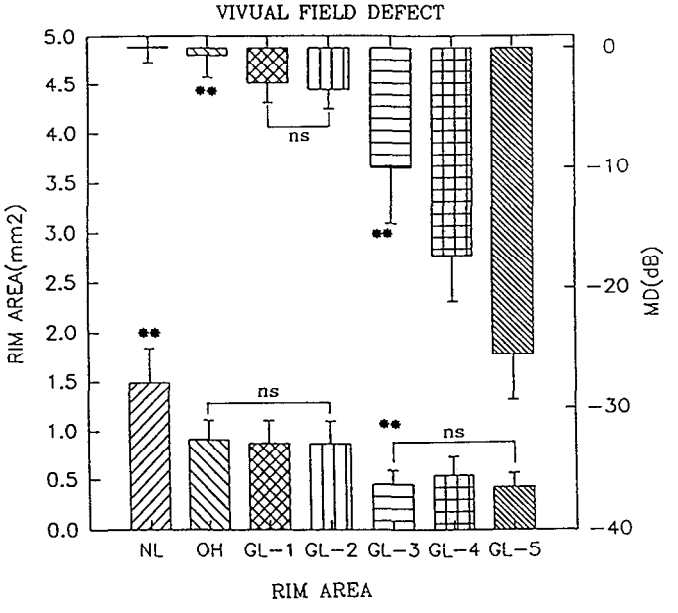

Fig. 4. Mean of rim area in lower columns and visual index MD in upper columns in normal (NL), ocular hypertensive (OH) and glaucomatous (GL) subjects. GL-1 to GL-5 are Aulhorn stages 1 to 5. Error bars represent SD; ★★ indicates $p<0.01$ and ns indicates not significant.

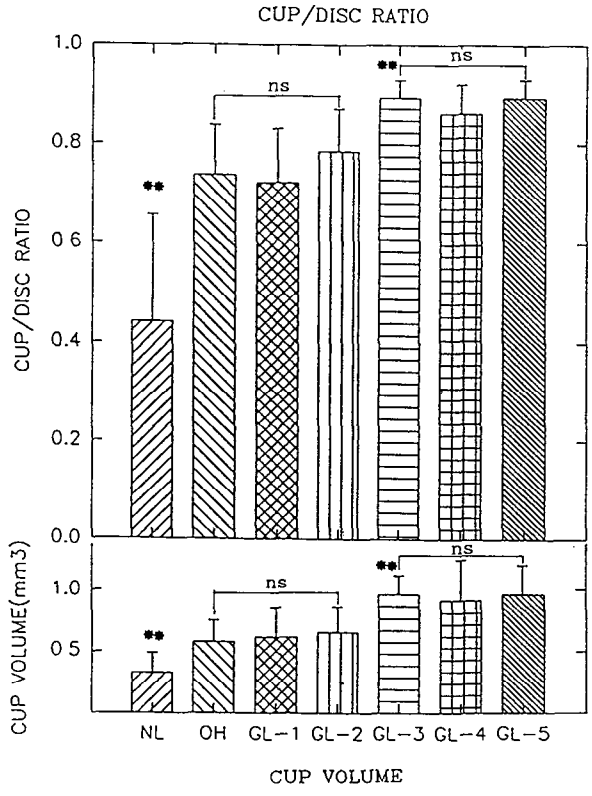

Fig. 5. Mean of cup/disc ratio in upper columns and cup volume in lower columns in normal (NL), ocular hypertensive (OH) and glaucomatous (GL) subjects. GL-1 to GL-5 are Aulhorn stages 1 to 5. Error bars represent SD; ★★ indicates $p<0.01$ and ns indicates not significant.

parameters was found among the groups from OH to Aulhorn stage 2 and among the groups from Aulhorn stages 3 to 5. MD decreased significantly from Aulhorn stages 3 to 5, while there was no significant difference in MD between Aulhorn stages 1 and 2.

Discussion

Linear regression analyses showed statistically significant correlations between optic disc parameters and the visual field index MD. These results were the same as reported previously[1-4]. These scatter diagrams of optic disc parameters plotted against MD suggested that the change of rim area as well as cup/disc ratio and cup volume was not linear but curvilinear. The change of optic parameters was considered to accelerate up to an MD of around -5.0 to -10 dB and to decelerate after that (Figs. 1, 2 and 3). This zone corresponds to the MD in those patients with Aulhorn stages 2 to 3. The relationship between optic disc cupping and Aulhorn stages of visual field defects revealed that optic disc cupping developed rapidly from NLs to OHs, while there were no visual field defects. Visual field defects progressed rapidly from Aulhorn stages 3 to 5, while optic disc cupping showed no difference (Figs. 4 and 5). These results confirmed Read and Spaeth's concept[5]. From these results, it can be concluded that optic disc changes precede visual field defects up to an MD of around -5.0 to -10 dB (Aulhorn stages 2 to 3) and thereafter MD functional damage develops more rapidly than morphological changes.

References

1. Airaksinen PJ, Drance SM, Douglas GR, Schulzer MS: Neuroretinal rim areas and visual field indices in glaucoma Am J Ophthalmol 99:107-110, 1985
2. Guthauser U, Flammer J, Niesel P: The relationship between the visual field and the optic nerve head in glaucomas. Graefe's Arch Clin Exp Ophthalmol 225:129-132, 1987
3. Caprioli J, Miller JM: Correlation of structure and function in glaucoma: quantitative measurements of disc and field. Ophthalmology 95:723-727, 1988
4 Matsubara K, Yamada T, Shirai H, Kitazawa Y: Correlation of visual field changes and optic disc measurements with computerized videographic image analyzer in glaucoma. Acta Soc Ophthalmol Jpn 92:1414-1418, 1988
5. Read RM, Spaeth GL: The practical clinical appraisal of the optic disc in glaucoma: natural history of cup progression and some specific disc-field correlations. Trans Am Acad Ophthalmol Otolaryngol 78:255-274, 1974
6. Funk J, Bornscheuer C, Grehn F: Neuroretinal rim area and visual field in glaucoma. Graefe's Arch Clin Exp Ophthalmol 226:431-434, 1988
7. Nanba K, Iwata K: Relationship between optic disc damages and visual field defects in glaucoma. In: Mills RP, Heijl A (eds) Perimetry Update 1990/91, pp 51-55. Amsterdam: Kugler Publ 1991
8. Aulhorn E: Sensoric functional damage. In: Heilmann K, Richardson KT (eds) Glaucoma: Conception of a Disease Pathogenesis, Diagnosis, Therapy, pp 157-168 Philadelphia: WB Saunders 1978

Optic disc topographic changes following intraocular pressure reduction in normal tension glaucoma and primary open angle glaucoma

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Abstract

Optic disc topographic changes after trabeculectomy were compared between 11 eyes of 11 normal tension glaucomas (NTG) and 16 eyes of 13 primary open angle glaucomas (POAG).

Optic disc measurements were performed using the Rodenstock Optic Nerve Head Analyzer Plus before surgery (Time 1) and at two months to six months after surgery (Time 2) The authors selected cup volume and rim area as disc parameters. There were no statistically significant differences in changes of intraocular pressure (IOP), cup volume and rim area between the two groups.

Although there was a statistically significant correlation between the change of IOP and the change of cup volume in POAG, no such correlation was observed in NTG These results suggest that the degree of disc topographic changes following IOP reduction in NTG are identical to that of POAG. However, changes of cup volume were not pressure related in NTG

Introduction

There have been many reports on the reversal of optic disc cupping associated with intraocular pressure (IOP) reduction in high tension glaucoma[1-5]. However, to the best of our knowledge no reports exist which address the possibility of the disc cupping recovering with IOP reduction in normal tension glaucoma (NTG).

In this study we measured optic disc topographic changes after trabeculectomy in NTG using a computerized image analysis system and compared the changes with those in primary open angle glaucoma (POAG).

Subjects and methods

The subjects were 18 eyes of 14 NTG patients and 21 eyes of 17 POAG patients. The diagnostic criteria for NTG were: maximum IOP was less than 21 mmHg; presence of glaucomatous visual field defects corresponded to optic disc changes; normal open angle; no intracranial or otolaryngological lesion; and no history of massive hemorrhage or hemodynamic crisis. Diagnostic criteria for POAG were: IOP exceeded 21 mmHg on at least one occasion; typical glaucomatous visual field defects; glaucomatous optic disc abnormality; and normal open angle. All subjects underwent trabeculectomy and maintained adequate IOP control after surgery (IOP < 20 mmHg) and underwent successful serial computerized image analyses. All NTG patients had trabeculectomy and mitomycin as an adjunctive therapy. On the other hand, POAG patients underwent trabeculectomy without an antimetabolite or with 5-fluorouracil or mitomycin.

The subjects were examined before trabeculectomy (Time 1) and two to six months after surgery (Time 2) for IOP, visual field, optic disc topography, refractive error, corneal curvature, and axial length. IOP measurements were made with a Goldmann applanation tonometer. The average IOP readings over one month before each topographic measurement were taken for both pre- and post-IOP value. The 30-2 central threshold field was obtained with a Humphrey Field Analyzer 630. The topographic and perimetric measurements were performed within

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three months. We used mean deviation (MD) as the index of degree of visual field loss. Optic disc topography was determined using a Rodenstock Optic Nerve Head Analyzer Plus. We used cup volume (CV, mm^3) and rim area (RA, mm^2) as parameters for optic disc changes. All measurements were corrected for optical magnification using Littmann's formula[6].

Statistical analyses were performed using the Wilcoxon signed-rank test for evaluating the differences between pre- and postoperative value of each parameter. The Mann-Whitney U test was used to evaluate the differences in parameters between NTG and POAG. Linear regression analyses and Spearman's correlation coefficients were used to evaluate the relationship between changes of parameters. The significance level was 0.05.

Results

In 15 eyes (83.3%) of 12 NTG patients and 17 eyes (81%) of 14 POAG patients, reduction of cup volume was observed by means of image analyses after surgery. Fisher's exact test failed to reveal any significant association between changes of cup volume and type of glaucoma.

Table 1. Subjects' background

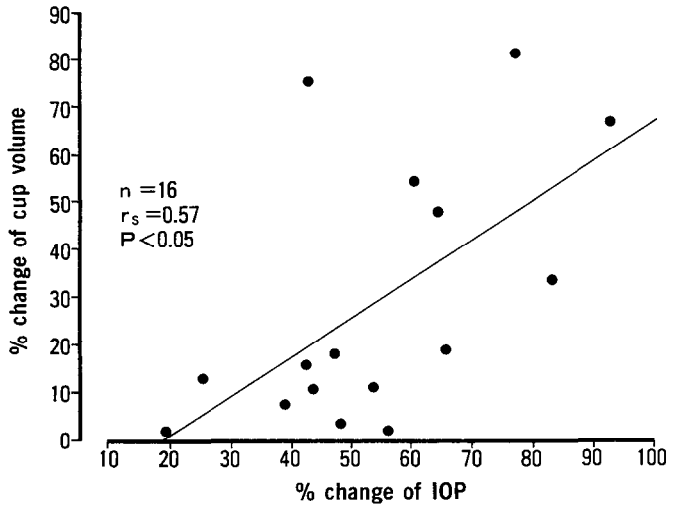
	NTG	*POAG*	*P*
M/F (eyes)	2/9	8/8	
Age (years)	57.4 ±9.2 (46~70)	52.3 ±12.0 (36~71)	NS
Refractive error (D)	-1.13±1.83 (-4.38~1.75)	-2.73± 3.39 (-8.50~3.0)	NS
Follow-up period (weeks)	15.9 ±4.1 (10~25)	13.0 ± 4.6 (8~23)	NS
Mean deviation (dB) -	-15.3 ±7.2 (-28.4~-1.5)	-15.6 ± 8.0 (-28.6~-3.8)	NS

Mean±SD; ( ): range; Mann-Whitney U test
NTG: normal tension glaucoma; POAG: primary open angle glaucoma; M; male, F: female; NS: not significant; SD: standard deviation

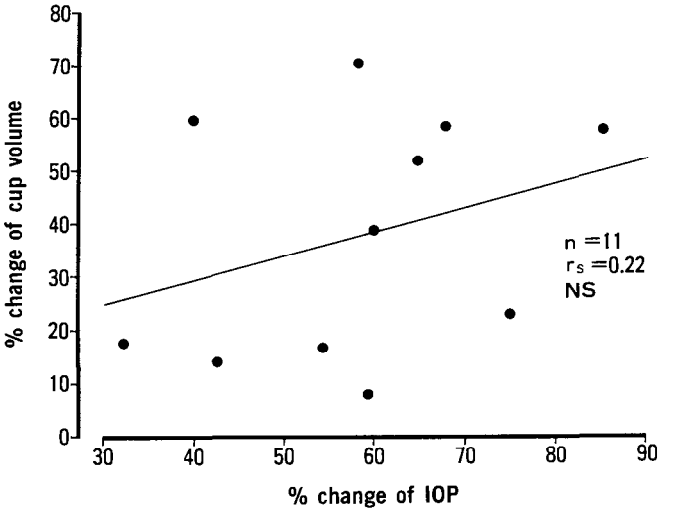
Table 2. Change of parameters

	NTG (n=11)	*POAG (n=16)*
IOP (mmHg)	**	
time 1	14.8 ± 2.4 #1	19.7 ± 4.3 #1
time 2	6.2 ± 2.6 #1	9.0 ± 4.3 #1
ΔIOP	8.7 ± 3.1 *	10.7 ± 4.9
%change	58.2 ±15.4	53.8 ±19.7
Cup volume (mm^3)		
time 1	0.62± 0.19 #2	0.58± 0.2 #2
time 2	0.40± 0.23 #2	0.43± 0.23 #2
ΔCV	0.22± 0.15	0.14± 0.14
%change	37.8 ±22.4	28.8 ±27.4
Rim area (mm^2)		
time 1	0.61± 0.46 #3	0.55± 0.32 #3
time 2	0.98± 0.65 #3	0.77± 0.48 #3
ΔRA	0.37± 0.39	0.23± 0.3
%change	100.6 ±133.8	50.7 ±56.4
Mean deviation (dB)+		
time 1	-15.28± 7.16	-15.70± 7.73
time 2	-15.74± 7.17	-14.33± 9.23
ΔMD	-0.42± 0.84	1.37± 2.75
%change	-4.3 ± 7.9	22.8 ± 1.3

Mean±SD; *: $P< 0.05$ (Mann-Whitney U test); **: $P<0.01$ (Mann-Whitney U test) #: $P <0.01$ (Wilcoxon signed-rank test) +: NTG:n=10, POAG:n=14
NTG: normal tension glaucoma; POAG: primary open angle glaucoma; IOP: intraocular pressure; ΔIOP: preoperative IOP minus postoperative IOP; ΔCV: preoperative cup volume minus postoperative cup volume; ΔRA: postoperative rim area minus preoperative rim area; ΔMD: postoperative mean deviation minus preoperative mean deviation; IOP:%change: ΔIOP/preoperative IOPx100; cup volume:%change: ΔCV/preoperative cup volume x 100; rim area:%change: ΔRA/preoperative rim area x 100; mean deviation:%change: ΔMD/preoperative mean deviation x 100; SD: standard deviation



Ⓐ %change of IOP versus %change of cup volume : POAG



Ⓑ %change of IOP versus %change of cup volume : NTG

Fig. 1. The relationship between %change of IOP and that of cup volume. *A.* %change of IOP *versus* %change of cup volume:POAG. POAG: primary open angle glaucoma. Relationship between the %change of IOP (preoperative intraocular pressure minus postoperative intraocular pressure/preoperative intraocular pressure x 100) and the %change of CV (preoperative cup volume minus postoperative cup volume/preoperative cup volume x 100) in POAG. Statistically, significant positive correlation was observed. *B.* %change of IOP *versus* %change of cup volume: NTG. NTG: normal tension glaucoma; NS: not significant. Relationship between the %change of IOP (preoperative intraocular pressure minus postoperative intraocular pressure/preoperative intraocular pressure x 100) and the %change of CV (preoperative cup volume minus postoperative cup volume/preoperative cup volume x 100) in NTG. No statistically significant correlation was observed.

Further, of those cases with a decrease of cup volume, four eyes of four NTG patients and one eye of one POAG patient developed ophthalmoscopically discernible hypotony maculopathy after surgery. Fisher's exact test failed to reveal any significant association between hypotony maculopathy and type of glaucoma. Finally, we adopted for our study 11 eyes of 11 NTG patients and 16 eyes of 13 POAG patients in whom a cup volume decrease was observed without

manifest hypotony maculopathy for evaluating the degree of optic disc changes after IOP reduction.

The background of the subjects in the two groups is listed in Table 1. There was no statistically significant difference in each parameter between NTG and POAG.

Changes of parameters in two groups are shown in Table 2. There was a statistically significant difference in IOP between time 1 and time 2 in each group. There was a statistically significant difference in IOP at both time 1 and time 2 between NTG and POAG. However, no significant difference in ΔIOP (time 1 - time 2) or %changes (time 1 - time 2/time 1 x 100) was found between the two groups. There were statistically significant differences in cup volume and rim area between time 1 and time 2 in two groups. No significant difference in changes of cup volume or rim area was demonstrated between NTG and POAG. There was no statistically significant difference in the mean deviation between time 1 and time 2 in two groups. No significant difference in changes of the mean deviation was demonstrated between NTG and POAG.

Although there was statistically significant correlation between the %change of IOP and the %change of CV in POAG (r=0.57, P<0.05) (Fig. 1A), no such correlation was demonstrated between the two parameters in NTG (Fig. 1B). On the other hand, no significant correlation was found between the %change of IOP and the %change of RA in either POAG or NTG.

Discussion

Nowadays, surgical reduction of IOP is recommended for NTG[7-11]. In this study, the reversal of cup volume was discernible in 83.3% of NTG and 81% of POAG. There was no statistically significant difference between the two subsets of glaucoma. Previously, Matsubara and coworkers reported that the reversal of cup volume was found in 84% of 19 eyes of 14 patients with high tension glaucoma who maintained satisfactory IOP control after surgery[4].

In the patients who had satisfactory IOP control with cup volume decrease and without hypotony maculopathy, it was documented that the degree of the reversal of cup volume and rim area in NTG was identical to that in POAG. Hence, the main cause of optic disc improvement in NTG might be anterior repositioning of a posteriorly displaced lamina cribrosa following IOP reduction, which has been claimed to be a mechanism of cup reversal observed in POAG. However, other causes might be related to the change of cup volume in NTG, since the change was found not to be pressure dependent (Fig. 1B). One possible cause was optic disc edema with hypotony, although it was not manifest ophthalmoscopically. However, if the anterior movement of the lamina cribrosa in NTG was dependent on the flexibility or fragility of the lamina itself, which has been suggested as one of the possible causes for development of disc excavation under so-called normal pressure, the cup volume reversal may not simply be proportional to the change of IOP.

Assessing the changes of visual field, statistically there was no significant difference between pre- and post-surgical mean deviation in two groups. Previously, we reported that mean deviation was significantly decreased at one year after surgery in 12 eyes of seven POAG patients[12]. In the present study, visual field improvement was not found during the two- to six-month follow-up. However, with a longer period of follow-up the visual field may possibly improve in NTG. Several reports support the notion that filtering surgery is effective for maintaining visual field stability in some cases[8-11].

To reduce IOP, which is one of the risk factors of NTG, seems to be useful for optic disc improvement.

References

1. Spaeth GL, Fernandes E, Hitchings RA: The pathogenesis of transient or permanent improvement in the appearance of the optic disc following glaucoma surgery. Doc Ophthalmol Proc Ser 22:111-126, 1980
2. Pederson JE, Herschler J: Reversal of glaucomatous cupping in adults. Arch Ophthalmol 100:426-431, 1982
3. Greeninge KC, Spaeth GL, Traverso CE: Changes in appearance of the optic disc associated with lowering of intraocular pressure Ophthalmology 92:897-903, 1985

4. Matsubara K, Fujitsuka Y, Tomita G et al: Measurements of reversibility of optic disc cupping in glaucoma using a computerized videographic image analyzer Acta Soc Ophthalmol Jpn 94:604-609, 1990
5. Shin DH, Bielik M, Hong YJ et al: Reversal of glaucomatous optic disc cupping in adult patients. Arch Ophthalmol 107:1599-1603, 1989
6. Littmann H: Zur Bestimmung der wahren Grosse eines Objektes auf dem Hintergrund des lebenden Auges. Klin Monatsbl Augenheilkd 180:286-289, 1982
7. Kitazawa Y, Yamamoto T: Contemporary treatment of normal-tension glaucoma. Ophthalmol Clin N Am 4:889-895, 1991
8. De Jong N, Greve EL, Hoyng PFJ et al: Results of a filtering procedure in low tension glaucoma. Int Ophthalmol 13:131-138, 1989
9 Abedin S, Simmons RJ, Grant WM: Progressive low-tension glaucoma. Treatment to stop glaucomatous cupping and field loss when these progress despite normal intraocular pressure. Ophthalmology 89:1-6, 1982
10. Hitchings RA: Low tension glaucoma: Is treatment worthwhile? Eye 2:636-640, 1988
11. Mellin KB: Filtering surgery in low tension glaucoma Dev Ophthalmol 18: 138-141, 1989
12. Matsubara K, Maeda M, Tomita G et al: The effect of the intraocular pressure reduction on glaucomatous disc changes and visual field defects. Acta Soc Ophthalmol Jpn 96:217-224, 1992

Repeatability of the Glaucoma-Scope measurements of optic nerve head topography

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Introduction

Optic nerve head status is a critical clinical indicator in the diagnosis and management of glaucoma[1]. Even among expert observers, subjective evaluation of optic nerve head topography is not highly reproducible[2]. Recently, computerized methods of optic nerve head (ONH) topography have become available using stereo-photogrammetry[3-7] and laser tomographic scanning[8]. The Glaucoma-Scope offers a new computerized method of measuring optic nerve head topography based on raster-stereography[9,10]. The repeatability of Glaucoma-Scope depth measurements must be established to provide a baseline for making clinical decisions on whether optic nerve head topography in an individual has changed over time.

Material and methods

A computerized system for measuring optic nerve head topography (Glaucoma-Scope, Ophthalmic Imaging Systems, Sacramento, CA) was used to acquire and analyze digitized images of the optic nerve head. Approximately 25 parallel horizontal dark/light line pairs are projected at an angle of 9° to the ONH using near infrared light. As the lines pass over the surface of the ONH, the lines are deflected proportionally to the depth of the surface. Video images record these deflections and computer algorithms translate them into depth numbers, computed from

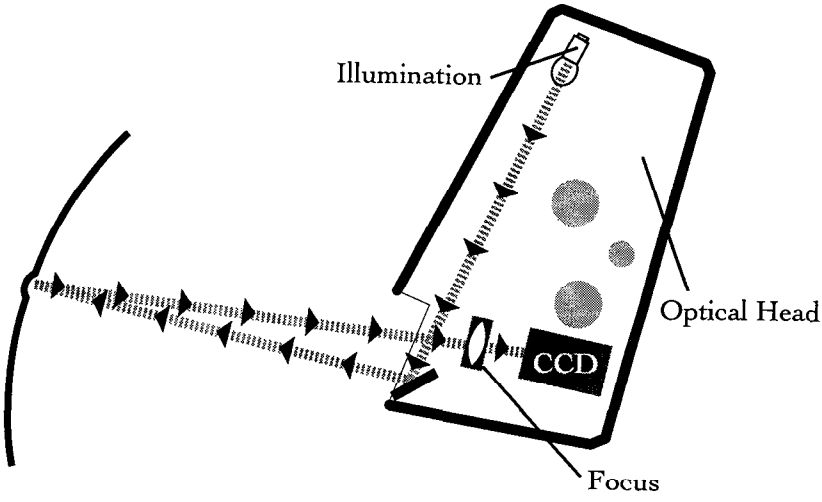

Fig. 1. Schematic diagram of Glaucoma-Scope optical pathway.

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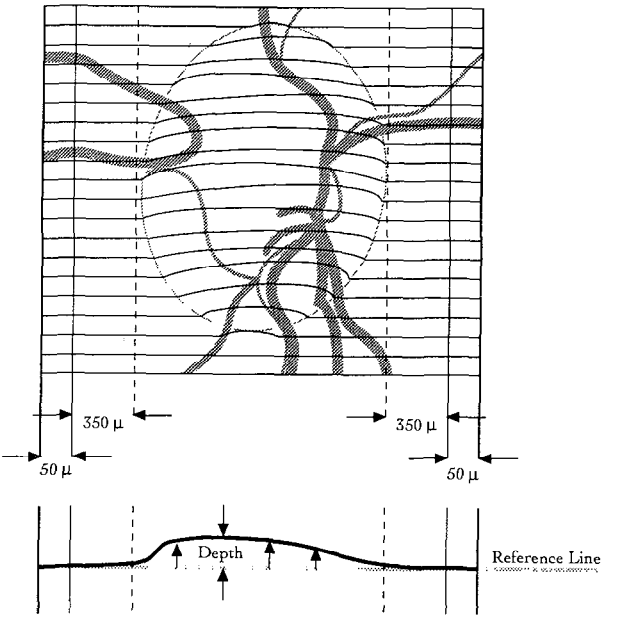
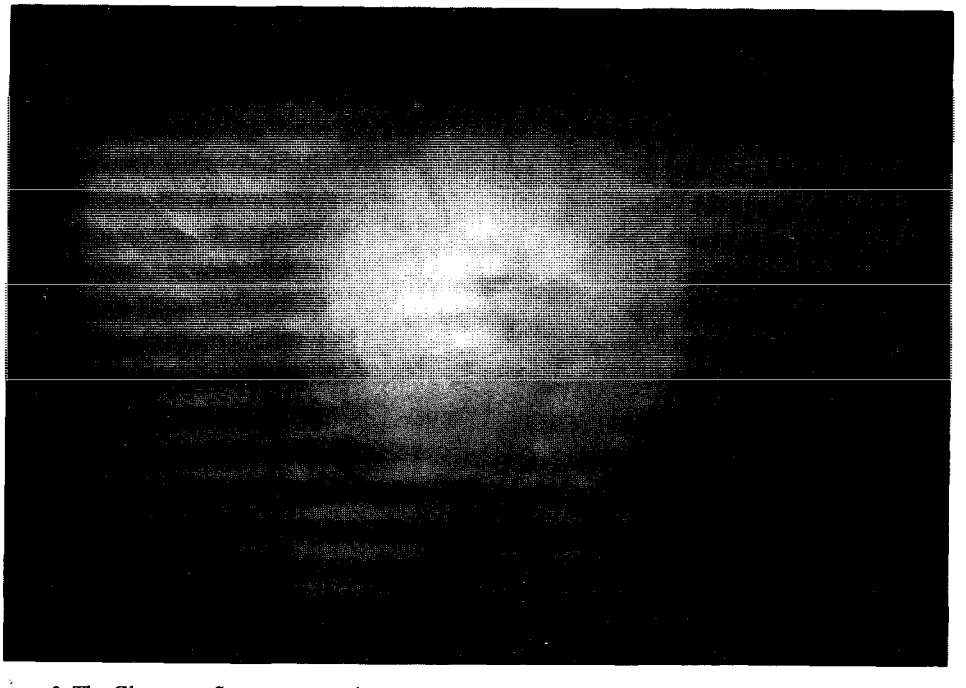


Fig 2 Each line in the pattern uses an individual reference plane defined by the nerve fiber layer height approximately 350 μm temporal and 350 μm nasal to the edge of the optic nerve head.



3. The Glaucoma-Scope captures images on a black and white monitor High quality images are not because data are calculated based only on horizontal line information.

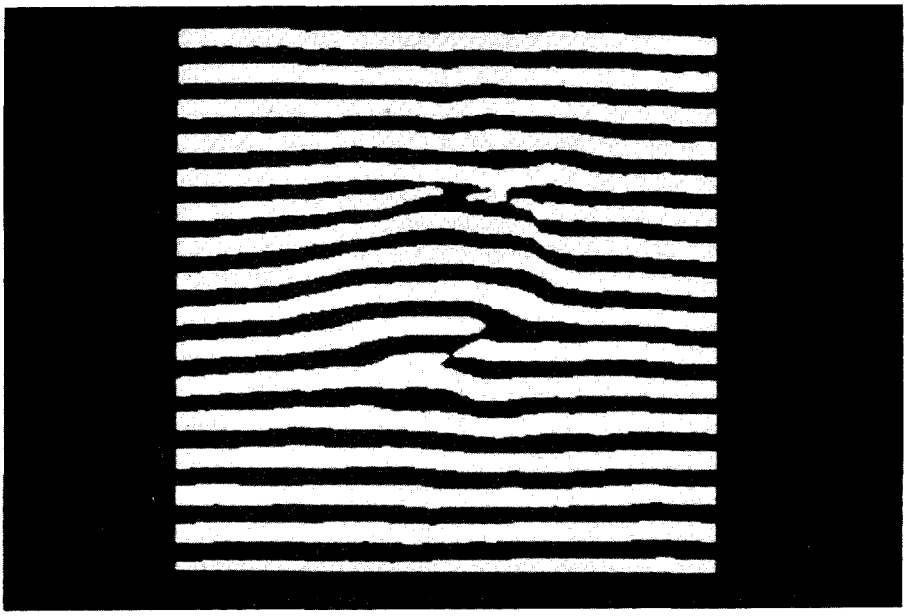


Fig. 4. The original image is reduced to high-contrast horizontal line information. Magnitude of the line deflection corresponds to the depth of an area.

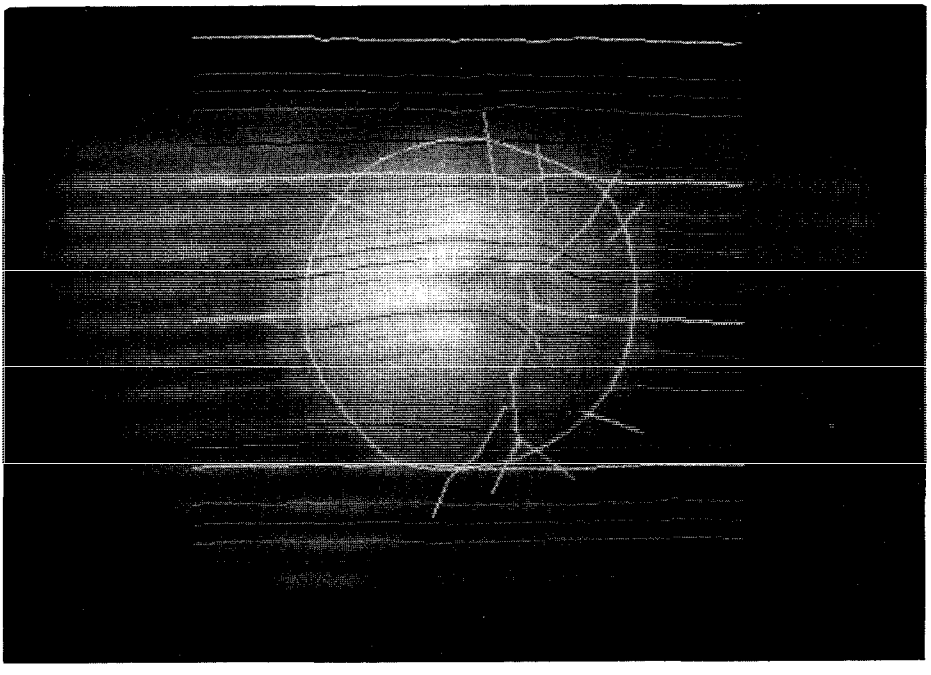


Fig. 5. Line data are superimposed on the original image with vessel tracings. Disc margin and vessel tracings are performed only at the patient's first visit to provide visual landmarks on the printed report. These tracings have no effect on the depth measurements.

approximately 8750 real data points (Fig. 1).

The reference surface for the depth measurements is defined by linear extrapolation of data falling in two vertical columns approximately 350 μm on either side of the optic nerve head (Fig. 2).

The Glaucoma-Scope consists of an optical head mounted in a slit-lamp type assembly. Patient alignment is accomplished while viewing a live image of the optic nerve head on the monitor. Minimum pupil size is approximately 4.5 mm. Once the patient is aligned, an image is captured by pressing a button (Fig. 3).

The operator selects an image for analysis on the basis of evenness of illumination and line contrast. For the patient's first examination, the operator selects a reference point for future image registration and outlines the disc margin and major vessels to provide landmarks on the printout. The margin and vessel drawings do not affect data calculation. For subsequent ex-

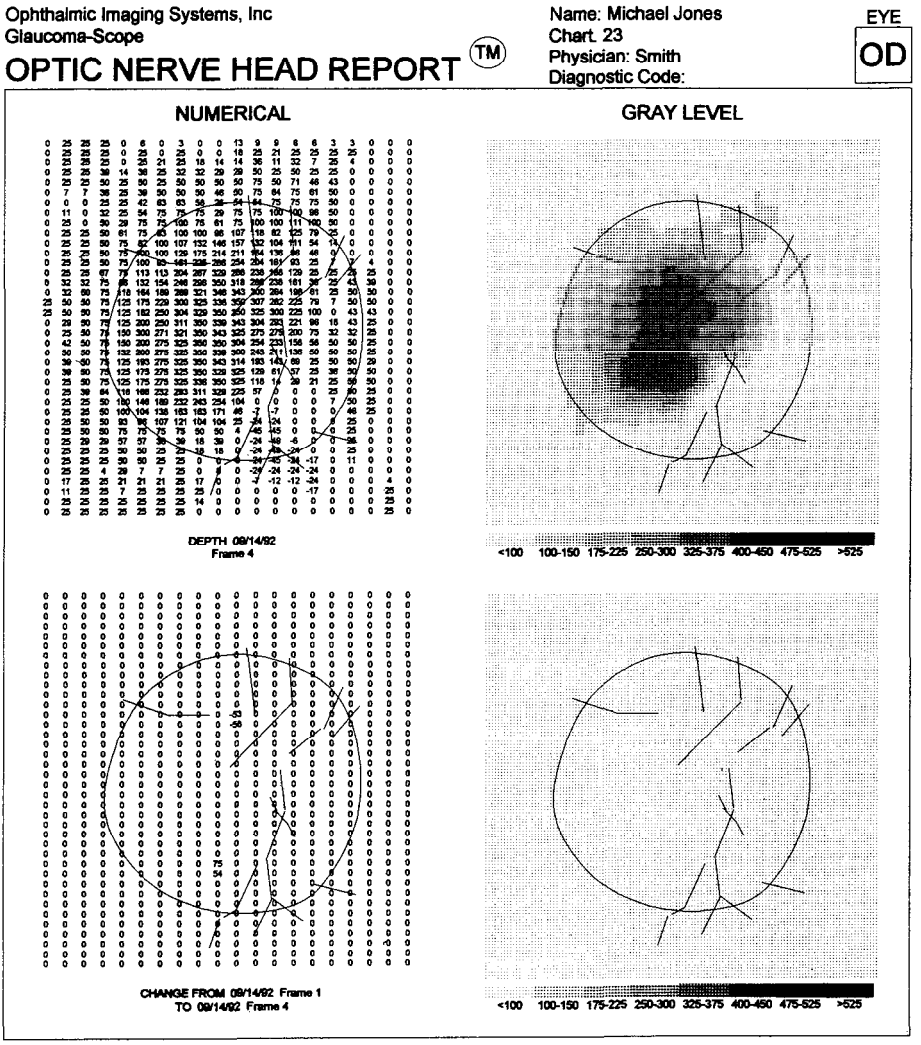


Fig. 6. The two plots at the top of the Optic Nerve Head Report list the numerical depth measurements in microns and the grayscale topography map of the optic nerve head. The two lower plots map change against a baseline visit in microns and in grayscale format.

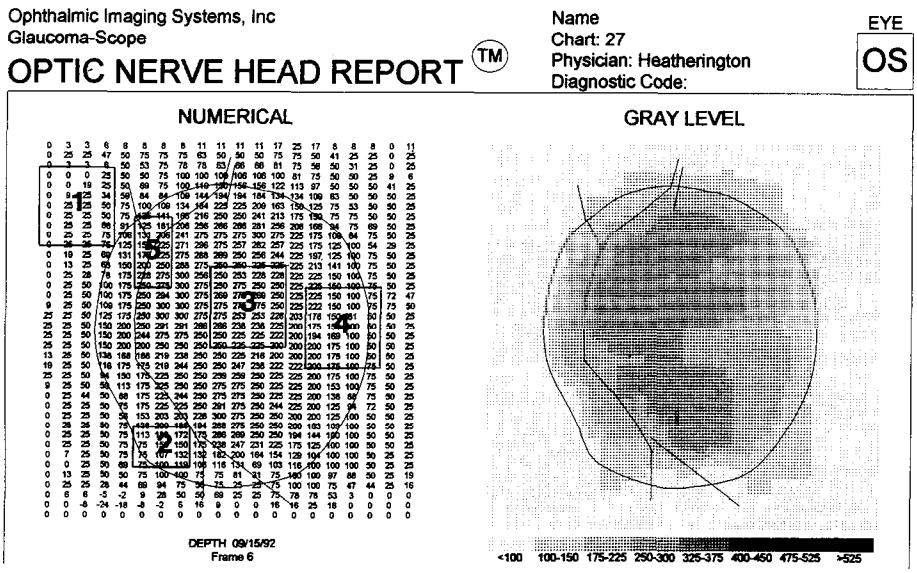


Fig. 7. This sample report illustrates the five areas of interest selected for each subject: 1. flat area outside the ONH; 2. flat area within the ONH; 3. bottom of the cup; 4. sloped area within the ONH; 5. area over a vessel.

aminations, the previously selected reference point appears in a window in the corner of the image. The operator selects a point on the current image that is near the reference point. Computer algorithms perform a best fit analysis on data in an area subtending approximately 4° surrounding the reference point to register the current and baseline images. An overlay of the disc margin trace and vessel information is automatically superimposed on the new image.

To analyze an image, the program first analyses data to remove all non-horizontal line information such as vessels. The remaining horizontal line information is contrast enhanced such that only black and white horizontal lines remain on the screen (Fig. 4). The next analysis step constructs continuous lines with appropriate deflections across the optic nerve head surface based on the high-contrast segments. A series of proprietary logical rules are applied to ensure that left and right segments are connected appropriately. The final analyzed lines are then superimposed with the disc margin and vessel tracing on the image (Fig. 5).

Data are reported in the Optic Nerve Head Report (Fig. 6). Each number in the printout represents the average depth of an area 75 μm × 100 μm in size (a "cell" containing 20 real data points). The report also includes an outline of the nerve head with the depths coded in gray scale. Results from two visits are also compared in the report with the difference in depth reported in both numeric and grayscale formats.

Study subjects consisted of ten normal volunteers aged 40 years and over with confirmed normal visual fields and IOP <21 mmHg, and 18 glaucoma patients with intraocular pressures greater than 21 mmHg prior to therapy and typical glaucomatous visual field loss as judged by the physician examiner. No constraints on refractive error were imposed. Each subject received information on the purpose of the study and signed an informed consent form.

One eye of each normal patient was chosen at random. For glaucoma patients, the eye was selected at random only if both eyes met the study criteria. All study eyes were screened for appropriate anterior chamber angle to ensure safe dilation and then dilated with phenylephrine and tropicamide.

The total variability of the Glaucoma-Scope measurements can be divided into two components: variability that occurs between two images captured sequentially during a single test session (within visit measurement variability) and variability that occurs between images captured at two different test sessions (between visit measurement variability). To determine measurement variability for each of these components, two visits were simulated for each subject in the following manner. Five consecutive images were acquired on the Glaucoma-Scope. Only

minor adjustments for alignment were made between images. These measurements were assigned to visit 1. The subject then went to a different room for stereo fundus photographs. The subject returned to the Glaucoma-Scope where five more consecutive images were acquired and assigned to visit 2. Between visit 1 and visit 2, the Glaucoma-Scope focus, alignment and illumination controls were reset to random positions.

The operator selected two images for processing out of the five images acquired during each visit. As in the clinical situation, images were selected on the basis of evenness of illumination around the optic nerve head and line contrast.

To estimate measurement variability, depth values were analyzed in groups of approximately 25 cells, comprising "areas of interest". The areas of interest were selected from the original video image such that they represented five types of optic nerve head topography: flat area outside the ONH, flat area within the ONH, bottom of the cupped area (this contained some slope information as well), sloped area within the ONH along the transition of rim to cup, and area over a vessel. Areas representing each of the five area types were selected for each subject. Each area of interest represents approximately 375 × 500 μm at the retina, an area large enough to be of clinical interest (Fig. 7).

A components of variance analysis was used to compute the variability of the difference between the depth of an area measured at the first and second visits. The analysis yields the standard deviation of the difference between depth measurements taken within the same visit (S_w), the standard deviation of the difference between depth measurements taken at different visits (S_b), and the combined total standard deviation (S_d).

For each image, an area of interest mean was obtained by averaging the cells included in the area. These area means were used to compute the within-visit means, Y_1 and Y_2, and within-visit variances, V_1 and V_2, at each visit. The average of these variances, V_w is the pooled within-visit variance for both visits. This variance was then averaged over all subjects. The square root of the averaged variance, S_w, is the study estimate for the within-visits standard deviation. The between-visit variance for each patient was computed from the following equation: $V_b = (1/2)(Y_1 - Y_2) - (V_w/J)$, where J is the harmonic mean of the number of images taken at the first visit and the number of images taken at the second visit[11]. The between-visit variances were then averaged over all patients and the square root of this average, S_b, is the study estimate for the between-visit standard deviation. The variability of the difference between two area depth measurements taken at separate visits is quantified by $S_d = [2(S_b^2 + S_w^2)]^{1/2}$.

The degrees of freedom (df) for the within-visit standard deviation from each patient is 2. The total for normal subjects is 10 × 2 = 20 df and for glaucomatous subjects is 18 × 2 = 36 df. The same 20 degrees of freedom for normal patients could also be obtained from one patient visit and 21 images, but that would limit the generalizability of the results.

To estimate the variability of a single cell image within visits, image to image standard deviation of corresponding cell values in the two images within each visit was computed. These standard deviations were then averaged over the entire image (680 values), over two visits and over all subjects in the population of interest. The resultant averaged standard deviation is an estimate of the variability of individual cell values in consecutive images taken within one visit.

Results

There were ten healthy eyes and 18 glaucomatous eyes tested. Of the total population, 13 were male and 15 were female. Average age of the subjects was 57.4 ± 12.0 years (mean ± SD). Average age of the normal subjects was 49.4 ± 11.2 years. Average age of the subjects with glaucoma was 61.9 ± 10.2 years. The average cup/disc ratio of the healthy subjects was 0.26 ± 0.18 (mean ± SD). The average cup/disc ratio of the glaucomatous eyes was 0.63±+ 0.20. These were significantly different ($p<0.05$ by two-sample t test).

The average cup depth in the total population was 213 μm with a maximum of 548 μm. Average cup depth for healthy and glaucomatous discs was 184 μm and 229 μm, respectively. Refractive error of the glaucoma population was 3.13 ± 2.72 diopters spherical equivalent. Two glaucomatous eyes were pseudophakic. Refractive error of the healthy eyes was 1.29 ± 1.74 diopters spherical equivalent. These were also significantly different ($p<0.05$ by two-samplc t test).

The SD of the differences of the depth measurements taken in the various area types both within visits and between visits is shown in Tables 1 to 3.

Table 1. Variability of depth measurements: total population (n=28) (μm)

Area type	*Area definition*	S_w	S_b	S_d
1	Flat area outside ONH	7 15	4.14	11.68
2	Flat area within ONH	12.58	1.43	17.91
3	Bottom of the cup	19.06	12.21	32.01
4	Sloped area within ONH	11.10	9.62	20.78
5	Area over a vessel	19.24	15.29	34.76
Total map	Single cell average	12 61		

Table 2. Variability of depth measurements: healthy discs (n=10) (μm)

Area type	*Area definition*	S_w	S_b	S_d
1	Flat area outside ONH	9.01	4.47	14.22
2	Flat area within ONH	17.87	0.0*	25.27
3	Bottom of the cup	16.44	11.75	28.58
4	Sloped area within ONH	12.88	10.37	23.39
5	Area over a vessel	20.60	13.09	34.53
Total map	Single cell average	11.64		

*S_b cannot be negative. A negative estimated is reported a zero, which indicates a very small or imprecisely determined true value

Table 3. Variability of depth measurements: glaucomatous discs (n=18) (μm)

Area type	*Area definition*	S_w	S_b	S_d
1	Flat area outside ONH	5.87	3.95	10.00
2	Flat area within ONH	8.30	7.56	15.88
3	Bottom of the cup	20.37	12.46	33.76
4	Sloped area within ONH	9.98	9 17	19.17
5	Area over a vessel	18.44	16 38	34.89
Total map	Single cell average	13.16		

The Glaucoma-Scope grayscale topography maps were judged to compare very well with the stereo fundus photographs for all subjects. While the protocol did not include an evaluation of the relationship of the Glaucoma-Scope Optic Nerve Head Report maps to computerized visual fields, the two measurements were noted subjectively to correspond well.

Discussion

We believe that the major sources of between-visit variability are the patient re-alignment and instrument readjustment. The main source of image-to-image variability within visits is the natural variability of the instrument and algorithm. We expect (and have observed) that both sources of variability can be reduced by refinements in the protocol and computer algorithms. The contribution of the within visit variability is further reducible by taking an average of multiple images[12].

The clinical utility of the Glaucoma-Scope to detect change in optic nerve head topography depends on its total measurement variability. As shown in Table 1, S_d is higher in areas of vessels and cups and lower in flat areas. This trend is also seen in the glaucomatous subpopulation reported in Table 3. S_d also tended to be higher in areas containing slopes compared to flat areas. This variability is thought to be due to differences in algorithm interpretation where line deflections are discontinuous, for example, in highly sloped regions and around vessels. In fact, one subject was excluded from the study group because the software algorithm failed to properly assign line pairs across a discontinuity (a steep cup edge). The manufacturer is addressing this problem in its next software update.

Because the cupped glaucomatous discs (cup/disc ratio of 0.63) in our study had a greater percent of their depth measurements in sloped areas than did the healthy subjects (cup/disc ratio of 0.26), the average standard deviation of a single cell of glaucomatous subjects of 13.16

μm is higher than the 11.64 μm found in the relatively flat discs of the healthy subjects. The average single sell SD for the entire population is 12.61 μm. The ± 2 SD interval for healthy and glaucomatous discs is 46.56 and 52.64 μm, respectively. Because the variability of the Glaucoma-Scope depth measurements varies with topography type, we believe the assessment of topographic change can best be answered by considering local measurement variability of the area in question.

Future studies will investigate the efficacy of using computer algorithms to divide the optic nerve head into areas of known variability. Table 4 outlines possible computer logic that may be applied.

Table 4. Proposed computer logic for local area selection

Area type	*Computer logic*
Flat area outside ONH	Area between 1-120 μm outside the disc margin
Flat area within ONH	Area between 1-120 μm within the disc margin
Bottom of the cup	Area within the disc margin >120 μm
Sloped area within ONH	Area of slope: 30°/60°/90° over defined cell area
Area over a vessel	Area within 50 μm of vessel trace

Repeatability of other computerized devices that measure optic nerve head depth has been studied (Table 5). Lusky and associates report a mean standard deviation of all depth measurements of 45 μm using the Retinal Tomograph (Heidelberg Engineering GmbH)[13]. Dandona and associates evaluated the Retinal Analyzer (Allergan Humphrey) and reported the 95% confidence interval for depth measurements inside the optic nerve head ranging from 165.6 μm for healthy subjects to 305.0 μm for subjects with elevated IOP and glaucomatous visual field loss[14]. Lim and associates evaluated the Imagenet (Topcon) optic nerve head analysis package and reported the 95% confidence interval of 280 μm for depth measurements across the image[15]. The Glaucoma-Scope average individual cell results (12.61 μm standard deviation and 50.44 μm ± 2 SD interval length) compare favorably with variability reported for previous computerized optic nerve head topography devices. Much additional work has been done to analyze reproducibility of optic nerve head measurements using other devices. Because the investigators typically report confidence intervals only for calculated disc parameters rather than raw depth measurements, these data are difficult to compare with the current study.

Table 5. Repeatability of depth measurements in computerized optic nerve head topography devices

Investigators	*Device*	*Subject type*	*Average individual cell image-to-image SD*	*Length of -2SD to+2SD interval for average cell*
Current study	Glaucoma-Scope (Ophthalmic Imaging Systems)	Healthy Glaucomatous	11.64 μm 13.16 μm	46.56 μm 52.64 μm
Lusky et al[13]	Retinal Tomograph (Heidelberg Engineering)	Not specified	45 μm*	180 μm
Dandona et al[14]	Retinal Analyzer (Allergan Humphrey)	Healthy Glaucomatous	Not reported	165.6 μm 305.0 μm
Lim et al[15]	Imagenet (Topcon)	Not specified	Not reported	280 μm

*"mean standard deviation" reported in the abstract

The Glaucoma-Scope depth measurements are highly reproducible for both healthy and glaucomatous subjects and correlate well with subjective assessment of the optic nerve head by stereo fundus photographs. Change in optic nerve head topography should be assessed by evaluating local variability in depth measurements.

References

1 American Academy of Ophthalmology: Preferred Practice Patterns, Primary Open-Angle Glaucoma, San Francisco, CA, December 1990
2. Lichter PR: Variability of expert observers in evaluating the optic disc Trans Am Ophthalmol Soc 74:532-572, 1976
3. Varma R, Steinman WC, Spaeth GL, Wilson RP: Variability in digital analysis of optic disc topography. Graefe's Arch Clin Exp Ophthalmol 226:435-442, 1988
4. Dandona L, Quigley HA, Jampel HD: Variability of depth measurements of the optic nerve head and peripapillary retina with computerized image analysis. Arch Ophthalmol 107:1786-1792, 1989
5. Mikelberg FS, Douglas GR, Schulzer M, Cornsweet TN, Wijsman K: Reliability of optic disk topographic measurements with a video-ophthalmograph. Am J Ophthalmol 98:98, 1984
6. Caprioli J, Klingbeil U, Seras M, Pope B: Reproducibility of optic disc measurements with computerized analysis of stereoscopic video images Arch Ophthalmol 104:1035, 1986
7. Shields MB, Martone JF, Shelton AR, Ollie AR, MacMillan J: Reproducibility of topographic measurements with the Optic Nerve Head Analyzer Am J Ophthalmol 104:581, 1987
8. Kruse FE, Reinhard OW, Burk, Hans-Eberhardt V, Gerhard Z, Ulrich H: Reproducibility of topographic measurements of the optic nerve head with laser tomographic scanning. Ophthalmology 96:1320-1324, 1989
9. Holm O, Krakau CET: A photographic method for measuring the volume of papillary excavations. Ann Ophthalmol December-January 1969-1970
10. Krakau CET, Torlegard K: Comparison between stereo- and slit image photogrammetric measurements of the optic disc Acta Ophthalmol 50:863-871, 1972
11. Scheffe H: The Analysis of Variance. New York: John Wiley and Sons 1959
12. Cox DR: Planning of Experiments. New York: John Wiley and Sons 1958
13. Lusky M, Taylor J, Bosem ME, Weinreb RN: Reproducibility of topographic measurements of the optic nerve head with the Retina Tomograph (abstract). Invest Ophthalmol Vis Sci 33:4 1992
14. Dandona L, Quigley HA, Jampel HD: Variability of depth measurements of the optic nerve head and peripapillary retina with computerized image analysis Arch Ophthalmol 107:1786-1792, 1989
15 Lim ES, Taylor S, Simmons ST: Variability of an optic disc change program (abstract). Invest Ophthalmol Vis Sci 30:3 1989

Computerized image analysis of glaucomatous optic disc color changes

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Introduction

Recently, an epidemiological study of glaucoma in Japan revealed that low tension glaucoma (LTG) was common[1]. Therefore, an exact evaluation of the optic disc is required in early diagnosis and follow-up observation of glaucoma. We modified a computerized color analysis system for the purpose of objective quantification of the optic disc color[2]. We have already reported good reproducibility and clinical usefulness for follow-up observation of glaucoma using this system[2,3]. In this study we report correlations among changes in disc rim color, visual field defect and cup area to disc area ratio (C/D.A) in primary open angle glaucoma (POAG).

Subjects and methods

The subjects were 40 eyes of 40 patients with early or middle stages of glaucoma. Magnified stereoscopic optic disc pictures were taken periodically in all cases using the same camera (Canon CF-60Z) and the same color film (Kodak ektachrome ASA 200) by the same photographer. For the periodic measurement of the visual field, an Octopus 201 automated perimeter was used in all cases. The eye with the more advanced visual field damage was studied. All eyes showed significant progression of visual field defects in the whole field when statistically evaluated by program Delta. The mean value of total loss of visual field sensitivity in subject eyes was 271.7±263.2 dB (mean±SD), and cup/disc ratio was 0.70±0.08 (mean±SD).

For the analysis of optic disc color, a computerized color analysis system was used (Fig. 1). The magnified stereoscopic optic disc lighted with a halogen lamp was photographed by a digital video camera (XC-711, Sony), and was stored in an image memory which had 512 x 512 pixels respectively in red, green and blue elements. In each color, the resolution of color intensity was 8 bit (256 steps) in each pixel. Two-hundred and fifty-six by 256 pixels out of 512 x 512 pixels stored into the image memory were subdivided into 16 x 32 pixels (16 x 8 blocks). The mean value of the color intensity in each block was digitized in 100 steps from 0 to 99 respectively in red, green and blue elements, which were superimposed on the original

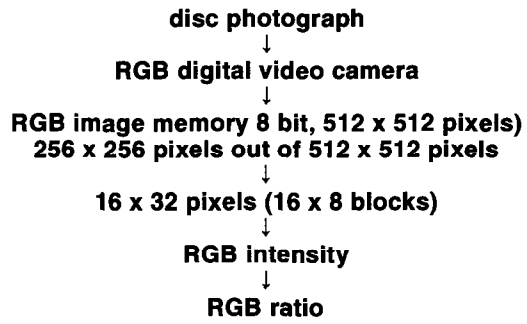

Fig. 1. Color analysis system.

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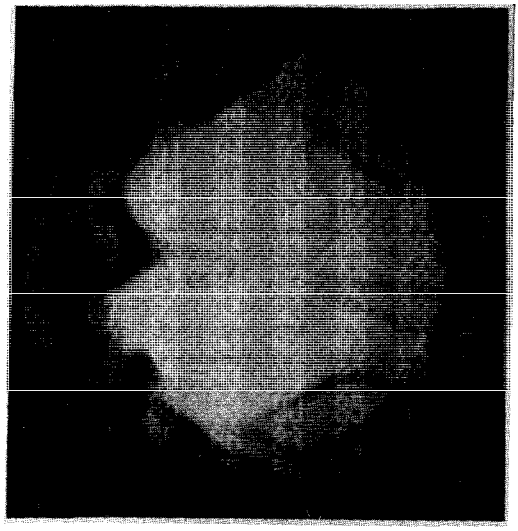

Fig 2

image of the disc on a color cathode ray tube (CRT) shown in Fig. 2, so that the color intensity of every part of the disc could be measured. Based on the analyzed level of actually measured color intensity, we paid attention to the ratio of each element of red, green and blue which were corrected such that the total value became 1 in order to investigate the influence of brightness of the picture[2,3]. For the purpose of quantification of the color change between two images acquired at different times, the change in the ratio of red element (ΔR) was calculated as follows: $\Delta R=(R2-R1)/R1 \times 100$. R1 and R2 are the ratios of the red element before and after progression of visual field defect[2]. For measurement of C/D.A a computerized digitizer was applied using the same magnified stereoscopic picture of the disc as the color analysis. The increase of C/D.A ($\Delta C/D.A$) between two photographs before and after progression was calculated. In addition, the temporal upper and temporal lower disc sectors were each divided into two areas named F1 and F2 according to the retinal nerve fiber pathway shown in Fig. 3. The

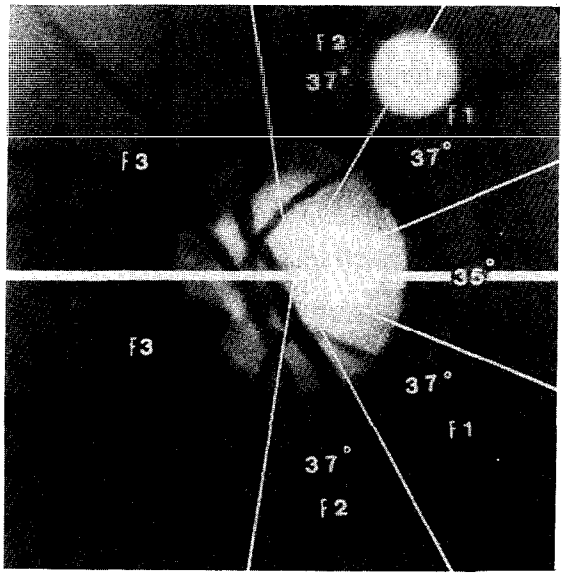

Fig. 3.

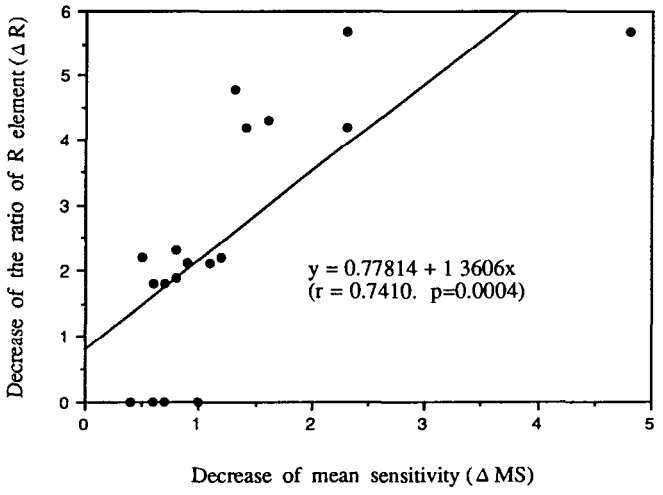

Fig. 4.

one F2 part out of the upper and lower F2 parts, which corresponded to the more progressive area between the nasal upper and lower part of the visual field was selected for color and topographic analysis in every case. As an index of progression of visual field damage, a decrease of mean sensitivity in the visual field (ΔMS) which presented more decrease of sensitivity between the nasal upper and lower areas of visual field was used. A comparison of visual field defects was performed between the two groups. The MS of each group was a mean value of mean sensitivities in the upper and lower nasal area of visual field of at least two different times of examination. In this study the correlation among ΔR, ΔC/D.A, and ΔMS was examined statistically in 40 POAG eyes.

Results

The correlation between ΔMS and ΔR in 18 eyes with total initial loss of visual field sensitivity under 100 dB is shown in Fig. 4. ΔR increased linearly with regard to the decrease of mean sensitivity (Pearson's r=0.7410, p=0.0004). The correlation between ΔC/D.A and ΔR in 18 eyes with total initial loss of visual field sensitivity under 100 dB is shown in Fig. 5. ΔR also increased linearly, correlated with an increase of ΔC/D.A (Pearson's r=0.4698, p=0.0492).

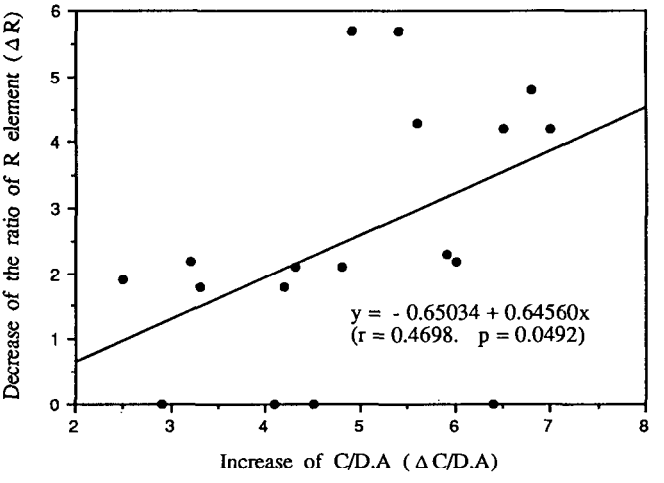

Fig. 5.

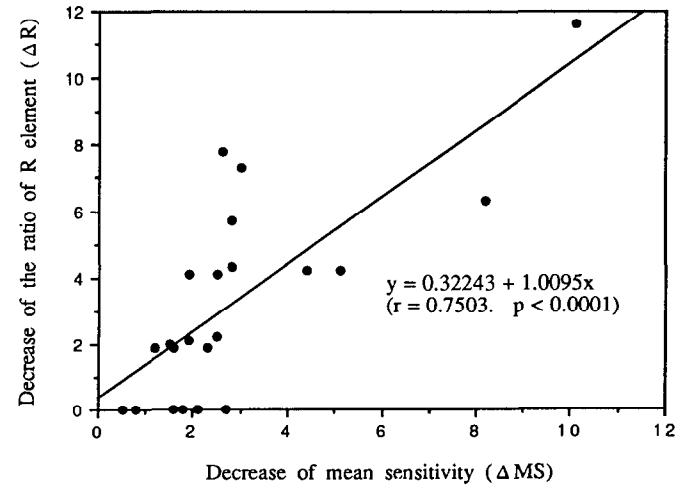

Fig 6

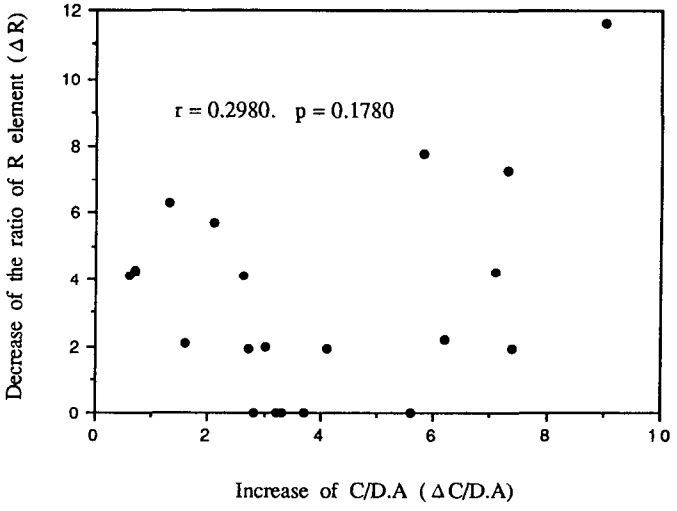

Fig. 7.

The correlation between ΔMS and ΔR in 22 eyes with total initial loss of visual field sensitivity over 100 dB is shown in Fig. 6. ΔR increased linearly with regard to a decrease of MS (Pearson's r=0.7503, p<0.0001). The correlation between ΔC/D.A and ΔR in 22 eyes with total initial loss of visual field sensitivity over 100 dB is shown in Fig. 7. Statistically, ΔR had no significant correlation with ΔC/D.A (Pearson's r=0.2980, p=0.1780).

Discussion

There have been many reports on topographic quantitative image analysis on glaucomatous optic discs, but only a few studies on the quantitative analysis of the optic disc rim color in glaucoma[4-7]. Robert and Hendrickson[8] reported on the disc rim color in glaucoma. However, as they measured a relative pallor value of only a few points on the disc rim, in their method it seems to be possible only to measure rim color change in wide rims, as in an initial stage of glaucoma, but impossible when the rim becomes narrow with the development of glaucomatous notching. In our modified system the optic disc was divided into 16 x 8 blocks. This small division of the optic disc enabled us to evaluate the rim color even in the narrow rim area of

the middles stages of glaucoma. Because the color intensity level in one block is the mean value of 16 x 32 pixels, this system has good reproducibility, a 1.8% intraphotographic and a 1.9% interphotographic coefficient of variation[2]. The ratio of red, green and blue element changes correlated with each other, so we paid attention to the change of the ratios of the red elements in order to simplify the analysis. The more the optic disc becomes pale, the more the ratio of the red element decreases[3].

In this study, the optic disc rim color changes correlated both with the decrease of mean sensitivity and the increase of C/D.A in the early stage of POAG with total initial loss of sensitivity under 100 dB. In the middle stage of POAG with total initial loss of sensitivity over 100 dB, the rim color related to mean sensitivity but not to C/D.A. Therefore, the rim color change in an early stage measured by this system might be based on a different pathological change from that in a middle stage. Several pathological examinations revealed that axon loss was reflected by a general decrease in the tissue volume of the anterior optic nerve head in moderately damaged glaucomatous eyes, and that there was near total collapse of the anterior nerve structure as a result of posterior bowing of the lamina cribrosa with severe damage[9-12]. The number of capillaries in pale optic discs is not significantly different from that in normal optic discs. But, when the loss of nerve fibers leads to a 50% decrease in nerve head substance, capillaries must atrophy to maintain a constant relationship between capillary number and tissue volume[13,14]. Based on these pathological findings, the rim color change in an early stage of POAG appears to be the result of thinning of the neural tissue of the rim of the optic disc and the consequent change in tissue composition and optical transparency, rather than of a loss of optic disc capillaries, whereas in a middle stage rim color change may be the result of near total collapse of the anterior nerve structure including a loss of optic disc capillaries.

References

1 Shiose Y, Kitazawa Y, Tsukahara A et al: Epidemiology of glaucoma in Japan. A nationwide glaucoma survey Jpn J Ophthalmol 35:133-155, 1991

2. Ito M, Miyazawa H, Mizokami K et al: Computerized image analysis in the optic disc color changes with the progression of visual field defects in glaucoma. In: Mills RP, Heijl A (eds) Perimetry update 1990/1991, pp 39-44. Amsterdam: Kugler & Ghedini Publ, 1991

3 Ito M, Miyazawa H, Mizokami K et al: An analysis of optic disc color change in cases of traumatic optic neuropathy Neuro-Ophthalmol Jpn 8:313-319, 1991

4. Mikelberg FG, Douglas GR, Schulzer M et al: Reliability of the optic disc topographic record with a video-ophthalmograph Am J Ophthalmol 98:98-102, 1984

5 Caprioli J, Klingbeil U, Sears M et al: Reproducibility of optic disc measurements with computerized analysis of stereoscopic video images. Arch Ophthalmol 104:1035-1039, 1986

6. Shields MB: The feature of computerized image analysis in the management of glaucoma. Am J Ophthalmol 108:319-323, 1989

7. Kitazawa Y, Funahashi M, Iwasaki Y et al: Image analysis of the optic disc and diagnosis and therapy of glaucoma. Folia Ophthalmol Jpn 40:2833-2848, 1989

8. Robert Y, Hendrickson P: Color appearance of the papilla in normal and glaucomatous eyes. A photopapillometric study. Arch Ophthalmol 102:1772-1775, 1984

9. Quigley HA, Green WR: The histology of human glaucoma cupping and optic nerve damage: clinicopathologic correlation in 21 eyes. Ophthalmology 86:1803-1827, 1979

10. Quigley HA, Addicks EM: Chronic experimental glaucoma in primates. II. Effect of extended intraocular pressure elevation on optic nerve head and axonal transport. Invest Ophthalmol Vis Sci 16:137-152, 1980

11. Quigley HA, Addicks EM, Green WR et al: Optic nerve damage in human glaucoma. II. The site of injury and susceptibility to damage Arch Ophthalmol 99:635-649, 1981

12. Radius RL, Pederson JE: Laser-induced primate glaucoma. II Histology Arch Ophthalmol 102:1693-1698, 1984

13. Quigley HA, Hohman RM, Addicks EM: Quantitative study of optic nerve head capillaries in experimental optic disc pallor. Arch Ophthalmol 93:689-699, 1982

14. Quigley HA, Hohman RM, Addicks EM et al: Blood vessels of the glaucomatous optic disc in experimental primate and human eyes. Invest Ophthalmol Vis Sci 25:918-931, 1984

Regional differences of functional and structural changes in glaucoma

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Abstract

The relationship between generalized and localized changes in visual field (VF) and retinal nerve fiber layer (RNFL) abnormalities in both eyes of 100 patients with early and moderate glaucoma was evaluated. VF and RNFL were divided into four sectors based on the nerve fiber layer anatomy with a red-free fundus photograph and a computerized digital image analysis system. The inferotemporal sectors in RNFL showed more significant localized loss than diffuse loss when compared with the arcuate sector. The regional differences in functional and structural changes may explain the mechanism of glaucomatous optic nerve damage.

Introduction

The relationship between elevated intraocular pressure (IOP) and glaucoma is well known; however, the role of IOP in producing optic nerve damage is still not clear. Characteristic features of glaucomatous optic nerve damage are the progression and pattern of its visual field (VF) defects. The earliest VF loss usually demonstrated an isolated paracentral scotoma in the Bjerrum area between 5- and 25-degrees from fixation. The VF defect then gets larger within the Bjerrum area, first contacting the horizontal raphe nasal to fixation, until linking to the blind spot. The 5-degree central and temporal VF are usually preserved until the late stage of the disease. Hoyt and Louis[1] reported that the above characteristic selective VF loss corresponded with the nerve fiber losses at the superior and inferior poles of the nerve in the early stage of glaucoma, where arcuate-area ganglion cell fibers were located. Quigley *et al.*[2-4] demonstrated that the superior and inferior parts of the lamina at the level of the sclera had larger pores and thinner connective tissue supporting the passage of nerve fiber bundles than the nasal and temporal parts, and concluded that the superior and inferior laminar zones were the sites for passage of Bjerrum-area ganglion cell axons and that they were most susceptible to glaucoma damage.

However, the regional differences of functional and structural changes during the various stages of primary open-angle glaucoma (POAG) have not been studied. The purpose of this study is to determine the relationship between the change of retinal nerve fiber layer (RNFL) and retinal sensitivity in each sectorial area of eyes with POAG.

Material and methods

The diagnostic criteria for POAG were:

- maximum IOP with 23 mmHg or above including diurnal tension curve;
- the presence of typical glaucomatous field defects with glaucomatous disc changes which are not attributable to other ocular or systemic pathologies.

In all patients, aided visual acuity was equal to or better than 0.7 and there was no history of ophthalmic surgery. The mean age of the patients was 54.0 ± 8.6 (SD) years. The visual field was classified into stages 0 to 4 by Goldmann or Humphrey perimetry according to Greve's modification of Aulhorn's classification; therefore, all the enrolled patients could be considered

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to have mild or moderate field changes. The mean deviation in all the patients was -8.08 ± 7.96 (SD) dB, the pattern standard deviation was 7.10 ± 4.95 (SD) dB. Based on the above criteria, one selected eye of each 100 patients with POAG was examined.

RNFL analysis

Red-free fundus photographs of the RNFL were taken using a previously described technique[5,6], and evaluated using a computerized digital image analysis system. The reproducibility of this system has been reported[5,6]. Two parameters were calculated for the evaluation of RNFL as determined from each photograph; they were derived from the image intensity obtained along a circular scanning line around the optic disc. The image intensity decrease (ID) is defined as the arithmetic mean of the differences in image intensity between measurement values in patients and the normal values stored in the analysis system. The value for ID is sensitive to diffuse RNFL loss. The image intensity variance (IV) is defined to local non-uniformity of RNFL loss; the value for IV is more sensitive to localized RNFL loss. It is small if RNFL loss is more or less even, and it is large in the presence of deep, localized RNFL loss.

The radius of the scanning line was two-fifths of the distance between the optic disc and the fovea. The scanning line was divided into five sectors as shown in Fig. 1, four 60-degree sectors and a nasal 120-degree sector. Two parameters were calculated on the scanning line in four 60-degree sectors but not on the nasal sector. The papillomacular fiber bundle area (sector ST and IT) was defined based on the topographical anatomy. Bjerrum nerve fiber bundle areas (sector SB and IB) were considered to be extensions of the nasal side of the vertical meridian.

RNFL analyses were carried out to evaluate the relationship between ID and IV in each RNFL sector.

VF analysis

All patients were examined using the central 30-2 program of the Humphrey Field Analyzer 630. In the examination with the central 30-2 program, a total of 76 points within 30 degrees of fixation were examined. On evaluation of regional characteristics in retinal sensitivity, we divided test points into four groups according to Wirtschafter's retinotopic projection[7] as shown in Fig. 2. RNFL sector SB corresponded to VF IB (inferior Bjerrum), sector ST to VF IT (inferotemporal), sector IT to VF ST (superotemporal) and sector IB to VF SB (superior Bjer-

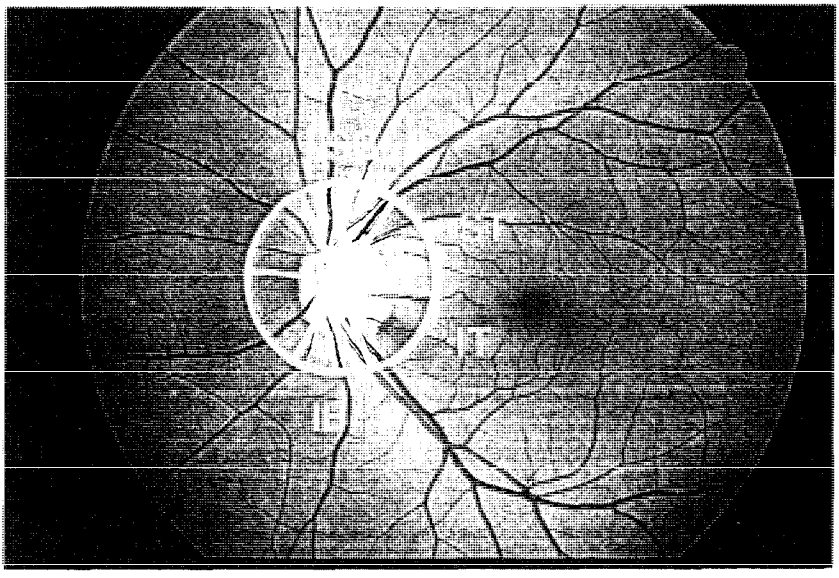

Fig. 1. Example of a red-free fundus photograph. A circle shows the scanning line, and analyzes each wedged line with an angle of 60 degrees. SB: superior Bjerrum: ST: superotemporal; IT: inferotemporal; IB: inferior Bjerrum.

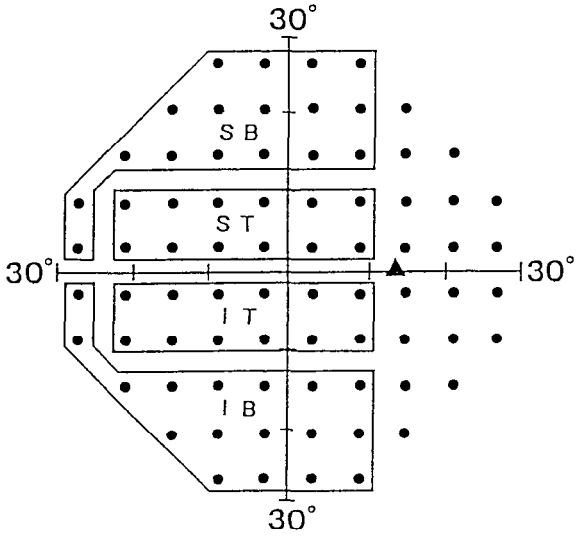

Fig. 2. Map of the central 30-2 program presented as the right eye. The 76 data points are divided into four analytic regions. SB: superior Bjerrum; ST: superotemporal; IT: inferotemporal; IB: inferior Bjerrum.

rum). Mean deviation (MD) is a weighted average deviation from the normal reference field, and sensitive to diffuse VF change. Corrected pattern standard deviation (CPSD) estimates the non-uniform deviation, expressing localized VF deviation. We calculated MD and CPSD as the visual field indices in each sector group, using formulas described by Flammer *et al.*[8,9], and analyzed the relationship between MD and CPSD in each VF sector.

Statistical analysis

Regression analyses were carried out between ID with IV for each RNFL sector, and MD with CPSD in each VF sector group. We also performed analysis of variance to compare the regression curves in RNFL analysis and VF analysis.

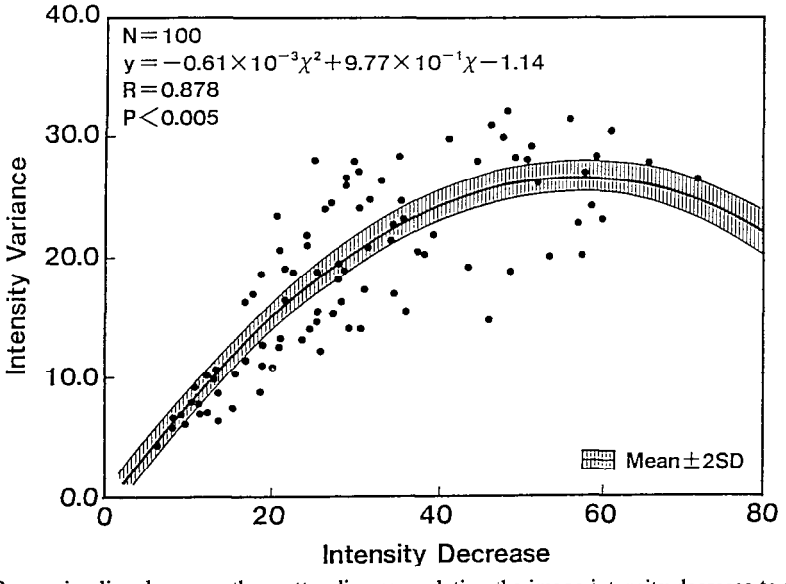

Fig. 3. Regression line drawn on the scatter diagram, relating the image intensity decrease to the image intensity variance of the entire RNFL area around the disc

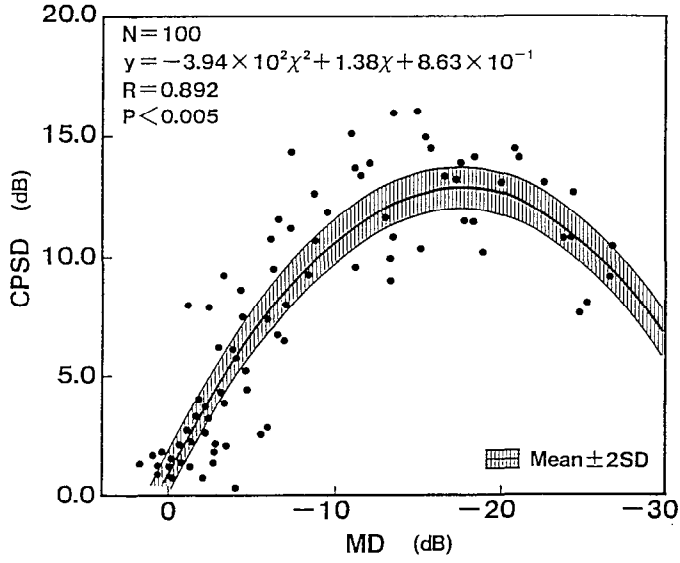

Fig. 4. Regression line drawn on the scatter diagram, relating MD to CPSD in the full field of program central 30-2

Results

The relationship between ID and IV on the RNFL area around the disc is shown in Fig. 3. Two RNFL indices were highly significantly related to a quadratic relationship ($Y = -8.61 \times 10^{-3}X^2 + 9.77 \times 10^{-1}X - 1.14 : r = 0.878, p<0.005$). The relationship between ID and IV of each 60-degree RNFL sector is shown in Fig. 4. The RNFL indices of all 60-degree sectors were highly significantly related to the quadratic relationship (SB: $R = 0.852, p<0.005$, ST: $r = 0.887, p<0.005$, IT: $r = 0.881, p<0.005$, IB: $r = 0.807, p<0.005$). Comparing the regression line in the relationship of ID on IV, sectors SB, ST and IB revealed no significant difference, but sector IT demonstrated more statistically significantly localized RNFL loss than sectors SB, ST and IB ($F = 207.1, p<0.005$).

The relationship between MD and CPSD on full VF of central 30-2 program is shown in Fig. 5. Two VF indices were highly significantly related to the quadratic relationship ($Y = -3.94 \times 10^{-2}X^2 + 1.38X + 8.63 \times 10^{-1} : r = 0.892, p<0.005$). The relationship between MD and CPSD

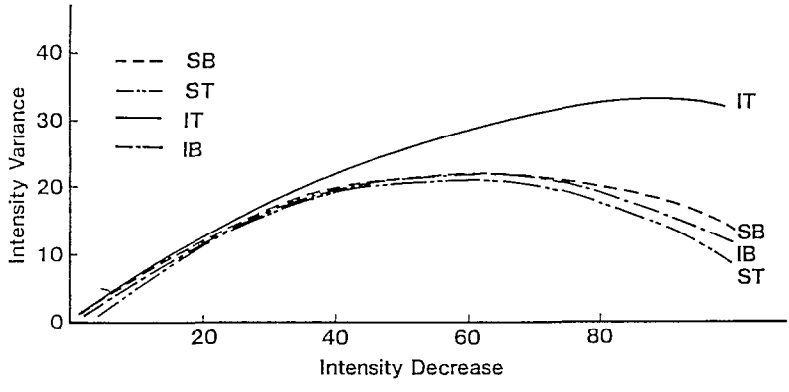

Fig. 5. Regression lines for diagram, relating the image intensity decrease to the image intensity variance of the divided RNFL sector; SB: $Y = -5\,49 \times 10^{-3}X^2 + 0\,682X - 3\,55 \times 10^{-1}, r = 0.852, p<0.005$; ST: $Y = -6.64 \times 10^{-3}X^2 + 7.52 \times 10^{-1}X + 4.61 \times 10^{-1}, r = 0.887, p<0\,005$; IT: $Y = -3.73 \times 10^{-3}X^2 + 6\,92 \times 10^{-1}X - 3.57 \times 10^{-1}, r = 0\,881, p<0\,005$; IB: $Y = -7\,04 \times 10^{-3}X^2 - 7\,65 \times 10^{-1}X - 1.51 \times 10^{-1}, r = 0.807, p<0.005$.

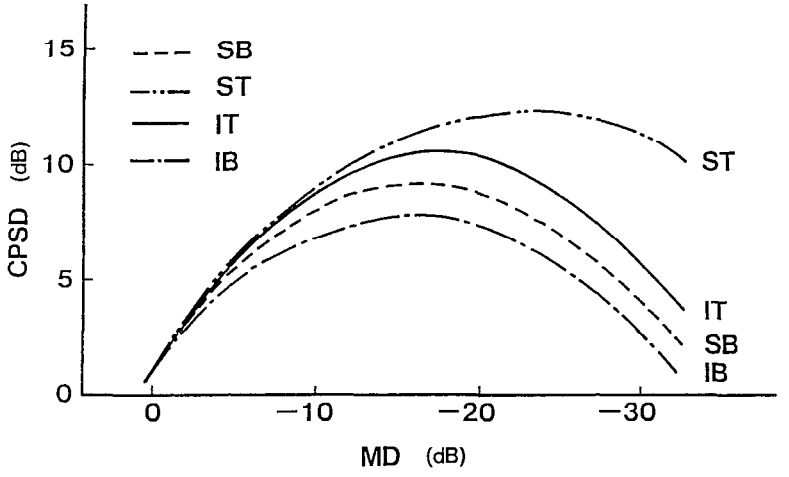

Fig. 6. Regression lines for relating MD to CPSD of the divided visual field; SB: $Y = -2.51 \times 10^{-2}X^2 - 7\ 71 \times 10^{-1}X + 1\ 50$, $r = 0\ 798$, $p<0.005$; ST: $Y = -2.96 \times 10^{-2}X^2 - 1.02X + 1.22$, $r = 0.878$, $p<0\ 005$; IT: $Y = -2.12 \times 10^{-2}X^2 - 9\ 52 \times 10^{-1}X + 1.14$, $r = 0.932$, $p<0\ 005$; IB: $Y = -2.63 \times 10^{-2}X^2 - 8\ 42 \times 10^{-1}X + 1.44$, $r = 0.752$, $p<0.005$.

of each VF sector is shown in Fig. 6. The VF indices of all VF sectors were highly significantly related to the quadratic relationship (SB: $r = 0.798$, $p<0.005$, ST: $r = 0.878$, $p<0.005$, IT: $r = 0.932$, $p<0.005$, IB: $r = 0.752$, $p<0.005$). Comparing the regression line in the relationship of MD and CPSD, VF SB, IT and IB sectors showed no significant difference, but VF SB demonstrated statistically more significantly localized VF change than VF SB, ST and IB ($F = 623.8$, $p<0.005$).

Discussion

We analyzed the characteristics of RNFL and VF changes in each sector in both eyes of 100 patients with early or moderate POAG. A previous study[10] showed a statistically highly significant correlation between the neural structure of the retina as evaluated with the new parameters calculated from our computerized digital image analysis system and the visual function measured using the VF indices calculated by the central 30-2 program of the Humphrey Field Analyzer. The index of ID related to diffuse retinal damage, whereas IV related to localized retinal damage. The present results with regard to RNFL evaluation showed excellent agreement with the quantitative assessment of VF change in each retinal sector. Our results demonstrated that the relationship between diffuse damage and localized damage both in RNFL and VF fitted a non-linear correlation function by quadratic regression analysis. RNFL analysis of the entire RNFL area around the disc demonstrates that at an early stage of glaucoma, increase in both ID and IV was consistent with the current knowledge of histopathological study, but in the moderate stage of glaucoma, increase of ID decrease seems to cause a decline in IV. In an RNFL which is severely disturbed, it is expected, for statistical reasons that further loss of RNFL will reduce IV, since this increases the symmetry of RNFL loss. However, there is more localized RNFL change in inferior temporal RNFL area compared to the other RNFL areas. Quigley and associates[11] reported that the damaged pattern in glaucoma nerves followed an hour-glass shape, with selectively greater damage in the vertical polar region; this most damaged site was quite close to the temporal zone which was most often best preserved, especially the inferior temporal which was the least damaged. There seems to be an abrupt transition from a privileged to a susceptible area at this point.

Current ideas with regard to typical glaucomatous VF loss have largely been developed by Aulhorn and Harms[12]. They showed the importance of small isolated scotomas, often with absolute scotomas. After the advent of computerized perimetry, diffuse depression of the differential light sensitivity throughout the entire VF was identified as the predominant pattern of

VF loss in patients with POAG. These findings have been confirmed by many other investigators[13,14]. The VF analysis of the whole field showed that, in the early VF defect, MD and CPSD increased simultaneously, but in the moderate stage, increase in MD seemed to be associated with a decline in CPSD. These relationships between two indices for VF corresponded well to the relationships between two RNFL parameters. However, we indicated that VF defect in the superior temporal sector showed more localized sensitivity loss compared to the other VF sectors. The most interesting issue is to detect the earliest glaucomatous changes in RNFL and VF, and to predict their progression. Recently, Tuulonen and Airaksinen[15] have shown that in most glaucomatous eyes the initial sign of RNFL abnormality was diffuse change, but in others these were localized changes alone or in combination with diffuse changes. They concluded that the differences of RNFL change resulted from the configuration of the optic nerve head.

We would like to emphasize that there is a regional difference in the pattern of structural and functional changes between the retinal sectors in patients with POAG. This leads to a hypothesis that the optic nerve has regional differences in susceptibility to elevated intraocular pressure.

References

1 Hoyt WF, Louis O: Visual field anatomy in the infrageniculate pathway of the primate; uncrossed and crossed retinal quadrant fiber projections and studied with Nauta silver stain Arch Ophthalmol 68:94-106, 1962
2. Quigley HA, Addicks EM, Green WR et al: Optic nerve damage in human glaucoma: the site of injury and susceptibility to damage. Arch Ophthalmol 99:635-649, 1981
3. Quigley HA, Addicks EM: Regional differences in the structure of the lamina cribrosa and their relation to glaucomatous optic nerve damage. Arch Ophthalmol 99:137-143, 1981
4 Quigley HA, Hohman RM, Addicks EM et al: Morphologic changes in the lamina cribrosa correlated with neural loss in open-angle glaucoma. Am J Ophthalmol 95:673-691, 1983
5. Yamazaki Y, Miyazawa T, Yamada H: Retinal nerve fiber layer analysis by a computerized digital image analysis system. Jpn J Ophthalmol 34:174-180, 1990
6. Yamazaki Y, Miyazawa T, Yamada H: The correlation between retinal nerve fiber layer defect and visual field defect in glaucoma In: Mills RP, Heijl A (eds) Perimetry Update 1990/91, pp 23-26. Amsterdam: Kugler Publ 1991
7. Wirtschafter JD, Becker WL, Howe JB et al: Glaucoma visual field analysis by computed profile of nerve fiber function in optic disc sectors. Ophthalmology 89:255-267, 1982
8 Flammer J, Drance SM, Augustiny L et al: Quantification of glaucomatous visual field defects with automated perimetry Invest Ophthalmol Vis Sci 26:176-181, 1985
9 Flammer J: The concept of visual field indices. Graefe's Arch Ophthalmol 224:389-392, 1986
10 Yamazaki Y, Koide C, Miyazawa T et al: Comparison of retinal nerve-fiber layer in high- and normal-tension glaucoma Graefe's Arch Ophthalmol 229:517-520, 1991
11. Quigley HA, Dunkerberger GR, Green WR: Chronic human glaucoma causing selectively greater loss of large optic nerve fibers Ophthalmology 95:357-363, 1988
12. Aulhorn E, Harms H: Early visual field defects in glaucoma In: Glaucoma Symposium, Tutzing Castle, pp 151-186 Basel/New York: Karger 1967
13 Airaksinen PJ, Drance SM, Douglas GR et al: Visual field and retinal nerve fiber layer comparisons in glaucoma. Arch Ophthalmol 103:205-207, 1985
14. Caprioli J, Sears M: Pattern of early visual field loss in open angle glaucoma. Doc Ophthalmol Proc Ser 49:307-315, 1987
15 Tuulonen A, Airaksinen PJ: Initial glaucomatous optic disk and retinal nerve fiber layer abnormalities and their progression Am J Ophthalmol 111:485-490, 1991

Positive correlation between rotation of the optic disc and location of glaucomatous scotomata

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Abstract

The authors studied the correlation between the location of glaucomatous scotomata and the shape of the optic disc in 32 eyes with high tension glaucoma. There was a positive correlation between the rotation (in- or out-rotation) of the optic disc and the distance between the most depressed point of the superior or inferior scotoma and the central fixation point (p=0.0386). Laterality of the most depressed point of the inferior hemifield was more pronounced in eyes with in-rotation of oval discs than in other eyes (p=0.0044). The most depressed point of glaucomatous eyes with round optic discs was more frequently within 10° of the central fixation point compared with eyes with oval optic discs (p=0.0131). From this study, it is clear that rotation of the oval optic disc and the shape of the optic disc are correlated with the distance between the most depressed point of the scotoma and the central fixation point.

Introduction

Damage to the nerve fiber layer by glaucoma is not uniform around the optic disc; severe damage can be observed locally. Less connective tissue at the superior and inferior poles of the disc, or macroscopic variations in the optic disc may correlate with nerve fiber layer vulnerability. There is an evidence that intrapapillary retinal vessels[1], local elevation of the floor of the cup[2], variable size of the optic disc[3,4], and tilting and rotation of the optic disc[5] are associated with specific types of retinal nerve fiber layer defects. It has been hypothesized that the location of early nerve fiber layer defects corresponds with areas of less connective tissue of the lamina cribrosa[6] and with areas having a large laminar pore size[7].

If the weak points of the optic disc exist strictly along the vertical meridian and at the superior and inferior poles of the optic disc, superior and inferior retinal nerve fiber layer defects will be symmetrical and the distance between the central fixation point and the most depressed point of a superior glaucomatous scotoma will be equal to the distance between the central fixation point and the most depressed point of an inferior glaucomatous scotoma. However, the optic disc of patients is frequently rotated around the anterior-posterior axis. When the weak points of the disc at the superior or inferior end of the long axis of the disc is rotated nasally or temporally, the distance between the superior scotoma and the central fixation point may differ from that between the inferior scotoma and the central fixation point.

To investigate this possibility, we examined the correlation between optic disc rotation and the location of glaucomatous scotomata in 32 eyes of 23 patients with high tension glaucoma.

Material and methods

We examined the optic disc, retinal nerve fiber layer defect and the visual field using the Octopus G1 program in 32 high tension glaucoma eyes of 23 patients. All the glaucomatous patients were consecutive outpatients of the Glaucoma Service at Kyoto University. In addition, all had clear media and a retinal nerve fiber layer defect with a mean defect of less than 17.5 dB. The diagnosis of high tension glaucoma was based on the existence of a glaucomatous visual field defect, glaucomatous cupping of the disc, and a high intraocular pressure (≥26

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Kyoto, Japan, October 20-23, 1992
edited by Richard P. Mills

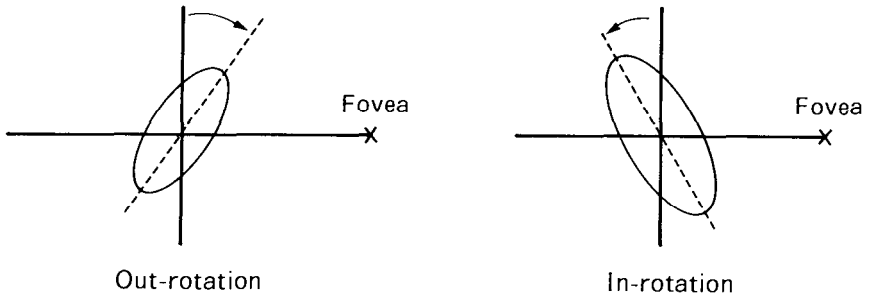

Fig. 1. In-rotation and out-rotation of the optic disc

mmHg) recorded on at least two occasions during the follow-up period. The visual field was assessed more than three times in each patient. The optic disc and the retinal nerve fiber layer defect were photographed with black and white film (ISO 100, Neopan SS, Fuji Film Co, Tokyo). The ovalness index (OI) was defined as the ratio of the long optic disc axis to the short optic disc axis. The shape of the disc was classified into 13 round shapes (OI<1.07) and 19 oval shapes (OI≥1.07). Eyes with an oval optic disc showing no rotation around the anterior-posterior axis and those with an irregular shape were excluded from this study. Out-rotation of the optic disc was defined as a rotation of the superior pole of the disc temporally. In-rotation of the optic disc indicates rotation of the superior pole nasally (Fig. 1).

The most depressed points (MDP) of the superior and inferior scotomata were recorded and mapped on a sheet. The distances between the MDP and the central fixation point were assessed and expressed in degrees (°). The lateral distance between the superior and inferior MDP was expressed in degrees as the difference in laterality (Fig. 2).

The laminar pores were examined in ten selected eyes with large glaucomatous cups. The optic disc was studied using a scanning laser ophthalmoscope (Rodenstock-Chu-O-Sangyo, Osaka). A focus plane was placed on the lamina cribrosa, as reported previously[8], and possible in-rotation or out-rotation of an area with large pores was examined by two ophthalmologists independently.

Statistical analysis

Data were saved using the Statistical Analysis System (SAS Japan, Tokyo) and analyzed by the chi-square test, Fisher's exact test and ANOVA.

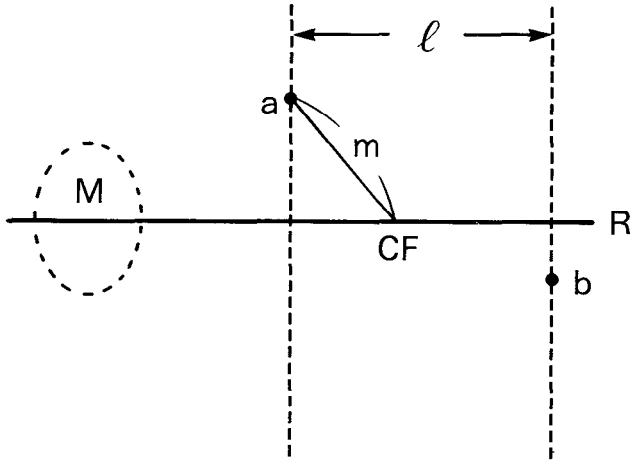

Fig. 2. Measurement of the distance between the most depressed points (MDP) of a scotoma and the central fixation point. a: the MDP of the superior scotoma; b: the MDP of the inferior scotoma; CF: central fixation point; m: the distance between the MDP of the superior scotoma and the central fixation point; l: the lateral distance between the MDP of superior and inferior hemifield scotomata; M: physiologic blind spot; R: horizontal raphe.

Results

The location of the most depressed point (MDP) of the superior and inferior hemifields in each group appears in Fig. 3a, b and c. When the optic disc was oval and in-rotated, the distance between the MDP of the superior scotoma and the central fixation point was shorter than the distance between the MDP of the inferior scotoma and the central fixation point in nine eyes, longer in two eyes and of equal distance in one eye (Fig. 4, Table 1). When the optic disc was oval and out-rotated, the distance between the MDP of the superior scotoma and the central fixation point was shorter than the distance between the MDP of the inferior scotoma and the central fixation point in two eyes, longer in four eyes and of equal distance in one eye (Fig. 5, Table 1). This difference in results was statistically significant by Fisher's exact test (p=0.0386). Examples of in- and out-rotated oval optic discs and a pattern of the visual field are shown in Figs. 4 and 5.

Table 1. Correlation between the most depressed point of the scotoma and the shape of the optic disc

	Group (A) oval disc in-rotation	*Group (B) oval disc out-rotation*	*Group (C) round disc*
Superior MDP closer to the CF	9/12 (75%)	2/7* (29%)	6/13 (46%)
Inferior MDP closer to the CF	2/12 (17%)	4/7* (57%)	5/13 (38%)
Equal distance	1/12 (8%)	1/7* (14%)	2/13 (15%)
Superior MDP within 10° of the CF	5/12 (42%)	3/7 (43%)	9/13 (69%)
Inferior MDP within 10° of the CF	3/12 (25%)	3/7 (43%)	10/13** (73%)

MDP: most depressed point of the scotoma; CF: central fixation point; *significantly different from Group (A) by Fisher's exact test (p=0.0386; **significantly greater than Group (A) by Fisher's exact test (p=0.0131)

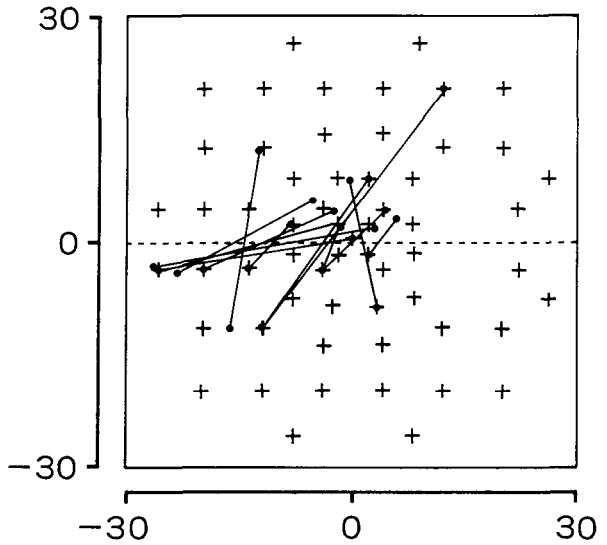

Fig. 3a.

Fig. 3. Scattergram depicting the location of the most depressed points (MDP) of the superior and inferior hemifields of eyes with in-rotated oval discs (3a), out-rotated oval disc (3b), and round optic disc (3c). The broken line indicates the horizontal raphe. The MDP of the superior scotoma of the in-rotated discs tend to be closer to the central fixation than the MDP of the inferior scotoma (p=0.0386). Laterality of the inferior MDP of eyes with in-rotated optic disc were greater than the laterality of the superior MDP. The MDP of eyes with round optic discs were more frequently within 10° of the central fixation compared to eyes with in-rotated discs (p=0.0131).

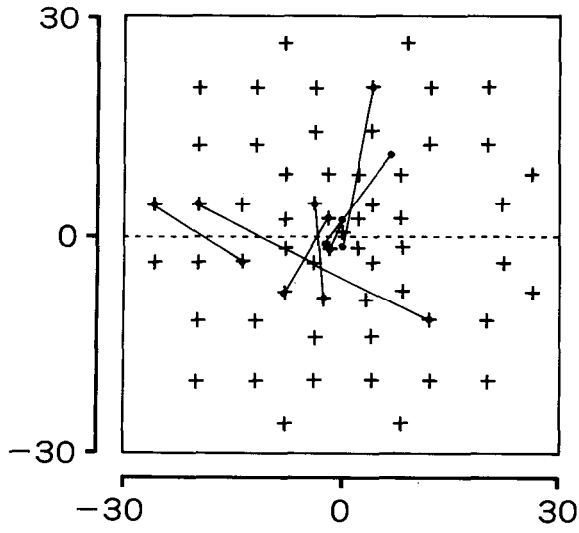

Fig. 3b.

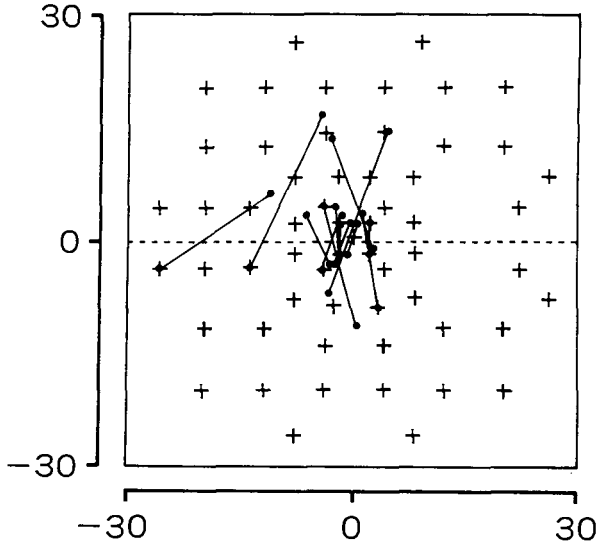

Fig. 3c.

Table 2 Correlation between the location of the most depressed point (MDP) of the scotoma and the shape of the optic disc

	Group (A) n=12 Oval disc with in-rotation	*Group (B) n=7 Oval disc with out-rotation*	*Group (C) n=13 Round disc*	*p value*
Laterality† (degrees)	12.3 ±10 2*	-3.6 ±14.3	1 6 ±6.4	0.0044
Distance between superior MDP and CF (degrees)	8.18± 4.03	12.99± 5.28	7.00±3.87	0.1810
Distance between inferior MDP and CF (degrees)	15 71± 3.79**	8.96± 4.96	5.70±3.64	0.0253

Laterality†: when the MDP of the inferior scotoma was located nasally to that of the superior scotoma, the numerical value was positive. When the inferior MDP was temporal to the superior MDP, the value was negative. *,**: significantly greater than Groups (B) or (C) (statistical analysis with ANOVA)

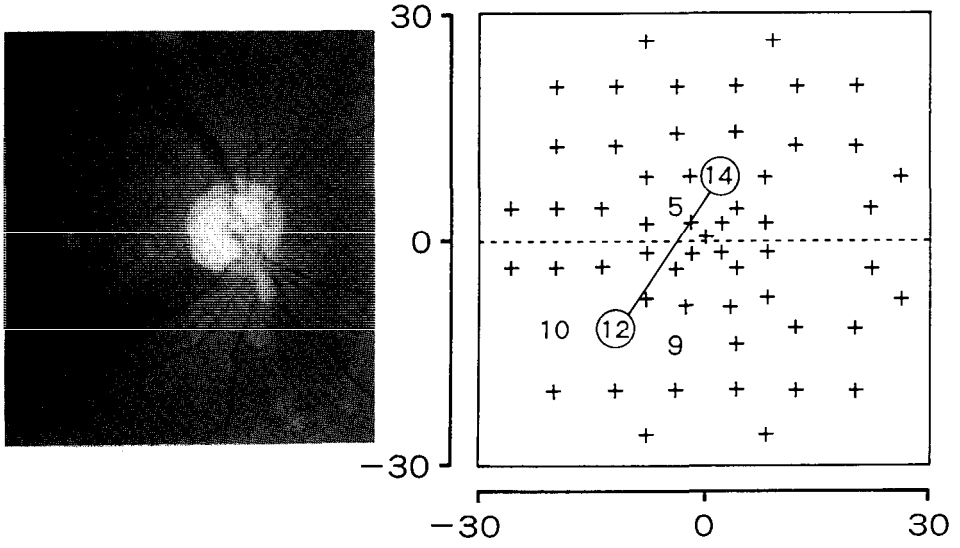

Fig. 4. An example of an in-rotated optic disc (left) and the visual field with the Octopus G1 program (right). The MDP of the superior hemifield was closer to the central fixation point than that of the inferior hemifield.

In eyes with round optic disc, the MDP of the scotoma was more frequently within 10° of the central fixation point than in eyes with oval discs (p=0.0131, Table 1).

The MDP of the inferior scotoma of in-rotated optic discs was 12.3 ± 10.2° lateral to the MDP of the superior scotoma. This laterality was significantly greater in in-rotated optic discs than in out-rotated optic discs (-3.6 ± 14.3°) or round discs (1.6 ± 6.4°) (p=0.0044, Table 2).

The distance between the MDP of the inferior scotoma and the central fixation point in eyes with in-rotated discs was significantly greater than in eyes with out-rotated oval discs or in eyes with round discs (p=0.0253, Table 2). A similar tendency was found in the distance between the superior scotoma and the central fixation point; however, this correlation was not significant (p=0.1810) probably because of the small sample size.

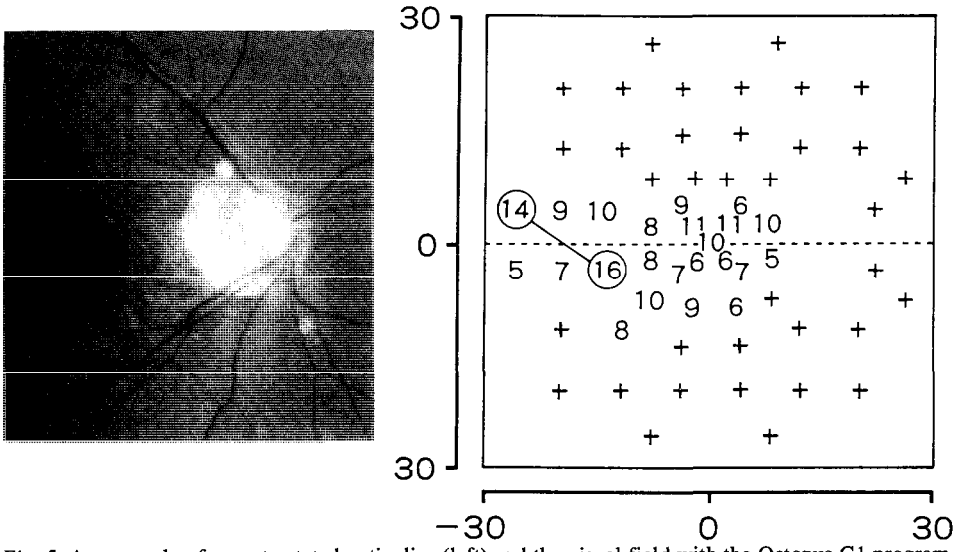

Fig. 5 An example of an out-rotated optic disc (left) and the visual field with the Octopus G1 program (right). The MDP of the inferior hemifield was closer to the central fixation point than that of the superior hemifield.

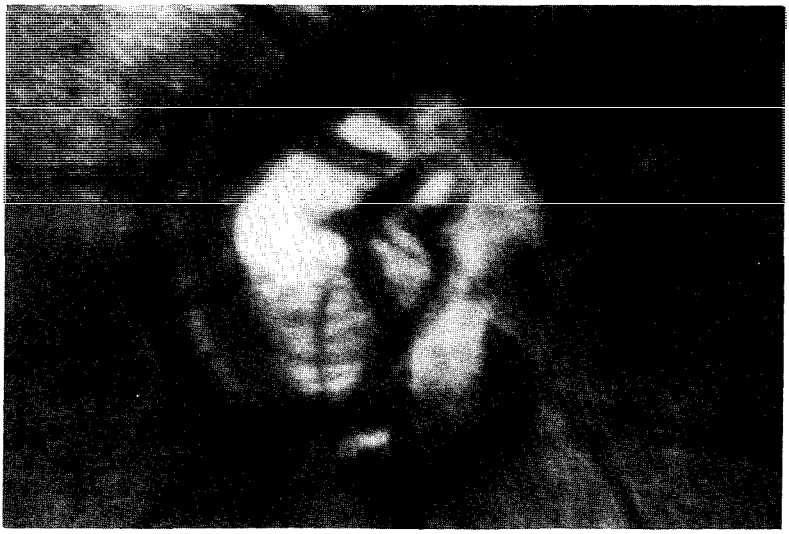

Fig. 6. Representative tomographic image of the lamina cribrosa obtained by scanning laser ophthalmoscope (Rodenstock). At the periphery of the optic disc, the laminar dots are larger along the long axis than along the short axis

The laminar pores of the optic disc can be visualized by the scanning laser ophthalmoscope. The laminar pores along the long axis of the disc were larger at the superior or inferior pole than at any other place, and these areas rotated with rotation of the disc. An example is shown in Fig. 6.

Discussion

There are some reports about the distance between scotomata and the central fixation point in eyes with normal tension glaucoma and high tension glaucoma[9,10]. The type of glaucoma is a probable factor in the relationship between the position of the scotoma and fixation. However, there may be other factors.

When the nerve fibers enter the optic disc, the strength of the laminar connective tissue at the entrance location may be another important factor in the local susceptibility of nerve fibers to glaucomatous damage. When the optic disc is rotated and nerve fibers from the paracentral region pass through the area with enlarged laminar pores, the nerve fibers will suffer more severe distortion by high intraocular pressure and more severe glaucomatous damage than nerve fibers from other regions of the optic disc.

In this study, the MDP of one hemifield was closer to the central fixation point than the MDP of the other hemifield when the associated vertical end of the optic disc was closer to the fovea centralis than the other vertical end. This finding may correspond with the result of our previous study which showed that in-rotation of the disc correlates with inferior dominant retinal nerve fiber layer defects, and out-rotation of the disc correlates with superior dominant retinal nerve fiber layer defect[11].

Other factors which may affect the location of the nerve fiber layer defect are the position of vessels and the refractive error. There is some evidence that retinal vessels in the optic nerve head are associated with the preservation of the nerve fiber layer[1]. If the positions of vessels in the disc are changed due to disc rotation, the shifted vessels may preserve the nerve fiber layer. Myopia is another factor, because the papillomacular bundle is frequently affected in eyes with myopia and glaucoma[4].

From this study, it is clear that rotation of the long axis of the optic disc correlates with the position of the most depressed point of the glaucomatous scotoma.

References

1. Chihara E, Honda Y: Preservation of nerve fiber layer by retinal vessels in glaucoma. Ophthalmology 99:208-214, 1992
2. Levene RZ: Unusual optic discs in primary open-angle glaucoma. Ann Ophthalmol 14:617-620, 1982
3. Chihara E, Honda Y: Multiple defects in the retinal nerve fiber layer in glaucoma. Graefe's Arch Clin Exp Ophthalmol 230:201-205, 1992
4 Chihara E, Tanihara H: Parameters associated with papillomacular bundle defects in glaucoma. Graefe's Arch Clin Exp Ophthalmol 230:511-517, 1992
5. Chihara E, Sawada A: Atypical nerve fiber layer defect in high myopes with high tension glaucoma. Arch Ophthalmol 108:228-232, 1990
6. Quigley HA, Addicks EM: Regional differences in the structure of the lamina cribrosa and their relation to glaucomatous optic nerve damage. Arch Ophthalmol 99:137-143, 1981
7 Ogden TE, Duggan J, Danley K, Wilcox M, Minckler DS: Morphometry of nerve fiber bundle in the optic nerve head of the human Exp Eye Res 46:559-568, 1988
8. Chihara E, Takahashi F, Chihara K: Assessment of optic disc topography with scanning laser ophthalmoscope. Graefe's Arch Clin Exp Ophthalmol 231:1-6, 1993
9. Caprioli J, Spaeth GL: Comparison of visual field defects in the low-tension glaucomas with those in the high-tension glaucomas. Am J Ophthalmol 97:730-737, 1984
10. King D, Drance SM, Douglas G, Schulzer M, Wijsman K: Comparison of visual field defects in normal-tension glaucoma and high-tension glaucoma. Am J Ophthalmol 101:204-207, 1986
11. Chihara E, Tanihara H: Relationship between disc shape and focal vulnerability of nerve fiber layer. Fol Ophthalmol Jpn 38:858-862, 1987

A measure for the thickness of the nerve fiber layer and the configuration of the optic disc excavation in glaucoma patients: a clinical study using the laser tomographic scanner

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Abstract

One hundred and fifty-three eyes (82 patients) with ocular hypertension (OH), primary open angle glaucoma (POAG), low tension glaucoma (LTG) and healthy persons were examined with the LTS and Octopus perimeter 201 to evaluate the following two questions: *1* Is there a parameter for the thickness of the nerve fiber layer in eyes with an Elschnig scleral ring? In 63 eyes of 63 patients with scleral ring the authors measured the difference in height between the scleral ring and the retina at three defined points 250 µm from the temporal margin of the optic disc: a. in 80% of the patients a smaller difference in height could be related to a greater visual field loss in the corresponding quadrant of the visual field; b. in healthy persons there was a decrease of the height difference with increasing age and a decrease with larger diameters of the optic nerve head. As this difference in height correlates with the visual field loss and clinical findings it might describe the thickness of the nerve fiber layer. *2.* Is there any difference in depth and configuration of the excavation in eyes with POAG and LTG? In comparison to POAG in the same stage of the disease, eyes with LTG showed: a. a greater depth of the excavation in all stages except stage I; b. a significantly steeper slope and a flatter and larger bottom of the excavation in stages I and II. Stages III to V showed no difference in the configuration of the excavation

Introduction

The laser tomographic scanner (LTS)[1] allows a quantifying examination of the optic nerve head. It operates with a confocal technique. The surface of the examined object was calculated from 32 transverse tomograms. The measured values can be represented either in a topographic diagram or as a pseudo three-dimensional image.

Questions

We were especially interested in two main questions:

1. Can we determine a measure for the thickness of the nerve fiber layer with the laser tomographic scanner? (HD)
2. Are there any quantitative differences in the configuration of the optic disc excavation in healthy eyes and eyes with POAG, LTG and ocular hypertension at the same stage of the disease?

HD

Confocal laser scan images allow the measurement of HD which is defined as the difference in height between distinct measuring points at the papillary margin (Elschnig scleral ring) and measuring points 250 µm peripherally to these. HD may permit conclusions concerning the thickness of the nerve fiber layer.

Does HD describe the thickness of the nerve fiber layer? Evidence can only be obtained indirectly by studying the relationship between HD and the clinical picture, for example the

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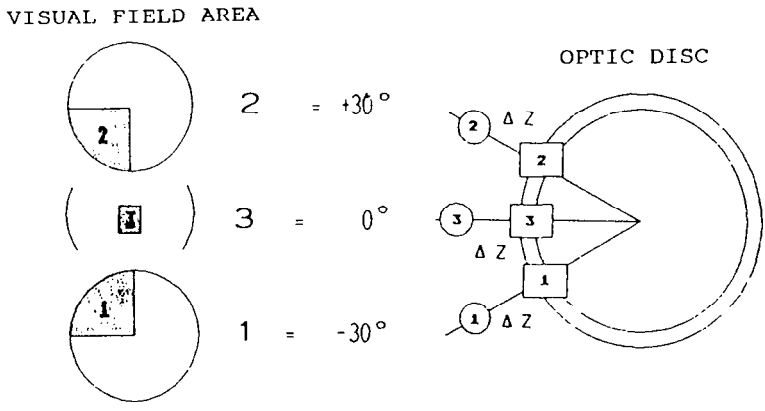

Fig. 1. Correlation of HD at the temporal papillary margin at -30° (1), +30° (2) and 0° (3) to the corresponding nasal upper (1) or nasal lower (2) visual field quadrant as well as to the center of the visual field (3).

area of visual field loss. A correlation of HD with the location of visual field loss and clinical findings suggests that HD may describe the thickness of the nerve fiber layer.

Configuration of optic disc excavation

Does the LTS allow quantification of differences in the configuration of optic disc excavation comparing eyes with primary open angle glaucoma and low tension glaucoma at the same stage of visual field loss?

Are there any differences in the configuration of the excavation of the optic disc between eyes with POAG stage I and low tension glaucoma stage I compared to healthy eyes and eyes with ocular hypertension?

Methods

HD

One hundred and fifty-three eyes of 82 patients with ocular hypertension (OH), primary open angle glaucoma (POAG), low tension glaucoma (LTG) and healthy controls were examined with the laser tomographic scanner (LTS). The Elschnig scleral ring was visible in 103 eyes of 52 patients. In these 103 eyes HD could be measured at three defined points at the temporal disc margin (Fig. 1). Visual fields were obtained with the Octopus Perimeter 201, program 31.

Configuration of optic disc excavation

In 82 eyes of 82 patients the configuration of optic disc excavation was calculated using the ratio of mean excavation depth to the maximal excavation depth and the third moment[2].

Results

HD

HD in glaucoma and healthy controls

Healthy eyes and eyes with early stages of glaucoma showed a larger value of HD in the area of the upper and lower arcuate nerve fiber bundles than in the papillomacular bundle. Eyes with advanced glaucomatous visual field loss demonstrated a significant decrease in HD (Kruskall-Wallis H test) in the upper and lower nerve fiber bundles compared to healthy controls. However, measurements in the papillomacular bundle of patients with advanced stages of glaucoma only revealed a slight decrease in HD compared to healthy eyes (Table 1).

HD and location of visual field defects

In 80% of patients, a correlation could be demonstrated between the size of HD and the location of the glaucomatous visual field loss comparing the upper and lower halves of the visual field (Fig. 2).

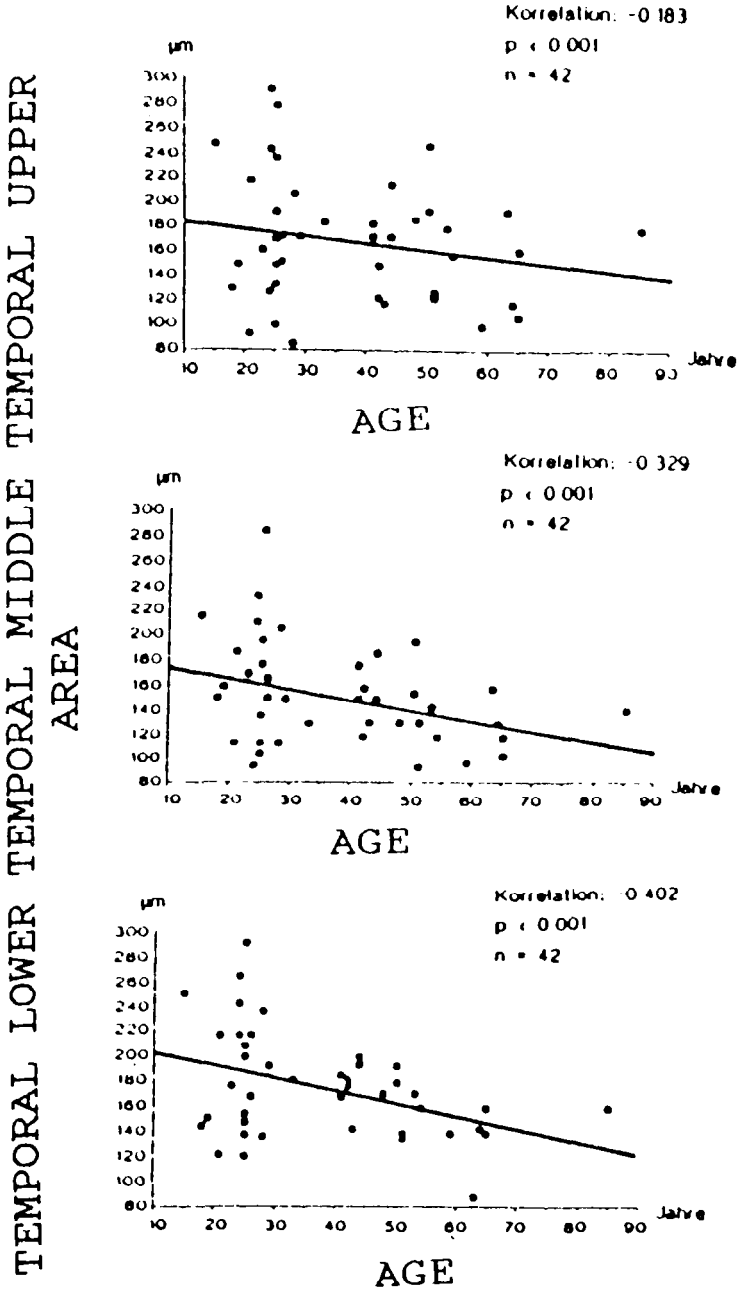

Fig. 2. Contingency table: comparison of the location of decreased values HD for the thickness of the nerve fiber layer (temporal top or bottom) to the location of the largest visual field defect (nasal top or bottom). In 80% (24/30) of patients with glaucoma, a correlation was found between the location of a decreased nerve fiber thickness (*e.g.*, temporal top) and the area of the largest visual field defect (*e.g.*, nasal bottom).

Table 1 Mean thickness of the nerve fiber layer at three defined measuring points at the temporal papillary disc margin in 52 eyes

Diagnosis	*n=52*	*Temporal upper (μm)*	*Temporal middle (μm)*	*Temporal lower (μm)*
Healthy	22	168±39	143±39	173±42
POAG (stages I and II)	17	173±30	143±28	173±38
POAG (stages I-V)	6	100±38	126±38	90±28
LTG (stages I and II)	3	154±45	131±38	161±43
LTG (stages III-V)	4	79±14	109±20	79±25

HD and age

HD was dependent on age in healthy patients. With increasing age a significant (χ^2 test) decrease of HD was apparent (Fig. 3).

HD and diameter of the optic disc

In healthy eyes a correlation could be demonstrated between the size of the optic disc and HD. HD decreased with increasing diameters of the optic disc (χ^2 test) (Table 2).

Table 2. Correlation of the diameter of the optic nerve head to the thickness of the nerve fiber layer

	Temporal upper < Temporal lower	*Temporal upper = Temporal lower*	*Temporal upper > Temporal lower*
Nasal upper < nasal lower	12	0	1
Nasal upper = nasal lower	1	3	2
Nasal upper > nasal lower	2	0	9

HD shows a significant decrease with larger diameters of the optic disc in all three measuring points

Configuration of optic disc excavation

In stages I and II of visual field loss, a significantly steeper slope and a significantly flatter bottom of the excavation could be demonstrated in low tension glaucoma compared to primary open angle glaucoma (Mann-Whitney U test). In advanced stages III to V, no significant differences were obvious in the configuration of optic disc excavation (Table 3; Fig. 4).

Table 3. Significant (*) and non-significant (ns) differences in the configuration of optic disc excavation calculated using either the ratio of effective mean excavation depth (HE) to the maximal excavation depth or the third moment showed corresponding results

Visual field loss	*Healthy*	*OH*	*POAG*	*LTG*
None	ns ———	ns		
Stage I		ns ———	ns | * ———	*
Stage II			* ———	*
Stages III-V			ns ———	ns

No significant difference in the configuration of optic disc excavation could be shown in healthy eyes compared to eyes with ocular hypertension and primary open angle glaucoma stage I (Mann-Whitney U test). However, a significant difference in the steepness of the slope of the excavation was found between healthy eyes and eyes with low tension glaucoma stage I (Table 4; Fig. 5). The change in configuration of the excavation, therefore, occurs one stage of the disease (defined as total loss in the visual field in dB) later in primary open angle glaucoma compared to low tension glaucoma.

A significant difference exists in the configuration of the excavation between these three diagnostic groups and low tension glaucoma stage I: already in stage I, eyes with low tension glaucoma demonstrate a steeper slope and a flatter bottom of the excavation of the optic disc.

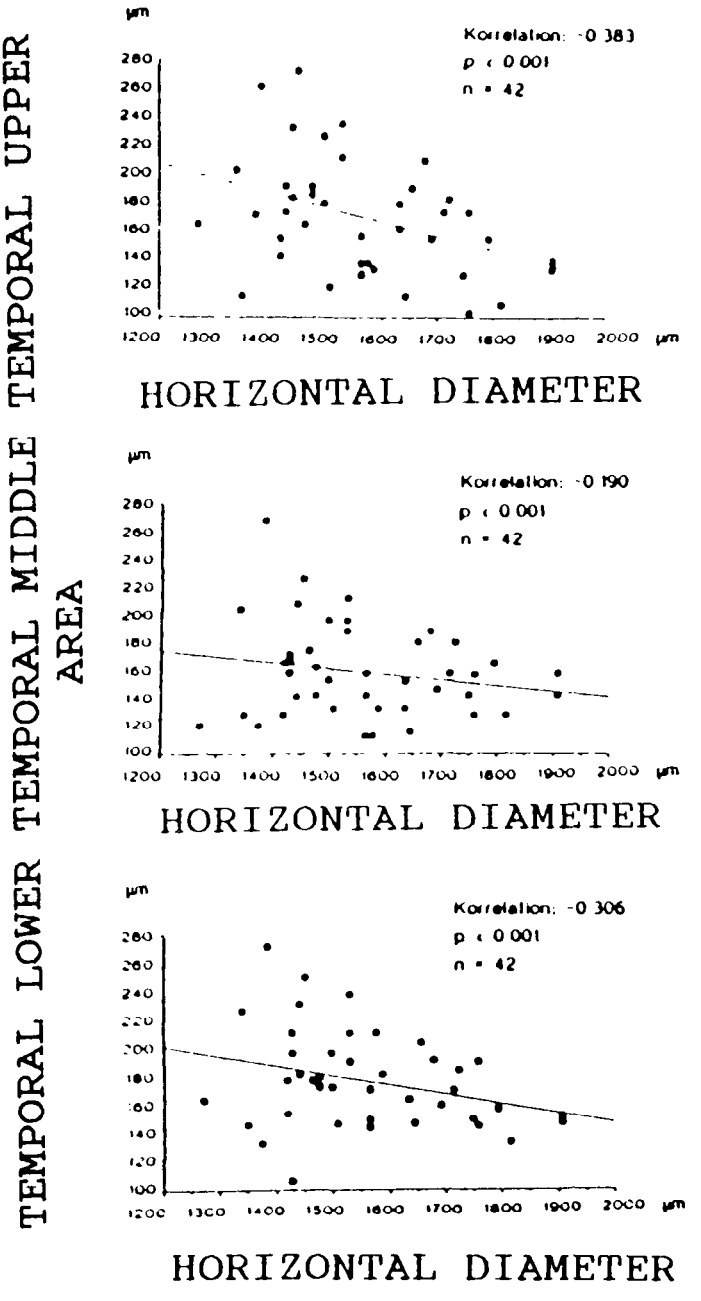

Fig. 3. Correlation of the age of the patient to the thickness of the nerve fiber layer: HD shows a significant decrease with increasing age of the patients in all three measuring points.

Eyes with primary open angle glaucoma only show a slight change in the configuration of the excavation in stages I and II. A distinct increase in the steepness of the slope of the excavation is not seen before the advanced stages III to V. Eyes with low tension glaucoma primarily demonstrate a steep slope and a flat bottom of the excavation, which changes only insignificantly in advanced stages III to V of the glaucomatous disease. This indicates differences in the etiology of the glaucomatous damage in the initial stages of the disease.

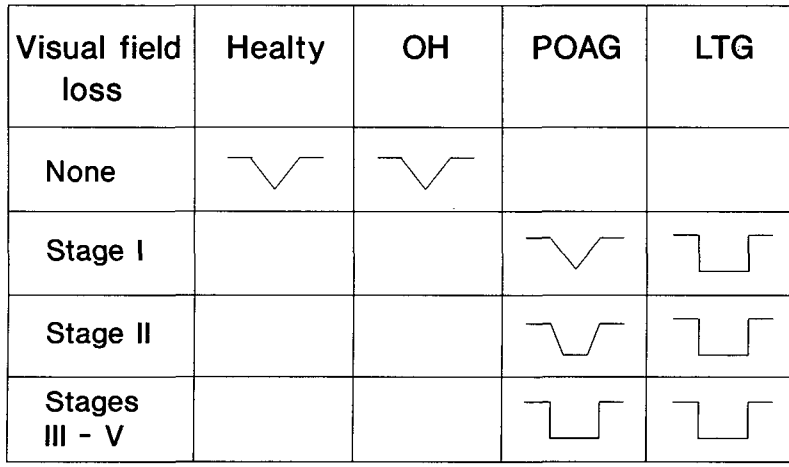

Fig. 4. There is no significant difference in the configuration of the excavation in healthy eyes, eyes with ocular hypertension and eyes with primary open angle glaucoma stage I: the excavation of the optic disc shows a flat slope and a relatively pointed bottom.

Discussion

HD

HD does not exclusively describe the thickness of the nerve fiber layer: parts of pigment epithelium and choroid are also included in HD. Our results, however, indicate that HD may indirectly provide evidence for the thickness of the nerve fiber layer, although it does not exclusively describe the nerve fiber layer. The correlation of HD with the clinical picture and location of visual field defects supports our hypothesis. To determine HD, an Elschnig scleral ring is required. Seventy-six percent of patients examined in this study had an Elschnig scleral ring; therefore, this technique is not generally applicable.

In this pilot study, we determined a new value HD and correlated it to clinical findings. In conclusion, the following surprising results can be represented:

- HD correlated with the stage of the glaucomatous disease and with the location of the visual field loss;
- HD could therefore be a measure for the thickness of the nerve fiber layer;
- an *in vivo* measurement of the nerve fiber layer would mean an important progress in the diagnosis of glaucoma;
- by increasing the number of confocal tomograms it could become a clinically applicable new measurement.

HD represents pointwise measurements at the papillary disc margin; therefore, the nerve fiber bundle defect, which causes the localized visual field defect, may be missed.

Configuration of optic disc excavation

No significant difference in the configuration of optic disc excavation was found comparing primary open angle glaucoma (POAG) stage I and healthy eyes. Therefore, determination of the configuration of optic disc excavation does not allow an early diagnosis in POAG.

This study evaluating the configuration of optic disc excavation confirms our prior results which showed distinct differences between primary open angle glaucoma and low tension glaucoma concerning:

1. *the location and depth of visual field defects* (defined as frequency of absolute and relative scotomas as well as quantified with program 31/Delta of the Octopus perimeter)[3-5];
2. *the size of the optic disc excavation;* in low tension glaucoma the excavation was larger at the same stage of visual field loss (examined ophthalmoscopically and quantified with the optic nerve head analyzer, OHNA)[6-8];

3. *the neuroretinal rim area;* low tension glaucoma showed a smaller neuroretinal rim area in the same stage of visual field loss and same size of the optic disc (quantified with OHNA)[8,9].

Additional differences in the morphology of the optic disc could be demonstrated in this study with the laser tomographic scanner:

4. *a significant difference exists in the steepness of the slope and the configuration of the bottom of the optic disc comparing POAG and low tension glaucoma in early stages of the disease*[2].

The differences in the configuration of optic disc excavation together with our prior results indicate a different pathogenesis involved in the early stages of POAG and low tension glaucoma.

There is a significant difference in the configuration of optic disc excavation comparing eyes with primary open angle glaucoma and eyes with low tension glaucoma stages I and II. No significant difference exists in stages III to V. No significant difference in the configuration of optic disc excavation is obvious between healthy eyes, eyes with ocular hypertension and eyes with primary open angle glaucoma stage I.

References

1. Maier H, Siebert M, Gramer E, Kampik A: Eine Masszahl für die Nervenfaserschichtdicke: Messungen mit dem Laser Tomographic Scanner. In: Gramer E (ed) Glaukom: Diagnostik und Therapie, pp 20-145. Stuttgart: Ferdinand Enke Verlag 1990
2. Maier H, Siebert M, Gramer E: Unterschiede in der Form der Papillenexkavation bei Glaucoma chronicum simplex und Glaukom ohne Hochdruck: Eine klinische Studie mit dem Laser Tomographic Scanner In: Gramer E, Kampik A (eds) Pharmakotherapie am Auge, pp 29-71. Heidelberg: Springer Verlag 1992
3. Gramer E, Mohamed J, Krieglstein GK: Der Ort von Gesichtsfeldausfällen bei Glaucoma simplex, Glaukom ohne Hochdruck und ischämischer Neuropathie: Indikationen zur vasoaktiven Therapie. In: Krieglstein GK, Leydhecker W (eds) Medikamentöse Glaukomtherapie, pp 115-121. Munich: JF Bergmann Verlag 1982
4. Gramer E, Althaus G: Quantifizierung und Progredienz des Gesichtsfeldschadens bei Glaukom ohne Hochdruck, Glaucoma simplex und Pigmentglaukom: Eine klinische Studie mit dem Programm Delta des Octopus Perimeters 201. Klin Mbl Augenheilk 191:184-198, 1988
5. Gramer E, Althaus G, Leydhecker W: Topography and progression of visual field damage in glaucoma simplex, low tension glaucoma, and pigmentary glaucoma with program Delta of Octopus Perimeter 201. In: Greve EL, Heijl A (eds) Doc Ophthalmol Proc Ser, Vol 49, pp 349-363. Dordrecht: Dr W Junk Publ 1987
6. Gramer E, Leydhecker W: Glaukom ohne Hochdruck: Eine klinische Studie. Klin Mbl Augenheilk 186:262-267, 1985
7. Gramer E, Leydhecker W: Zur Pathogenese des Glaukoms ohne Hochdruck Z Prakt Augenheilk 6:329-333, 1985
8. Gramer E, Bassler M, Leydhecker W: Cup/disc ratio, excavation volume, neuroretinal rim area of the optic disc in correlation to computer perimetric quantification of visual defects in glaucoma with and without pressure: clinical study with the Rodenstock Optic Nerve Head Analyzer and the program Delta of the Octopus Computer Perimeter 201. In: Greve EL, Heijl A (eds) Doc Ophthalmol Proc Ser, Vol 49, pp 329-348. Dordrecht: Dr W Junk Publ 1987
9. Gramer E, Althaus G, Leydhecker W: Lage und Tiefe glaukomatöser Gesichtsfeldausfälle in Abhängigkeit von der Fläche der neuroretinalen Randzone der Papille bei Glaukom ohne Hochdruck, Glaucoma simplex, Pigmentglaukom: Eine klinische Studie mit dem Octopus Perimeter 201 und dem Optic Nerve Head Analyzer. Klin Mbl Augenheilk 189:190-198, 1986

Relation of asymmetrical differences of visual fields between open angle glaucoma eyes with measurements of optic disc cupping, pallor, and retinal nerve fiber layer thickness

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Abstract

The authors measured optic disc cupping, area of pallor and retinal nerve fiber layer thickness in 36 high pressure open angle glaucoma eyes with asymmetric visual field loss. The asymmetry of visual field loss between eyes showed a mean difference of 4.99 decibels indicating an early stage of glaucoma. The asymmetry between eyes showed significant differences and correlations between the functional measurements of visual field loss and the structural measurements for the optic disc cup volume and area. In particular, retinal nerve fiber layer thickness and area of pallor showed no correlations or differences with visual field loss between eyes. They conclude that either cupping had increased in the eye with the greater visual field loss prior to any change in pallor or retinal nerve fiber layer thickness or that pallor and nerve fiber layer thickness had already increased in the eye with the lesser visual field loss prior to an increase in cupping.

Introduction

In open angle glaucoma, functional loss is usually measured by perimetry. For structural changes of the optic nerve new methods have been developed, particularly the measurement of optic disc cupping, pallor and retinal nerve fiber layer thickness. The determination of the relationships between structural changes and functional loss would be of value for both diagnosis and for following patients with open angle glaucoma[1-5].

We have previously addressed this issue by examining the relationship between measurements in individual eyes of patients with high pressure open angle glaucoma of optic disc cupping, pallor and retinal nerve fiber layer thickness with measurements of corresponding eyes of visual field thresholds by automated perimetry[2]. The only significant correlation for the total disc was for cup area. However, there were significant correlations between quadrants of the visual field and corresponding quadrants of the disc for cup volume and area, pallor area and retinal nerve fiber layer thickness.

Since much of the lack of correlation could be due to large variations of visual field loss and abnormality of the disc in individual eyes, the purpose of this study is further to determine this correlation between structure and function by measuring differences between eyes, particularly in patients with asymmetric visual field loss. Using semi-quantitative methods, we have previously determined a significant correlation between asymmetric visual field loss and asymmetric optic disc area of pallor in open angle glaucoma[6]. With the availability of newer reproducible and quantitative techniques, we wish to determine the strength of this correlation, not only for the whole disc, but also for various quadrants of the disc as well as for the retinal nerve fiber layer using absolute measurements of these structures.

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This study was done while Dr. Vinay Nangia was a Glaucoma Fellow at Tufts University School of Medicine

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Methods

We studied 72 eyes of 36 patients with primary high pressure open angle glaucoma, 16 males and 20 females of whom there were 25 whites and 11 blacks with a mean age ± standard deviation of 70.8 ± 14.0 years. Nineteen eyes were emmetropic, 22 eyes had myopia of less than 5 diopters, and 31 eyes had hyperopia of less than 5 diopters. The diagnosis of open angle glaucoma was made if ocular pressures were greater than or equal to 21 mmHg on at least two independent examinations with the presence of characteristic optic disc damage and visual field loss. Visual field loss was either localized or localized with some general depression of the visual field. Patients with pigmentary dispersion and exfoliation syndrome were excluded. All eyes had a corrected visual acuity of 20/40 or better. Subjects were selected as showing asymmetric visual field loss on the basis of inspection of the gray scales and also the threshold values in the printout of the Octopus 31 or G1 programs.

Optic disc photography and visual field examinations were performed within a maximum of 12 months of each other. Optic disc area was measured from single colored projected disc photographs. The disc area was converted into absolute units using the formulae of Littman and Bengtsson-Krakau[7-9]. Optic disc cupping[10] and retinal nerve fiber layer thickness at the optic disc margin[11] were measured by photogrammetry from simultaneous stereophotographs. For measurement of cup area, the cup edge was defined as the topographic edge, that is the change of slope from cup wall to neuroretinal rim. The volume profile of the cup was measured by determining the cross-sectional area of the cup at various depth levels (1 to 6) from top to bottom of the cup[12]. Disc pallor was measured by computerized image analysis with manually applied plan points from single colored photographs[13]. For measurements of quadrants the optic disc was divided by the means of a St. Andrews cross. All measurements of the optic discs and retinal nerve fiber layer value are expressed in absolute units using the absolute disc area measurements as a conversion factor.

The reproducibility of our measurements was determined as a percent coefficient of variation (standard deviation/mean × 100) for duplicate measurements. For optic disc cup volume, the mean (median) percent coefficient variation ± standard deviation was 5.02 (4.02) ± 3.79; for optic disc area of pallor, it was 5.31 (4.61) ± 3.95; for cup depth, it was 4.73 (3.13) ± 4.60; for cup area, it was 6.15 (4.65) ± 5.09; for cup slope, it was 6.57 (5.32) ± 5.99; for retinal nerve fiber layer thickness, it was 6.40 (5.73) ± 4.52 and for optic disc area, it was 1.39 (0.99) ± 1.40.

The visual field thresholds were measured with the Octopus 2000R perimeter using programs 31 or G1. Twenty visual fields were done with program 31 and 16 visual fields with program G1. For the total field for 72 eyes, the mean ± standard deviation for percent false positives

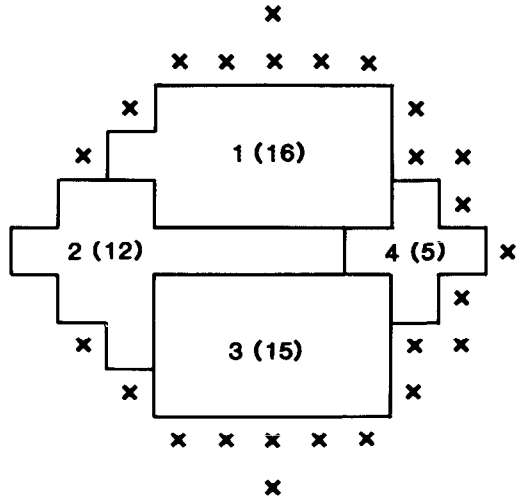

Fig. 1. Data points of right eye used on visual field program 31 to obtain corresponding superior, inferior nasal and temporal quadrants of optic disc. The numbers identify the quadrants. The numbers in brackets indicate the number of points used to obtain mean threshold values for each quadrant. The "X" indicates points that were excluded (from O'Brien *et al.*[1]).

was 5.2 ± 7.3 and for percent false negatives it was 5.7 ± 9.1. The reproducibility or the RMS value was 2.55 ± 1.10. Fig. 1 shows how the division of the central 30° field was divided into quadrants to correspond with the appropriate disc quadrants as previously described[1].

For each pair of eyes, one eye was designated as the eye with the least visual field loss or larger visual field threshold. The other eye was then indicated as the eye with the smaller visual field threshold or with the greater visual field loss. Optic disc and retinal nerve fiber layer thickness measurements were then made of the eyes with the larger or smaller visual field thresholds in a masked manner. The values of optic disc and nerve fiber layer measurements for each eye always corresponded accordingly to the eye with larger or smaller visual field thresholds.

Spearman rank correlation tests were used to test the significance of correlations[14]. Correlations were determined as differences between eyes of larger minus smaller visual field thresholds with the differences between optic disc and retinal nerve fiber layer measurements which were for the corresponding eyes with the larger or smaller visual field threshold values. Differences between eyes with larger or smaller visual threshold were determined as significant in comparison to zero difference with a "*t*" test. Two tailed tests were used in determination of significance.

Results

Table 1 shows the ocular characteristics of the 36 patients with primary high pressure open angle glaucoma. The mean visual field threshold in the eye with the larger visual field threshold or lesser visual field loss was 20.0 decibels compared to 15.0 decibels of the eye with the smaller visual field threshold or greater visual field loss. The percent difference between the means of larger minus the smaller thresholds was 28.6% with a mean difference of 4.99 decibels (Fig. 2). This difference was highly significant (p = 0.000). Similar analyses of the ocular pressures showed that there was significant difference between the eyes with the larger and the smaller visual thresholds with the eyes with the smaller visual thresholds having a higher ocular pressure than the eyes with the larger visual field thresholds. An analysis of refractive error showed no significant difference between eyes.

Table 2 shows similar measurements for the optic disc cup values, *i.e.*, volume, area, depth

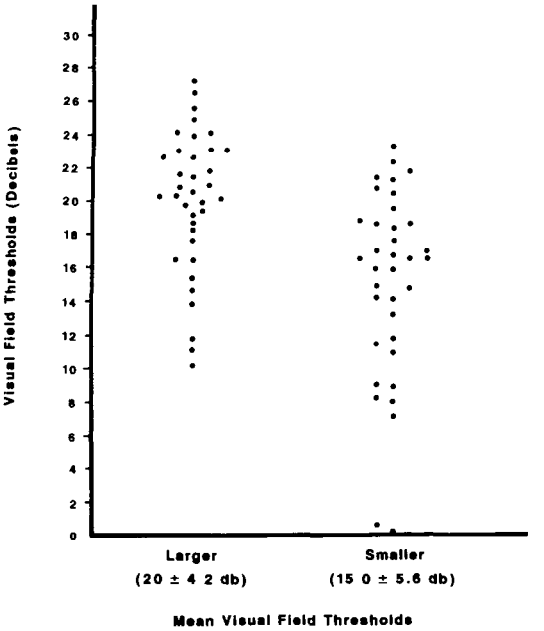

Fig. 2. Scatterplot of visual field thresholds of eyes with larger (20.0 ± 4.2 dB) and smaller (15.0 ± 5.6 dB) threshold values (difference p = 0.0001).

Table 1. Ocular characteristics of open angle glaucoma eyes: mean ± standard deviation (n=36)

	Larger	*Smaller*	*%* difference*	*Larger minus smaller*	*t test p*
Mean visual field threshold value (dB)	20.0±4 2	15.0±5.6	28.6	4.99±3.91	0.000
Ocular pressure (mmHg)**	20.9±4 6	22.3±5.3	-6.5	-1.36±3.16	0.014
Refractive error (dB)**	0 38±1.79	0 32±1.72	17 1	0.06±0.66	NS

*: % difference: $\frac{\text{larger minus smaller}}{\text{larger + smaller/2}} \times 100$

**: Values correspond to eyes with visual field threshold values respectively with ocular pressure determined at the time of examination of the visual field

NS: Non-significant

Table 2. Measurements of total disc for open angle glaucoma patients: mean ± standard deviation (n=36)

	*Larger**	*Smaller**	*%* difference*	*Larger minus smaller*	*t test p*
Cup volume (mm^3)	0.557±0.255	0.658±0 309	-16.6	-0 10±0 16	0.0004
Cup area (mm^2)	1 29 ±0 60	1.43 ±0.73	-10 3	-0.14±0.37	0.03
Cup depth (mm)	0.440±0 170	0.476±0.185	-7.9	-0.04±0.12	0.07
Cup slope (degrees)	44.8 ±8.83	46.4 ±8.80	-3.5	-16.5±74.1	NS
Area pallor (mm^2)	0.846±0.448	0 831±0.414	1.8	0.02±0.39	NS
Retinal nerve fiber layer thickness (mm)	0.302±0.102	0.312±0.093	-3 6	-0.01±0.11	NS
Disc area (mm^2)	2.56 ±0.88	2.65 ±0 94	-3.5	-0 08±0.32	NS
Volume profile cross-sectional area (mm^2)					
level 1	1 57 ±0.63	1 70 ±0 72	-8.0	-22.8±35.3	0.0005
level 2	1 13 ±0 52	1 24 ±0.58	-9.3	-22.7±32.5	0.0002
level 3	0.75 ±0.43	0.87 ±0.52	-14.8	-28.8±44 3	0.0004
level 4	0.44 ±0.36	0.56 ±0.46	-24.0	-22.6±37.5	0.0009
level 5	0 23 ±0 30	0.32 ±0.39	-32.7	-11.4±29.8	0.03
level 6	0.11 ±0.21	0.15 ±0.23	-30.7	-3.8±17.0	NS

*: Eyes with larger and smaller disc and retinal nerve fiber layer measurement correspond to eyes with larger and smaller visual field threshold measurements, respectively

**: % difference: $\frac{\text{larger minus smaller}}{\text{larger + smaller/2}} \times 100$

NS: non-significant

Table 3. Percent differences* of corresponding eyes for larger minus smaller of mean threshold values for quadrants

	Superior	*Inferior*	*Temporal*	*Nasal*
MTV**	$19\ 5^{VS}$	42.9^{VS}	31.6^{VS}	23.1^{VS}
Cup volume	-23.4^{VS}	$-17\ 0^{VS}$	-7.9^{NS}	-16.6^{S}
area	-14.0^{S}	-16.0^{VS}	-7.5^{NS}	-10.1^{NS}
depth	-4.1^{NS}	-9.5^{S}	-3.9^{NS}	-12.7^{VS}
slope	-6.7^{NS}	4.2^{S}	0.2^{NS}	-5.1^{NS}
pallor	-0.5^{NS}	-2.9^{NS}	4.4^{NS}	-2.3^{NS}
Retinal nerve fiber layer thickness	1.8^{NS}	-2.6^{NS}	$10\ 6^{NS}$	-2.5^{NS}

*: % difference: $\frac{\text{larger minus smaller}}{\text{larger + smaller/2}} \times 100$

**: Mean threshold of visual field - quadrant of visual field for MTV refers to disc quadrant. Therefore, superior MTV = inferior visual field, inferior MTV = superior visual field, temporal MTV = nasal visual field and nasal MTV = temporal visual field

VS: $p<0.01$

S: p 0.05 to 0.01

NS: non-significant

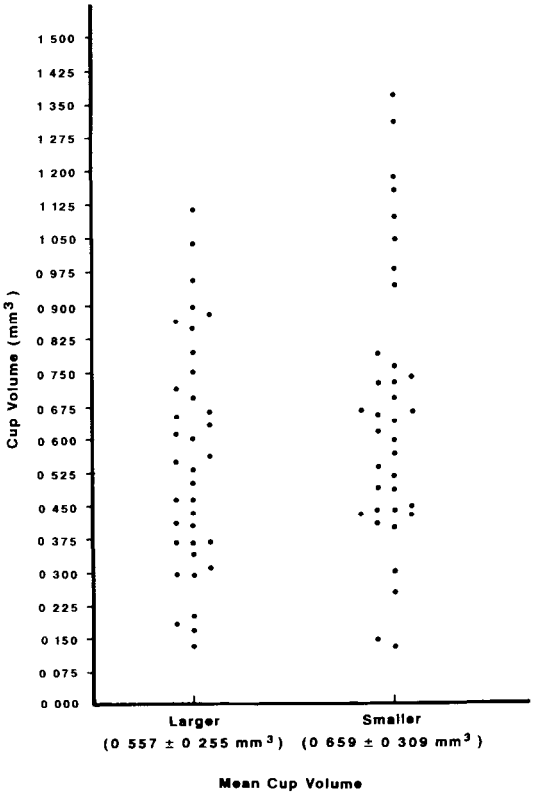

Fig. 3 Scatterplot of values of optic disc cup volume in eyes with larger and smaller visual field thresholds. Note that the eyes with the smaller visual field thresholds have the larger mean cup volume (0.659 ± 0.255 mm^3) than the eyes with the larger visual field threshold (0.557 ± 0.255 mm^3) (difference $p = 0.0004$).

and slope, area of pallor and retinal nerve fiber layer thickness as well as volume profile on cross-sectional areas of the cup from levels 1 to 6. The differences between the eyes with the larger visual field thresholds minus the smaller visual thresholds showed significant differences only for cup volume and cup area as well as for levels 1 to 5 of the volume profile curve. Figs. 3 to 5 also show the distribution of measurements of cup volume, area of pallor and retinal nerve fiber layer thickness for the eyes with the larger and smaller visual field threshold.

Table 3 shows the mean percent differences for the four quadrants between eyes with the larger visual field thresholds minus the eyes with the smaller visual field thresholds for the disc and the retinal nerve fiber layer measurements. The visual fields were determined for the four quadrants (Fig. 1) and corresponding optic disc and retinal nerve fiber layer thickness measurements were obtained using the St. Andrew's cross as described in the methods. In all quadrants there was a very significant difference in mean visual field thresholds. Similarly for cup volume, significant differences were observed in all quadrants except for the temporal quadrant. For cup area, only superior and inferior quadrants showed significant differences. For depth, only the inferior and nasal quadrant showed a significant difference. For cup slope, the only significant difference was in the inferior quadrant. For pallor and nerve fiber layer thickness, none of the quadrants showed a significant difference.

Table 4 shows the Spearman correlations for the total disc of the differences between eyes for visual field thresholds *versus* differences for the same eyes for optic disc cupping and pallor and retinal nerve fiber layer thickness measurements. The only significant correlations were obtained for cup volume and cup area.

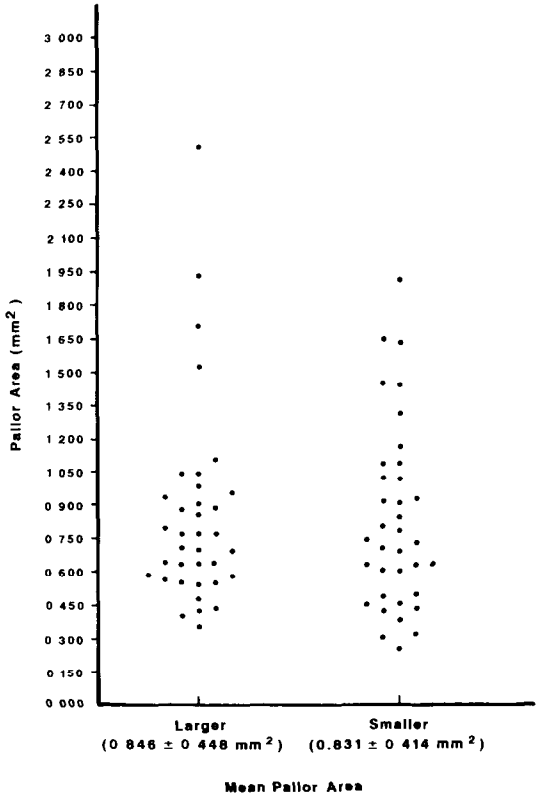

Fig. 4. Scatterplot of values of optic disc areas of pallor in eyes with larger and smaller visual field thresholds. Note that the eyes with the larger visual field thresholds have a larger mean pallor area (0.846 ± 0 448 mm^2) than the eyes with the smaller visual field thresholds (0.831 ± 0.414 mm^2) but this difference is non-significant.

Table 4. Spearman rank correlations (r_s) of differences of visual field threshold values (dB) (larger minus smaller) with corresponding differences of optic disc and retinal nerve fiber layer measurements (larger minus smaller) for total disc (n=36)

	r_s	p
Difference cup volume	-0.3833	0.05-0.01
Difference cup area	-0 4911	<0.01
Difference cup depth	-0.0090	NS
Difference cup slope	-0.2175	NS
Difference pallor area	-0.1210	NS
Difference retinal nerve fiber layer thickness	0.1977	NS

Similar observations were noted for the quadrants with significant correlations occurring between differences in visual field thresholds and differences of cup volume and area. No such significant correlations were observed for retinal nerve fiber layer thickness or pallor except for the inferior quadrant (r_s = -0.3336, p = 0.05).

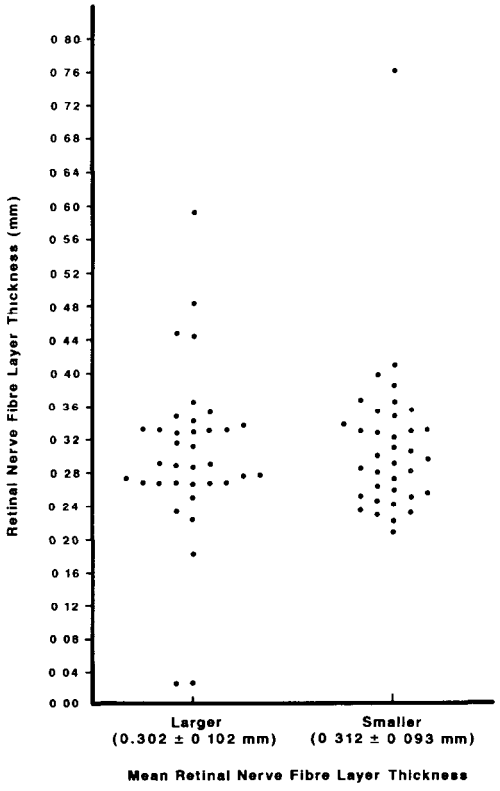

Fig. 5. Scatterplot of values of retinal nerve fiber layer thickness in eyes with larger and smaller visual field thresholds. Note that the eyes with the larger visual field thresholds have a smaller mean retinal nerve fiber layer thickness (0.302 ± 0.102 mm) than the eyes with the smaller visual field threshold (0.312 ± 0.093 mm) but the difference is non-significant.

Discussion

Our observations indicate that there was an adequate range of measurements for all the disc measurements. Evaluation of the measurements of the optic disc and retinal nerve fiber layer shown in Table 2 of the relationship of the standard deviation to the mean in comparison to the standard deviation to the mean of visual field thresholds (Table 1) indicated that there was an adequate range of values to allow for observations of significant correlations.

Utilizing the differences between eyes for correlations of visual field loss with structural characteristics obviates only systemic or patient factors that might impair a significant correlation between optic disc and retinal nerve fiber layer thickness measurements with visual field thresholds. We also expected that there would be less variation of measurements of eyes in the same individual compared to the variation of measurement of eyes of different individuals, thereby minimizing the ocular factors that could interfere with the correlation. There were highly significant differences between eyes of visual field loss and significant differences were obtained between eyes with the optic disc cup measurements, particularly its volume and area (Table 2). Similarly, significant correlations between eyes of visual field loss and differences in optic disc and retinal nerve fiber layer measurements were only observed for optic disc cup volume and area (Table 4).

The patients whom we studied showed only a mean difference between eyes of visual fields of 4.99 decibels. This indicates that the visual field loss is relatively small in extent since even the eye with the higher or larger thresholds had a mean value of 20.0 decibels. Thus, this population of subjects comprised early visual field loss and this study tests the sensitivity of

the optic disc and retinal nerve fiber layer measurements for detection of early disease. We were surprised at the lack of significant correlations and differences observed for retinal nerve fiber layer thickness and area of pallor which was also seen for the quadrants except for the inferior quadrant which had a significant correlation of differences of pallor with visual field differences.

Nanba *et al.*[15] also measured cup volume, cup area, rim area and cup disc ratio with the Rodenstock Optic Nerve Head Analyzer in 35 patients with chronic open angle glaucoma (23 patients with primary open angle glaucoma) who had asymmetrical visual field loss (Humphrey visual field program 30-2). They also obtained significant linear correlations ($p£0.05$) only between difference in cup area and difference in mean deviation ($r=0.451$) as well as between difference in cup volume and difference in mean deviation ($r=0.44$). Thus, our results for measurement of cup parameters are similar to their analyses.

In the present study, we could not observe the correlation of differences of pallor between eyes with differences in visual field loss which we observed in our previous study[6] which had subjects with more advanced glaucomatous visual fields. In this previous study, visual fields were determined with the Goldmann perimeter and pallor was measured with semi-quantitive techniques.

Lack of differences in retinal nerve fiber layer thickness and area of pallor between the eyes suggests two possibilities. The first is that in this population of eyes with early visual field loss, pallor has already increased and retinal nerve fiber layer thickness has decreased to be equivalent in the two eyes (Table 2).

The values of optic disc area of pallor and retinal nerve fiber layer thickness are similar to those previously measured in open angle glaucoma eyes[16]. This suggests that optic disc abnormalities for pallor and also for retinal nerve fiber layer loss have already manifested themselves in eyes with little or no visual field loss. Thus retinal nerve fiber layer thickness and optic disc pallor would be sensitive measurements of optic nerve damage with little or no visual field loss. We have already verified that optic disc pallor increases with the development of visual field loss[17] and also is predictive of future visual field loss[18]. Furthermore, optic disc pallor increases in ocular hypertensive eyes without the development of visual field loss[19]. It has also been demonstrated that retinal nerve fiber layer defects develop before visual field loss occurs in ocular hypertensive eyes[20]. Also, visual field loss in one eye is a risk factor for the development of visual field loss in the other eye indicating that the eye without visual field loss probably has optic nerve damage[21].

The other possibility for the lack of correlations and differences between eyes of visual field loss with retinal nerve fiber layer thickness and optic disc pallor may be due to the eye with the smaller thresholds or greater visual field loss developing cupping before increases of area of pallor or decreases in retinal nerve fiber layer thickness. With the higher pressures in the eyes with smaller visual field thresholds (Table 1) and if degeneration of axons occurs up from the lamina cribosa[22], then cupping could occur before decreases in retinal nerve fiber layer thickness at the disc margin. However, the greatest difference in cupping between the eyes was primarily near the surface of the cup (Table 2). In our technique, retinal nerve fiber layer thickness is measured at the optic disc margin[11]. Cupping in glaucoma is thought to be due primarily to the loss of axons[23]. This possibility, however, does not explain the lack of differences for area of pallor. Area of pallor and cup volume and cup area are significantly correlated[1]. Future longitudinal studies on follow-up of open angle glaucomas with asymmetric visual field loss can aid in determining which of these two possibilities are valid.

References

1. O'Brien C, Schwartz B, Takamoto T: Correlation of optic disc cupping, pallor and retinal nerve fiber layer thickness with visual field loss in chronic open angle glaucoma. In: Mills RP, Heijl A (eds) Perimetry Update 1990/91, pp 15-22. Amsterdam: Kugler Publ 1991
2. Weber J, Dannheim F, Dannheim D: The topographical relationship between optic disc and visual field in glaucoma. Acta Ophthalmol 68:568-574, 1990
3 Autzen T, Pugesgaard T, Work K: Automated static perimetry and nerve fibre layer defects in glaucoma and controls Acta Ophthalmol 68:677-680, 1990

4. Zingirian M, Rolando M, Campagna P: Correlation between functional and morphometric parameters in glaucoma In: Bonomi L, Orzalesi (eds) Glaucoma: Concepts in Evolution. Proceedings of an International Symposium held in Verona, Italy, June 16, 1991, pp. 115-123. Amsterdam: Kugler Publ 1991
5 Lachenmayr, BJ, Airaksinen PJ, Drance SM, Wijsman K: Correlation of retinal nerve-fiber-layer loss, changes at the optic nerve head and various psychophysical criteria in glaucoma. Graefe's Arch Clin Exp Ophthalmol 229:133-138, 1991
6. Schwartz B: Correlation of pallor of optic disc with asymmetrical visual field loss in glaucoma. Acta XXII Concilium Opththalmologicum, Paris 1974, 2:633-638. Paris: Masson Publ 1974
7. Littmann H: Zur Bestimmung der wahren Grosse eines Objektes auf dem Hintergrund des lebenden Auges. Klin Mbl Augenheilk 180:286-289, 1982
8. Littmann H: Zur Bestimmung der wahren Grosse eines Objektes auf dem Hintergrund eines lebenden Auges. Klin Mbl Augenheilk 192:66-67, 1988
9 Bengtsson B, Krakau CET: Some essential optical features of the Zeiss fundus camera Acta Ophthalmol 55:123-131, 1977
10. Takamoto T, Schwartz B: Reproducibility of photogrammetric optic disc cup measurements Invest Ophthalmol Vis Sci 26:814-817, 1985
11. Takamoto T, Schwartz B: Photogrammetric measurement of nerve fiber layer thickness Ophthalmology 96:1315-1319, 1989
12. Takamoto T, Schwartz B: Stereo measurement of the optic disc cup shape: volume profile method Technical Papers of the 50th Annual Meeting of the American Society of Photogrammetry, pp 352-358, 1984
13. Nagin, P, Schwartz B, Nanba K: The reproducibility of computerized boundary analysis for measuring optic disc pallor in the normal optic disc Ophthalmology 92:243-251, 1985
14. Siegel S, Castellan NJ Jr: Nonparametric Statistics for the Behavioral Sciences, 2nd edn. New York: McGraw-Hill 1988
15. Nanba K, Iwata K, Nagata K: Relationship between optic disc damage and visual field defects in glaucoma. In: Mills RP, Heijl A (eds) Perimetry Update 1990/91, pp 51-55. Amsterdam: Kugler Publ 1991
16. Peigne G, Schwartz B, Takamoto T: Similarities of total disc parameters for glaucoma-like and open-angle glaucoma discs matched by optic disc area size. In: Krieglstein GK (ed) Glaucoma Update IV, pp 86-94. Berlin/Heidelberg: Springer-Verlag 1991
17 Tuulonen A, Nagin P, Schwartz B, Wu D-C: Increase of pallor and fluorescein filling defects of the optic disc in the follow-up of ocular hypertensives measured by computerized image analysis. Ophthalmology 94:558-563, 1987
18. Linner E, Schwartz B: The predictive value of computerized visual field/disc pallor as indicator of future glaucoma development In: Mills RP, Heijl A (eds) Perimetry Update 1990/91, pp 45-49. Amsterdam: Kugler Publ 1991
19. Nagin P, Schwartz B: Detection of increased pallor over time using computerized image analysis in untreated ocular hypertension. Ophthalmology 92:252-261, 1985
20. Sommer A, Katz J, Quigley HA, Miller NR, Robin AL, Richter RC, Witt HA: Clinically detectable nerve fiber atrophy precedes the onset of glaucomatous field loss. Arch Ophthalmol 109:77-83, 1991
21 Harbin TS Jr, Podos SM, Kolker AE, Becker B: Visual field progression in open-angle glaucoma patients presenting with monocular field loss. Trans Am Acad Ophthalmol Otol 81:OP253-OP257, 1976
22. Quigley HA, Addicks EM: Chronic experimental glaucoma in primates. II. Effect of extended intraocular pressure elevation on optic nerve head and axonal transport. Invest Ophthalmol Vis Sci 19:137-152, 1980
23. Quigley HA, Green WR: The histology of human glaucoma cupping and optic nerve damage: clinicopathologic correlation in 21 eyes. Ophthalmology 86:1803-1827, 1979

Comparison of visual field defects and optic disc cupping in low tension glaucoma and primary open angle glaucoma

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Abstract

The authors compared the relationship of cup to disc ratio, the pattern of visual field defects and total loss between 34 eyes with POAG and 40 eyes with LTG. As a result of matching the stage of involvement, a difference in clinical characteristics between POAG and LTG could not be found.

Furthermore, dividing the subjects into two groups by their initial intraocular pressure level when diagnosed as glaucoma, in the groups whose glaucoma was detected by disc appearance with normal intraocular pressure, the proportion of eyes with a notch which tended to show sensitivity loss in the paracentral area was high. This study suggests that differences in the discovery route of glaucoma may act as a selection bias.

Introduction

Differences in the characteristics of visual field defects in patients with primary open angle glaucoma (POAG) and low tension glaucoma (LTD) have been reported by several authors, while others have found no differences. POAG is generally discovered by high intraocular pressure and/or disc cupping, whereas LTG is only discovered by fundus examination. In a comparative study between POAG and LTG, this causes differences in the stage of disease in the groups being compared, and differences in clinical features may be produced.

In this study, matching the stage of involvement, the relation of disc cupping to visual field defects was compared between POAG and LTG. Furthermore, the subjects were divided into two groups by the difference of initial intraocular pressure level and studied as to whether this difference played a role in producing different findings as a selection bias.

Subjects and methods

Our study included 34 eyes of 26 patients with POAG (13 male and 13 female, median age 40.7) and 40 eyes of 25 patients with LTG (13 male and 12 female, median age 48.7).

Entry criteria for LTG included peak intraocular pressure below 21 mmHg found on diurnal tension curves, typical glaucomatous optic disc cupping, glaucomatous visual field defects and absence of any other ocular or intracranial conditions that might affect the visual fields.

Furthermore, the subjects were divided into two groups by the initial intraocular pressure level when glaucoma was diagnosed, consisting of an HT group (initial intraocular pressure higher than 21 mmHg, 23 eyes with POAG) and an LT group (initial intraocular pressure below 21 mmHg, 40 eyes with LTG and 11 eyes with POAG).

In analyzing the stereoscopic disc photographs, the character of the cup was divided into a generalized enlargement type and a notching type, and vertical cup to disc ratios (C/D ratio) was also determined.

Visual fields were tested by an Octopus 201 using program 31. The patterns of visual field defects were divided into three groups: (P type: sensitivity loss in paracentral area; B type: loss in Bjerrum area; and N type: loss in nasal peripheral area) (Fig. 1). Total loss in decibels was employed as the measure of the degree of visual field defects.

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edited by Richard P. Mills

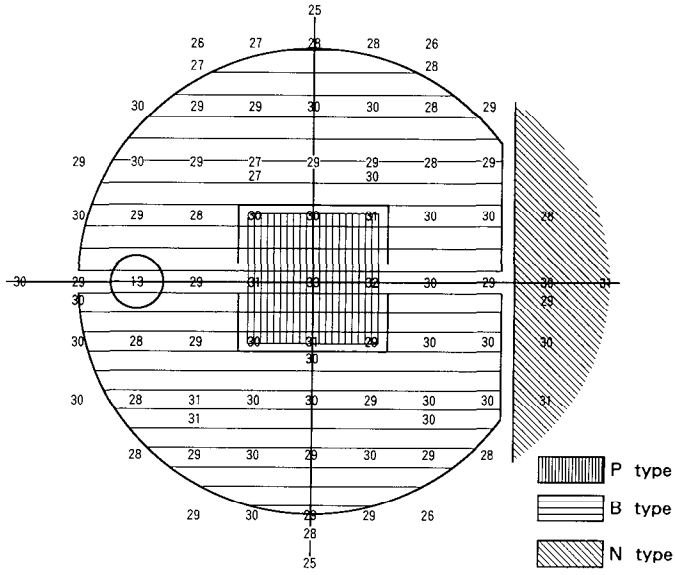

Fig. 1. The pattern of visual field defects.

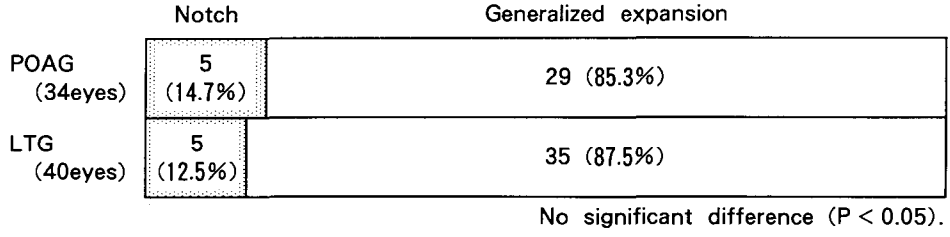

Fig. 2. The character of the cupping.

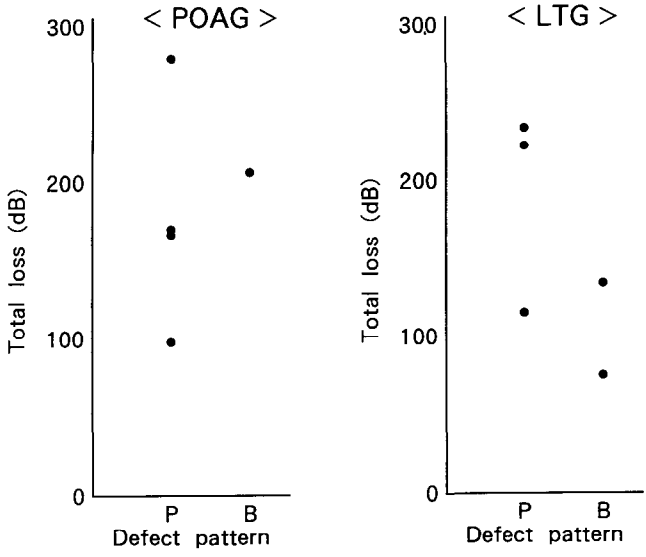

Fig. 3 Total loss correlated with the pattern of visual field defects in eyes with a notch.

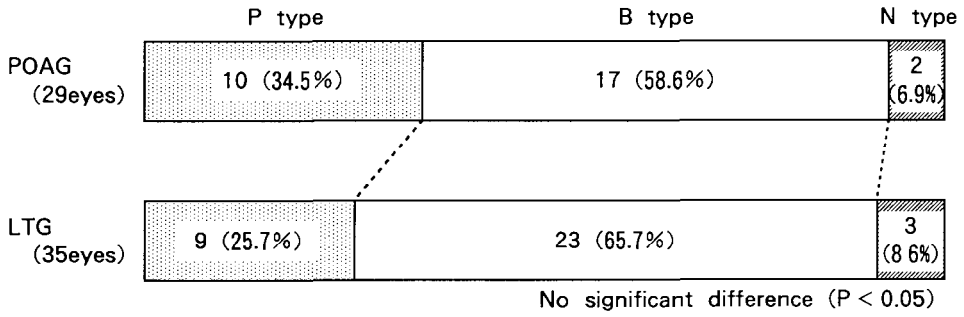

Fig. 4. The proportion of the three patterns of visual field defects in eyes with generalized expansion.

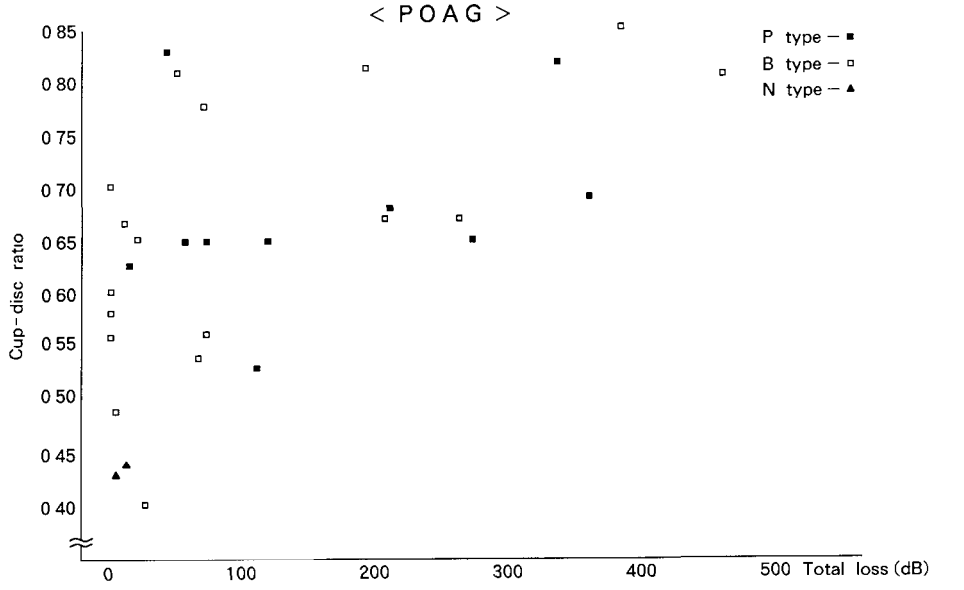

Fig. 5. The relation among cup to disc ratio, total loss, and the pattern of visual field defects in eyes with generalized expansion (POAG).

The relationship of the C/D ratio, the pattern of visual field defects and of total loss was compared between POAG and LTG and also between the HT and LT groups.

Results

There was no statistically significant difference in the proportions of the cup type between POAG and LTG (Fig. 2).

In the eyes with a notch many showed P type defects (Fig. 3) but there was no difference in the type of visual field defects between POAG and LTG.

In the eyes with generalized expansion, the proportion of the type of visual field defects in POAG was not different from that in LTG (Fig. 4). The relationship of C/D ratio, the type of visual field defects and of total loss is shown in Figs. 5 and 6. There was a remarkable similarity of distribution between POAG and LTG. In eyes with P type defects, larger cups were found in spite of lower total loss. In most eyes with B type defects, total loss was below 100 dB. The correlation between C/D ratio and total loss in eyes with P type defects was different from that in eyes with B type defects, but there was no difference between POAG and LTG.

Most of the eyes with a notch were included in the LT group (a statistical significant difference existed) (Fig. 7). These eyes tended to show P type defects and the percentage of cases

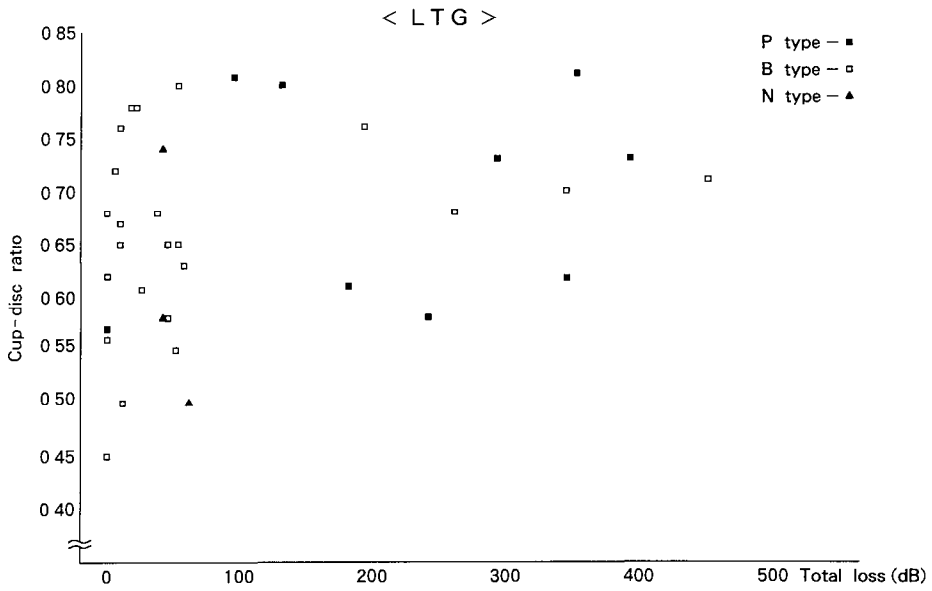

Fig. 6 Relationship of CID ratio, total loss, and the pattern of visual field defects in eyes with generalized expansion (LTG).

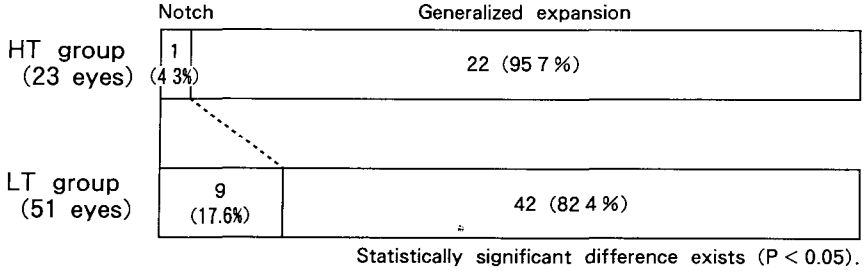

Fig. 7. The character of the cupping.

that showed P type defects in the LT group was higher than that in LTG (Fig. 8). However a statistically significant difference in the pattern of visual field defects was not found between the HT and LT group, or between POAG and LTG.

Discussion

Differences in the appearance of the optic nerve head in patients with POAG and LTG, such as the greater degree of the cup, a pale, sloping, moth-eaten cup and greater thinning of the neuroretinal rim area, have been reported[1-3]. Differences in the pattern of the visual field defects have also been reported, such as defects closer to fixation, a steeper slope, and greater depth of scotomas[4,5]. But other investigators have found no difference in the clinical characteristics between POAG and LTG[6,7]. These different findings may in part be due to the difference in the stage of involvement in the groups being compared and it is necessary to match equal stages for comparison. So in this study, the character of the cup was divided into notching type and generalized expansion type and the pattern of the visual field defects was divided into three groups. The relationship between the C/D ratio, the pattern of visual field defects, and total loss was compared between POAG and LTG. Our study suggested that, after matching the stage of involvement, there was no significant difference in the clinical features between POAG and LTG.

Raised intraocular pressure often arouses suspicion of POAG, while LTG is detected only by the optic nerve head appearance. One of the reasons for different findings may be this

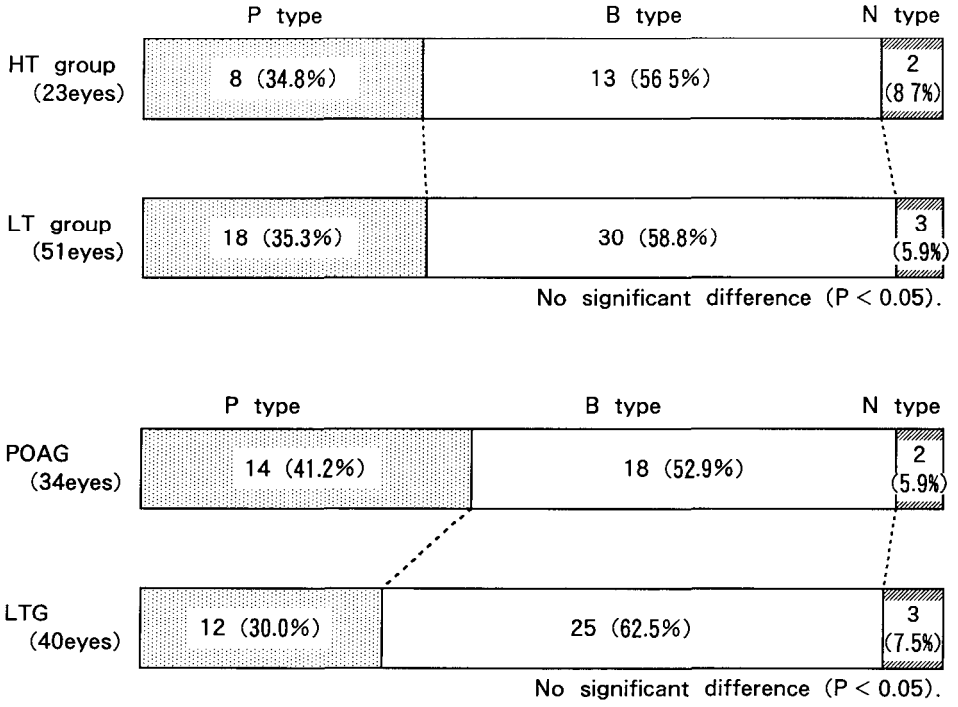

Fig. 8. The proportion of the pattern of the visual field defects.

difference in the detection method of glaucoma. We therefore divided the subjects into two groups by their initial intraocular pressure level, one of them had raised intraocular pressure and the other had typical glaucomatous cupping with normal intraocular pressure, and compared their clinical characteristics. In the group whose glaucoma was detected by disc appearance, the proportion of the eyes with a notch was higher, and they tended to show sensitivity loss in the paracentral area. Mizokami *et al.* reported that detection rate of visual field defects by fundus screening depended on the pattern of glaucomatous defects and was highest in eyes with paracentral scotoma[8]. The findings that LTG showed visual field defects closer to fixation may be influenced by this detection method. Our study suggests that the difference of the discovery route of glaucoma may act as a selection bias.

References

1. Levene RZ: Low tension glaucoma. A critical review and new material. Surv Ophthalmol 24:621-664, 1980
2. Greve EL, Geijssen HC: The relation between excavation and visual field in glaucoma patients with high and low intraocular pressures. Doc Ophthalmol Proc Ser 35:35-42, 1983
3. Caprioli J, Spaeth GL: Comparison of the optic nerve head in high- and low-tension glaucoma. Arch Ophthalmol 103:1145-1149, 1985
4. Anderton S, Hitchings RA: A comparative study of visual fields of patients with low-tension glaucoma and those with chronic simple glaucoma. Doc Ophthalmol Proc Ser 35:97-99, 1983
5. Caprioli J, Spaeth GL: Comparison of visual field defects in the low-tension glaucomas with those in the high-tension glaucomas. Am J Ophthalmol 97:730-737, 1984
6. Motolko M, Drance SM, Douglas GR: Visual field defects in low-tension glaucoma. Comparison of defects in low-tension glaucoma and chronic open angle glaucoma. Arch Ophthalmol 100:1074-1077, 1982
7. Phelps CD, Hayreh SS, Montague PR: Visual fields in low-tension glaucoma, primary open angle glaucoma and anterior ischemic optic neuropathy. Doc Ophthalmol Proc Ser 35:113-124, 1983
8. Mizokami K, Shiose Y, Kitazawa Y, Tsukahara A, Akamatsu T, Futa R, Katsushima H, Kosaki H: Tonometry, fundus photography and automated perimetry in glaucoma screening. In: Mills RP, Heijl A (eds) Perimetry Update 1990/91, pp 75-78. Amsterdam: Kugler Publ, 1991

NEURO-OPHTHALMOLOGY

Visual field indices for lesions of the central visual pathways

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Abstract

The analysis system PERIDATA provides a number of new indices for the differentiation of patterns of visual fields by calculation of loss variance of the whole 30° field divided by loss variance in confined areas, *e.g.*, in hemifields and quadrants. A further index compares the fields of fellow eyes with regard to the congruence of a homonymous or heteronymous arrangement. The authors applied these indices to the normative database of the Octopus computer perimeter (n=836), and to visual fields in lesions of the chiasm (n=202), the optic tract (n=52), and of the suprageniculate pathway (n=30). Chronic glaucoma (n=128) and optic neuritis and neuropathies (n=83) served as controls. The hemifield index correctly identified 94% of fields of healthy eyes as normal, and 97% of fields with typical hemianopic alterations due to lesions of the central pathway as abnormal. An affected hemifield index was observed in 20% of glaucomatous eyes and 8% of eyes with neuropathies. The quadrant index was normal in 94% of healthy eyes and abnormal in 97% of eyes with central lesions. Forty-three percent of glaucomatous eyes and 25% of eyes with neuropathies presented with an abnormal quadrant index due to nasal nerve fiber defects. The combined index for congruence turned out to lie in the heteronymous range in all pairs of chiasmal lesions, 60% of these with abnormal values The index of congruence was definitely abnormal in the homonymous range in all lesions of the optic tract and further centrally. The new indices facilitate the interpretation of visual fields in neuro-ophthalmology and may be applied in expert systems.

Introduction

Global indices of the visual field[1] usually represent the mean loss or loss variance. Abnormal fields can be separated from normal ones by means of those indices[2], and perhaps, with certain restrictions[3,4], be followed over time[5]. These indices disregard the pattern of localized alterations. A differentiation of peripheral and central optic nerve lesions is therefore not possible[2]. We tested new indices for the differential diagnosis of lesions of the visual pathways.

Material and methods

The computer perimetric analysis system PERIDATA, introduced by Weber[6], provides a number of regional indices characterizing the "conformity" of the field by calculation of loss variance of the whole 30° field divided by loss variance within each region[7]. A further index compares the visual fields of fellow eyes by a probability calculation of the similarity of the two fields. The direct comparison gives an index for homonymous congruence, whereas the comparison with a mirror image of the left eye results in an index for heteronymous congruence[8]. The combined index as the logarithm of homonymous divided by the heteronymous index is positive in homonymous, negative in heteronymous congruence.

We applied the conformity indices for hemianopic and quadratic alterations and the index for congruence to the normative sample[9] of the G1 program of the computer perimeter Octopus (n= 836, respectively, 321 pairs), and to visual fields in lesions of the chiasm (n=202, respectively, 94 pairs), the optic tract (n=52, respectively, 25 pairs), and of the suprageniculate visual pathways (n=30, respectively, 15 pairs). One hundred and twenty-eight glaucomatous fields

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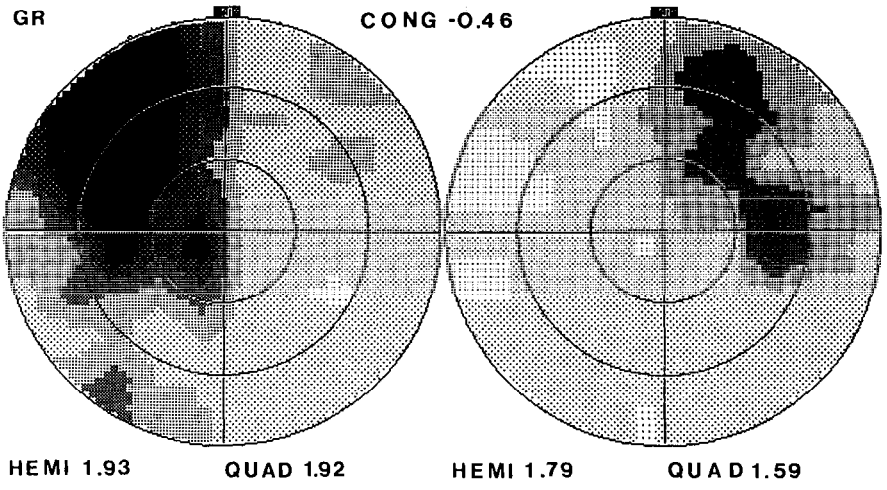

Fig. 1a.

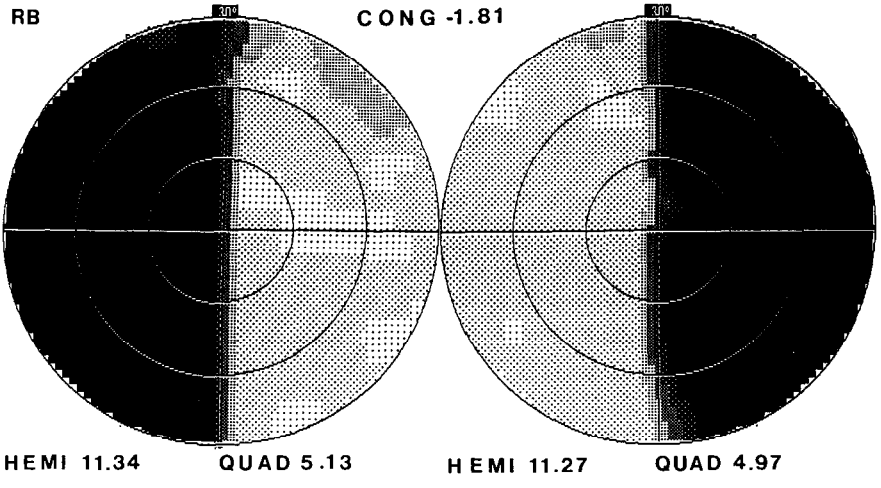

Fig. 1b.

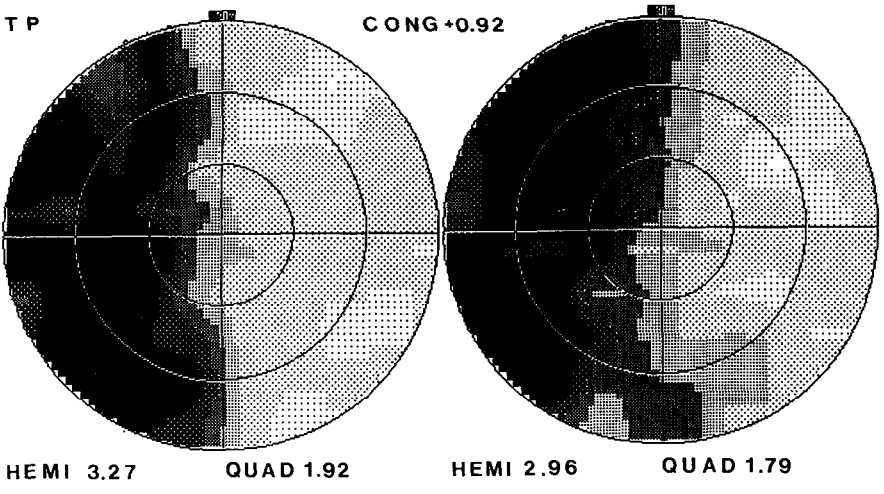

Fig. 1c.

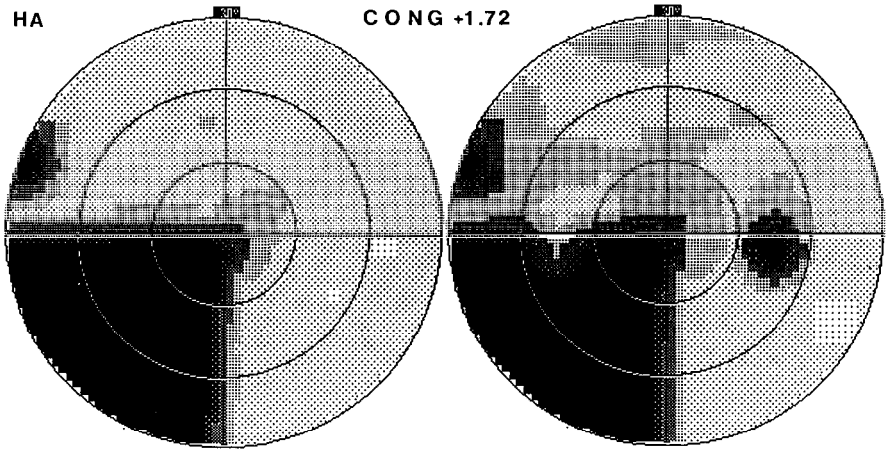

Fig. 1d.

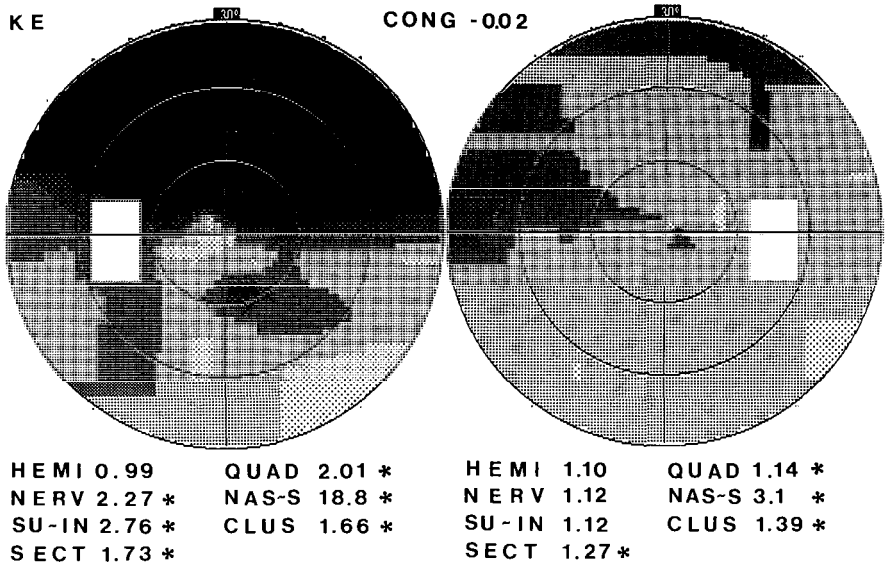

Fig. 1e.

Fig. 1. Pairs of visual fields, grayscale printout of deviation from normal sensitivity. Values of hemi- and quadrant indices under each field, index of congruence between pairs *a.* Advanced bitemporal hemianopia due to craniopharyngioma. Bilateral highly abnormal hemi-index, less abnormal quadrant index. Most abnormal index of congruence of this sample. *b.* Moderate bitemporal quadranopia from pituitary adenoma. Hemi- and quadrant indices in the same order, more pronounced in the left eye Moderately abnormal index of congruence in the heteronymous range. *c.* Pronounced homonymous hemianopia to the left with some incongruence due to crossing of the midline in the right eye following removal of a craniopharyngioma with lesion of the optic tract. Hemi-index even more affected than quadrant index. Index of congruence markedly deviating in the homonymous direction *d.* Congruent homonymous quadranopia after infarction of posterior cerebral artery. Quadrant index even more abnormal than hemi-index, index of congruence considerably more advanced than in *c.*. *e.* Chronic simple glaucoma with advanced nerve fiber defects in the left and mild nasal step in the right eye Abnormal indices marked with an asterisk. Hemi-index normal, quadrant index abnormal in both eyes Index of congruence perfectly normal. Further indices for pattern recognition, as nerve fiber bundles (nerv), nasal steps (nas-s), altitudinal asymmetry (su-in), 6°-clusters (clus) and sectors (sect), are beyond the scope of this contribution.

(43 pairs) and 83 fields with optic neuritis and neuropathies (31 pairs) served as a control.

All fields of the central lesions had been interpreted in masked fashion by one of us (FD), and classified as typically mild (n=63, Fig. 1b OD) or severe hemianopic changes (n=93, Fig. 1a and b OS, 1c OS, 1d), advanced hemianopic changes with extension into the adjacent hemifield (n=58, Fig. 1c OD), and atypical changes or defects not related to lesions of the central pathway (n=36).

Results

The results are listed in Table 1. All normal and glaucomatous visual fields, but only abnormal fields due to neuropathy and fields with typical changes due to central lesions, were used for the calculations. Using a cut-off value of 1.15, the hemi-index correctly classified 94%, and the quadrant index 97%, of fields of healthy eyes as being normal. We modified the cut-off value of the quadrant index to 1.11 to achieve the same specificity of 94% for both indices.

Table 1. Visual field indices in normals, glaucoma, optic neuropathy, lesions of whole central visual pathway (CNS) and of chiasm, optic tract and suprageniculate pathway

	Normals	*Glaucoma*	*Neuropathy*	*CNS*	*Chiasm*	*Tract*	*Supra-geniculate*
hemi:							
n	836	128	63	156	103	37	16
mean	1.071	1.075	1.043	2.959	2.991	3.225	2.144
SD	0.128	0 123	0.098	2.736	2.586	3.533	1.005
min	0 98	0.98	0.98	0.98	1.07	1.16	1.32
max	1.8	1 63	1.46	19.12	13.06	19.12	4.61
n path	50	26	7	151	98	37	16
% path	6	20	11	97	95	100	100
quad:							
n	863	128	63	156	103	37	16
mean	1.03	1.18	1.115	1.983	1.834	1.99	2.285
SD	0.052	0.246	0.201	1.1	1.009	1.386	0.924
min	0.97	0.98	0.98	1.06	1.06	1.12	1.2
max	1.44	2.57	2.15	8.34	5.83	8.34	4.21
n path	53	62	19	152	97	37	37
% path	6	48	30	97	94	100	100
cong:							
n	321	43	31	69	43	18	8
mean	-0 061	-0.08	-0.15	0.002	-0.521	0.781	1.06
SD	0.12	0.116	0.086	0 81	0.424	0.495	0.408
min	-0.5	-0 36	-0.18	-1.81	-1.81	0.19	0.55
max	0.58	0.3	0.23	2 25	-0.05	2.25	1.72
homo							
n path	5	3	1	26/26	0	18	8
% path	2	7	3	100	0	100	100
hetero							
n path	7	1	0	27/43	27	0	0
% path	2	2	0	63	63	0	0

The hemi-index of the two control samples, glaucoma and neuropathies, was slightly, but not significantly, higher than the one for the normal population (Table 1).

The hemi-index labelled 151 of 156 fields with typical hemianopic alterations due to lesions of the central pathway as abnormal (sensitivity 97%). All five missed fields only had mild changes from chiasmal lesions, four of them disclosed an abnormal quadrant index. There was no apparent difference between the three subgroups of central lesions. The area under ROC curve[2] was 0.938 for the hemi-index, 0.944 for MD.

The values of the quadrant index were moderately elevated in neuropathies with clinically obvious defects, even more so in glaucomatous eyes. Of the 156 fields of typical central lesions only six (sensitivity 97%) were labelled as normal with this index, all of which belonging to mild chiasmal defects. The three groups of central lesions did not differ for the quadrant index.

The values for the index of congruence are closely grouped around zero in all 321 available pairs of normal eyes. The two control samples, glaucoma and neuropathies, presented with values in the same order. The normal range of 2 SD was exceeded in only three glaucomatous subjects, in one with a neuropathy in the homonymous direction, and in one glaucoma patient in the heteronymous direction.

All pairs of fields of chiasmal lesions had negative values, and were therefore lying in the heteronymous direction. Sixteen of these (40%) were still situated within 2 SD of normal values. Eight of these 16 were unilaterally affected. In two others, the vertical meridian was already crossed by the defect in one eye. In the remaining eyes, the defects were asymmetrical with mild alterations at least in one eye.

All pairs of fields from lesions of the optic tract and of the supragenicular pathway deviated in the homonymous direction exceeding 2 SD, with a wide range of values. A separation of these two subgroups with the index of congruence is limited, due to the small sample and to the different extent of defects. This differentiation is possible in individual cases, however (Fig. 1c and d).

Comments

Programs for the interpretation of visual fields[10] require a classification of defects. Conventional automated systems for the interpretation of visual fields using global indices[1,11] neglect patterns of localized alterations. Calculation of mean deviation of sensitivity in parts of the field[12] and cluster analysis[13-15] are the first steps towards a regional analysis. Analysis of altitudinal symmetry, as provided in STATPAC 2 of the Humphrey perimeter[16], applies specifically to glaucoma. Expert systems with neural nets only exist in experimental versions[17-19]. Analysis of congruence between fellow eyes[8] was not possible.

The perimetric analysis system PERIDATA provides a series of regional indices[7] and an index of congruence[8]. Our findings for a different program, G1 of the Octopus compared to program 20-2 and 30 S of the Humphrey computer perimeter, in a different normal population[9], roughly confirm the specificity of the hemi-index at 94% compared to that previously established at 90%[20]. A modification of the cut-off value between normal and affected was necessary for the quadrant index to keep specificity in the same magnitude of 94% for both indices.

We could also confirm the sensitivity of the hemi-index[20]. This index and MD were equally able to separate affected from normal fields. Two control samples gave additional proof of the differential diagnostic power of this index for lesions of the peripheral and central visual pathway. The quadrant index was, as expected, sensitive to both hemianopic defects of central lesions and nasal nerve fiber defects of peripheral lesions of the optic nerve.

The index of congruence allowed, as already established[8], a perfect separation of homonymous and heteronymous alterations. Bitemporal defects are often asymmetrically arranged, giving rise to weaker deviations of this index (40% within 2 SD of the normal range in our material). A tendency towards heteronymous binasal values in glaucoma[8] was not apparent in our sample, however. Abnormal values for this index may be underestimated in comparison to abnormal values of the regional indices of conformity due to the logarithmical calculation of this combined index (Fig. 1b, c and d).

A number of further indices are available in the PERIDATA system[2,7] (Fig. 1e). The adequate interpretation of these values requires experience, however. The perspective for a real expert system is a combined interpretation of those indices, optimized in larger samples, and released by the system in cleartext[15] including the probabilities. Such an expert system will never replace the ophthalmologist with his clinical responsibility, who is able to summarize all clinical data to an entity and to keep the individuality of the patient and possible artifacts in mind.

Acknowledgements

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References

1 Flammer J: The concept of visual field indices. Graefe's Arch Clin Exp Ophthalmol 224:389-392, 1986
2. Damms T, Dannheim F, Ahlers S: A visual field index for nerve fibre bundle defects. This Volume, pp 9-13
3 Werner EB, Bishop KI, Koelle J, Douglas GR, Leblanc RP, Mills RP, Schwartz B, Whalen WR, Wilensky JT: A comparison of experienced clinical observers and statistical tests in detection of progressive visual field loss in glaucoma using automated perimetry. Arch Ophthalmol 106:619-623, 1988
4 Chauhan BC, Drance SM, Douglas GR: The use of visual field indices in detecting changes in the visual field in glaucoma Invest Ophthalmol Vis Sci 31:512-520, 1990
5. Gramer E, Althaus G: Quantifizierung und Progredienz des Gesichtsfeldschadens bei Glaukom ohne Hochdruck, Glaucoma simplex und Pigmentglaukom: Eine klinische Studie mit dem Programm Delta des Octopus-Perimeters 201 Klin Mbl Augenheilk 191:184-198, 1987
6 Brusini P, Nicosia S, Weber J: Automated visual field management in glaucoma with the Peridata program. In: Mills RP, Heijl A (eds) Perimetry Update 1990/91 Amsterdam: Kugler Publ 1991
7. Weber J, Papoulis C, Schmitz A: Neue diagnostische Hilfen in der automatischen Perimetrie. Ophthalmologe 89: 1992
8 Weber J: The quantification of congruence between the right and left visual field. Presented at the Xth International Perimetric Society Meeting, Kyoto, Japan, October 20-23, 1992
9. Haas A, Flammer J, Schneider U: Influence of age on the visual fields of normal subjects. Am J Ophthalmol 101:199-203, 1986
10 Stürmer J, Vollrath-Junger C, Lautenbach K, Gloor B: Computerized visual field analysis. In: Heijl A (ed) Perimetry Update 1988/89. Amsterdam: Kugler Publ 1989
11. Heijl A, Lindgren G, Olsson J: A package for the statistical analysis of visual fields. Doc Ophthalmol Proc Ser 49:153-168, 1987
12. Bebié H, Fankhauser F: Statistical program for the analysis of perimetric data. Doc Ophthalmol Proc Ser 26:9-10, 1981
13. Chauhan BC, Henson DB, Hobley AJ: Cluster analysis in visual field quantification. Doc Ophthalmol 69:25-39, 1988
14 Åsman P, Heijl A: Spatial considerations in cluster analysis for detection of glaucomatous field loss. In: Mills RP, Heijl A (eds) Perimetry Update 1990/91. Amsterdam: Kugler Publ 1991
15. Funkhouser A, Hirsbrunner HP, Fankhauser F, Flammer J: Octosmart: a computerized aid for interpreting visual field examination results. In: Mills RP, Heijl A (eds) Perimetry Update 1990/91. Amsterdam: Kugler Publ 1991
16. Heijl A, Lindgren G, Lindgren A, Olsson J, Åsman P, Myers S, Patella M: Extended empirical statistical package for evaluation of single and multiple fields in glaucoma: STATPAC 2. In: Mills RP, Heijl A (eds) Perimetry Update 1990/91. Amsterdam: Kugler Publ 1991
17. Kelman SE, Perell HF, D'Autrechy L, Scott RJ: A neural network can differentiate glaucoma and optic neuropathy visual fields through pattern recognition. In: Mills RP, Heijl A (eds) Perimetry Update 1990/91. Amsterdam: Kugler Publ 1991
18. Nagata S, Kani K, Sugiyama A: A computer-assisted diagnosis system using a neural network. In: Mills RP, Heijl A (eds) Perimetry Update 1990/91. Amsterdam: Kugler Publ 1991
19 Shapiro LR, Johnson CA: Evaluation of the diagnosis of visual fields. In: Mills RP, Heijl A (eds) Perimetry Update 1990/91 Amsterdam: Kugler Publ 1991
20. Papoulis C, Weber J: Symmetry analysis in pituitary adenoma. In: Mills RP, Heijl A (eds) Perimetry Update 1990/91 Amsterdam: Kugler Publ 1991

Foveal sensitivity: correlation with central visual acuity

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Introduction

Central foveal sensitivity can be obtained on most automated static perimeters. This requires eccentric fixation provided on most machines with a small diamond of target lights. While this has been available as an option, only recently has this been default set on the Humphrey Field Analyzer. There has been very little written or studied about foveal sensitivity in patients with disease. Recently, we presented data on the reproducibility of foveal sensitivity in patients with normal acuity. We attempted a retrospective study of foveal sensitivity in patients with various optic neuropathies and retinal pathology undergoing automated static perimetry. We were particularly interested in the correlation of foveal sensitivity and visual acuity, and whether there was relatively better correlation with various forms of optic neuropathy or retinal disease. In addition, we investigated whether there was a relative trend of sensitivity impairment with regard to similar visual acuities dependent on pathology.

Material and methods

In a pilot study, all automated visual fields done on the retina, cornea and neuro-ophthalmology services at the University of Virginia over the past 12 months were reviewed. This total of over 800 fields was screened for acceptable reliability coefficients (less than 1/3 false positives or false negatives), visual acuity of less than 20/50 or foveal sensitivity of less than 30 dB and an ability to exclude all but a single diagnosis as the etiology of the patients' reduced acuity. A total of 22 visual fields was analyzed in the optic neuropathy group and 19 visual fields were analyzed in the retina anterior segment pathology group.

Analysis

Visual field data with accompanying acuities were grouped by diagnosis and analyzed for average foveal sensitivity and visual acuity. In addition each group was studied by regression analysis obtaining an R value as well as a slope and intercept of a linear regression model. In addition, SAS analysis was done with regard to contributions of correlations within and across the various diagnostic groups.

Results

The individual fields were separated into those due to optic neuropathies and those related to retinal and media pathology. We did look at specific etiologies within the optic neuropathy group. It was interesting that, overall, the groups were fairly similar in terms of acuity across the various optic neuropathies. The average visual acuity within the optic neuropathy group as a whole was 20/60 with a corresponding foveal sensitivity of 21.6. The anterior segment/retinal group had an average acuity of 20/100 but a foveal sensitivity of 25.6. Thus, the optic neu-

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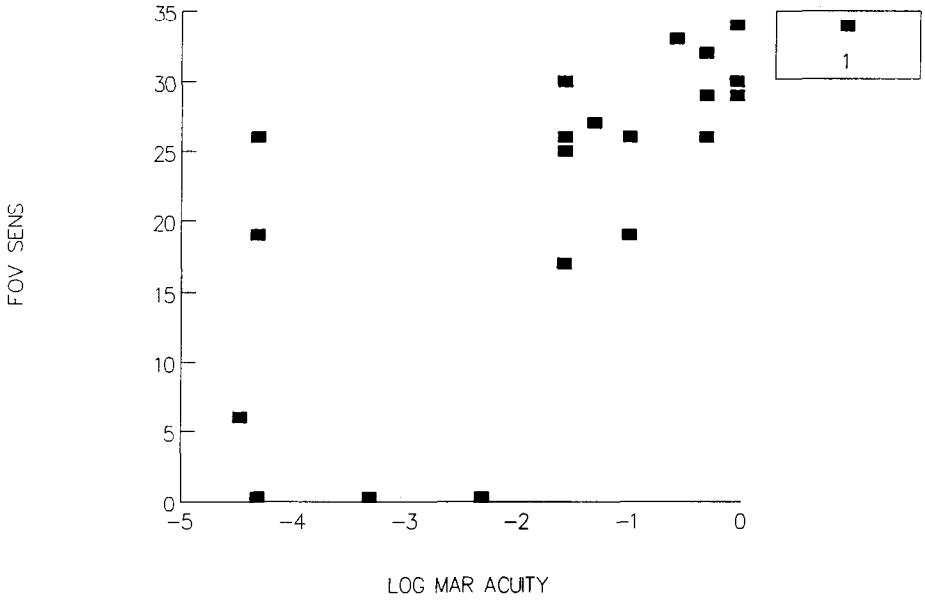

Fig. 1. Optic neuropathies.

ropathy group had a lower average foveal sensitivity despite having a better Snellen acuity. Patients with cataract had the highest foveal sensitivities for a similar reduction in acuity. Corresponding foveal sensitivity was closely matched in the toxic, ischemic, inflammatory and compressive groups but was substantially higher in the hereditary group. The R squared value for the optic neuropathy group was 0.482. Similarly, the R squared of the retina group was 0.364. This contrasts with an R value of 0.76 previously demonstrated in patients without optic neuropathy and relatively good central acuity. With later additional optic neuropathy patients there was a wide range of correlation coefficients. When analyzed individually, the R squared values ranged from 0.029 for the toxic group to 0.768 for the compressive group. We plotted

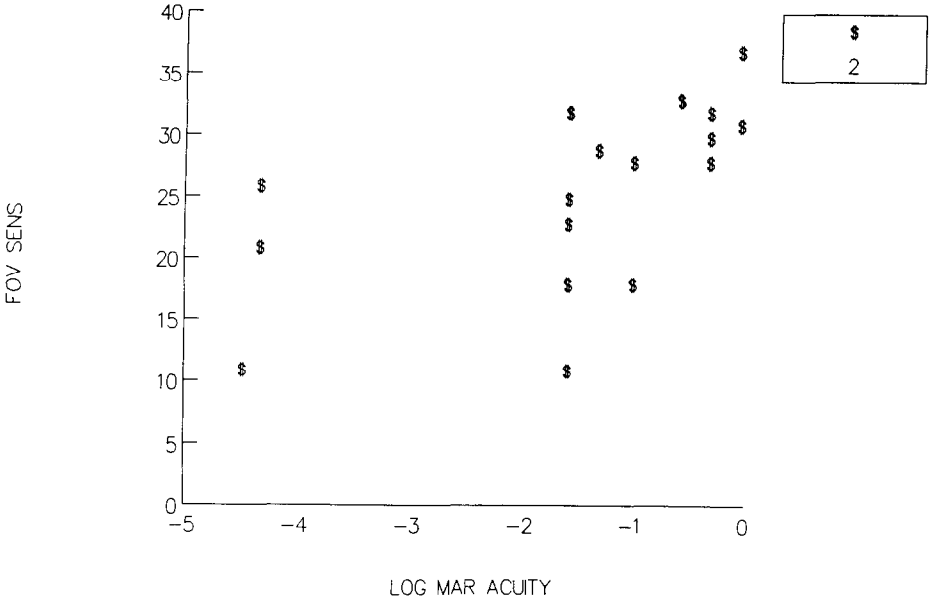

Fig. 2. Retina/media opacities.

the foveal sensitivity against the log of the visual acuity fraction.

As can be seen in Fig. 1, while there is a tendency towards correlation, there is a wide range of values in those patients with optic nerve compromise. When the foveal sensitivity was plotted against visual acuity for those patients with retina or media opacities there was a similar loose correlation (Fig. 2). As can be seen by comparing the two graphs the overall sensitivities in the anterior segment/retina group are higher than those in the optic neuropathy group.

Discussion

Foveal sensitivity has a high reproducibility rate in normal patients. It would seem to match the reproducibility obtained at the four points closest to fixation as demonstrated on the test-retest strategy which formed the basis of STATPAC. As acuity is reduced foveal sensitivity also tends to drop. The lack of complete correlation, however, raises several interesting questions. It is not surprising that foveal sensitivity tends to be higher for patients with retina and media disease (cataracts) for similar levels of acuity when compared to optic neuropathies. Presumably this relates to the disorganization of receptor channels without loss of the receptor and ganglion cell function. This must be particularly true in the case of cataracts with light scattering as well as patients with epiretinal membranes and those with cystoid macular edema. Those retinal pathologic processes that tend to completely eliminate foveal receptors were associated with substantial decrease in sensitivity (macular scars, subretinal neovascular membrane and laser burns). Macular holes were variable as foveal sensitivity could be substantially reduced. On the other hand, small changes of fixation could lead to paracentral viewing with a substantial improvement in foveal sensitivity in spite of reduced central acuity.

In those patients with optic neuropathies, there was substantial variation in the correlation between foveal sensitivity and acuity. In those patients with compressive optic neuropathies, the correlation was the highest. This is not surprising in view of the usual presence of a relative central scotoma. Frisén's model of optic neuropathies as a percentage loss of afferent channels probably best applies to these patients who seem to have a profound relative loss of central function as the optic neuropathy progresses. It is interesting to speculate that those slowly developing compressive optic neuropathies with relative preservation of central function including foveal sensitivity may actually have their pathophysiology on a secondary vascular compromise basis. One can speculate that the much poorer correlation of patients with ischemic optic neuropathy revolves around the tendency to horizontally split fixation. This may lead to variability on the basis of problems with fixation and thus potentially poor correlation. Inflammatory disease seems to be intermediate, possibly related to the higher incidence of central dysfunction similar to those patients with compressive optic neuropathies. The increased fluctuation may be related to the variable involvement and the changing functional status of the optic nerve fibers best illustrated by the variable natural history. The hereditary fields seem to have no correlation at all with good foveal sensitivity over a wide range of acuities. The mechanism of visual reduction in these patients remains unclear. Similarly the toxic optic neuropathies demonstrated much lower foveal sensitivity but a wide scatter across acuity levels.

The most intriguing finding in several of the patients studied was that in those patients where foveal sensitivity seemed to be out of expected alignment with visual acuity, often the acuity changed on follow-up. Whether this in fact is predictive of visual acuity changes or simply represents scotomatous encroachment towards fixation with relative splitting of macular function and thereby variable response remains moot. It does raise the issue as to whether there may be some additional information conveyed by assessment of foveal sensitivity. Clearly this is not an independent variable but may offer substantial increase information when obtained in conjunction with sensitivity at extra foveal points. Thus, the subset of patients where acuity does not seem to match foveal sensitivity may be associated with a higher frequency of retinal or media pathology. Lack of correlation may also occur in those patients with paracentral field defects and thus variable fixation. It may well be that these are the patients who have a higher incidence of visual acuity fluctuation with time. Whether in fact this turns out to be predictive remains to be analyzed in a prospective fashion. It would probably be worth while to specifically look at those fields with foveal sensitivity out of the range expected for the patient's acuity.

Conclusions

1. Foveal sensitivity does tend to correlate with visual acuity, although far less well than in patients with normal optic nerve function.
2. Correlation coefficient is best for compressive optic neuropathies.
3. Retinal disease, ischemic optic neuropathy and especially toxic pathology have a poor correlation between foveal sensitivity and acuity. Inflammatory optic neuropathies have an intermediate correlation.
4. Levels of foveal sensitivity are higher with retinal disease and media opacity (cataracts) than with optic neuropathies.
5. Changes in foveal sensitivity may antedate and, thus, predict changes in visual acuity in patients with changing optic neuropathies.
6. Foveal sensitivity provides additional data with regard to optic nerve function and should be routinely obtained as part of automated static perimetry.

Detection of homonymous visual field defects with flickering random dot pattern

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Abstract

This study was carried out on 80 patients (37 male, 43 female) suffering from a homonymous hemianopia of various origin. The scotomata were detected by conventional perimetry - automated grid perimetry with the Tübingen Automatic Perimeter (TAP) or in some cases kinetic perimetry with the Tübingen Manual Perimeter (TMP) or by the white-noise field of the Tübingen Electronic Campimeter (TEC), respectively Evaluating the examinations of each eye separately, 39 cases showed pathological results in conventional perimetry while white-noise field campimetry was normal. The opposite constellation occurred very rarely (only in two of a total of 158 examinations) In 117 cases, both methods concordantly showed pathological results. Thus, about 75% of all hemianopic visual field defects, detected with conventional perimetry, were perceived in white-noise field campimetry. In ten of a total of 80 patients the lesion of the visual pathway had occurred two years or more before examination, leading to a homonymous hemianopia, clearly detectable with conventional perimetry Even then, with white-noise field campimetry, eight of these patients perceived their homonymous defects as well.

Introduction

Patients with circumscribed visual field defects caused by lesions of the third neuron (retinal nerve fiber layer, optic nerve, chiasm, optic tract) are able to perceive their scotomata immediately while looking at randomly distributed black and white squares (12′ × 12′) flickering with high frequency (≈ 30 Hz) resulting in a field of apparently moving stimuli comparable to the white-noise field on a TV screen. Transforming negative scotomata into positive defects, white-noise field campimetry is able to demonstrate them to the patient so that he can directly perceive his functional loss. This makes white-noise field campimetry a very fast screening method for detection of visual field defects. However, this method was thought to be much less sensitive in detecting isolated supra-geniculate lesions (fourth neuron), especially if these had occurred more than two years previously[1]. It was an aim of this study to look into this assumption in a sufficient number of patients.

Methods

For conventional examination of the visual fields, in most patients (n=67), the Tübingen Automatic Perimeter (TAP 2000, Oculus, Dutenhofen) was used. Its threshold-related, slightly supra-threshold strategy with subsequent exploration of the defect area, guarantees a comparatively time-saving examination. The method is independent of the examiner and has a high density of stimuli (191 test points in the central 30° area). Thereby the location and dimension of the detected scotoma can be exactly determined and precisely compared with the findings of noise-field campimetry.

The remaining 13 patients were examined with kinetic perimetry (Tübingen Manual Perimeter). With this method, examination time for conventional perimetry could be cut down in patients with problems of general well-being.

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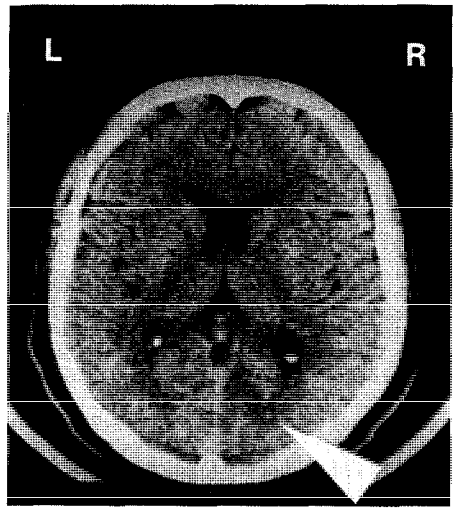

infarction of right occipital lobe

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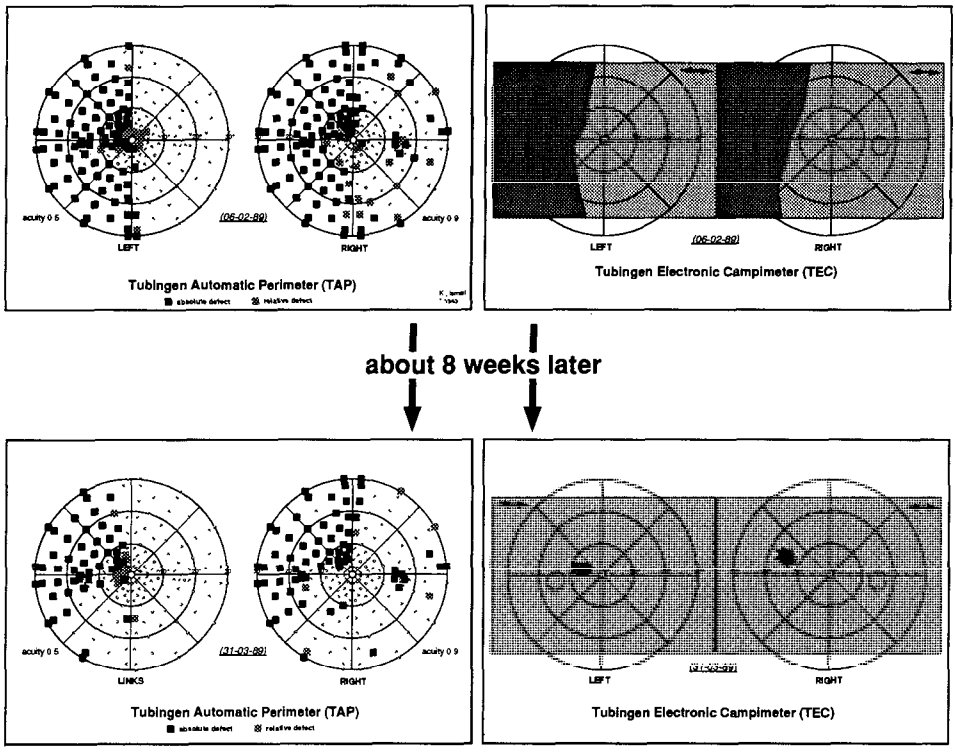
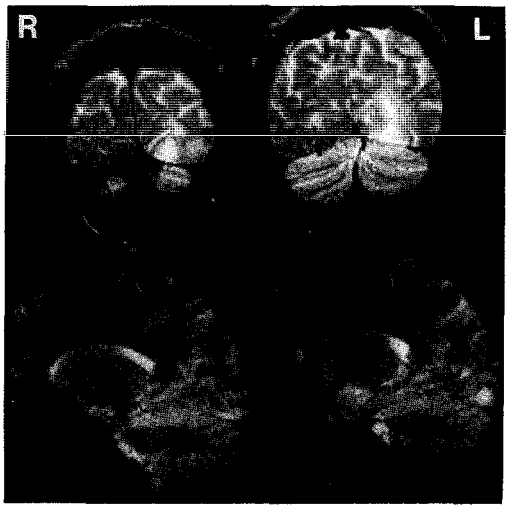


Fig. 1a. Infarction of right occipital lobe Top: axial CT scan. Results of conventional perimetry (Tübingen Automatic Perimeter; left side) and white-noise field campimetry (right side). In the follow-up period there is a slight regression of homonymous hemianopia in automated grid perimetry but an almost complete regression of the scotomata in white-noise field campimetry.



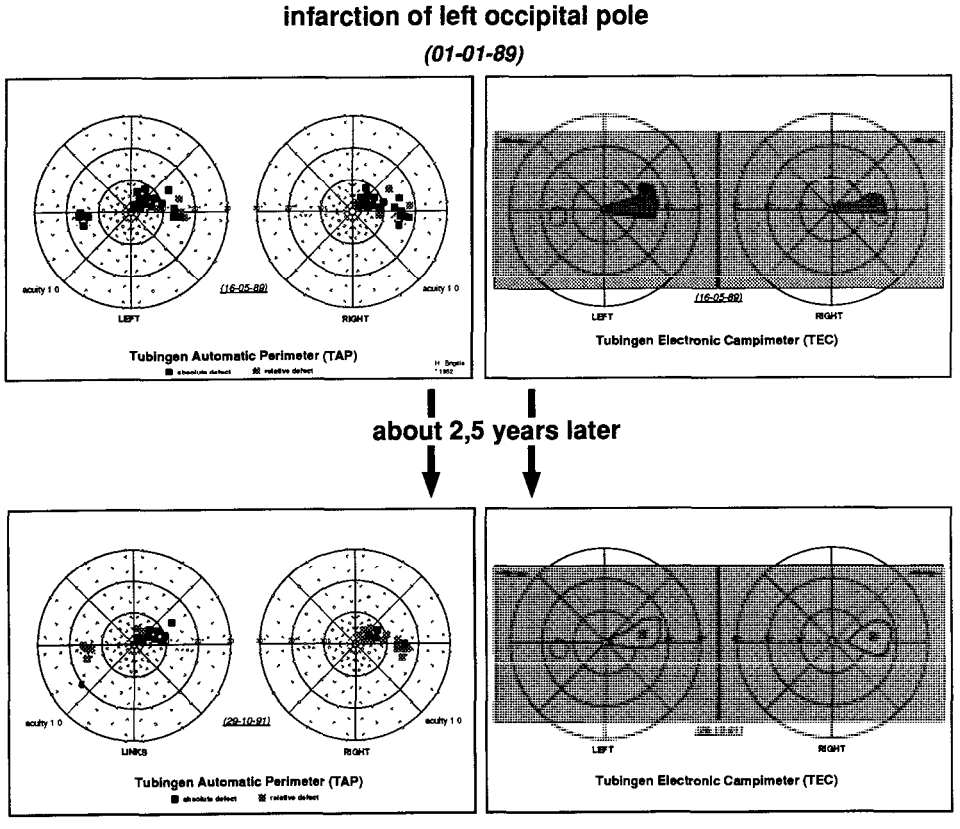


Fig. 1b. Infarction of left occipital pole with respect for the calcarine fissure. Top: coronal and sagittal NMR scans. During the follow-up period (about 2.5 years) scotomata remained nearly constant with conventional perimetry and white-noise field campimetry.

For white-noise field campimetry, we used the Tübingen Electronic Campimeter (TEC, Oculus, Dutenhofen), technical data of which are described elsewhere in detail[1-4]: with this campimeter an area of 35° (horizontal) × 24° (vertical) of the central visual field can be examined, at a distance of 30 cm between the eye and the surface of the screen. A high resolution black and white TV screen is used to present the patient an equal number of randomly distributed black and white square dots with a flicker frequency of 30 Hz. Each dot has a visual angle of about 12′ × 12′. The luminance of the light dots is 200 cdm^{-2} and that of the dark dots 0.8 cdm^{-2}, respectively. A black target in the center of the screen is used to stabilize fixation. The head of the patient is positioned in a head-rest. If necessary, adequate near-correction (glasses with small frame) is provided. The fellow eye is covered with an opaque patch. Direct inspection and video monitoring of the examined eye is used to control fixation.

As described elsewhere[4,5], the examiner asks the patient in a standardized way about the perception of the noise-field. Most of the circumscribed disturbances (scotomata) in the noise-field are described as "clouds". These can be differentiated from the surrounding normal noise-field by the following qualities:

- change in brightness perception (possible states are: darker, equal, brighter);
- change in noise perception, *i.e.*, "apparent" movement of dots (possible states are: increased, unchanged, reduced, deficient).

Patients

The investigations were carried out in 80 (= 100%) patients (43 female, 37 male) who were examined at the University Eye Hospital, Tübingen (Department of Pathophysiology of Vision and Neuro-Ophthalmology) because of an homonymous hemianopia. The patients were aged between 15.2 and 83.2 years (mean, 45.0 years; median, 42.1 years; SD = 18.0 years). White-noise field examinations were conducted by one examiner (U.S.) only.

In most cases (51 of 80) (63.8%), homonymous hemianopia was caused by vascular or hemorheological disorder. Eighteen cases (22.5 %) suffered from space occupying lesions, and four patients (5%) from an inflammatory or from a traumatic process, respectively. In three patients the reason for the homonymous visual field defect could not be definitely detected at the time of ophthalmological examination.

In only 42 cases, the exact onset of the visual field defect could be established: the duration of homonymous hemianopia at the time of ophthalmological examination ranged from several hours to 16.6 years. About 75% of all homonymous visual field defects had a duration of less than one year (median, 0.16 year).

In 40 patients CT or NMR scans were performed at the Department of Neuroradiology, Tübingen. Twenty-six of these patients (65.0%) suffered from a morphological defect in the supra-geniculate region (optic radiation or visual cortex) exclusively. In one patient (2.5%), the lesion was located in the lateral geniculate body exclusively. Two persons (3.3%) showed a lesion of the third neuron (posterior chiasm or optic tract). In six patients (15.0%), the homonymous hemianopia was caused by a combination of geniculate and supra-geniculate lesion. In two persons (3.3%), there was a combination of infra- and suprageniculate lesion. In three patients (7.5%), neuroradiological examinations did not show a clear pathological process with regard to the visual pathway.

In conventional perimetry the homonymous scotomata showed a complete congruence between both eyes in 48 patients (60.0%), a reduced congruence between both eyes in 27 cases (33.8%), and no congruence between both eyes in four persons (5.0%).

Results

Initial examinations only

In contrast to the above-mentioned data, it is useful to evaluate the results of each eye separately. There may be the possibility that, despite the post-chiasmal lesion which normally causes a homonymous visual field defect, one method fails to detect any scotoma or shows a visual field defect in one eye only. Additionally, localization, extent of visual field defect and quality of noise perception may differ between right and left eyes. In this way, with conven-

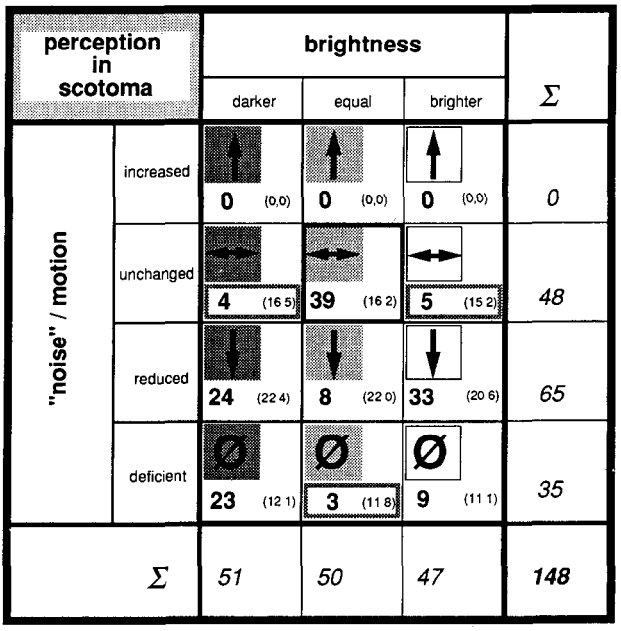


Fig. 2. Scheme for depicting of white-noise field findings. Perception of brightness (symbolized by different gray patterns) as well as perception of noise (motion) (represented by arrows or symbols) is shown In all cells of the contingency table, the expected frequency value is listed in brackets next to the real frequency value. The expected frequency value is computed as follows: row-Σ * column-Σ / total-Σ.

tional perimetry we obtained results in a total of 158 eyes. One person suffered from a short-term migrainous homonymous hemianopia; in this case only white-noise field campimetry could be conducted.

With regard to conventional perimetry, 54 results showed a complete homonymous hemianopia. There were 16 defects of the upper and ten defects of the lower quadrant of the visual field. Forty-four homonymous defects were larger, 30 smaller than one quadrant. The rest had different types of scotomata.

In 79 conventional perimetric results, there was a defect in the left, in 66 results there was a scotoma in the right half of the visual field, and nine cases showed a bilateral defect of the visual field. The remainder lacked a clear-cut respect for the vertical meridian or did not detect any scotoma at all.

In 90 conventional perimetric findings, there was a macular sparing, 47 cases showed incomplete and 12 cases complete macular splitting. The remainder did not allow an exact evaluation of this (peri-) central region.

The patients' descriptions concerning brightness and movement sensation perceived in the defect area of white-noise field are depicted in Fig. 2: Scotomata in white-noise fields are usually characterized by changes in both, perception of brightness and perception of noise.

The contingency table (Fig. 3, left side) shows that 39 cases had pathological results in conventional perimetry while white-noise field perimetry was normal. The opposite constellation occurred very rarely (only in two of a total of 158 examinations). In 117 cases, both methods concordantly showed pathological results. Thus, about 75% of all hemianopic visual field defects, detected with conventional perimetry, were perceived with white-noise field campimetry.

Exceeding the rate of detection, the agreement (concordance) between white-noise field campimetry and conventional perimetry is also of interest. Four ranks of the scale allow an adequate evaluation:

- good concordance: scotomata detected with white-noise field campimetry are congruent to a very high degree compared to those detected with conventional perimetry → 43 cases (27.2%);

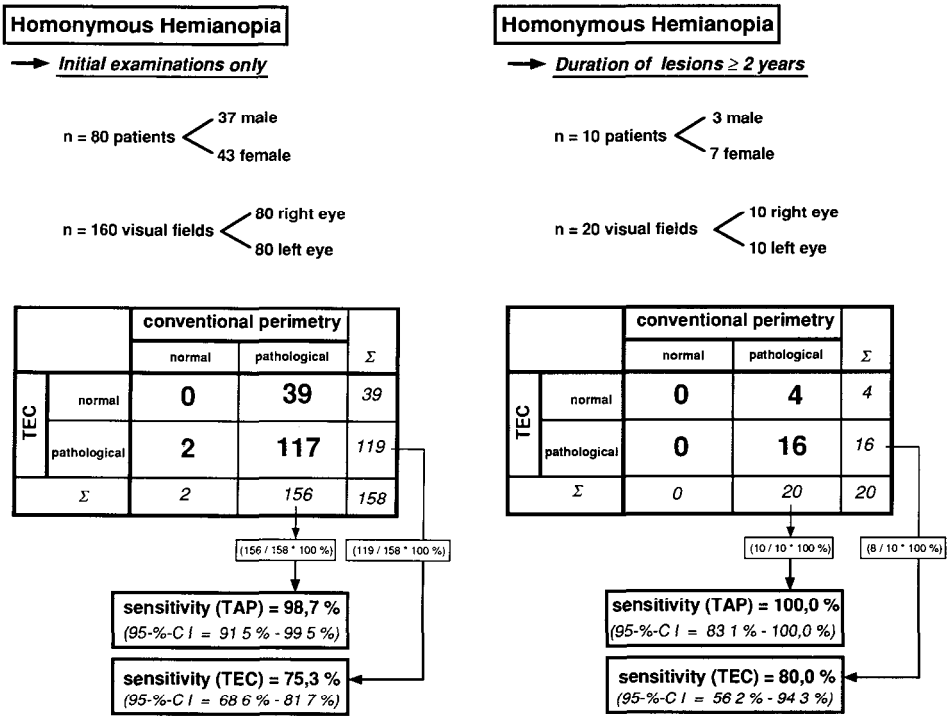


Fig. 3. Comparison of normal or pathological results found with the Tübingen Automatic Perimeter (TAP) or white-noise field campimeter (TEC). These findings are shown for initial examinations only (left side) and duration of lesions ≥ 2 years (right side).

- sufficient concordance: scotomata detected with white-noise field campimetry are only partially congruent compared to those detected with conventional perimetry → 51 cases (32.3%);
- poor concordance: scotomata were detected with both methods, but show only minor or no congruence between each method → 23 cases (14.6%);
- insufficient concordance: scotomata were detected with one method only → 41 cases (25.9%).

Follow-up examinations

Considering the follow-up examinations of this study exclusively, ten patients suffered from a homonymous visual field defect for at least two years. In six patients CT or NMR scans were carried out at the Department of Neuroradiology: four of these patients showed isolated supra-geniculate defects, one patient suffered from a geniculate and supra-geniculate lesion.

In this group, four cases (each eye was evaluated separately) showed pathological results in conventional perimetry, while white-noise field perimetry was normal. In the other 16 examinations, both methods concordantly showed pathological results (Fig. 3, right side). Concordance was good in nine cases (45%), sufficient in four cases (20%), poor in three cases (15%) and insufficient in four cases (20%).

Two typical controversial results in the follow-up of supra-geniculate lesions are depicted in Fig. 1a and b.

Discussion

The capabilities of white-noise field campimetry in detection of circumscribed visual field defects caused by lesions of the third neuron (retinal nerve fiber layer, optic nerve, chiasm,

optic tract) have been discussed and appreciated by several authors[1-10]. This method is able to transform negative scotomata into positive ones which are directly perceivable by the patient. In glaucomatous visual field defects Gramer *et al.*[8] attributed a "sensitivity" between 63.3% and 95% to this new method, depending on the stage of glaucoma. Shirato and co-workers[10] found a "sensitivity" of 91% in this group of patients with a slightly modified technique. In both studies, the results of conventional perimetry were taken as a baseline for comparison with this new method. More recently, Schiefer and co-workers[5] found insufficient correspondence between conventional perimetry and white-noise field campimetry in 25.4% of patients with ocular hypertension or different types of glaucoma. In another study[9], this new method was attributed a sensitivity of 91.8% for detection of lesions of the third neuron.

However, white-noise field campimetry fails to detect congenital scotomata (*e.g.*, blind spot) or visual field defects acquired in early childhood[1-4,11,12].

White-noise field campimetry was also thought to be much less sensitive[1-4] in detecting isolated supra-geniculate lesions (fourth neuron). Particularly if these defects had occurred several years previously, this method was assumed to be unable to detect these scotomata at all[1]. This is of major importance since a considerable number of patients with homonymous hemianopia could be missed if white-noise field campimetry were to be used as a general screening for visual field defects.

According to the findings of Kölmel[13], the vast majority of homonymous visual field defects in this study was caused by supra-geniculate lesions, as well.

The study presented here shows that white-noise field campimetry has only a moderately reduced sensitivity (75.3%) in the detection of homonymous visual field defects compared to its sensitivity detecting lesions of the third neuron. This study cannot support the results of former investigations attesting white-noise field campimetry the absolute inability to detect homonymous visual field defects existing for more than two years. However, 20% of all patients suffering from a homonymous hemianopia lasting for more than two years were not able to perceive their scotomata in the white-noise field. There are several reasons for this difference:

In contrast to conventional automated grid perimetry, which measures sensitivity concerning luminance differences, white-noise field campimetry additionally tests perception of motion. Recent investigations were able to show that the visual pathway in humans is divided into at least two systems which differ morphologically and functionally[13-22]: the parvo-cellular system being responsible for the transmission of information with high spatial frequency as well as data with color or stereoscopic relevance, and on the other hand the magno-cellular system which conducts information with high temporal frequency. Both systems seem to be responsible for transmission of brightness information.

As Riddoch[23] stated at the beginning of this century, in occipital (*i.e.*, supra-geniculate) lesions there are mechanisms producing a so-called "stato-kinetic dissociation": test points presented in a static manner (*i.e.*, luminance differences as the only distinguishing feature of the stimulus against the background) were not perceived at all, whereas moving these targets made them perceivable for this group of patients. "Blindsight"[19,24] could be partially explained by this mechanism. It is probably caused by a "recruitment" of accessory (presumably "archaic") parts of the visual pathway that bypass the actual lesion[4,13,14,19,20,25,26]. As in some cases the scotomata completely fade in white-noise field campimetry and on the other hand remain constant in conventional perimetry, it can be concluded that these accessory pathways are only an incomplete substitute, especially concerning perception of motion[4]. As this fading process sometimes takes several weeks to months, it can be presumed that the "recruitment" of accessory visual pathways is done only after a latency period. Perhaps, for example the specific neuronal pathways responsible for perception of motion or structure differ in resistance to lesions and re-establish function with marked differences in time and degree of recovery[4,16].

To gain more information about the exact localization and "repair mechanisms" of this system, two methods could be followed:

- PET (positron emission tomography) during white-noise field stimulation, similar to other stimulation experiments[27-31].
- Exact topographical reconstruction[32] of site and extent of any lesions leading to homonymous hemianopias. Using this method, the question may be answered as to whether there is a spatial accumulation of all those lesions leading to a pathological hemianopic visual field defect in conventional perimetry with white-noise field campimetry being normal.

References

1. Aulhorn E, Köst G: Noise-field campimetry: a new perimetric method (snow campimetry). In: Heijl A (ed) Perimetry Update 1988/89, pp 331-336. Amsterdam: Kugler Publ 1989
2. Aulhorn E: Pathophysiologie der glaukomatösen Gesichtsfeldausfälle. Fortschr Ophthalmol 85:601-606, 1988
3. Aulhorn E, Köst G: Rauschfeldkampimetrie: Eine neuartige perimetrische Untersuchungsmethode. Klin Mbl Augenheilk 192:284-288, 1988
4. Schiefer U, Köst G, Aulhorn E: Rauschfeld-Untersuchungsergebnisse mit dem Tübinger Elektronik Kampimeter (TEC): Ein Vergleich mit herkömmlichen perimetrischen Verfahren. Fortschr Ophthalmol 87:508-515, 1990
5. Schiefer U, Ulrich WD, Ulrich C, Wilhelm H, Aulhorn E: Rauschfeld-Kampimetrie vor und während künstlicher Augeninnendrucksteigerung: Einsatzmöglichkeiten in der Glaukomdiagnostik. Der Ophthalmologe 89:477-488, 1992
6. Bachhuber TM, Lachenmayr BJ: Detektion von Gesichtsfelddefekten bei Netzhaut-, Sehnerv- und Sehbahnerkrankungen mit der Rauschfeld-Kampimetrie. Fortschr Ophthalmol 1992 (in press)
7. Damm G, Lachenmayr BJ: Erfassung glaukomatöser Gesichtsfelddefekte mittels der Rauschfeld-Kampimetrie. Fortschr Ophthalmol 88:838-842, 1991
8. Gramer E, Roesen B, Siebert M: Sensitivität der Rauschfeldkampimetrie als Screeninguntersuchung bei Glaukom. Fortschr Ophthalmol 88:538-545, 1991
9. Schiefer U, Wilhelm H, Miliczek KD, Zrenner E: Detection of visual field defects: flickering random dot pattern vs. automated grid perimetry. Invest Ophthalmol Vis Sci 33(4):971, 1992
10. Shirato S, Adachi M, Hara T: Subjective detection of visual field defects using home TV set. Jpn J Ophthalmol 35:273-281, 1991
11. Aulhorn E, Schiefer U, Herzau V: Die Wahrnehmung des Blinden Flecks bei der Rauschfeldkampimetrie: Ein zusätzliches diagnostisches Kriterium bei Papillenveränderungen. Fortschr Ophthalmol 87:516-520, 1990
12. Fahle M, Aulhorn E: "Der geheimnisvolle Blinde Fleck". Klin Mbl Augenheilk 195:110, 1989
13. Kölmel HW: Die homonymen Hemianopsien. Berlin/Heidelberg/New York: Springer Verlag 1988
14. Baumgartner G: Physiologie des zentralen Sehsystems. In: Gauer OH et al (eds) Physiologie des Menschen, Vol 13. Munich/Vienna/Baltimore: Urban & Schwarzenberg 1978
15. Merigan WH, Eskin TA: Spatio temporal vision of macaques with severe loss of P_β retinal ganglion cells. Vision Res 26:1751-1761, 1986
16. Quigley HA, Sanchez RM, Dunkelberger GR, L'Hernault NL, Baginski TA: Chronic glaucoma selectively damages large optic nerve fibers. Invest Ophthalmol Vis Sci 28:913-920, 1987
17. Reese BE, Cowey A: Segregation of functionally distinct axons in the monkey's optic tract. Nature 331:350-351, 1988
18. Schiller PH, Logothetis NK, Charles ER: Functions of colour-opponent and broad-band channels of the visual system. Nature 343:67-70, 1990
19. Weiskrantz L, Warrington EK, Sanders MD, Marshall J: Visual capacity in the hemianopic field following a restricted occipital ablation. Brain 97:709-728, 1974
20. Wree A: Verknüpfung von Retina und visuellen Zentren des Gehirns Augenarzt 22:165-171, 1988
21. De Yoe EA, Van Essen DC: Concurrent processing streams in monkey visual cortex. TINS 11:219-226, 1988
22. Zihl I, Von Cramon D, Mai N: Selective disturbance of movement vision after bilateral brain damage. Brain 106:313-340, 1983
23. Riddoch G: Dissociation of visual perception due to occipital injuries with especial reference to appreciation of movement. Brain 40:15-57, 1917
24. Pöppel E: Residualsehen: ein Artefakt? In: Herzau V (ed) Pathophysiologie des Sehens, pp 110-112. Stuttgart: Enke 1984
25. Eysel UT: Neuronale Mechanismen zur Auffüllung retinaler Skotome. In: Herzau V (ed) Pathophysiologie des Sehens, pp 10-19. Stuttgart: Enke 1984
26. Perenin MT, Jeannerod M: Subcortical vision in man. TINS 2:204-207, 1979
27. Bosley TM, Dann R, Silver FL, Alav A, Kushner M, Chawluk JB, Savino PJ, Sergott RC, Schatz NJ, Reivich M: Recovery of vision after ischemic lesions: positron emission tomography. Ann Neurol 21:444-450, 1987
28. Corbetta M, Miezin FM, Dobmeyer S, Shulman GL, Petersen SE: Attentional modulation of neural processing of shape, color, and velocity in humans. Science 248:1556-1559, 1990
29. Kushner MJ, Rosenquist A, Alavi A, Rosen M, Dann R, Fazekas F, Bosley T, Greenberg J, Reivich M: Cerebral metabolism and patterned visual stimulation: a positron emission tomographic study of the human visual cortex. Neurology 38:89-95, 1988
30. Mora BM, Carman GJ, Allman JM: In vivo functional localization of the human visual cortex using positron emission tomography and magnetic resonance imaging. TINS 12:282-284, 1989
31. Zeki S, Watson DG, Lueck CJ, Friston KJ, Kennard C, Frackowiak RSJ: A direct demonstration of functional specialization in human visual cortex. J Neurosci 11:641-649, 1991

32. Wahler-Lück M, Schutz T, Kretschmann HJ: A new anatomical representation of the human visual pathways. Graefe's Arch Clin Exp Ophthalmol 229:201-205, 1991
33. Eysel UT, Gonzalez-Aguilar F, Mayer U: Late spreading of excitation in the lateral geniculate nucleus following visual deafferentation is independent of the size of retinal lesions. Brain Res 204:189-193, 1981
34. Hinrichsen KV: Funktionsentwicklung des ZNS beim Menschen. Dtsch Ärztebl 88:2701-2706, 1991
35. Magnussen S, Mathiesen T: Detection of moving and stationary gratings in the absence of striate cortex. Neuropsychologia 27:725-728, 1989

A comparison of the visual fields in children with psychosomatic disorders versus psychogenic visual disorders

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Abstract

It is well known that patients with psychogenic visual disorders (PVD) exhibit characteristic visual fields. However, the visual fields of patients with psychosomatic disorders (PSD) without PVD have not been well investigated. Twenty-one children with PVD, *i.e.,* who complained of decreased vision but were shown to have a visual acuity of 1.0 or better, and 21 children diagnosed with PSD by a pediatrician, were included in this study. Kinetic and static perimetry were performed on these two groups and the results were compared. Upon initial Goldmann kinetic perimetry, 21% of the 42 eyes in the PVD group showed severe constriction, 10% crossed isopters, 7% irregular isopters, 7% mild constriction, and 5% spiral isopters. The remaining 50% of eyes in the PVD group had normal fields. In contrast, 5% of the 42 eyes in the PSD group showed irregular isopters while the remaining 95% had normal fields. Humphrey Field Analyzer program 30-2 or 24-2 was also performed on the patients with normal Goldmann fields (including those whose Goldmann fields normalized during follow-up). Of 17 eyes with PVD (nine patients), ten showed diffuse depression, four showed localized depression, and three were normal. Of 32 eyes with PSD (16 patients), 16 showed diffuse depression, one showed localized depression, and 15 were normal. All eight eyes with PVD whose Goldmann fields normalized during follow-up showed abnormal Humphrey static fields. The percentage of visual fields indicating high fixation losses, false negative errors, or short-term fluctuation, was greater in the PVD group than in the PSD group. Although 95% of eyes in the PSD group showed normal Goldmann kinetic fields, 53% revealed abnormal Humphrey static fields. In the PVD group, even when Goldmann fields normalized during follow-up, functional visual field loss in the Humphrey static fields was common, and response characteristics were unusual

Introduction

Emotional disorders can sometimes manifest themselves in various physical conditions. Visual dysfunction without organic cause has been called by various names, such as psychogenic visual disorder (PVD), hysterical amblyopia, hysterical blindness, and ocular conversion reaction. Regardless of this, the predominant symptom of PVD is decreased vision, although thorough ophthalmological examination is unrevealing. Characteristic visual field defects are common, such as generalized constriction and spiral visual field. Psychosomatic disorders (PSD), on the other hand, also occur without organic cause and exhibit physical dysfunction. However, predominant symptoms are various, such as headache, abdominal pain, and refusal to attend school. Some patients with PSD also complain of visual symptoms, such as blurred vision, amaurosis, and micropsia. As in PVD patients, upon ophthalmological examination, no organic cause for the visual complaints in these PSD patients is found. However, the visual fields in PSD have not previously been well investigated. Therefore, we performed kinetic and static perimetry on patients with PVD and patients with PSD, in order to analyze and compare the influence of psychogenic factors on their performance in visual field testing.

Subjects and methods

Twenty-one children with PVD (mean age: 10.5 ± 2.1 years; six boys, 15 girls), and 21 children with PSD (mean age: 11.9 ± 2.8 years; 11 boys, ten girls) were included in this study.

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All patients with PVD had been detected as having decreased visual acuity in school screening programs and had been subsequently referred to the Department of Ophthalmology. Normal ophthalmological examination and lack of objective refractive error in these patients led to the diagnosis of functional visual loss, which was confirmed by demonstration of a visual acuity of 1.0 or better by the use of plano or trick lenses, or by persuasion. Equivalent plus and minus diopter lenses were used together in the trick lens method such that the overall power was plano. PVD patients in whom a visual acuity of at least 1.0 could not be demonstrated were excluded from our study because of the possibility of an organic lesion. Patients with PSD had been diagnosed by pediatricians on the basis of recurrent physical symptoms, such as headache, abdominal pain, and refusal to attend school, in the absence of organic disease following extensive work-up. All these patients had normal ophthalmological examinations, with best corrected visual acuities of 1.0 or better (refractive errors, if present, were within 5 diopters of spherical power).

Upon the initial visit, Goldmann kinetic perimetry (GP) was performed on each patient and the result was classified by type of visual field defect. Static perimetry using the Humphrey Field Analyzer (HFA) was performed only on those patients who showed normal kinetic visual fields upon initial testing and on those patients whose kinetic visual fields were normalized during follow-up. The Humphrey Field Analyzer program 30-2 or 24-2 (target size: III) was used in the static visual field test. Abnormal static visual fields were classified as having localized field loss or diffuse field loss. Patients whose Humphrey fields showed a total deviation of more than ten scattered points and a mean deviation (MD) worse than the lower 5% probability level for normals in the STATPAC, were classified as having diffuse visual field loss. The Humphrey field was considered unreliable in the presence of a short-term fluctuation (SF) greater than 2.5, a false positive error (FPE) or false negative error (FNE) of 33% or greater, or fixation losses (FL) of greater than 20%.

Results

The age distribution of the two groups is shown in Fig. 1. There was no statistically significant difference in the mean ages. Seventy-one percent of the patients in the PVD group were female compared to 48% in the PSD group.

Of the 21 patients with PVD (42 eyes), 21 eyes in 11 patients exhibited abnormal kinetic visual fields. Their initial Goldmann visual fields were classified as having severe constriction in nine eyes (21% of total), crossed isopters in four eyes (10%), irregular isopters in three eyes (7%), mild constriction in 3 eyes (7%), spiral isopters in 2 eyes (5%), and normal field in 21 eyes (50%). Of the 21 patients with PSD (42 eyes), only one patient (both eyes) showed abnormal kinetic fields (irregular isopters), while the remaining 20 patients (40 eyes) had normal

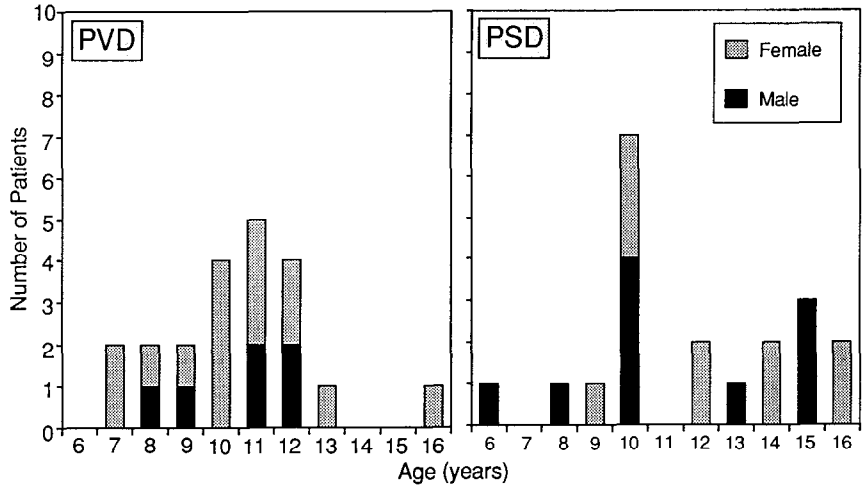

Fig. 1. Age distribution in the PVD and PSD groups.

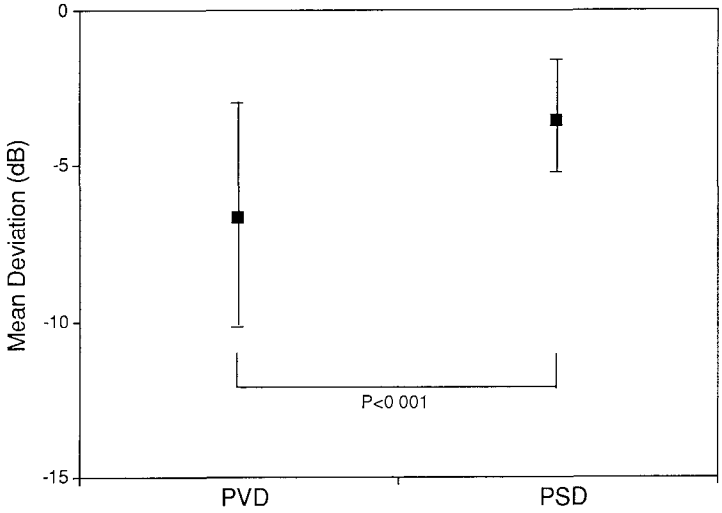

Fig. 2. Average mean deviation (MD) of the static visual fields. The difference in average MD between PVD and PSD groups was statistically significant ($p<0.001$, Scheffe F test).

fields. In summary, 50% of the patients in the PVD group exhibited some kind of kinetic field abnormality, whereas only 5% of the patients in the PSD group showed this.

In the PVD group, static Humphrey perimetry was performed on nine patients (17 eyes) in whom the initial Goldmann kinetic field was normal (nine eyes) and in whom the kinetic fields normalized during the follow-up period (eight eyes). Ten eyes showed diffuse field loss, four eyes showed localized field loss (two peripheral rim defects, one inferior arcuate defect, and one dot-like loss), and three eyes had normal fields. All eight eyes with PVD, whose kinetic fields normalized during follow-up, showed abnormal static fields. Static perimetry was also performed on 16 patients (32 eyes) with PSD whose initial kinetic fields were normal. Sixteen eyes showed diffuse field loss, one eye showed localized field loss, and 15 eyes had normal fields. In summary, abnormal static visual fields were seen in 82% of patients in the PVD group, and also in 53% of patients in the PSD group even if the kinetic fields were normal. The average mean deviation (MD) of all static fields in the PVD and PSD groups was -6.5 - 3.6 and -3.4 ± 1.8, respectively (Fig. 2). The difference in the average MD between the PVD and the PSD groups was statistically significant ($p<0.001$, Scheffe F test). In the PVD group, the average

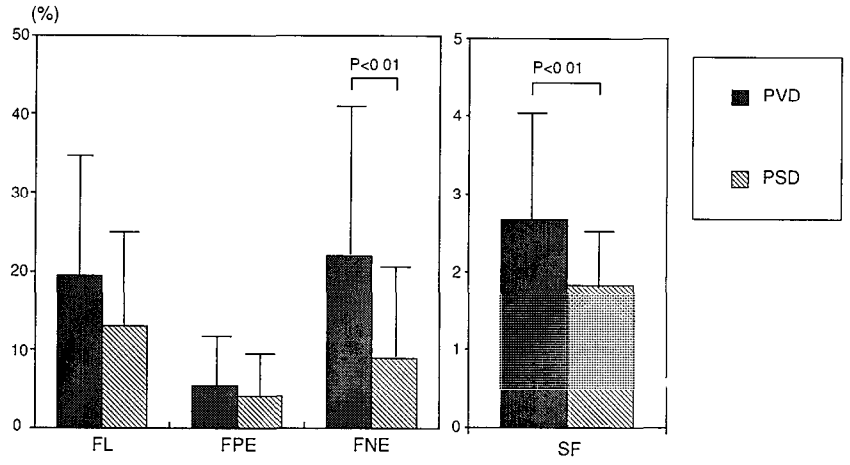

Fig. 3. Averages of reliability indices. The left ordinate represents the mean percentages of FL, FPE, and FNE. The right ordinate represents the mean SF. Averages of FNE and SF were significantly higher in the PVD group than in the PSD group ($p<0.01$, Scheffe F test).

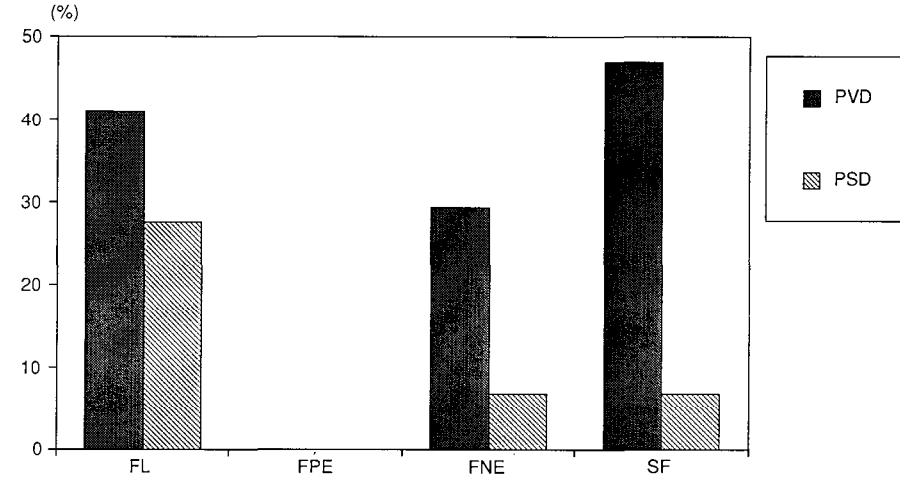

Fig. 4. Percentage of visual fields showing abnormal reliability indices. Percentages of abnormal FNE and SF in the PVD group were much higher than in the PSD group.

MD in those patients who exhibited normal kinetic fields, and in those patients whose fields normalized during follow-up, was -6.3 ± 4.4 and -6.8 ± 2.6, respectively. The difference in average MD here was not statistically significant however.

Mean percentages for various reliability indices on static perimetry in the PVD group were 19.5 ± 15.3% for FL, 5.5 ± 6.8% for FPE, 22.1 ± 19.2% for FNE. These percentages in the PSD group were 13.2 ± 12.4% for FL, 3.9 ± 5.9% for FPE, 8.5 ± 11.9% for FNE. The mean SF is in PVD and PSD groups were 2.6 ± 1.4 and 1.8± 0.7, respectively (Fig. 3). The differences in mean FNE and SF were statistically significant between the two groups ($p<0.01$, Scheffe F test). In the PVD group, the percentages of the static visual fields showing abnormal reliability indices for FL, FPE, FNE, and SF, were 41% (7/17), 0%, 29% (5/17), and 47% (8/17), respectively. In the PSD group, these percentages were 27% (8/32), 0%, 7% (2/32), and 7% (2/32), respectively. Abnormal FPE was not seen in either group. The percentage of the visual fields showing abnormal FL, FNE, or SF, was higher, in each case, in the PVD group than in the PSD group (Fig. 4).

Discussion

The predominance of females in psychogenic visual disorders has been reported by many authors[1-4], ranging from 72% to 79% of patients. In our series, females constituted 71% of patients with PVD, in agreement with those reports. This tendency was not seen in the PSD group.

Slettenberg *et al.*[1] reported that isolated visual acuity loss was the most common finding in PVD (43%), followed by combined visual acuity loss and visual field constriction (37%). Yasuna[3] reported that all 26 children in his study had constricted visual fields on tangent screen testing, mostly of a tubular nature with characteristic constant and steep borders. In contrast, in our series, only 50% of patients with PVD showed abnormal kinetic fields. Seventeen percent of patients had either crossed or irregular isopters, which may also be characteristic of PVD fields. These abnormal visual fields may represent either exhaustion, lack of concentration, or response variability. Despite the same baseline psychological disturbance, only one patient with PSD showed abnormal kinetic fields.

Chronicity of abnormal visual functions in PVD has been reported in several follow-up studies[1,5]. Overall, adult patients tended to continue to have visual dysfunction because of long-standing insoluble emotional conflicts, while children had a better chance of visual recovery because their emotional problems were more amenable to resolution. In our study, although we did not observe patients for long periods, all patients whose kinetic fields normal-

ized during follow-up showed abnormal static fields. This may suggest that their visual dysfunction continued for a longer period than expected.

Kuroiwa[6] reported that, using the Octopus automated static perimeter (program 21), irregular peripheral limits and focal depressions forming a peculiar "flower petal-like" pattern, were seen in all patients who showed constricted or spiral visual fields on Goldmann kinetic perimetry. Yamada and Kono[7] also noted that "polka dot-like" defects displayed on the Humphrey screening program most likely corresponded to spiral kinetic defects. Of 17 static fields in the PVD group in our study, 14 (82%) showed abnormal fields (ten diffuse loss, four localized loss) in the presence of normal kinetic fields. Furthermore, the depression of the fields in the PVD group was in general much more profound than that in the PSD group. Fifty-three percent of static fields in the PSD group were abnormal, indicating that either abnormal visual function in asymptomatic PSD patients is not uncommon, or that the normal values for threshold in the STATPAC are lower than appropriate for our patient population leading to a higher incidence of abnormal findings. We would need to test control subjects for a comparison to resolve this issue.

Regarding response properties in PVD patients, Kuroiwa[6] also reported that sensitivities in the static fields are quite variable with respect to spatial and temporal aspects, and that FNE responses were particularly common, although FPE responses were not. In our study, even when the kinetic fields were normal, the response properties in the static fields showed the same tendency as shown in the cases with abnormal kinetic fields. Compared with the PSD group, a high FNE rate and abnormal SF were more likely to occur in the PVD group, perhaps characteristic of the performance of these patients. In both groups, a high FP rate was not noted despite a high FL rate. This may also represent a paradoxical phenomenon seen in these groups. In conclusion, although PVD and PSD patients possess a similar underlying psychological dysfunction, their performance in visual field testing were quite different.

References

1. Slettenberg O, Bertelsen T, Høvding G: The prognosis of patients with hysterical visual impairment. Acta Ophthalmol 67:159-163, 1989
2. Kathol RG, Cox TA, Corbett JJ et al: Functional visual loss: Follow-up of 42 cases. Arch Ophthalmol 101:729-735, 1983
3 Yasuna ER: Hysterical amblyopia in children. Am J Dis Child 106:558-563, 1963
4. Van Balen ATM, Slijper FEM: Psychogenic amblyopia in children. J Pediatr Ophthalmol Strabismus 15:164-167, 1978
5 Rado RT, Meyer GG, Keltner R: Visual conversion reaction in children and adults. J Nervous Mental Dis 166:580-587, 1978
6. Kuroiwa M: Visual field in psychogenic disorder. Jpn J Ophthalmol 90:68-76, 1986
7 Yamada S, Kono M: Static visual field in psychogenic visual disturbances. Jpn Rev Clin Ophthalmol 83:175-181, 1991

Perimetry in psychogenic visual disturbances

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Abstract

In perimetry performed on children with psychogenic visual disturbances, it has been reported that spiralling fields, concentric contraction and tubular fields are seen. In the present study, normal visual fields were obtained in all cases by Goldmann kinetic perimetry starting from the smallest targets in 11 patients with psychogenic visual disturbances who had shown visual field abnormalities in other hospitals. However, when Humphrey static perimetry was performed on the same day, contradictory results with sporadic scotomas within the range which was clearly seen with kinetic perimetry were obtained. These results differed from the conventional concept, and appear to be one of the characteristics of psychogenic visual disturbances.

Introduction

Psychogenic visual disturbances occur in the form of visual impairment as a physical symptom of the effects of a highly stressful environment in children. Recently, these disturbances have tended to increase[1].

Children with psychogenic visual disturbances are known to show abnormalities in various ophthalmological examinations. In visual acuity examinations, normal visual acuity has been reported with the suggestive therapeutics method and lens neutralization method, and there have also been reports of spiralling fields and concentric contraction in kinetic perimetry and tubular fields in campimetry[2].

In the present study, normal visual fields were obtained in all cases when measurements were made by the smallest target which could be confirmed in kinetic perimetry in patients with psychogenic visual disturbances who had shown visual field abnormalities at other hospitals[3].

However, when the same patients were examined using a Humphrey Field Analyzer, contradictory results with sporadic scotomas within the same area clearly seen with kinetic perimetry were obtained. These examination results were completely different from what was expected, and they are considered to be one of the characteristics of the psychogenic visual disturbances reported here.

Subjects and methods

Among 127 cases of suspected psychogenic visual disturbances (33 males and 94 females) seen at the Department of Ophthalmology, Kobe University, during a period of seven years and seven months from June 1984 to January 1992, 53 cases (15 males and 38 females) in whom perimetry could be performed were used as subjects.

Perimetry was performed using a Goldmann perimeter, but the measurements were not made from the usual V-4 target. The measurements were made using gradually larger targets starting from the smallest target (I-1, if possible) which could be confirmed visually. In some of the subjects, examinations using a Humphrey Field Analyzer perimeter were also performed.

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Results

Age

As shown in Table 1, the age range was from six to 22 years.

Table 1. Patients with psychogenic visual disturbances capable of perimetry

Age	*Male*	*Female*	*Total*
6	1	1	2
7	2	8	10
8	4	4	8
9	2	4	6
10	1	5	6
11	0	3	3
12	1	1	2
13	1	3	4
14	1	2	3
15	1	2	3
16	0	1	1
17	0	1	1
18	1	1	2
19-	0	2	2
Total	15	38	53

Initial visual acuity

Discrepancies from hand movement to 1.0 were seen, but the visual acuity improved to 1.0 as measured by suggestive therapeutics or the plano-lens method in 34 cases (64%) on the same day.

Visual field

Normal visual fields were detected in all 53 subjects by Goldmann perimetry. Abnormal visual fields were found in 11 of 12 cases who had undergone perimetry at other hospitals, but these cases all showed normal visual fields when they were re-examined at the authors' department. However, sporadic scotomas were found with Humphrey automated perimetry even in cases showing normal results with Goldmann perimetry.

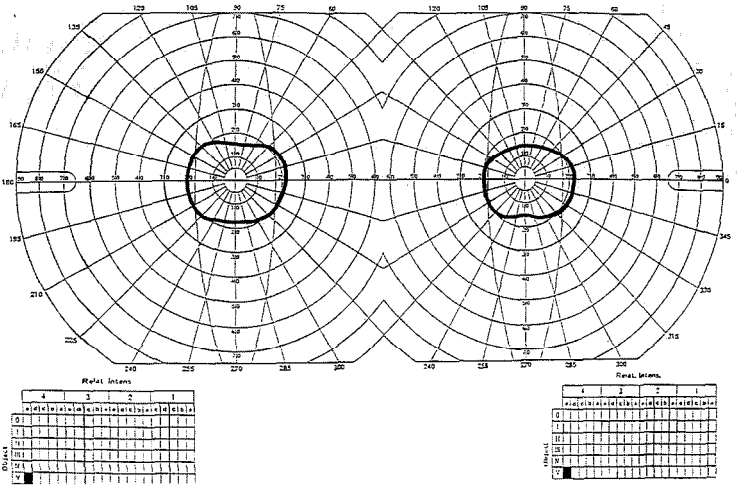

Fig. 1. Perimetry of case 1 performed at another hospital.

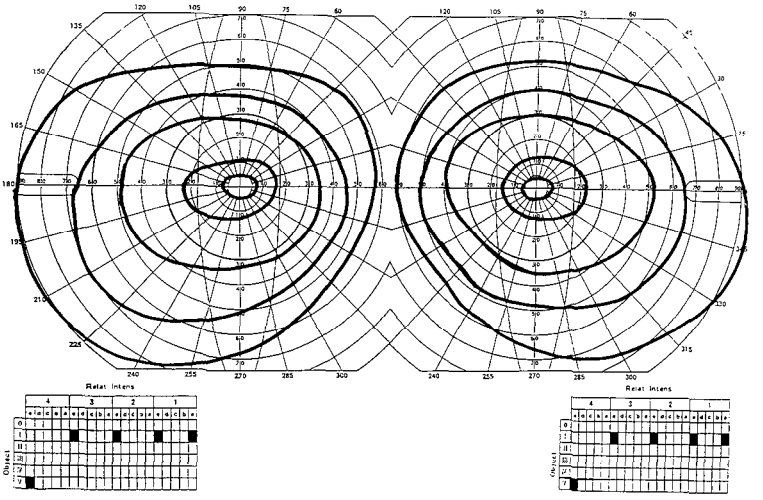

Fig. 2. Goldmann perimetry of case 1 performed at our department.

Case reports

The following are reports of two typical cases:

Case 1: KN, a ten-year-old female

- Chief complaint: visual disturbances.
- Current history: visual disturbances were noted in an examination at school. In an examination by a local doctor, RV = 0.5 (n.c.), LV = 0.5 (n.c.), NRV = 0.1 (n.c.) and NLV = 0.1 (n.c.). ERG was normal. In static and kinetic perimetry, concentric contraction was found (Fig. 1). She was referred to our department for a detailed examination.
- Past and family histories: nothing of note. Among the background factors, the mother worked outside the home and sometimes returned home late at night.
- Visual acuity on initial examination: RV = 0.6 (0.7: ± 3.0 D), NRV = 0.4 (n.c.); LV = 0.7 (0.8: ± 3.0 D), NLV = 0.4 (0.5: + 1.0 D).
- Anterior segment of the eyes, ocular media and ocular fundus: Nothing of note.
- CFF: Right 33-45 Hz and left 35-45 Hz were observed.

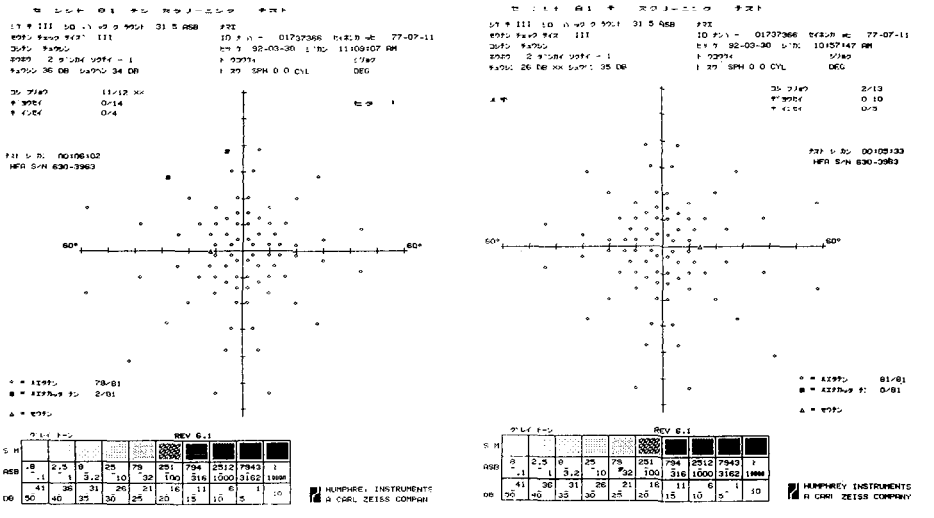

Fig. 3. Humphrey perimetry of case 1.

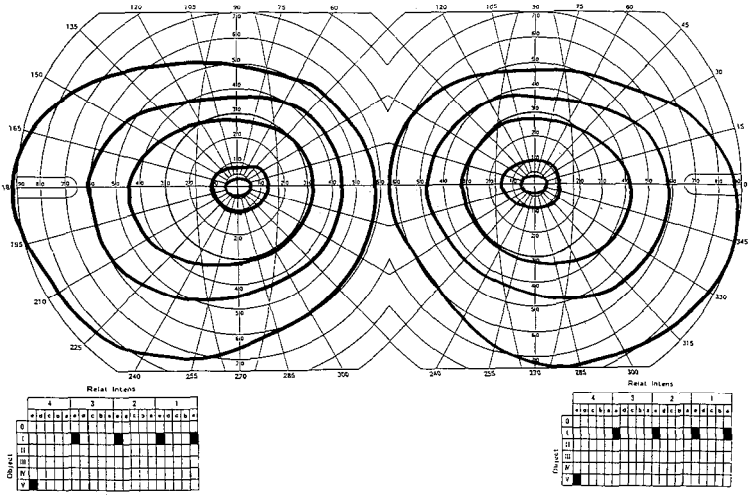

Fig. 4. Goldmann perimetry of case 2 performed at our department.

- Color vision examination: since an abnormality in panel D-15 had been pointed out at another hospital, the Ishihara type color vision examination was performed at our department but the results were normal.
- Goldmann perimetry: the visual field was normal (Fig. 2). When the visual acuity was re-examined after perimetry, RV = 1.0, LV = 1.0, NRV = 1.0 and NLV = 1.0. and both far and near vision were easily improved without suggestive therapy.
- Course: she was examined several times thereafter, but good visual acuity with RV = 1.0 and LV = 1.0 was retained.

Case 2: YT, a ten-year-old female

- Chief complaint: visual disturbances
- Current history: visual disturbances were seen during a visual examination at school. She consulted a doctor, but there was no improvement. RV = 0.1 (0.4: -1.0 D), LV = 0.1 (0.3: -1.5× +cyl. 0.5 D A180°). She was referred to our department.
- Past and family histories: nothing of note. Among her background factors, her family had moved away from near her grandmother's house. Her grandmother was very fond of her.

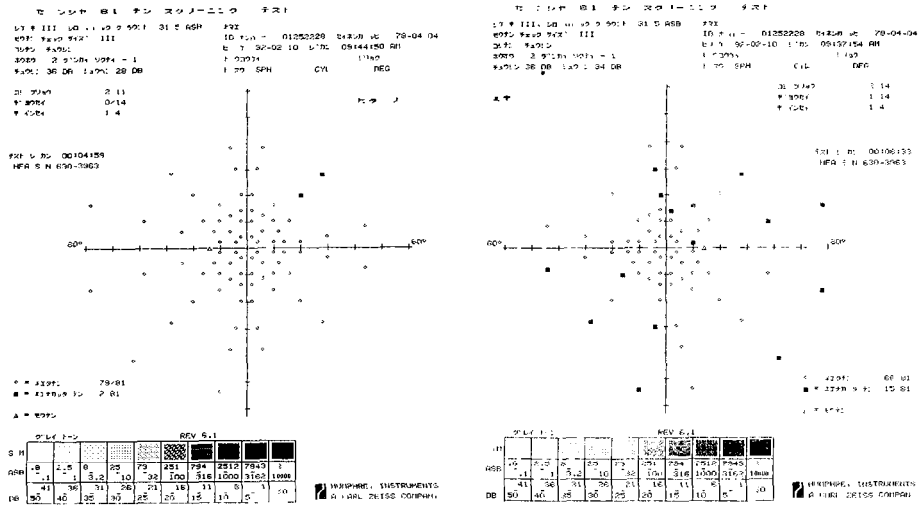

Fig. 5. Humphrey perimetry of case 2.

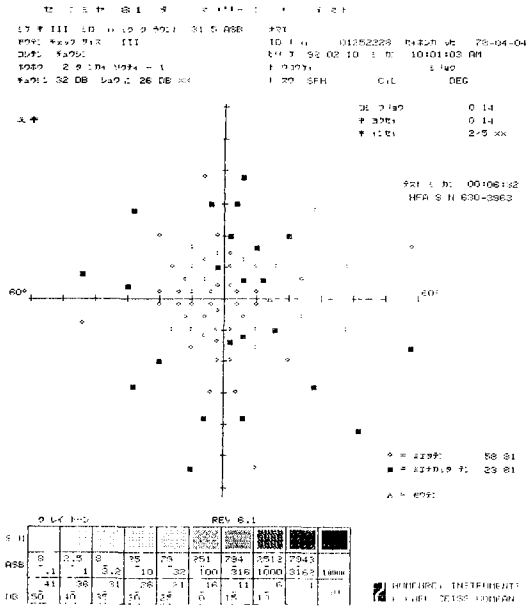

Fig. 6. Second examination of the right eye with Humphrey perimetry (case 2)

- Visual acuity: RV = 0.3 (1.0: -1.5 D), LV = 0.3 (1.0: -2.0 D).
- Visual field: with Goldmann kinetic perimetry, a normal visual field was obtained (Fig. 4). However, with Humphrey perimetry, scotomas were seen at many sites in the right eye and at two sites in the left eye within the range which was clearly seen with Goldmann perimetry (Figs. 5 and 6).

Discussion

When perimetry is performed in cases of psychogenic visual disturbances, characteristic spiralling fields, concentric contraction and tubular fields have been found. However, since these visual fields are also seen in mental and organic diseases, it is necessary to perform diagnosis by exclusion for cases which are not psychogenic.

Psychogenic visual disturbances are diagnosed on the basis of frequent contradictions since the results of each visual examination are apt to change; the lack of any objective findings matching the examination results; and the fact that the cause of the disturbance is found in the patient's family or environment.

It has long been considered that the mechanism of onset of psychogenic visual disturbances involves the appearance of concentric contraction and spiralling fields based on a complex mixture of factors such as problems related to the intensity of the test light, time and the spatial arrangement in kinetic perimetry, as well as psychological factors including anticipation, intention and fatigue[4].

The results of our examinations in the present study showed normal kinetic visual fields in all 11 cases where abnormal fields had been detected at other hospitals. Therefore, the factors which affect the results of perimetry include not only the patients' problems, but also various problems related to the examiners. Consideration must be given to the elimination of psychogenic factors, and it is important to form a better rapport with the patients. It is also important to devise a suitable method of examination. When evaluation was difficult in these patients using a perimetry method starting with the usual large targets, perimetry was performed starting from the smallest target which the patient could confirm visually and gradually making the targets easier to see. With this method, it is important to have a rapport with the patients and to perform the measurements diligently.

In some cases, Humphrey automatic perimetry was performed, but sporadic scotomas were

observed with Humphrey perimetry even in cases where normal results were obtained with Goldmann perimetry performed on the same day. These contradictory results are considered to be characteristic of psychogenic disorders. With Goldmann perimetry, the examination is performed on a 1:1 basis between the patient and the examiner, communication being maintained with the patient throughout the examination, but in automatic perimetry, good results are not obtained because the relation is limited to that between the patient and a machine. Kuroiwa[4] reported that wreath-shaped fields appeared with Octopus perimetry in cases of psychogenic visual disturbances, and Yamade and Kono found abnormalities with sporadic scotomas in 12 of 16 cases of static perimetry[5]. These results were similar to those obtained in the present study.

References

1. Oguchi Y: Psychogenic visual disturbances in school children. Ophthalmology (Japanese) 26:139-145, 1984
2. Harrington DO: The Visual Fields. St Louis: CV Mosby Co 1964
3. Suda K, Mori Y, Shirabe H, Ohike M, Yamamoto M: Visual fields of psychogenic visual disturbances Jpn Orthoped J 20:151-158, 1992
4. Kuroiwa M: Visual field in psychogenic disorder. Acta Soc Ophthalmol Jpn 90:1490-1498, 1986
5 Yamade S, Kono M: Static visual field in psychogenic visual disturbances. J Clin Pract 85:1245-1251, 1991

Perimetric and fluorescein angiographic findings in carotid artery obstructive disease

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Abstract

Thirty-four patients with carotid stenosis, recruited from a vascular surgery ward, were studied by fluorescein angiography and visual field examination. Arm-retina time and artero-venous passage time are stressed. Two particular unreported fluorescein signs were noted. Light sensitivity reduction was the main visual field defect observed.

Introduction

Ocular signs and/or symptoms in obstructive disease of the carotid circle are referred to in the literature as having a frequency of between 40% and 88%[1,2].

Although a carotid stenosis larger than 50% is already considered to be hemodynamically significant, appreciable ocular complications nearly always occur in much larger stenoses (80-90%)[3].

Apart from the degree of stenosis, the ocular picture is influenced by embolization of the atheromatic plaque and formation of a more or less effective compensatory circle[4,5].

The ocular patterns relating to an obstructive pathology of the carotid artery may be acute: amaurosis fugax, occlusion of the central artery of the retina or of one of its branches; or chronic: chronic ischemic retinopathy (CIR) and ocular ischemic syndrome (OIS)[3,6,7].

This study aims at assessing the changes of the chorioretinal circle in the obstructive pathology of the carotid artery on the basis of fluorescein angiography and visual field examinations.

Material and methods

We studied 34 consecutive patients (23 males and 11 females aged from 56 to 78 years, mean 69.5 years) hospitalized at the Vascular Surgery Clinic of the University of Genoa between December 1989 and February 1992. Patients were considered for inclusion in the study if a lesion of the wall at echo-doppler ultrasonography examination of the supraoptic vessels (SAV) was documented (Fig. 1). The severity of carotid stenosis was defined to be significant when it was ≥80%.

At the Retina Service of the Eye Clinic of the University of Genoa, each patient underwent a routine ophthalmological examination, dilated fundus biomicroscopy, fluorescein angiography and visual field examination in both eyes. Patients presenting with media opacities, glaucoma and historically important cerebrovascular diseases were excluded from the study.

Fluorescein angiography: in view of the age and the cardio-circulatory characteristics of the patients, we considered arm-retina times greater than 20 seconds as being significant. For choroidal and retinal arteriovenous filling times we considered >10 and >15 seconds, respectively, as being pathologic. We did not carry out evaluations of retinal arteriovenous passage times in the two patients who presented with an occlusion of the central artery of the retina.

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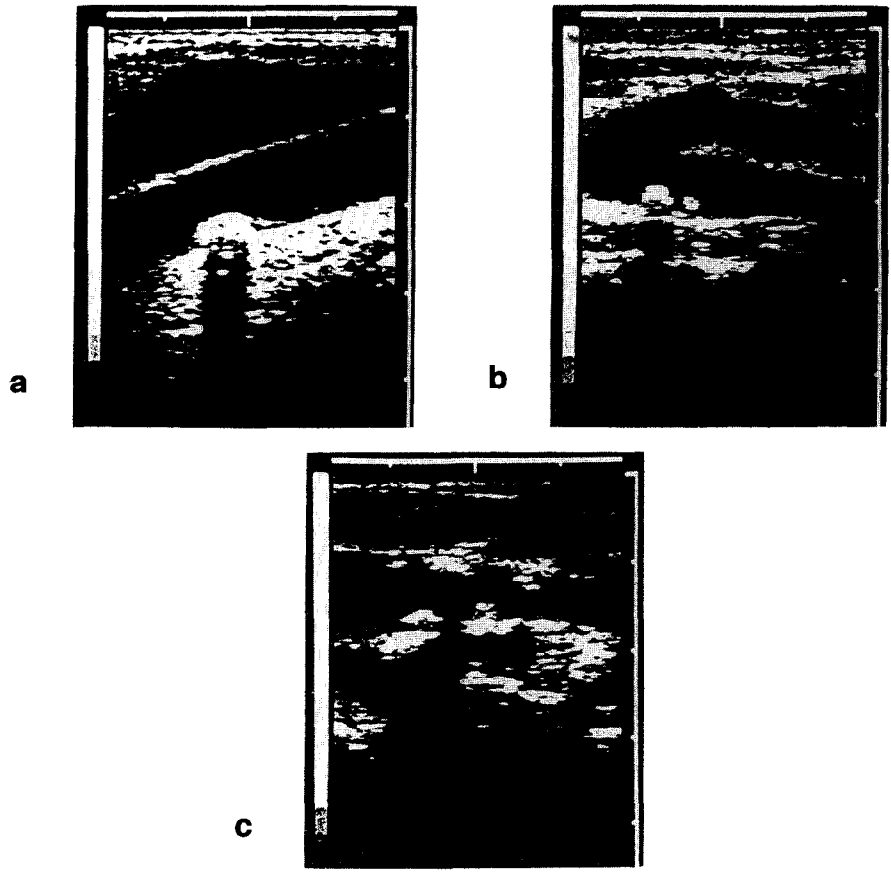

Fig. 1a. Common carotid artery. Fibrocalcific plaque on the posterior wall (cone of shadow), slightly stenosing, with a smooth surface. *b.* Carotid bifurcation. Two small fibrocalcific plaques on the posterior wall of the internal carotid artery. *c.* Internal carotid artery. Marked stenosis for the presence of fibrocalcific, non-homogenous plaques with irregular surface.

When an occlusion of an arterial branch was present, the assessment was carried out on those parts of the retinal circle which were not occluded; in the same way, we did not consider the corresponding part of the visual field in the perimetric evaluation.

The visual field was examined either by computerized perimetry using the Perikon PCL90 perimeter with the DS/K program, which explores the peripheral visual field by the kinetic method and the central area by the threshold static method, with a pattern analogous to that of the central 30-2 Humphrey program; or by manual kinetic Goldmann perimetry. The perimetrist was unaware of the diagnosis.

In all patients data of fluorescein angiography and perimetry changes referred to the eye ipsilateral to the carotid stenosis of greater severity, even though they were not hemodynamically significant. The data of the contralateral eye were only recorded but not evaluated.

Statistical analysis was carried out using Fisher's exact test.

Results

Tables 1 and 2 analytically show the overall observations found in the patients studied, as well as the incidence of the various ocular signs in relationship to the presence of a significant or not significant carotid stenosis. In 22 (64.7%) of the 34 patients studied, the stenosis was

hemodynamically significant, and in 12 (35.3%) it was not significant. Considering our cases as a whole, chorioretinal circulatory changes were present in 76.4%. If we consider only the hemodynamically significant obstructions, these changes were present in 90.9% of the patients. For each of the ocular signs considered, we then calculated the significance level with respect to the two grades of stenosis. In this way, only the increase in arm-retina time and especially the increase of arteriovenous passage time were found to be significantly correlated to the carotid stenosis. Table 3 shows the data of the visual field examination.

Table 1.

Signs and symptoms considered	*Carotid stenosis >80% (22 cases)*	*Carotid stenosis <80% (12 cases)*
Amaurosis fugax	54.5%	50%
Arm-retina time increase	54 5%	-
Arteriovenous passage time increase	63.6%	-
Choroidal filling delay	63.6%	33.3%
Retinal arterial occlusion	27.2%	33.3%
Ocular ischemic syndrome	9.1%	-
Papillary staining	27.2%	-
Choriocapillaris atrophy	18.2%	16.6%
Perimetric defects	100%	33.3%

Table 2.

Signs and symptoms considered	*Carotid stenosis >80% (22 cases)*	*Carotid stenosis <80% (12 cases)*	*P**
Amaurosis fugax	12	6	0.569
Arm-retina time increase	12	0	0.01409266
Arteriovenous passage time increase	14	0	0.0078709
Choroidal filling delay	14	4	0.2589724
Chronic ischemic retinopathy	0	0	0 9999999
Retinal arterial occlusion	6	4	0.5326285
Ocular ischemic syndrome	2	0	0 4380951
Papillary staining	6	0	0.09815078
Choriocapillaris atrophy	4	2	0 6543385
Perimetric defects	22	4	0 07428395

*Fisher's exact test

Table 3.

Perimetric defects	*Carotid stenosis >80% (22 cases)*		*Carotid stenosis <80% (12 cases)*		*P**
Light sensitivity reduction	18	(81.8%)	2	(16.6%)	0.03825105
Nerve fiber bundle defect	9	(40.9%)	2	(16 6%)	0.2502483
Quadrantanopia	1	(4.5%)	0		0.6571428
Homonymous hemianopia	2	(9.1%)	2	(16.6%)	0.4721669

*Fisher's exact test

Discussion

In other studies the conditions of the chorioretinal circle were assessed above all in patients with severe stenosis of the carotid artery[3,8]. However, we also considered cases in which the carotid hemodynamic defect was moderate. In spite of this, the percentage of changes of the chorioretinal circle observed by us was similar to that found in preceding studies[3,9].

The degree of chorioretinal changes seen in our study was found to be, on the whole, less

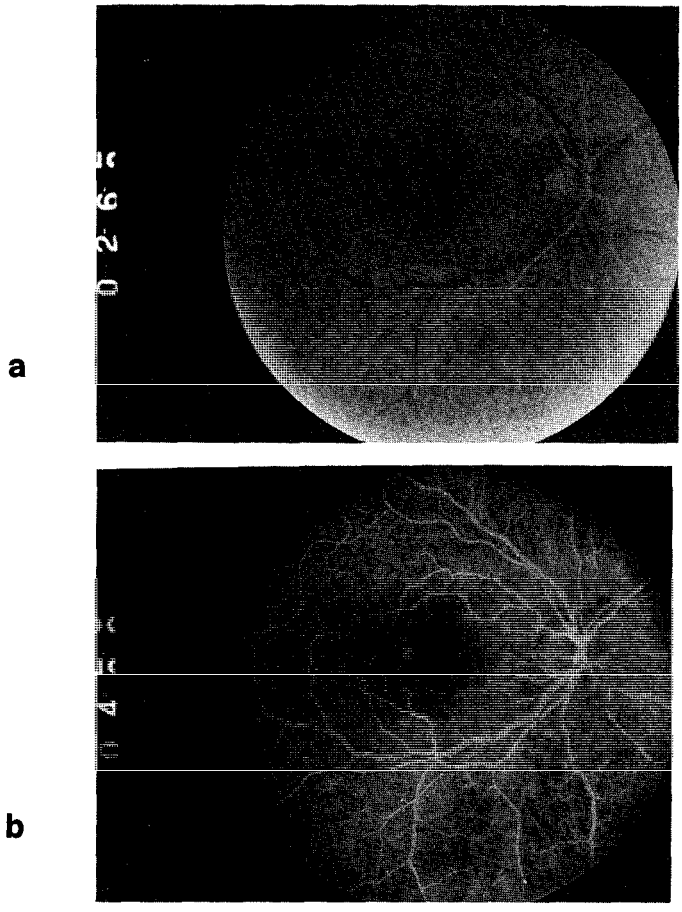

Fig. 2. Sixteen seconds after arterial filling, venous filling still has to be completed.

severe than that reported in other studies; this is probably due to the different manner of recruitment of patients, which, in our case, took place in a vascular surgery clinic and not in an eye clinic.

In accordance with data from the literature, the fluorescein angiographic finding we observed most frequently was the increase in retinal arteriovenous passage time (10″) (Fig. 2). We believe it to be noteworthy that this sign was present, and in a fairly high percentage (63.6%), only in the hemodynamically significant carotid stenoses.

As far as the increase in arm-retina time is concerned, we agree with those authors who consider this difficult to assess, since it is much influenced by factors of the general circulation. However, we found it in half the cases (54.5%) with significant stenosis.

Delayed choroidal filling was observed in both groups of significant and not significant obstruction (63.6% and 33.3%, respectively), with a greater percentage with regard to that reported in the literature.

The incidence of retinal arterial occlusions is too low to be able to correlate it with the severity of carotid stenosis; one can, rather, consider this retinal occlusion to be in relation to the tendency that an atheromatous plaque of the carotid artery has to ulcerate and produce emboli[11]. Of great interest are today's possibilities of diagnosis with echo-doppler ultrasonography for assessing the embolic potential of the carotid atheroma[12,13].

The optic disc staining, which we and other authors observed in only a few cases of significant carotid stenosis (27.2%), is a fluorescein angiographic finding not easily interpretable[3,14,15]. In six of the cases we studied, the consequences of occlusion of the central artery

of the retina were present with a subatrophic optic disc; in these cases, optic disc impregnation may be related to a diffusion of the staining from the ciliary circle of the optic disc. Instead, in four other cases, there were focal areas of diffusion from the superficial capillaries of the optic disc.

The presence of areas of atrophy of the choriocapillaris and of the pigment epithelium is a finding which has not previously been reported and which we observed in six cases. It could be the result of a prolonged ischemic process of the choroid: the final stage of those perfusion defects of the choroid was seen as a slowing of choriocapillary filling.

The most frequent perimetric change (58.8%) observed by us was a reduction of light sensitivity which also involves the areas spared by the localized defects. This finding, however, was not correlated either to the presence of carotid stenosis or to the severity of the stenosis ≥80%.

The frequency of light sensitivity reduction is at least in part related to the fluorescein angiography observation of a significant increase in retinal arteriovenous passage time and suggests the possibility of functional suffering of the retina on an ischemic basis, but also of the optic tracts and of the cerebral cortex.

The presence of nerve fiber bundle defects, always related to a reduction of light sensitivity, occurred less frequently in our study group; in these cases, with fluorescein angiography, we were not able to show changes of the chorioretinal circle corresponding topographically to the

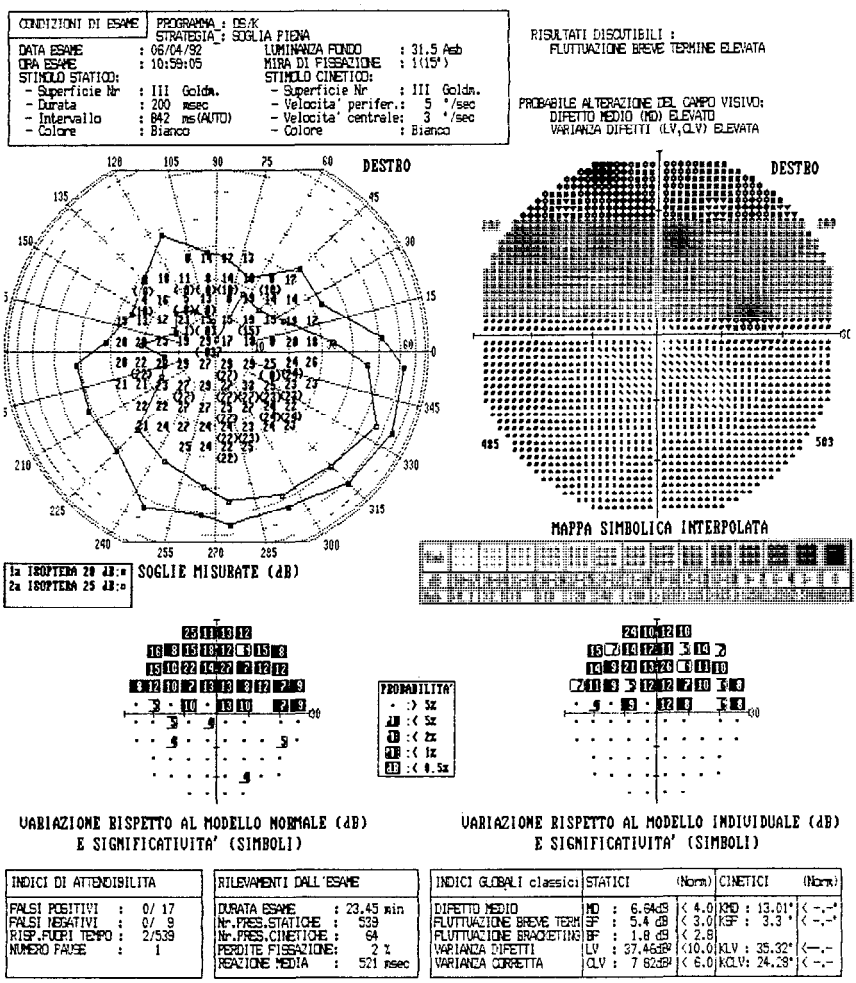

Fig. 3. Monocular pronounced light sensitivity decrease in the superior hemifield associated with isopter contraction in a case with no fluorescein angiography signs of optic disc ischemia.

visual field defect. According to most authors, perimetric fiber damage may be the result of microemboli in the retinal circle or disseminated along the optic tracts[16]. It is, however, possible that micro-occlusions of the ciliary arteries at the level of the optic disc may be involved in visual field defects rather than prolonged or chronic ischemia[17]. In our series, visual field defects of homonymous hemianopic type were, in all cases, related to concentric contraction of the peripheral isopters of the surviving hemifield, showing the presence of unsuspected chronic ischemic damage, in the absence of a history of acute cerebrovascular pathology[18] (Fig. 3). On fluorescein angiography we observed, together with the hemianopia, slowing of choroidal or retinal circle filling times. The areas of the visual field corresponding to those of the retina which had acute ischemic phenomena, and characterized by absolute scotomas of different morphology, were not considered in our evaluation.

Conclusions

Our study confirms the frequency of the consequences of carotid circulatory insufficiency on the chorioretinal circle, in which hemodynamic changes were not necessarily related to severe carotid obstructions. Therefore, just as the finding of typical ocular patterns indicates an obstructive pathology of the carotid artery and necessitates further diagnostic procedures, in all cases of hemodynamic changes of the carotid, even if moderate, it may be useful to carry out an ophthalmological evaluation. Our observations show that fluorescein angiography is particularly sensitive in finding initial chorioretinal hemodynamic changes, and also irreversible lesions, which are hardly visible with simple ophthalmoscopy. Furthermore, the greater incidence of visual field defects, which was represented especially by an overall reduction of light sensitivity in patients who had a carotid stenosis of >80% also confirms the influence of this chronic vascular pathology on retinal light sensitivity measured by perimetry.

References

1. Fisher CM: Observation of the fundus oculi in transient monocular blindness. Neurology 9:333, 1959
2. Hayreh SS: Central retinal vein occlusion: differential diagnosis and management Trans Am Acad Ophthalmol Otolaryngol 83:379, 1977
3. Kahn M, Green R, Knox DL, Miller NR: Ocular features of carotid occlusive disease. Retina 6:239, 1986
4. Hollenhorst RW: Ocular manifestation of insufficiency of thrombosis of the internal carotid artery. Am J Ophthalmol 47:753, 1959
5. Kearns TP, Hollenhorst RW: Venous stasis retinopathy of occlusive disease of the carotid artery. Proc Staff Meet Mayo Clin 38:304, 1963
6. Kearns TP: Ophthalmology and carotid artery. Am J Ophthalmol 88:714, 1979
7. Frovig AG: Bilateral obliteration of the common carotid artery. Acta Psychiat Neurol (Suppl) 39: 1946
8. Sanborn GE, Magargal LE: Carotid artery disease and the eye. In: Duane TD, Jeager EA (eds) Clinical Ophthalmology, Vol 3. Philadelphia: Harper and Row 1985
9. Borgia L, Zinicola E, Cardillo Piccolino F, Allegri P, Lucertini G, Cariati P: Studio fluoroangiografico del circolo corioretinico in patologia ostruttiva della carotide. Boll Ocul (Suppl 4) 71:457-464, 1992
10. Ridley M, Walker P, Heller A et al: Ocular perfusion in carotid artery disease. Am Acad Ophthalmol New Orleans 1986
11. Kuntz S, Chaine G: Pathologies oculaires liées aux stenoses et aux occlusions carotidiennes. J Fr Ophtalmol 14:407-414, 1991
12. Arruga J, Sanders MD: Ophthalmologic findings in 70 patients with evidence of retinal embolism. Ophthalmology 1336-1337, 1982
13. Liboni A, Zamboni P: La Carotide Extracranica: Patologia e Chirurgia. Lainate (MI): Parke Davis 1990
14. Sarkies NSC, Shilling JS, Russel RWR: Fluorescein angiography in carotid disease. Trans Ophthalmol Soc UK 105-489, 1986
15. Brown GC, Magargal LE: The ocular ischemic syndrome. Int Ophthalmol 11:239, 1988
16. Abela BM, Felke P, Krakau CET, Lindgarde F: Evaluation of the visual fields in patients with clinically-diagnosed transient ischemic attacks and minor stroke from the carotid artery territory. In: Mills RP, Heijl A (eds) Perimetry Update 1990/1991, p 127. Amsterdam: Kugler Publ 1991
17. Heckenlively JR, Yee RD, Krauss HR et al: Visual physiologic and ocular evaluation in carotid occlusive disease. Doc Ophthalmol Proc Ser 27:131-138, 1981
18 Marmion VJ: Amaurosis fugax and visual field loss. In: Heijl A (ed) Perimetry update 1988/89, pp 143-150. Amsterdam: Kugler Publ 1989

Primary empty sella syndrome with visual field defect

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Introduction

There are several reports[1-4] that patients with primary empty sella syndrome (PESS) sometimes show many patterns of visual field defects (VFD) including bitemporal hemianopsia, irregular defect, and glaucoma-like VFD. But the complete explanation of VFD in patients with PESS is not defined. In this study, we evaluated visual fields and optic disc appearances in 16 eyes of eight cases with PESS and also MRI of optic chiasma and optic nerve was performed.

Methods

The subjects were eight cases with PESS. Sex ratio was 3:5 (male:female). Their ages ranged from 44 to 75 years. Intraocular pressure, visual field, and optic disc appearance were examined ophthalmologically. The diagnosis of PESS was made by MRI findings.

Radiological characteristics of empty sella in MRI are as follows: (1) massive intrasellar CSF; (2) pituitary gland lying on the floor of the sella; (3) decrease in thickness of the pituitary gland; (4) straight and stretched pituitary stalk in the sella; and (5) enlarged sella turcica.

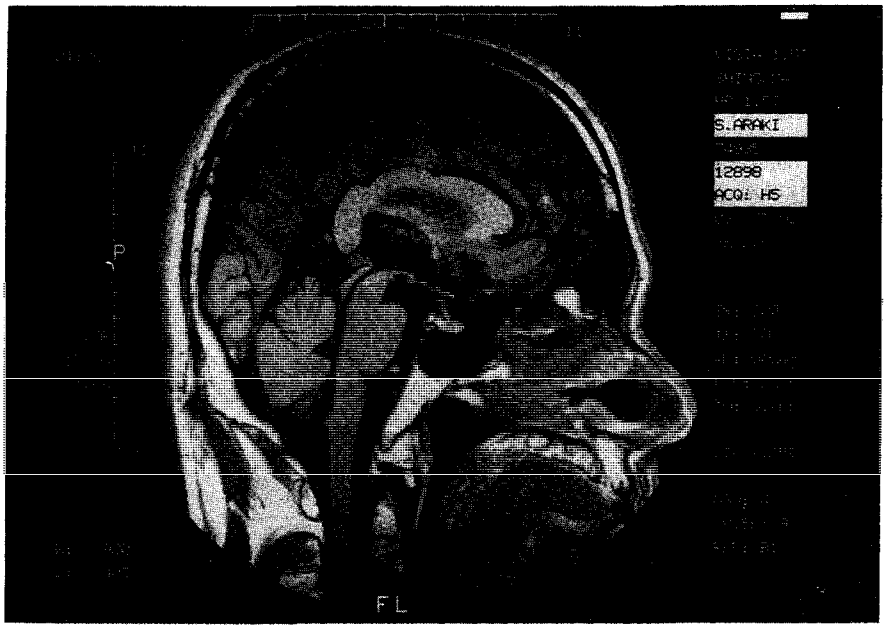

Fig. 1. Magnetic resonance imaging (MRI).

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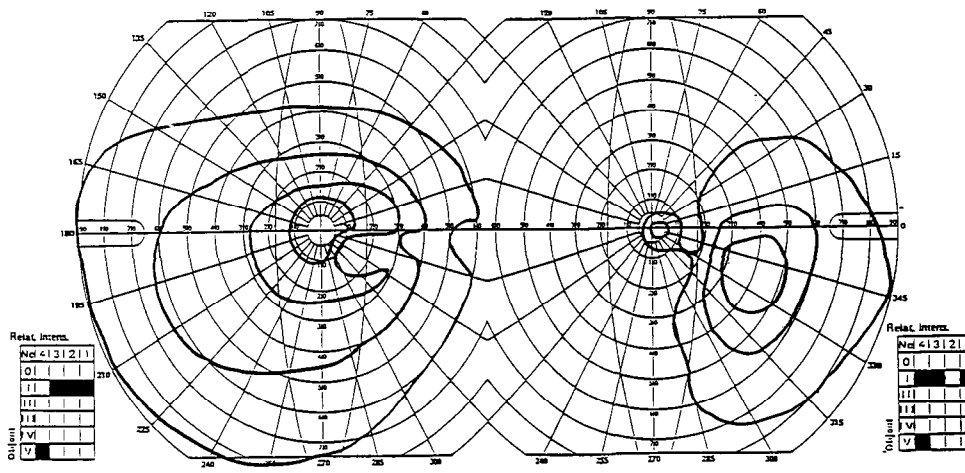

Fig. 2. Goldmann perimetry.

Results

Case report: A 60-year-old man complained of headache and visual blurring of a few years' duration. On admission he was noted to have optic disc atrophy in the right eye without other neurological signs. The anterior segments of both eyes were normal on slit-lamp examination except for incipient cataract. MRI study (Fig. 1) showed an empty sella. Goldmann perimetry (Fig. 2) showed glaucoma-like VFD. Diurnal IOP did not exceed 21 mmHg. A follow-up MRI showed no change in sella size or shape. The summary of eight cases with PESS is listed in Table 1. Fifty percent of cases showed VFD including glaucoma-like VFD, irregular VFD, and bitemporal hemianopsia. The distribution of patterns of VFD is shown in Fig. 3. No abnormalities and deviations were observed with the optic nerve and chiasma in four patients. In the other patients we could not detect the details.

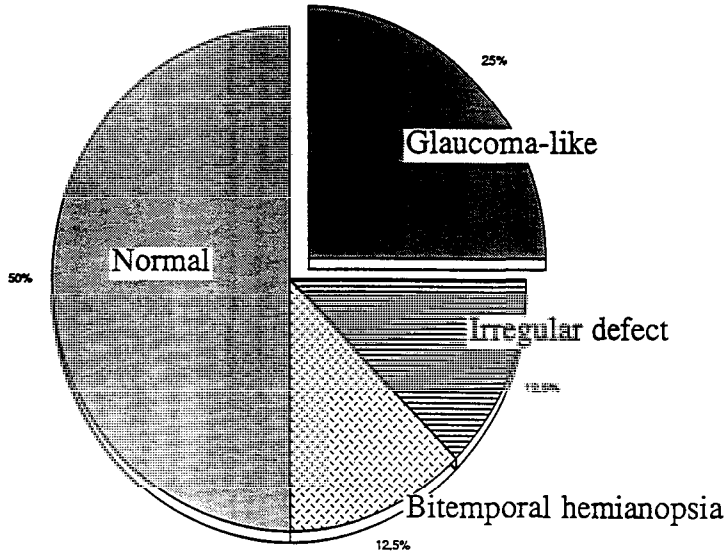

Fig. 3. Distribution of patterns of VFD.

Table 1. Results

Case	*Age*	*Sex*	*Visual Field*	*MRI of the optic nerve and chiasma*
1*	60	M	glaucoma-like	no abnormality
2*	73	F	glaucoma-like	no abnormality
3	67	F	irregular defect	detail unknown
4	58	M	bitemporal hemianopsia	detail unknown
5	68	M	normal	detail unknown
6	44	F	normal	no abnormality
7	75	F	normal	no abnormality
8	74	F	normal	detail unknown

* Diurnal IOP did not exceed 21 mmHg

Discussion

Possible mechanisms for VFD in patients with PESS are thought to be as follows: (1) mechanical damage; (2) blood supply deficiency; and (3) arachnoiditis. There are two hypothetical mechanisms for glaucoma-like VFD in patients with PESS.

1. Axoplasmic flow may be disturbed under various conditions like compression, blood supply deficiency, and inflammation of the optic nerve induced by empty sella, and it may produce an optic disc appearance consistent with glaucomatous optic disc change[5].
2. The deviation of the optic nerve and chiasma and the attrition of the nervous axonal tissue may cause a negative pressure in the optic nerve sheath, which may have the same stretching results as a rise of intraocular pressure[6].

Since the anatomical abnormality of the optic nerve and chiasm were not observed in our two cases with glaucoma-like VFD, the results did not support the mechanical damage theory of the optic nerve in PESS. Although the co-existence of an intracranial lesion and a glaucoma-like optic disc appearance may not be by chance, the complete explanation for this co-existence is yet to be found. We are inclined to think that the mechanism of glaucoma-like optic disc appearance in our two cases is the same one as in glaucoma. The structural instability of the lamina cribrosa is thought to be one of the most important factors in optic disc change in glaucoma. On the other hand, arachnoidal abnormality or weakness is one of the postulated causes of PESS. The same structural weakness of collagen tissue may explain the co-existence of the two conditions.

References

1. Buckman MT et al: Primary empty sella syndrome with visual field defects. Am J Med 61:124-128, 1976
2. Harri R et al: Co-existence of empty sella syndrome and low tension glaucoma. Acta Ophthalmol 67:367-370, 1989
3. Yamabayashi S et al: A case of low tension glaucoma with primary empty sella. Br J Ophthalmol 72:852-855, 1988
4. Shinoda Y et al: Empty sella syndrome with visual field disturbance. Jpn J Ophthalmol 27:248-254, 1983
5. Neetens A et al: Low tension glaucoma: a presenting sign of the empty sella syndrome. Neuro-Ophthalmology 7:123-131, 1987
6. Koizumi K et al: Two cases of glaucomatous optic disc changes secondary to intra cranial lesions. Jpn J Clin Ophthalmol 44:149-154, 1990

Temporal wedge-shaped visual field defects associated with optic nerve hypoplasia

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Introduction

Temporal wedge-shaped visual field defects associated with sectorial optic nerve hypoplasia is a relatively rare condition[1]. Patients are usually unaware of any defects before examination[1,2]. However, one of the two patients with wedge defects described here noticed a sudden temporal field loss in her left eye. The other case was found to have a temporal defect while being examined for floaters. Temporal wedge defects were unilateral in these two patients. In the contralateral eyes, automated static perimetry revealed sensitivity loss possibly due to subtle hypoplasia of the optic nerve.

Case reports

Case 1

A 20-year-old woman suddenly noticed temporal blurring in her left eye without headache or ocular pain. Her ophthalmologist found a temporal visual field defect in her left eye despite normal visual acuity and normal fundi in both eyes. A computed tomographic scan was normal.

On referral, her visual acuity was RE: 1.2 and LE: 1.2. Refraction was RE: -3.00 D sphere and LE: -3.5 D -0.5 D ×90. Pupillary light reaction and slit-lamp examination were normal in both eyes. Intraocular pressure was RE: 18 mmHg and LE: 16 mmHg. Goldmann perimetry revealed a wedge-shaped visual field defect which broke out temporally from the blind spot in her left eye. Slight depression of the inferior part of the inner isopters was detected in the right eye (Fig. 1). Automated static perimetry revealed a sensitivity loss in the central visual field in addition to the defect in the temporal field in the left eye. In the right eye, diffusely reduced sensitivity in the central visual field was recognized (Fig. 2). Funduscopy of the right eye showed a small and hyperemic optic disc with a blurred margin. The left optic disc was also small with the upper and lower margins blurred. No hemorrhages or exudates were recognized in the fundi. Disc-macula distance to disc diameter ratio (DM/DD) was RE: 3.3 and LE: 3.5. Red-free fundus photographs revealed a nerve fiber layer defect (NFLD) in the nasal portion of the left optic disc. An NFLD was also detected in the upper part of the right optic disc (Fig. 3). Echography of the optic nerve showed no abnormality. MR imaging was normal. Follow-up Goldmann perimetry and automated static perimetry six months after the initial examination showed identical results. Systemic examination showed no abnormal data.

Case 2

A 24-year-old woman consulted her ophthalmologist because of flying flies in the right eye. Fundus examination revealed a slightly elevated, small disc in the right eye. On referral, her corrected visual acuity was RE: 1.5 (-2.25 D sphere), LE: 2.0 (emmetropia). Pupillary light reaction and intraocular pressure were normal in both eyes. Goldmann perimetry revealed a narrow wedge-shaped visual field defect that broke out temporally from the blind spot in her

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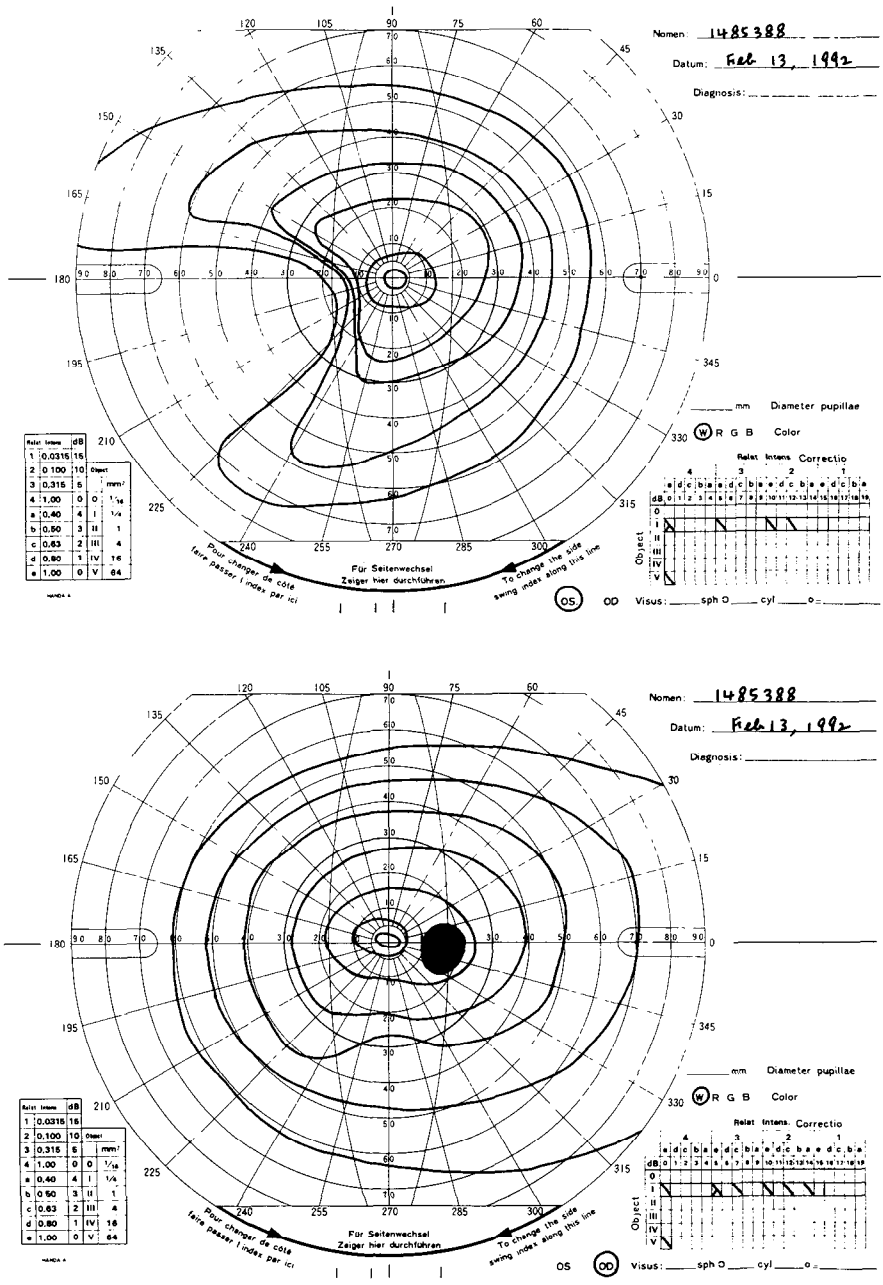

Fig. 1. Unilateral temporal wedge-shaped visual field defect (left eye) Mild depression of the inner isopters of the inferior visual field (right eye).

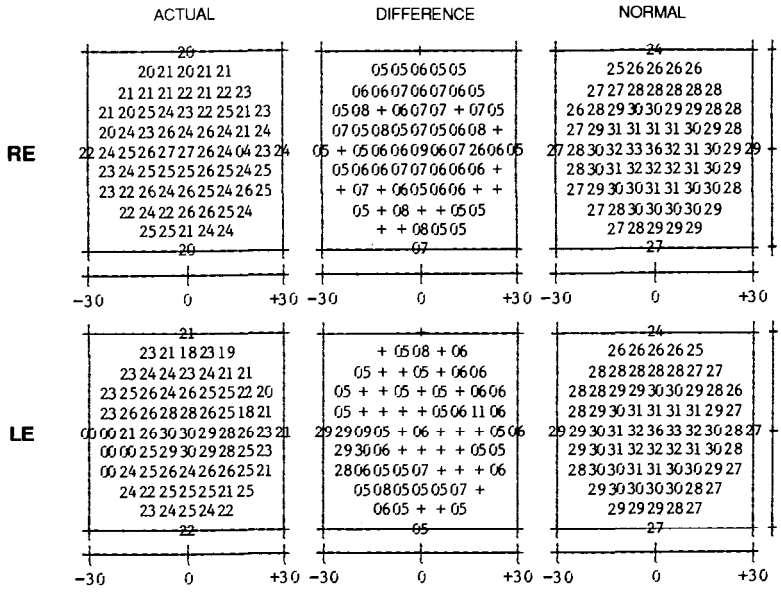

Fig. 2. Octopus program No. 31. Many scattered points are also involved in the right eye.

left eye (Fig. 4). Automated static perimetry revealed sensitivity loss in the central visual field in addition to the defect in the temporal field in the right eye. In the left eye, a loss of sensitivity was also detected (Fig. 5). The right optic disc was small with a white ring. The left optic disc was also small with a blurred margin. DM/DD was RE 4.1 and LE 3.6. Red-free fundus photographs showed NFLD in the nasal sector of the right optic disc (Fig. 6). Echography of the optic nerve was normal. Follow-up visual field examination 15 months later showed identical results.

Discussion

Temporal wedge field defects in these two patients were attributed to nasal hypoplasia of the optic nerve for the following reasons:
1. no progress on repeated perimetry;
2. anomalous morphology of the optic disc;
3. no systemic disorders related to the optic nerve lesion;
4. normal intraocular pressure.

The contralateral eyes in these two patients repeatedly demonstrated loss of sensitivity which was presumably due to subtle hypoplasia of the optic nerve. Automated static perimetry may be useful in detecting subclinical visual field loss in cases with subtle hypoplasia of the optic nerve.

Temporal wedge-shaped visual field defects associated with sectorial optic nerve hypoplasia may be noticed suddenly. Close fundus examination and follow-up perimetry can eliminate unnecessary studies.

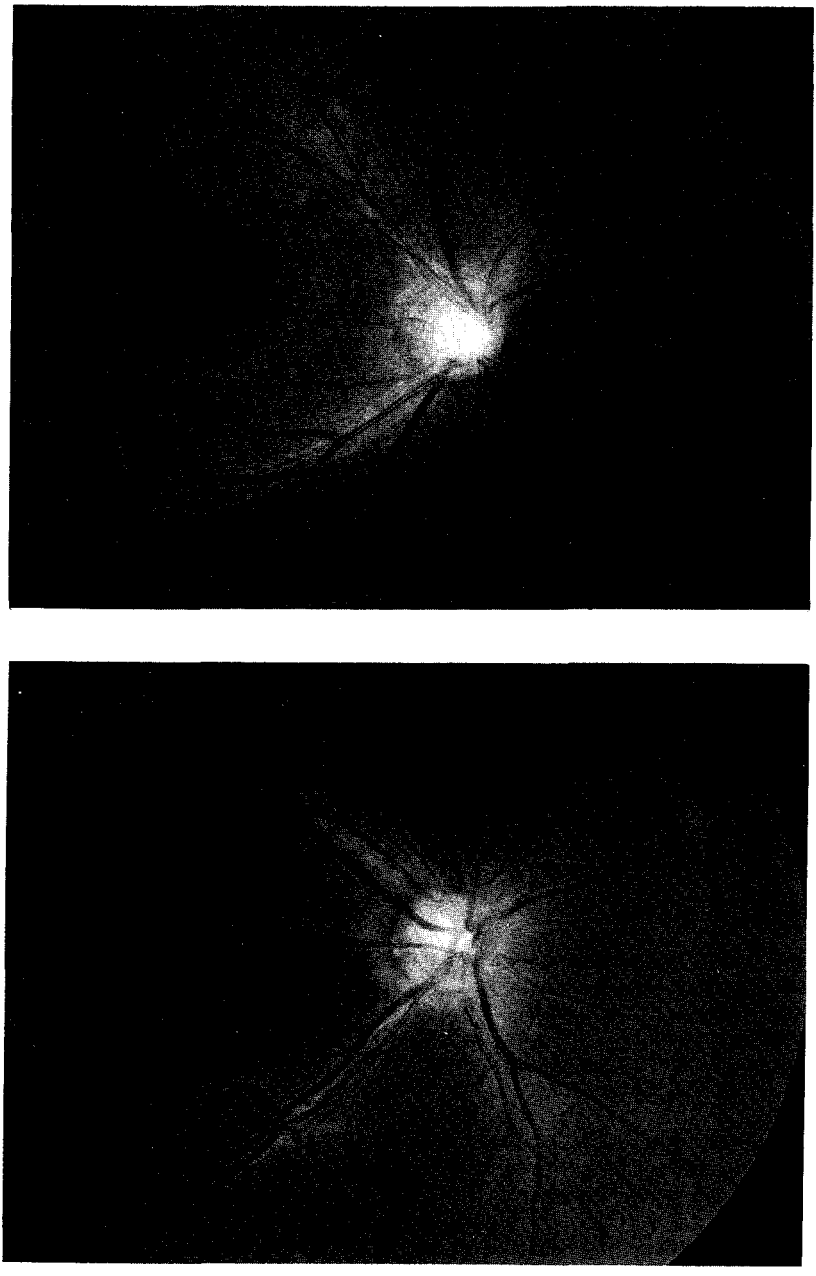

Fig. 3. Red-free fundus photographs showing absence of nerve fiber striations in the nasal peripapillary retina (left eye) Slit-like defect at 11 o'clock (right eye).

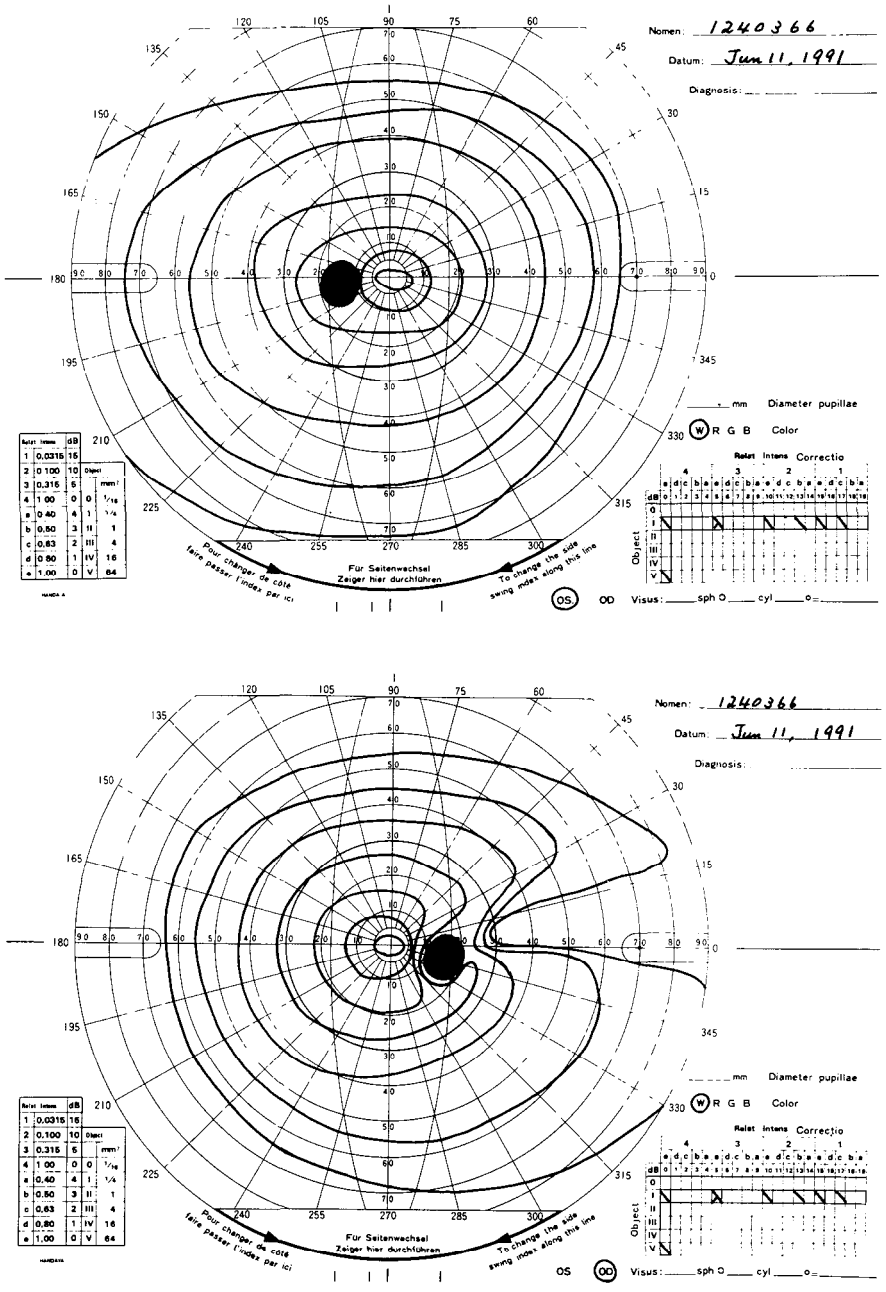

Fig. 4. Unilateral wedge defect in the right eye.

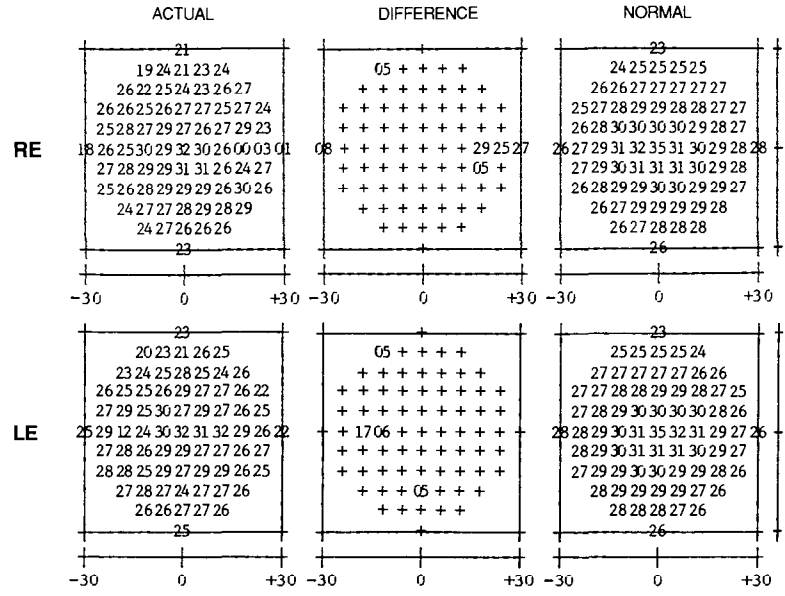

Fig. 5. Two points involved in the "normal" left eye. Fixation was good with no errors.

References

1. Buchanan TAS, Hoyt WF: Temporal visual field defects associated with nasal hypoplasia of the optic disc. Br J Ophthalmol 65:636-640, 1981.
2. Namba T, Wakakura M, Shirakawa S, Ishikawa S: Sectorial hypoplasia of the optic nerve. Neuro-Ophthalmol Jpn 4:444-450, 1987

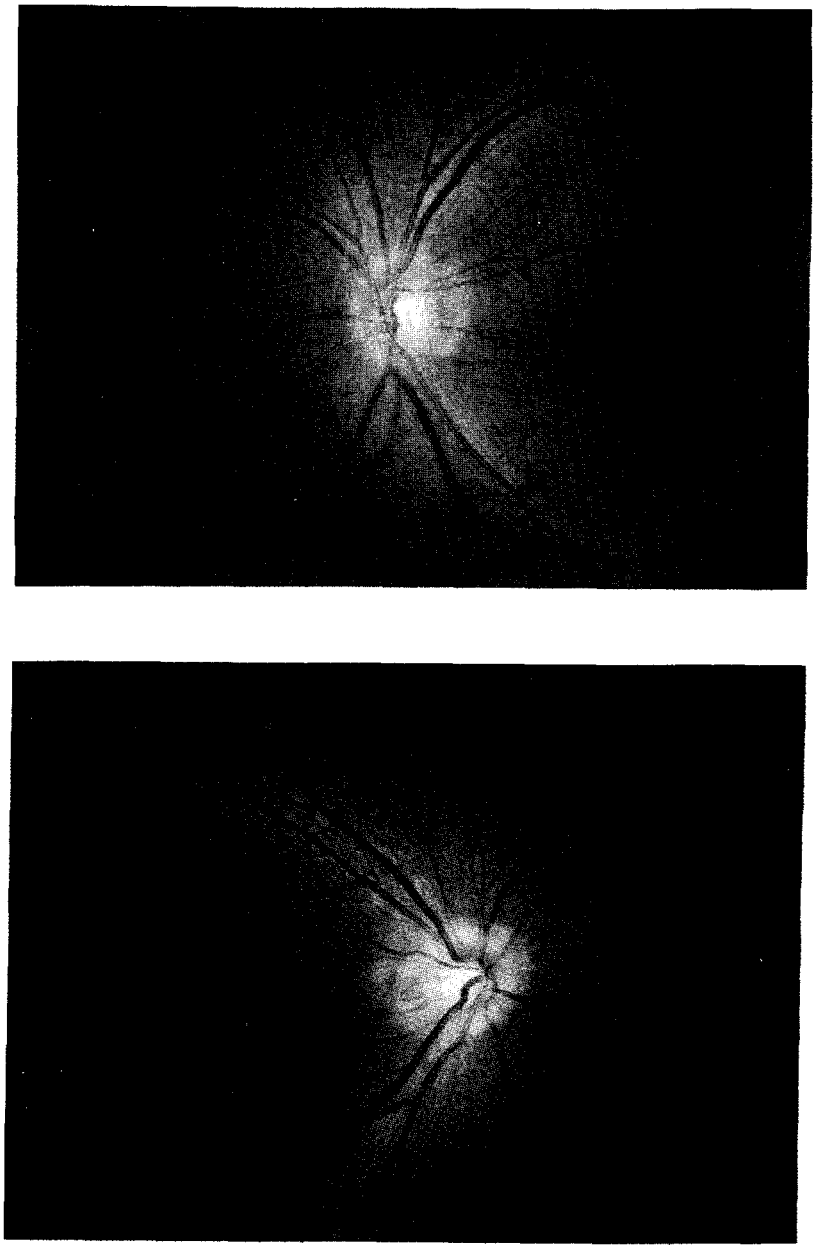

Fig. 6. Obscuring of nerve fiber striations in the nasal peripapillary retina (right eye). Left optic disc is also small with blurred margin.

Visual field defects in migraine patients

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Abstract

Visual field defects, together with diplopia and blurred vision are often reported by patients during attacks of migraine. Previous studies reported the influence of age and disease duration on the outcome of this symptom without studying the type of migraine, and whether its frequency plays a role in this visual function loss. Thirty-eight patients affected by migraine, diagnosed by a neurologist, including forms with and without "aura" were studied. An Octopus 2000R, program G1, was used to examine the visual field. In this study, patient's age and duration of disease did not show a significant correlation with the visual field loss, while migraine attack frequency showed a significant correlation. The mean defect of the VF was indeed greater in those patients with a higher frequency of migraine attacks Migraine involves vascular disregulation as an important pathogenetic factor. VF loss described in this disease may be considered to be very close to that described in certain vascular conditions of the eye.

Introduction

According to the International Headache Society (IHS) classification[1], migraine includes two main forms: migraine "with aura" and migraine "without aura". From a clinical point of view, migraine "with aura" is characterized by focal neurological signs which precede, accompany or follow the headache. In this type of migraine, the most frequent signs are: diplopia, blurred vision, and visual field (VF) loss. Migraine "without aura" is commonly considered when the headache is the main symptom of the disease.

Regarding the pathogenetic basis of migraine, great importance has been attributed to a vascular mechanism and, more recently, to serotoninergic system disregulation. It has been theorized that visual function disturbance, occurring during migraine attacks, might have some similarity to visual function disturbance observed in certain ocular pathologies.

A previous study reported a correlation between migraine duration and VF loss including an age influence in the VF loss outcome[2]. We think special attention should be directed towards the type of migraine: with or without aura.

It is our intention to study whether VF loss occurs more easily in one of these two types of migraine and whether the frequency of the attacks plays a role in VF loss.

Material and methods

Thirty-eight patients, nine men and 29 women, with a mean age of 38 years, ranging from 17 to 56 years, were studied. All of these patients were referred by a neurologist with a diagnosis of migraine. Eleven of them had migraine "with aura", 27 of them "without aura". An accurate medical history of each patient was recorded with special attention being given to the duration and frequency of migraine attacks. No patient presented with an ocular pathology after a complete clinical examination.

The mean visual acuity was 0.9, with a range of from 0.8 to 1.2. No patient presented with an IOP level higher than 19 mmHg, measured with a Goldmann tonometer.

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The visual field of both eyes in each patient was explored with the G1 program of the Octopus 2000R computerized perimeter. The mean of the mean defect observed in both eyes was correlated with age, duration and frequency of migraine. A statistical analysis was carried out using Student's *t* test to verify whether there was a significant correlation among these variables.

Results

Seventeen patients (42%) showed the presence of visual field defects. Ten patients had a unilateral VF defect, seven patients a bilateral VF defect. Nine patients were affected by migraine with aura and eight by migraine without aura. No relationship was therefore found between VF loss and type of migraine. No relationship was found between the patient's age and the visual field defect.

The mean duration of the disease in the selected patients was 15 years, with a range from two to 30. This variable did not correlate statistically with the visual field defect outcome.

The frequency of migraine attacks in the selected patients was variable, ranging from a minimum of one attack to a maximum of eight attacks per month. VF loss was greater in those patients with a higher frequency of attacks ($p<0.001$).

Discussion

Ocular symptoms are often described in patients affected by migraine even in the absence of any ocular pathology. A previous paper reported visual field loss in 21 migraine patients of over 60 years of age (35%)[2], but did not consider which type of migraine was affecting them.

In our study with a restricted group of 38 patients, we found visual field defects in 17 patients (42%). We did not find a correlation between age of patient, disease duration or visual field loss. We did find a significant correlation between frequency of migraine crisis and visual field loss. We did not observe a higher percentage of visual field loss in either of the two types of migraine considered. A larger study group would lead to more precise percentages and statistical power.

Surely VF loss is more frequent in migraine patients than commonly believed.

Some of these VF defects present certain analogies with other vascular conditions of the eye.

References

1. Headache Classification Committee of IHS classification and diagnostic criteria for headache disorders, cranial neuralgias and facial pain. Cephalgia (Suppl) 8:1-94, 1988
2. Lewis RA, Vijayan N, Watson C, Keltner J, Johnson CA: Visual field loss in migraine. Ophthalmology, 96: 321-326, 1989
3. Trobe JD, Glaser JS: The Visual Fields Manual. Gainesville, FL: Triad Publishing Co
4. Burde RM, Savino P, Trobe JD: Clinical Decisions in Neuro-Ophthalmology. St Louis: CV Mosby Co 1985
5. Wirtshafter JD: Examination of the peripheral visual field. Arch Ophthalmol 105:761-762, 1987
6. Meinberg O, Mattle H, Jenni A, Flammer J: Quantitative versus semiquantitative perimetry in neurological disorders. In: Proceedings of the Sixth International Visual Field Symposium. Dordrecht: Dr W Junk Publ 1985

Evaluation of the blind spot in automated perimetry using a spatially adaptive strategy: optimization of the procedure by means of computerized simulation

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Abstract

A strategy for relatively fast and precise measurement of the blind spot has been proposed. It delineates the blind spot by detecting its borders in four to six different locations. This study was undertaken to investigate the possibility of further reducing the duration of the procedure, keeping within the basic principles of this strategy. For optimizing the strategy, the authors developed a method using computerized simulation to generate a blind spot and to test a number of measurement algorithms in various clinical conditions. A comparative study of various algorithms for threshold determination was conducted, in terms of number of questions required at each step of the procedure, keeping in mind the necessity of preserving a sufficient precision for the procedure. Attempts were also made to replace various stages of the procedure by an extrapolative calculation. Robustness of the system was assessed by simulating answers from poorly collaborative subjects. It was found that the optimization obtained in this study using both a combination of different algorithms according to the stages of the procedure and an extrapolative calculation reduced the time needed to measure the blind spot, without actual reduction in the accuracy of the method.

Introduction

A procedure for relatively rapid and precise measurement of the blind spot has been proposed by Safran *et al.*[1-3]. It is used to assess width and height of the blind spot, based on the assumption that its shape is close to an ellipse, the main axis of which being vertically oriented. It is performed using a 1-level strategy, and it involves six stages, which have been described in detail elsewhere[4] (Fig. 1).

In the original presentation of the strategy, a simple algorithm, based on the method of limits, was used to locate the border of the blind spot along lines of tested points. It consisted of the successive testing of adjacent points located in rows, starting from the presumed center of the blind spot, until light stimulus is perceived in two successive locations, suggesting that the border had been crossed.

The present study set out to reduce the duration of the procedure further, in keeping with the basic principles of this strategy. To optimize the strategy, we developed a computerized simulation system[5] which was able to generate blind spots and to test a number of measurement algorithms, in various clinical conditions.

Blind spots were simulated based on the values of blind spot parameters obtained from normals in a previous study, including location of the center, width, height, and width/height ratio[4]. In addition, to simulate the behavior of the tested subject in the vicinity of the borders of the blind spot, we defined a psychometric function[5] describing the probability of positive response by the tested subjects, according to the locations of the stimulus and the blind spot.

We set out to optimize the strategy according to three main principles:

The first principle consisted of a comparative study of various algorithms for threshold determination, in terms of the number of required questions at each step of the procedure, keeping in mind the need to maintain sufficient precision. In classical procedures of automated peri-

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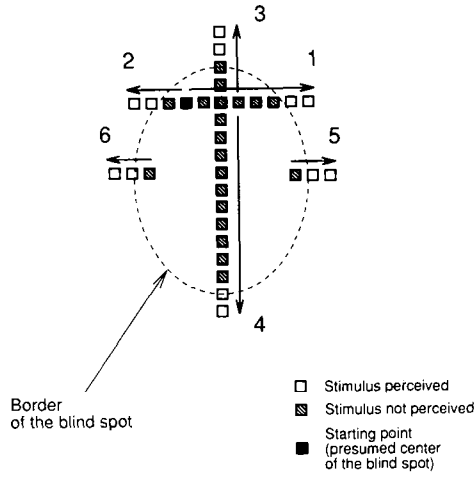


Fig. 1. Spatially adaptive strategy developed for the evaluation of the blind spot, before optimization. Numbers indicate succession in measurement stages. The procedure is conducted as follows. First, from the presumed center of the blind spot (as determined in previous studies), successive locations are tested along a horizontal line at 0.5° intervals, until the stimulus is perceived at two adjacent points, indicating the edge of the blind spot (stage 1) The procedure is then repeated, testing in the opposite direction until, again, the stimulus is perceived at two adjacent points (stage 2). The center of the segment thus defined is then calculated, and the vertical axis of the blind spot is drawn from this point (stages 3 and 4). The apparatus then calculates the center of the vertical segment. If its position does not correspond to the point initially taken as the theoretical center, the two halves of a new horizontal line, passing through the mid-point of the vertical segment, are then tested using points situated just above the points along the first horizontal line (stages 5 and 6).

metry using a vertical approach to the island of vision, the bracketing algorithm using steps of four and then of two units of light intensity is usually considered optimal for determining light sensitivity thresholds[6]. However, measuring the surface of the blind spot involves specific conditions, related to the horizontal nature of the approach to the island of vision, and the two-dimensional nature of the evaluated parameter. In addition, the selected algorithm takes into account both blind spot dimensions and spatial resolution capabilities of the perimeter.

The second optimization principle resulted from our previous observations of locations in the visual field in the vicinity of the presumed center of the blind spot, which were insensitive to light stimuli in 30 normal tested subjects[4]. This implies that there are questions which often provide little, if any, useful information for the measurement procedure. The optimization procedure should therefore exclude the automatic testing of such locations. Thus, instead of starting the procedure at the presumed center of the blind spot, rows of testing spots should start in the vicinity of the presumed locations of the borders of the blind spot, which have been determined in previous studies.

Thirdly, the optimization approach should include attempts to replace when possible the systematic use of the recentering stages of the procedure (stages 5 and 6) by an extrapolative calculation.

Methods

Evaluated algorithms

We compared eight algorithms, each capable of localizing the border of a scotoma in a row of tested points. Some of them are similar in type to the classical algorithms used in Octopus perimetry, except that the latter measure sensitivity values (dB), whereas those we tested evaluate distance values, in multiples of 0.5° units, *i.e.*, the maximal spatial resolution of the Octopus 2000R perimeter. The tested algorithms belonged to three main categories.

The first category is that of bracketing algorithms. Tested procedures were the following:

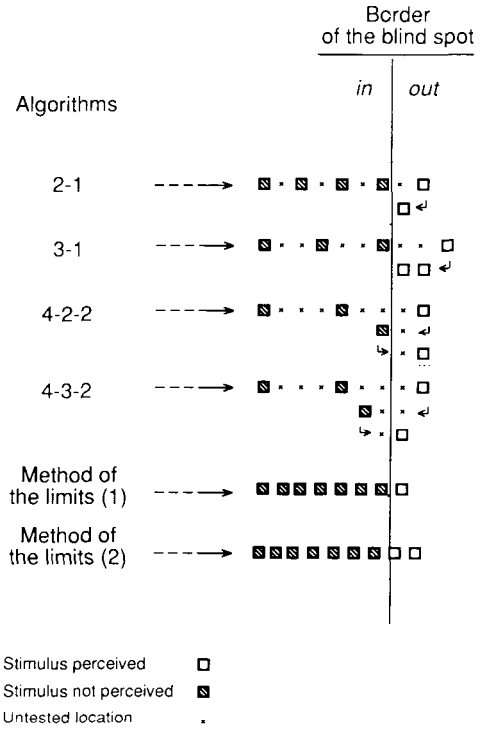


Fig. 2. Algorithms compared in the simulation procedure

a. 4-unit step in the direction of the threshold, then 2-unit step backwards, then 1-unit step forwards again (algorithm 4-2-1);
b. 4-unit, then 2-unit, then 2-unit steps (algorithm 4-2-2);
c. 4-unit, then 3-unit, then 1-unit steps (algorithm 4-3-1);
d. 3-unit, then 2-unit, then 1-unit steps (algorithm 3-2-1);
e. 3-unit and 1-unit steps (algorithm 3-1); and
f. 2- and 1-unit steps (algorithm 2- 1).

The first four algorithms perform three threshold crossings whereas the latter two perform only two threshold crossings (Fig. 2).

Algorithms of the second category are based on the method of limits[7]. These are series of contiguous locations which are successively tested until the border of the blind spot is crossed. We evaluated two variants of these algorithms: (a) stopping the procedure as soon as a change in answers occurs, suggesting the border has been crossed (limits 1); (b) investigating the transitional area further, until two adjacent locations are found showing consistent answers, on each side of the presumed border (limits 2).

Algorithms of the third category are dichotomic in nature. They define successive, gradually decreasing intervals which include the border of the blind spot. The intervals are designed to include irregularities in the transition area between the inside and outside of the blind spot, due either to subject errors or to intrinsic variations in sensitivity. Initial steps of 4 units were used in this procedure.

Starting locations

A procedure was designed to locate the starting location in each row of points tested in the vicinity of the presumed border of the blind spot. This determination is based initially on values of blind spot parameters found in normal subjects[4]. In the subsequent stages of the procedure, it was based on the results obtained in earlier stages of the measurement procedure in the test

subject.

Thus, in the first stage (Fig. 1) the presumed border of the blind spot was situated on the temporal side of the presumed center, at a distance equal to the normal horizontal radius. In stage 2, it was located symmetrically on the other side of the presumed center. In stage 3, it was situated above the mid-point of the horizontal segment which had been measured, its distance from the center being calculated from the width/height ratio determined in normal subjects[4]. In stage 4, the lower border of the blind spot was situated below the mid-point of the horizontal segment, at a distance equal to that of the upper border. The approach to stages 5 and 6 was similar to that of stages 1 and 2, except that the presumed center is replaced by the center of the segment measured in stage 4.

For those algorithms which proceed initially by steps of 4 units (of 0.5° each), the rows of tested points start at a location 2 units outside the presumed border of the blind spot. For those algorithms which proceed in 2-unit and 3-unit steps, they start one unit outside the presumed border. For strategies based on the method of limits, they start right at the presumed border.

Extrapolative calculation

Stages 5 and 6 of the strategy were replaced by an extrapolative calculation, under specific conditions. The extrapolation was based both on values obtained in stages 1 to 4, and on the mathematical equation describing an ellipse, which enables its width to be determined when its vertical axis plus one additional location on its border are known. Width values were extrapolated when both of the following conditions were met: (a) the distance between the true center and the horizontal segment measured in stages 1 and 2 was less than one-half the height of the blind spot divided by the square root of two, *i.e.*, it was highly unlikely that measuring the width again would greatly affect the overall assessment of the blind spot; and (b) an extrapolated value of the width was less than the measured height, a situation which did not suggest, at first sight, that an error had arisen during measurement.

Simulation procedure

We simulated both normal and pathologically enlarged blind spots in subjects who collaborated well and in others who collaborated poorly. Special software was designed for the purpose.

Normal blind spots were randomly generated according to a gaussian distribution of the following blind spot parameters, based on values which we had previously determined in normal subjects[4]: center coordinates, width, height, and height/width ratio. Abnormally enlarged blind spots were generated based on randomly computed values of center coordinates, according to a gaussian distribution previously determined in a series of affected patients (personal, unpublished data). In addition, width and height values were randomly selected using a uniform distribution, ranging between upper normal values (mean normal values +2 SD) and 12 or 25 degrees, for width and height values, respectively. Simulating subjects who collaborated well was performed using a false answer probability of 0.05[7], and those who collaborated poorly using a false answer probability of 0.3.

We evaluated each algorithm for each stage separately. The algorithm we evaluated was used to carry out the stage being considered, while a method of limits, free of subject errors and border fluctuations, was used for the other stages, for obtaining reference values.

For each tested algorithm, two series of 5000 blind spots were randomly generated. The first series was used for simulating normal blind spots, and the second for simulating enlarged ones. The number of questions asked and the accuracy of the methods were estimated.

Tested algorithms were ranked according to the median number of questions asked and the degree of accuracy. After excluding those algorithms which had a particularly large margin of error, we made a statistical comparison of the two which ranked best with regard to the number of questions. For this purpose, we made a new simulation of 5000 cases and tested the two strategies for each simulated blind spot. The significance of differences in performance was evaluated by a paired t test. The choice of algorithm was made under four conditions for each stage: with normal and enlarged blind spots, and with subjects who were collaborative or poorly collaborative.

The entire procedure for examining the blind spot was simulated, using for each stage the

algorithm which had been selected for that stage and making extrapolations where these were applicable. This was done separately under the four test conditions indicated above. A second simulation was then performed without extrapolation. Finally, all these results were compared with a simulation using the method of limits, discussed earlier.

Because of the possibility that the tested subjects give false answers, we had to consider the possibility of false positive answers occurring in succession, precluding the localization of the blind spot and resulting in an examination failure. In the simulation series, these failures were detected, counted and excluded from the quantified analysis of the procedure evaluation.

Results

Table 1 indicates the algorithm which was found to be the best for each test condition and for each stage. As a result, the algorithm 2-1 was finally chosen for stages 1 and 3, and the algorithm 3-1 was selected for stages 2 and 4; the methods of limits 1 algorithm was selected for stages 5 and 6.

Table 1. Algorithms selected at each stage of the simulated examination procedure, according to the size of the blind spot and the degree of subject collaboration

	Normal blind spots collaborative subjects	*Enlarged blind spots collaborative subjects*	*Normal blind spots non-collaborative subjects*	*Enlarged blind spots non-collaborative subjects*
Stage 1	2-1*	3-1	2-1*	3-1
Stage 2	3-1	3-1*	3-1	3-1*
Stage 3	2-1*	2-1	2-1*	2-1
Stage 4	2-1	3-1*	2-1	3-1*
Stage 5	limits 1*	limits 1*	limits 1*	limits 1*
Stage 6	limits 1*	limits 1*	limits 1*	limits 1*

*indicates that, in the considered condition, the selected algorithm was significantly better than any other tested algorithm ($p<0.05$ with the Student's t test)

The results of simulating the entire measurement procedure using the selected algorithms, are shown in Fig. 3, with regard to the number of questions asked and the measurement error in evaluating the mean diameter, in relation to the degree of collaboration of the tested subjects. The algorithms chosen for collaborative subjects were also the best for poorly collaborative subjects. Using the chosen algorithms, accuracy was relatively good, in the clinical sense, with either collaborative or poorly collaborative subjects.

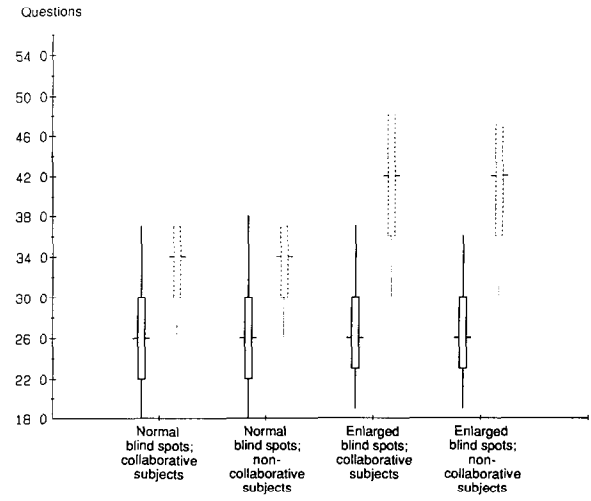
Extrapolation to replace stages 5 and 6 gave the following results:

a. with normal blind spots, in either collaborative or poorly collaborative subjects, a gain of more than seven questions at the 50th percentile without any real loss of accuracy in measuring the mean diameter of the blind spot (reaching only 0.01° and 0.04°, respectively, in collaborative and poorly collaborative subjects);
b. with enlarged blind spots, in either collaborative or poorly collaborative subjects, a gain of more than 15 questions at the 50th percentile, with a minimal loss of accuracy in measuring the mean diameter of the blind spot (0.02° and 0.04°, respectively, in collaborative and poorly collaborative subjects showing enlarged blind spots).

Failed examinations occurred in 1.7% of collaborative subjects with normal blind spot, and in 0.7% of collaborative subjects exhibiting an enlarged blind spot. Two percent and 0.7% of poorly collaborative subjects showing normal and enlarged blind spots, respectively, showed examination failures.

Discussion

Using the optimized strategy for measuring the blind spot, an average of only 26 questions was found sufficient to conduct the examination in normal subjects, without actually reducing the accuracy of the procedure. This compares favorably with either the 88 locations needed to



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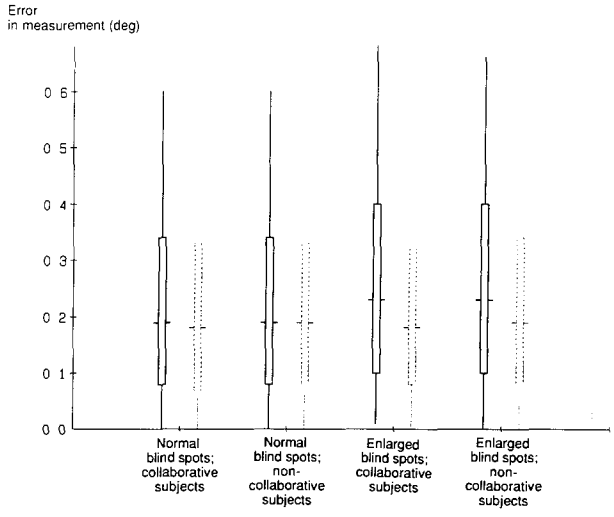

B

Fig. 3. Results of the simulated procedure, with regard to (A) the number of questions asked, (B) the error in evaluation of the mean diameter, using at each stage the algorithm previously determined as optimal. Four conditions were considered, according to the degree of collaboration of the simulated tested subject, and the normality in the dimension of the generated blind spots. Five, 25, 50, 75 and 95 percentiles are presented. Empty boxes show the results obtained using the evaluation procedure with a mathematical extrapolation of stages 5 and 6, whereas streaked boxes show the data obtained using the complete measurement procedure.

measure a normal blind spot using a regular grid of points at one-degree intervals over a limited range of eight by ten degrees, or the approximately 95 points required when using the spatially adaptive Octopus 15 program[8]. Improvement is also substantial in comparison with the adaptive strategy which we originally developed, necessitating a mean of 47 locations when evaluating a normal blind spot[4] (Fig. 4).

An essential concern in using adaptive strategies is the robustness of the system when examining poorly collaborative subjects, who frequently give false answers. When we evaluated the relative effect of poor collaboration on the various algorithms tested, we found that algo-

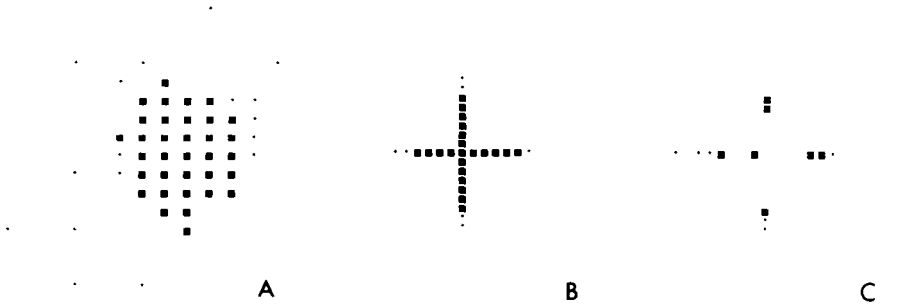

Fig. 4. Evaluation of the blind spot in the same eye, using successively (A) conventional adaptive strategy (Octopus program 15), (B) the original spatially adaptive strategy which we developed, and (C) the optimized version of our strategy. Highest spatial resolution is 1° with program 15, and 0.5° with the remaining strategies. Locations with unperceived stimuli are shown by full boxes, and those with perceived stimuli are indicated by dots Reduction in the number of required questions using the optimized strategy is evident.

rithms which had been chosen on the basis of their performance with collaborative subjects, whether normal or pathological, were also the most robust when used with poorly collaborative subjects. This reinforced our choice.

The results obtained in simulations of abnormally large blind spots should be interpreted with caution. Indeed, it is difficult to simulate the sensitivity gradient at the borders of such blind spots, as it differs from that of the normal blind spot[9] and may also vary considerably from one subject to another. It should also be noted that subjects presenting with alterations in visual function occasionally show increased fixation instability as a result of difficulty in perceiving the fixation light stimulus. In our procedure, this condition was approximated by using a high rate of false answers in so-called non-collaborative subjects.

Interestingly, the bracketing algorithm 4-2-2, which was found to be optimal for the determination of the differential light threshold using the regular approaches by automated perimetry[7], proved rather poor for spatial examination under the specific conditions used for measuring the blind spot.

A dichotomic algorithm could have been useful, by virtue of its speed of convergence and the theoretical robustness of the means of attenuating errors caused by the subject. Simulations showed this approach to be not as good as the other algorithms tested, probably because of the relatively low ratio between the spatial resolution of the measuring equipment and the size of the blind spot.

This study clearly illustrates the interest of simulation in developing optimal examination strategies. Its conclusions should, of course, be tested clinically. It would also be useful to develop an additional procedure for limiting the number of "examination failures" resulting from the occurrence of repeated false positive answers, which invalidate the procedure and which occur using the present strategy in 1.7% of collaborative subjects showing normal blind spots.

References

1. Safran AB, Mermoud C, de Weisse C, Désangles D, Lang R: Developpements pour une stratégie de mesure de la tache aveugle. Klin Monatsbl Augenheilk 198:498, 1991
2. Safran AB, Mermoud C, Désangles D, de Weisse C, Mermillod B: Stratégie de mesure de la tache aveugle par périmétrie automatisée: la signification des "points isolés". Ophtalmologie 6:92-96, 1992
3. Safran AB, Mermoud C, de Weisse C, Désangles D, Mermillod B: A new spatially adaptive strategy for the evaluation of the blind spot by means of automated perimetry. (in preparation)
4. Safran AB, Mermoud C, de Weisse C, Désangles D: Evaluation of the blind spot using high resolution automated perimetry: values in normal subjects (in preparation)
5. Mermoud C, Safran AB, Estreicher J, Liebling TM: A computer method for simulating the examination of the blind spot. This Volume, pp 293-296

6. Bebié H: Computerized techniques of threshold determination In: Whalen WR, Spaeth GL (eds) Computerized Visual Fields, What They Are and How to Use Them, pp 29-44. Thorofare, NJ: Slack Inc 1985
7. Bebié H, Fankhauser F, Spahr J: Static perimetry: strategies. Acta Ophthalmol 54:325-338, 1976
8. Haefliger IO, Flammer J: Increase of the short-term fluctuation of the differential light threshold around a physiologic scotoma. Am J Ophthalmol 107:417-420, 1989
9 Haefliger IO, Flammer J: Fluctuation of the differential light threshold at the border of absolute scotomas. Ophthalmology 98:1529-1532, 1991

A computer method for simulating the examination of the blind spot

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Abstract

The authors have developed a new strategy for measuring the blind spot with automated perimetry. In order to optimize this procedure, computer simulation tests must be performed to compare various algorithms. They developed a simulation method which takes into account (a) the problems involved in generating blind spots which are comparable to those in the test subjects, and (b) the development of a psychometric function adapted to spatial investigation of the blind spot. Blind spots were generated in a random manner, according to the normal distribution based on previous observations in 30 normal subjects. A new psychometric function was developed, based on the principles laid down by other authors. The authors had to redefine it, as those other authors had used it for determining one-dimensional values, whereas in the present procedure the psychometric function had to take into account the probability of the subject perceiving a stimulus of constant intensity moving in a two-dimensional space, that is, on a surface. The authors evaluated parameters involved in this new psychometric function by analyzing the observations made on a series of normal subjects, regarding the fluctuations in measurement values of the blind spot, respectively, at the superior, inferior, nasal and temporal borders

Introduction

In automated perimetry, the development and comparative evaluation of new measurement strategies are impeded by the difficulty of finding enough test subjects, and by the overall duration of the examination. A system of simulation, which takes into account as accurately as possible the various factors involved, largely overcomes this problem.

We have developed a new strategy for measuring the blind spot[1-3]. In order to optimize this procedure, comparative tests must be made of various algorithms. Thus, it should be possible to ascertain which are most rapid, as well as sufficiently accurate and robust, for the specific purpose of measuring the blind spot. This is best done by simulated tests using a computer.

For this purpose, three problems should be considered:

a. the generation of blind spots comparable to those of the subjects to be tested;
b. a psychometric function adapted to measurement of the blind spot; and
c. the parameters of this psychometric function within the framework of variations in sensitivity at the edges of the blind spot, and the degree of collaboration of the test subjects.

Blind spots were randomly generated on the basis of prior observations made in 30 normal subjects[4]. The psychometric function was based on principles developed by Spahr[5], and by Bebié *et al.*[6], in their simulation work for threshold determination in automated static perimetry. This function, however, had to be redefined, as it was used in previous work for testing algorithms for measuring a sensitivity threshold in a one-dimensional condition, whereas in our own procedure the psychometric function had to take into account the probability of the subject perceiving a stimulus of constant intensity moving in a two-dimensional space, *i.e.*, on a surface. We adjusted the parameters of this new psychometric function by analyzing the observa-

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tions made on a series of normal subjects, regarding the fluctuations in measurement values of the blind spot.

Design of the model

Generation of blind spots

The shape of the blind spot was assumed to be close to an ellipse, which is defined by the coordinates of its center and its vertical and horizontal axes. Mean values and standard deviations of these parameters were measured in a series of 30 normal subjects[4]. We assumed that these values follow a normal distribution curve. In this study, reference values were obtained using stimuli 10 dB in intensity below the mean sensitivity at the border of the blind spot[2], in order to allow satisfactory discrimination between normal and abnormally enlarged blind spots.

Blind spots were generated using a quasi-normally distributed random number generator for their various parameters, according to the reference values obtained in normal subjects.

Adaptation of the psychometric function to a two-dimensional examination

Bebié *et al.* introduced a psychometric function expressing the probability of a positive response by a subject as a function of the intensity of a stimulus S, the mean sensitivity. At this point, the standard deviation R of this sensitivity, and the probability α of the subject giving a false answer are other variables. They assumed that immediate sensitivity follows a normal distribution curve[5,6]. Those authors presented the following approximation for calculating this function:

$$P(S) = \alpha + (1-2*\alpha)/(1 + \exp((S-S_o) * 1.8/R)$$

We have adapted this psychometric function to the two-dimensional nature of the evaluated parameter. For simplicity, we assumed that the values of successive measurements of the distance between the center and border of the blind spot follow a normal distribution curve.

Let ρ be the distance between the center of the blind spot and the point being tested, δ be the mean distance between the center and the border of the blind spot along a line joining the center to the point being tested, and ϕ the angle which the axis under consideration forms with the horizontal axis of the blind spot, expressed in radians (Fig. 1). We introduced a value R', analogous to R, to represent fluctuations in this distance. In equation (1), after substitution of ρ and the mean value δ, the probability of perception is:

$$P(\rho) = \alpha + (1-2*\alpha)/(1 + \exp(\rho-\delta) * 1.8/R'(\phi))$$

where $R'(\phi)$ expresses fluctuations in the distance around δ, which is then evaluated. Taking into account the respective R values of the horizontal (h) and vertical (v) radii closest to the tested location, calculation of $R(\phi)$ is performed as follows:

$$R'(\phi) = R'_h + \sin^2(\phi)\,(R'_v - R'_h)$$

For any point *T* whose coordinates are found to be (x,y), ρ and δ are calculated as follows:

$$\rho = \mathrm{sqrt}((x - cx)^2 + (y-cy)^2)$$

where cx and cy are the coordinates of the center of the blind spot.

$$\delta = a * b / \mathrm{sqrt}((b * \cos(\phi)^2) + (a * \sin(\phi)^2)$$

where a and b, respectively, are the horizontal and vertical radii of the blind spot. ϕ is the angle which the axis under consideration forms with the horizontal axis of the blind spot, expressed in radians. It is calculated as follows:

$\phi = \pi / 2$ if x = cx
$\phi = \mathrm{arctg}((y - cy) / (x - cx))$ otherwise

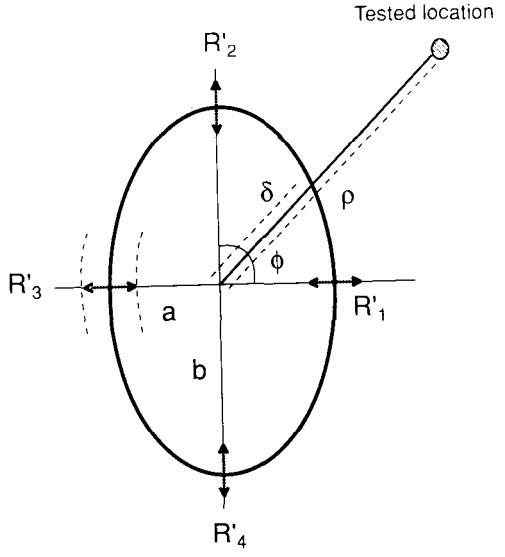

Fig. 1. Blind spot parameters considered in the psychometric function. R' represents fluctuation in the location of the blind spot border

The contribution of fixation instability to fluctuations in measurements

Let the theoretical coordinates of the tested point be x and y, the actual coordinates of the tested point be x' and y', and, with the simplifying assumption that changes in gaze direction during fixation are distributed normally, let σ_x and σ_y, respectively, be the standard deviations of fixation instability according to the x and y axes. The probability of seeing according to fixation instability is $P_S(x', y')$. $P_S(x', y')$ is chosen such that its level lines are closed curves composed of four elliptic sectors, as follows:

$$\left(\frac{x'}{a_i}\right)^2 + \left(\frac{y'}{b_j}\right)^2 = c^2$$

where i and j equal 1 or 2 according to whether x', y' are positive or negative, respectively. This way of modelling permits a more precise rendering of asymmetries in the blind spot.

Considering that the measured dimensions of the blind spot show short-term fluctuations, which are due to (a) the steepness of the sensitivity slope at the border of the blind spot, (b) false replies given by the subject being tested, and (c) instability of fixation, the probability of seeing might be expressed as follows:

$$P(x,y) = \int_{-2.5\sigma_x}^{2.5\sigma_x} \left(\int_{-2.5\sigma_y}^{2.5\sigma_y} P'(x',y') \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}\left(\left(\frac{x'-x}{\sigma_x}\right)^2 + \left(\frac{y'-y}{\sigma_y}\right)^2 \right)} dy \right) dx$$

This approach differs from the one described in the preceding section, and has not been used for our simulation procedure so far.

Experimental evaluation of fluctuations in the blind spot measurements

Using the spatially adaptive strategy which we recently developed[1-3], the blind spot was evaluated in one eye of 15 normal subjects, 25 to 48 years of age. The procedure was performed ten times in succession in each tested eye. Nasal, temporal, superior and inferior radii were separately measured with respect to a constant location in the visual field, and respective fluctuation was computed. For each considered radius, the standard deviation of the measured

values was determined, then the standard deviations obtained from all individuals were averaged.

Mean computed standard deviations were the following: for the nasal radius, 0.47 ± 0.32; for the temporal radius, 0.56 ± 0.19; for the superior radius, 0.89 ± 0.42; for the inferior radius, 0.86 ± 0.29.

Comments

Measurements of the blind spot in normal subjects[4], which we used as reference, were themselves subject to some imprecision due to short-term fluctuation in the measured values, and also to subject errors. We nevertheless considered that such changes were compensated from one subject to another, and therefore could be ignored.

When delineating the blind spot, fluctuations in measurements results from a number of factors, including the slope in sensitivity at the borders of the blind spot (determining the R′ value), the magnitude of fixation instability (as expressed by σ) and the false answers given by the subject (α).

For estimating these parameters, the optimal approach is experimental. However, when performing an examination by conventional automated perimetry, differentiating the factors contributing to the measured fluctuations is impossible. The false answers component can be excluded using well trained, collaborative subjects showing a negligible rate of false answers, as determined with the catch trials. In contrast, distinguishing the respective roles of the R′ and σ parameters is not realizable using regular computerized perimetry.

It is conceivable that, eventually, static fundus perimetry[7] and high resolution eye movement recording will prove invaluable for the definition of these parameters. It should be emphasized, however, that both slope in sensitivity at the borders of the blind spot and fixation instability vary greatly between normal subjects, and even more between normal and visually affected individuals[8]. Therefore, precise definition of these parameters is probably not essential in the development of a simulation system for the evaluation of the blind spot.

As a result, in the computer simulation system which we eventually used for testing various algorithms to optimize the measurement procedure[9], we applied the psychometric function defined here above (P (ρ)). Considering this function as a global representation of the measured fluctuations which occur when delineating the blind spot, as a result of both slope in sensitivity and fixation instability, we used the fluctuation standard deviations measured in our experimental procedure as R′ values, taking into account the estimations made respectively at the nasal, temporal, superior and inferior borders of the blind spot.

References

1 Safran AB, Mermoud C, de Weisse C, Désangles D, Lang R: Développements pour une stratégie de mesure de la tache aveugle. Kin Mbl Augenheilk 198:498, 1991
2. Safran AB, Mermoud C, Désangles D, de Weisse C, Mermillod B: Stratégie de mesure de la tache aveugle par périmétrie automatisée: la signification des "points isolés". Ophtalmologie 6:92-96, 1992
3. Safran AB, Mermoud C, de Weisse C, Désangles D, Mermillod B: A new spatially adaptive strategy for the evaluation of the blind spot by means of automated perimetry. (in preparation)
4 Safran AB, Mermoud C, de Weisse C, Désangles D: Evaluation of the blind spot using high resolution automated perimetry: values in normal subjects (in preparation)
5. Spahr J: Optimization of the presentation pattern in automated static perimetry. Vision Res 15:1275-1281, 1975
6. Bebié H, Fankhauser F, Spahr J: Static perimetry: strategies. Acta Ophthalmol 54:325-338, 1976
7. Van de Velde FJ, Jalkh AE, Elsner AE: Microperimetry with the scanning laser ophthalmoscope. In: Mills RP, Heijl A (eds) Perimetry Update 1990/91, pp 93-101. Amsterdam: Kugler Publ 1991
8. Haefliger IO, Flammer J: Fluctuation of the differential light threshold at the border of absolute scotomas. Ophthalmology 98:1529-1532, 1991
9. Safran AB, Mermoud C, Eistreicher J, Liebling TM: Evaluation of the blind spot in automated perimetry, using a spatially adaptive strategy: optimization of the procedure by means of computerized simulation. This Volume, pp 285-292

TEST STRATEGIES AND SCREENING

A multi-fixation campimeter for the detection of glaucoma

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Abstract

A hand-held multi-fixation campimeter has been developed for the detection of glaucoma in situations where other forms of perimetry are impossible The chart consists of a white screen with a central black test stimulus and a series of numbers, which are read by the patient so that the stimulus passes through known points in the central 15-degree field. This paper summarizes the results of an evaluation which shows that when a 1.5/400 black stimulus is used this test is positive in a high proportion of glaucomatous eyes with absolute visual field loss, but with a false positive rate of approximately 10% in patients over the age of 60 years. A new modification of the chart is described, which examines 60 points in the central 25-degree field with a range of three stimulus sizes

Introduction

The multi-fixation campimeter is a tangent screen having a series of numbered fixation targets distributed eccentrically in relation to a central test stimulus so that when the numbers are read by the patient from the correct distance the stimulus is automatically positioned at known points in the visual field; any numbers associated with disappearance of the stimulus are crossed out on a miniature version of the campimeter on a record sheet so that the results are comparable with those obtained conventionally[1].

Multi-fixation campimetry is a type of oculo-kinetic perimetry (OKP) in that the eye is encouraged to move during the examination. The advantages of multi-fixation campimetry over conventional "oculo-static" methods are that, first, the stimulus does not need to be moved around the screen by a perimetrist or machine, and, second, the need for monitoring the patient's direction of gaze is reduced, and in many patients eliminated, because the eye needs to be held still only for a second at a time. These simplifications allow visual field examination to be administered by relatively unskilled perimetrists and also enable selected patients to perform self-examination without constant supervision. The low cost and simplicity of multi-fixation campimetry create a potential for making visual field examination a routine procedure in the community, to facilitate the detection and monitoring of glaucoma and other diseases when other methods are not possible.

When the multi-fixation campimeter was first developed, a chart testing 100 points in the central 25-degree visual field was shown to correlate reasonably well with conventional perimetry, both in a hospital glaucoma clinic[2] and in neuro-ophthalmology[3]. However, this chart was found to be unsuitable for the screening of glaucoma by non-ophthalmologists because the examination of 100 points was too time-consuming (*i.e.*, four to seven minutes per eye), and because non-specialists were incapable of selecting the most relevant parts of the field to examine or of assessing the results (Sheldon and Damato, unpublished data). Accordingly, a study was initiated to develop a rapid screening test for intermediate and severe glaucomatous visual field loss, which was simple, convenient, and inexpensive. First, the points on the 100-

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number chart which were most useful were identified, and found to be located 12.5 degrees from fixation superiorly and 15 degrees nasally and infero-nasally[4]. Next, a hand-held multi-fixation campimeter was prepared, which had 23 numbered fixation targets. This test took approximately one minute per eye to perform and one or more points were missed in about 90% of eyes with unequivocal glaucomatous visual field loss and approximately 10% of age-matched non-glaucomatous eyes[5]. Problems arose, however, because the patients tended to read the numbers too quickly and to hold the chart too close to the eye. A 26-number chart was therefore developed, which tested additional points in the high-risk areas of the field, and which had a rigid side-arm connecting the eye-occluder to the chart.

The aim of the present study is to evaluate the 26-number glaucoma screening chart and to identify ways in which the campimeter can be improved so to enable gross visual field loss to be identified in situations which preclude other methods.

Material and methods

The 26-N glaucoma screening test

The glaucoma screening chart is a hand-held card, with a single test grid on each side for testing each eye, respectively (Fig. 1). An eye occluder is attached to the lateral edge of the card by a rigid side-arm so that the chart is held at 40 cm from the eye and so that the test cannot be performed if the wrong eye is occluded. The test grid has a 1.5 mm diameter black stimulus on a white background and 26 numbers, which are light-blue in color so as not to be confused by the patient with the stimulus. The numbers are arranged in a spiral to examine the field at 12.5 degrees from fixation superiorly and 15 degrees nasally and infero-nasally, with additional points being examined empirically so as to detect rare para-central defects. The

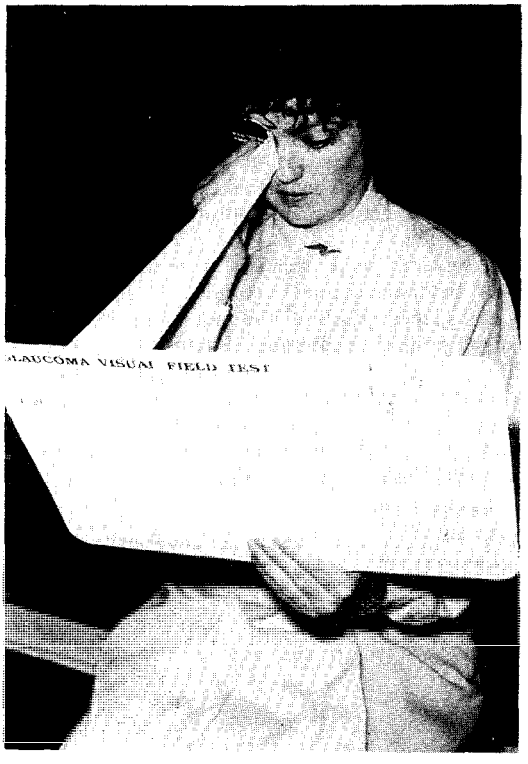

Fig. 1. The hand-held multi-fixation campimeter, which has a test grid on both sides of the card, for each eye, respectively, and an eye-occluder attached to the lateral edge of the card by a rigid side-arm.

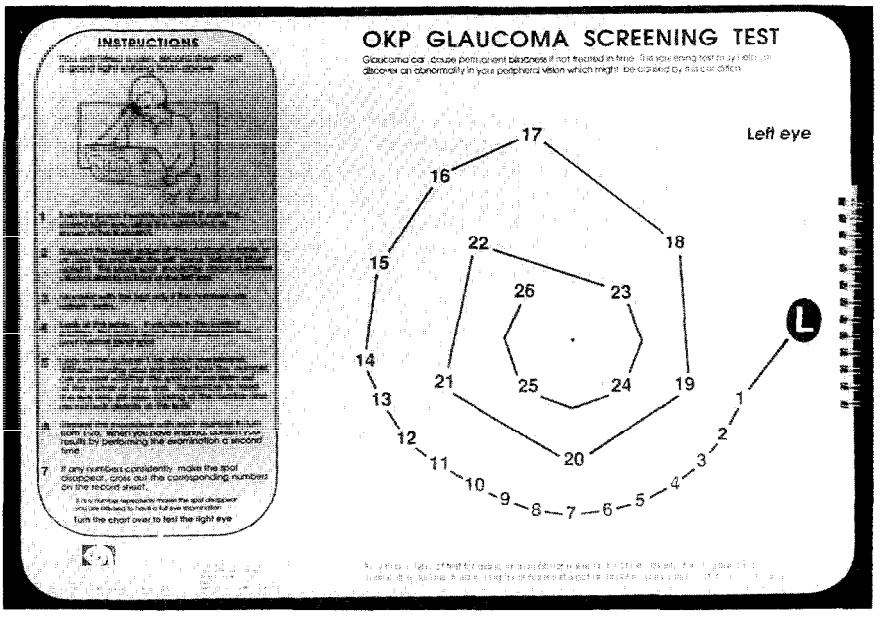

Fig. 2. The test card for the left eye showing the test grid, with 26 numbered fixation targets and the letter "L" for the blind-spot, and a set of instructions.

letters "L" or "R" correspond to the left and right blind spot, respectively, and are used to help the patient understand the principles of the examination. The test is accompanied by instructions, which are printed on the chart itself and separately (Fig. 2). These advise the patient to look at each number for about one second (to avoid the Troxler phenomenon) and to identify any numbers associated with disappearance of the stimulus, using a special record sheet. The examiner is advised to sit in front of the patient, so as to be able to monitor the patient's direction of gaze, and to confirm any results by covering and uncovering the stimulus with a white card while the patient looks at a number and indicates when the stimulus appears and disappears. The result is abnormal if any number is consistently associated with disappearance of the stimulus when the test is repeated.

Methods

The patients were selected from a hospital glaucoma clinic unless they appeared very frail or if the visual acuity was worse than 6/12. The controls consisted of hospital workers, persons accompanying patients to hospital, and patients attending a refraction clinic, who had a vision of 6/9 or better and no evidence of concurrent or previous eye disease.

The multi-fixation campimetry was performed twice for each eye but for the purposes of this study the stimulus was not covered and uncovered in order to avoid bias by the examiner. The conventional perimetry was performed with the Dicon 3000 autoperimeter, or the Tübinger, Friedmann, or Henson visual field analyzers.

The severity of glaucomatous visual field loss was categorized independently by four examiners, according to Aulhorn and Karmeyer's classification[6], and an average score for each field was obtained.

The study was conducted in two stages. First, a 1.5 mm stimulus was used. Later, when the results achieved with this stimulus were known, further patients and controls over the age of 60 years were examined with a 3.0 mm stimulus.

Results

1.5 mm stimulus

A total of 222 eyes of 126 individuals were examined (mean age 66.4 years, range 16-91). All patients completed the multi-fixation campimetry, which was positive in 45% of 58 eyes with only relative visual field loss (Grade 1), 81% of 32 eyes with absolute scotomas separate from the blind spot (Grade 2), 100% of 28 eyes with defects extending to the blind spot (Grade 3), and all four eyes with altitudinal defects (Grade 4). The glaucoma screening test was also positive in 25% of 95 eyes without definite visual field loss detected conventionally on the same day in patients attending the glaucoma clinic for reasons such as high intraocular pressure, optic disc changes, and definite glaucoma in the fellow eye. False negative results occurred in four eyes having relative scotomas with a depth of less than 0.5 log units, 19 eyes with relative loss deeper than 0.5 log units, two eyes with small absolute scotomas within 15 degrees, and six eyes with more peripheral loss.

In 186 right eyes of healthy controls, the false positive rate was 1% in patients below the age of 60 years, 9% between the age of 60 and 70 years and 13% in individuals over the age of 70 years.

3.0 mm stimulus

A total of 144 glaucomatous eyes of 88 patients aged 60 or more (mean age 70 years, range 60-85) were examined with a 3.0 mm stimulus. The glaucoma screening test was positive in 33% of 43 eyes with relative loss (Grade 1), 56% of 45 eyes with absolute scotomas separate from the blind spot (Grade 2), 80% of 20 eyes with scotomas extending to the blind spot (Grade 3), and 100% of 23 eyes with altitudinal defects (Grade 4). None of the 31 controls over the age of 60 years gave a false positive result.

Discussion

Automated threshold perimetry is useful when a glaucoma suspect is being assessed in a special clinic, but is not suitable for the screening of glaucoma in the community on a large scale, in many situations, because it would be too time consuming and difficult for many patients and also because of the logistical problems that would be created by the large number of patients having subtle visual field abnormalities due to age-related changes. At present, a high proportion of glaucoma sufferers are detected only after they have developed extensive absolute defects in the central field. If visual field examination can be performed routinely in the community, then individuals with such advanced disease might be detected sooner, when there is a better opportunity to preserve useful vision.

In the present study, about 90% of eyes with absolute scotomas were detected with a 1.5 mm stimulus, but with a false positive rate of about 10% in patients over the age of 60 years. In a population with a prevalence of glaucoma of 1%, there would be about ten false positive cases for each true case of unequivocal glaucoma detected with the 26-N glaucoma screening chart, whereas if the prevalence of glaucoma is 2% then the ratio would be about 1:6. These rates are far from ideal, but may compare favorably with the results of tonometry and ophthalmoscopy (provided that the non-ophthalmologists in the community have the resources and skills to perform these examinations). Such false positive results are not necessarily a problem if more detailed examination can be performed immediately, without undue inconvenience or cost to the patient. The false positive results in elderly patients are eliminated when a 3.0 mm stimulus is used, but at the cost of missing more patients with relative defects and small absolute scotomas. It would be useful to know the proportion of untreated glaucoma sufferers over the age of 70 years having only relative visual field defects in both eyes and how such defects would progress without treatment.

The results of the present study suggest that the sensitivity and specificity of the glaucoma screening chart would improve if the examination is modified according to the age and visual acuity of the patient. Patients under the age of 60 years with normal visual acuity should be examined with a smaller stimulus to 20 or 25 degrees, whereas older patients and those with

reduced visual acuity should be tested with a larger stimulus. For these reasons, there have been a number of changes in the design of the multi-fixation campimeter. Firstly, the new prototype has 60 numbered fixation targets which spiral outwards to an eccentricity of 25 degrees from fixation. This is so that more peripheral defects can be detected and so that the pattern of any defect can be investigated, thereby allowing differential diagnosis. In addition, the campimeter should also be useful in conditions other than glaucoma. Secondly, the blind spot is surreptitiously examined three times during the test (by numbers 10, 20-21, and 32) so that the perimetrist can assess the reliability of the patient. Thirdly, the sensitivity of the examination can be varied by means of three interchangeable black stimuli (1/330, 2/330 and 3/330). The criteria for abnormality would need to be revised, pending the results of a clinical evaluation, as a single missed point would no longer be appropriate. The format of the hand-held chart with the eye-occluder being attached to the chart by a rigid side-arm is being retained as it has proved more acceptable than wall charts and desk-top charts for occasional use by non-ophthalmologists. The new prototype still has printed stimuli, to minimize cost, and these are black on a white background so as to reduce the need for standardization of ambient lighting conditions[7]. Other stimuli, such as flickering light diodes, blue light stimuli, grey stimuli, and motion-detection stimuli are all feasible with multi-fixation campimetry, probably at a lower cost than with the conventional "oculo-static" examination technique, and these merit investigation.

In conclusion, there is a need for a simple and inexpensive method of visual field examination for routine use in the community (*i.e.*, "popular perimetry"). The sensitivity of such a test must be varied not only according to the age and visual acuity of the patient, but also according to the capabilities of the examiner. The hand-held multi-fixation campimeter provides a means for the detection of gross visual loss by inexpert perimetrists but is intended only for situations where conventional methods are impractical.

References

1. Damato B: Oculo-kinetic perimetry: a simple visual field test for use in the community Br J Ophthalmol 69:927-931, 1985
2. Alvarez EV, Damato BE, Jay JL, McClure E: Comparative evaluation of oculo-kinetic perimetry and conventional perimetry in glaucoma. Br J Ophthalmol 72:258-262, 1988
3. Alvarez EV, Damato BE, Wakakura M, McFadzean RM: Oculo-kinetic perimetry: a visual field test for neuro-ophthalmic patients. Neuro-Ophthalmology 8:23-30, 1988
4. Damato BE, Ahmed J, Alvarez EV, Allan D, McClure E, Jay JL: The detection of glaucomatous visual field loss by oculo-kinetic perimetry: which points are best for screening? Eye 3:727-731, 1989
5. Damato BE, Chyla J, McClure E, Jay JL: A hand-held OKP chart for the screening of glaucoma: preliminary evaluation. Eye 4:632-637, 1990
6. Aulhorn E, Karmeyer K: Frequency distribution in early glaucomatous visual field defects. Doc Ophthalmol 14:75-83, 1977
7. Mutlukan E, Damato BE: The dark perimetric stimulus. Br J Ophthalmol 76:264-267, 1992

Assessment of usefulness of hand-held oculo-kinetic perimetry

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Abstracts

Oculo-kinetic perimetry (OKP), developed by Damato, is a new and simple method of visual field examination in which the patient's eyes instead of the target move during the examination The authors evaluated OKP in patients with known glaucomatous scotoma and compared OKP results with those obtained by conventional kinetic Goldmann perimetry to assess its usefulness in detecting visual field defects. No visual field defect was detected at Aulhorn stages 0-1 or 1 using OKP Of three eyes at stage 2, two were found to be positive using OKP. Glaucomatous visual field defects were successfully detected using OKP in all 14 eyes at stages 3 or 4. In stage 0-1 to stage 4 eyes, the sensitivity of OKP was 80% and the specificity was 100% The detection threshold of OKP is presumably comparable to the I-4 or I-3 stimulus of the Goldmann perimeter. OKP may be a useful tool for the screening of glaucoma

Introduction

A recent nation-wide mass screening study of the incidence of glaucoma revealed it to occur in 3.8% of the total population of Japan[1]. Although visual field testing is essential for glaucoma screening, conventional methods of visual field testing, such as Goldmann perimetry, require skilled technicians and are time-consuming. Although some automated visual field analyzers do not require an experienced operator, they are so expensive that their usefulness in mass screening is limited. Oculo-kinetic perimetry (OKP) developed by Damato, is an inexpensive and easy-to-use method. However, there are few reports regarding the usefulness of OKP in glaucoma screening. We evaluated OKP in patients with known glaucomatous scotoma and compared OKP results with those obtained by conventional kinetic Goldmann perimetry to assess its usefulness in detecting visual field defects.

Material and methods

Patients

Fifty-one eyes of 30 patients (21 males and nine females) with a mean age of 56.3 years (age range: 16-73 years) were studied. The patients were selected from among those who visited the Glaucoma Clinic of Miyazaki Medical College. Patients with ocular diseases other than glaucoma were excluded from the study. Studied eyes included 20 eyes with primary open angle glaucoma, six with chronic angle closure glaucoma, six with normal tension glaucoma, nine with secondary glaucoma, two with congenital glaucoma and eight with ocular hypertension. The results of Goldmann perimetry were classified according to Aulhorn's classification modified by Greve *et al.*[2].

Oculo-kinetic visual field test

The procedure was essentially the same as that reported by Damato *et al.*[3]. The patient was seated at a desk with one eye occluded, wearing appropriate glasses or contact lenses. We

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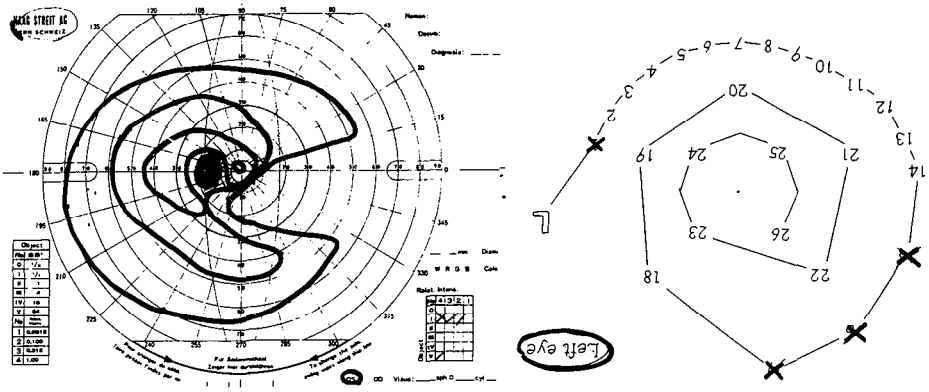

Fig. 1 Visual field test results in a 14-year-old girl with primary open angle glaucoma. OKP results are inverted to facilitate comparison with Goldmann perimetry results. The blind spot revealed by OKP is the same as that revealed by Goldmann perimetry.

ensured that the room lighting was adequate and that there was no on-coming bright light which might cause glare. The examiner, seated in front of the patient to observe both eyes, always the right eye first, so that any fatigue effect in the second eye examined could easily be identified. A patch was placed in the patient's left hand and the right edge of the chart in the right. The patient was asked to cover the left eye by holding the patch, folded inwards, against the closed eyelid or against the spectacle lens. It was then confirmed that both the patient's head and the chart were not tilted. The position of the chart was adjusted so that it faced the patient squarely with the stimulus located directly in front of the right eye at a distance of 40 cm. The patient was then asked to look at the letter "R" and to state whether the central 1.5 mm black stimulus was visible. When the spot in the blind spot had disappeared the test was started. The patient was asked to look at each number in turn, from 1 to 26, reading the number aloud and saying "yes" when the spot was seen, and "no" when it was not. The chart was then flipped over and used for the left eye with the same method. Any numbers associated with disappearance of the stimulus were recorded on a miniature version of the chart on a record sheet. The test was positive if any point was consistently missed. Fig. 1 shows an example of the relationship between Goldmann perimetry and OKP results.

Results

The minimal visual acuity that could be examined with OKP was 0.09. All patients who started the OKP and Goldmann perimetry examinations were able to complete them.

Comparison of Goldmann perimetry and OKP results

Fig. 2 shows the rate at which visual field defects were successfully detected using OKP in eyes grouped according to Aulhorn's classification. No visual field defect was detected in Aulhorn stages 0-1 or 1 using OKP. Of three eyes at stage 2, two were found to be positive using OKP. Glaucomatous visual field defects were successfully detected using OKP in all 14 eyes at stages 3 or 4. In two stage 5 eyes, the center stimulus was not recognized in one, and visual field defects were detected in the other. OKP could not be performed in eight eyes at stage 6 as the center stimulus could not be recognized.

Specificity and sensitivity

In 17 eyes at stages 0-1 to 4, the sensitivity of OKP was 80% and the specificity was 100%.

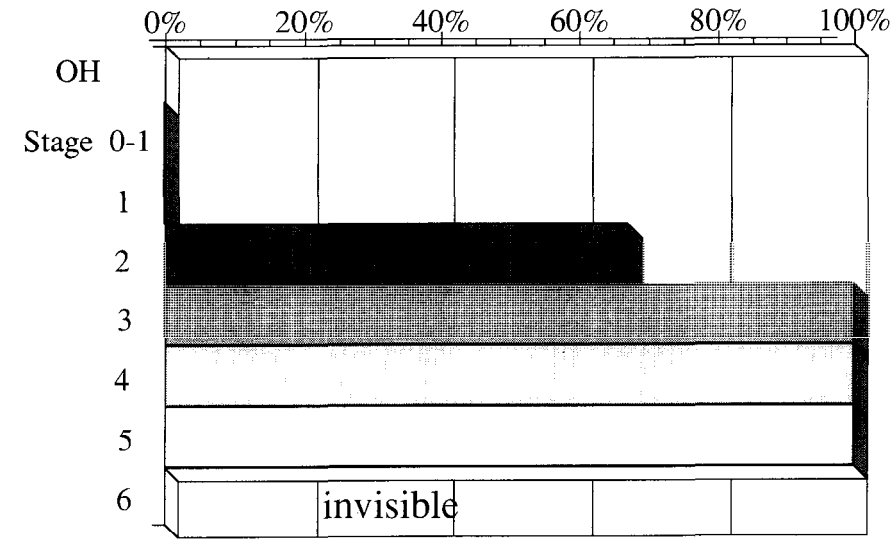

Fig. 2. OKP positive rate in Aulhorn's classification.

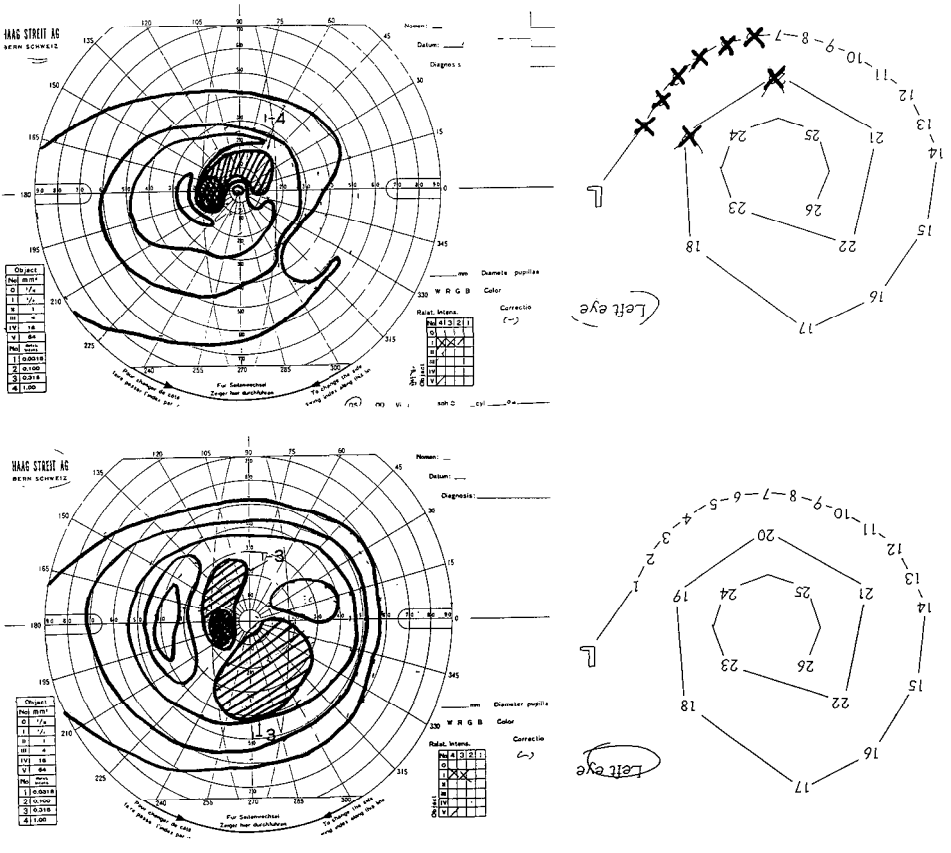

Fig. 3. In both these patients a scotoma was revealed by Goldmann perimetry; however, OKP results were only positive in patient 1 (above). Note that the isopter consistent with the scotoma of patient 1 is I-4 while that of patient 2 (below) is I-3.

Detection threshold of OKP

Fig. 3 shows the OKP results for two patients with scotoma in the Bjerrum area. OKP revealed visual field defects in patient 1 but not in patient 2. The visual acuity of both patients was 1.2. OKP revealed a scotoma consisting of isopter I-4 in patient 1, while it did not reveal one consisting of isopter I-3 in patient 2. OKP also revealed a scotoma consisting of isopter I-4 in another patient. These results suggest that the detection threshold of OKP is presumably comparable to the I-4 or I-1 stimulus of the Goldmann perimeter.

Discussion

In 1985, Damato developed a simple, inexpensive, easy-to-use new method of perimetry[4,5]. It was referred to as "oculo-kinetic perimetry" because it was the subject's eye rather than the test target that moved. It initially consisted of a black tangent screen on which the numbers 1 to 100 were arranged around a central white stimulus. Alverez *et al.* examined 67 eyes of 37 patients and investigated the usefulness of OKP by the method of comparing the results with those of Dicon 3000 static perimetry and Tübingen kinetic perimetry[6]. The results were identical in 88% of eyes tested and approximately comparable in another 6%. They later suggested that OKP was a useful tool for the measurement of visual field defects in neuro-ophthalmic practice and that its wide potential application should be recognized[7]. Thereafter, Damato *et al.* identified a small subset of points on this chart which were not detected specifically by the glaucomatous eye[8], and developed a more simplified OKP[9]. We investigated the usefulness of this simplified hand-held OKP. Damato *et al.* reported that the hand-held OKP test was positive in 93% of 27 eyes with a glaucomatous defect[8]. Suyama *et al.*[9] evaluated the central visual field within 15 degrees from the point of fixation in 25 eyes with glaucomatous visual field defect using OKP combined with conventional kinetic Goldmann perimetry and static Humphrey automated perimetry. They reported that the findings obtained with OKP were identical to those with conventional visual field tests in all eyes.

We compared the detection rate of glaucomatous visual field detect with OKP with that with Goldmann perimetry. OKP was negative in all eyes which showed no visual field defect with Goldmann perimetry. OKP was also negative in all eyes at Aulhorn stages 0-1 or 1. These results suggest that OKP is not a more sensitive test than Goldmann perimetry. Although Damato reported that in some cases OKP results were positive in eyes in which Goldmann perimetry results were negative[8], we did not observe this. OKP had a sensitivity of 67% in the detection of scotoma in eyes at Aulhorn stage 2, and of 100% in eyes at Aulhorn stage 3 or higher. In our patients with early or intermediate-stage glaucoma (Aulhorn stages 0-1 to 4), the sensitivity of OKP was 80% and the specificity 100%. These results suggests that OKP is sufficiently sensitive and specific for glaucoma screening and that it is accurate despite its simple design. However, it should be kept in mind that the sensitivity of OKP is limited and that glaucoma in eyes at Aulhorn stages 0-1 to 2 may not be detected with OKP. Our experience suggests that OKP is an easy-to-use test, the total examination time is only three minutes and that the directions are easily understood by patients. However, the device itself requires improvement, since it is easily damaged by frequent use.

References

1. Shiose Y, Kitazawa Y, Tsukahara S et al: Epidemiology of glaucoma in Japan: a nationwide glaucoma survey. Jpn J Ophthalmol 35:133-155, 1991
2. Greve EL, Langerhorst CT et al: Perimetry and other visual function tests in glaucoma. In: Cairns JE (ed) Glaucoma, Vol 1. London: Grune & Stratton Publ 1986
3. Damato BE, Chyla J, McClure E et al: A hand-held OKP chart for the screening of glaucoma: preliminary evaluation. Eye 4:632-637, 1990
4. Damato BE: Oculokinetic perimetry: a simple visual field test for use in the community. Br J Ophthalmol 69:927-931, 1985
5. Damato BE: Assessment of the visual field by anyone, anywhere and at any time. Trans Ophthalmol Soc UK 104:681-685, 1985

6. Alvarez E, Damato BE, Jay JL et al: Comparative evaluation of oculokinetic perimetry and conventional perimetry in glaucoma. Br J Ophthalmol 72:258-262, 1988
7. Alvarez E, Damato BE, Wakakura M et al: Oculokinetic perimetry: a visual field test for neuro-ophthalmic patients. Neuro-Ophthalmol 8:23-30, 1988
8. Damato BE, Ahmed J, Allan E et al: The detection of glaucomatous visual field defects by oculokinetic perimetry: which points are best for screening? Eye 3:727-739, 1989
9. Suyama H, Wakakura M et al: Oculokinetic perimetry for glaucoma Jpn J Clin Ophthalmol 45:179-183, 1991

Clinical evaluation of the oculo-kinetic perimetry glaucoma screener

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Abstract

The ability of the oculo-kinetic perimetry (OKP) glaucoma screener to detect glaucomatous visual field loss was evaluated. OKP was used to examine 60 normal subjects, and 60 glaucoma patients with a glaucomatous visual field loss demonstrated with the central 30-2 program of the Humphrey Field Analyzer (HFA). The HFA was also used to measure thresholds at the same test locations used by OKP, in order to estimate the depth of field loss which could be detected by OKP No defects were found in any of the normal eyes with either OKP or HFA 30-2, thus giving a specificity of 100% for both instruments in our sample of normal subjects. On average, the sensitivity of OKP was 78.4% in our sample of glaucoma patients. While OKP detected defects in all glaucomatous eyes with moderate or advanced defects, it failed to detect abnormalities in more than half the eyes identified by HFA as having early defects. The 50th and 95th percentiles of sensitivity loss demonstrable with OKP were 24 dB and 34 dB, respectively. The authors conclude that the ability of OKP to detect early glaucomatous visual field loss is rather limited.

Introduction

Oculo-kinetic perimetry is a simple perimetric screening method developed by Damato in which the patient fixates a number of locations in turn, and reports whether a single fixed stimulus can be seen[1]. The technique lends itself to implementation in the simplest of formats,

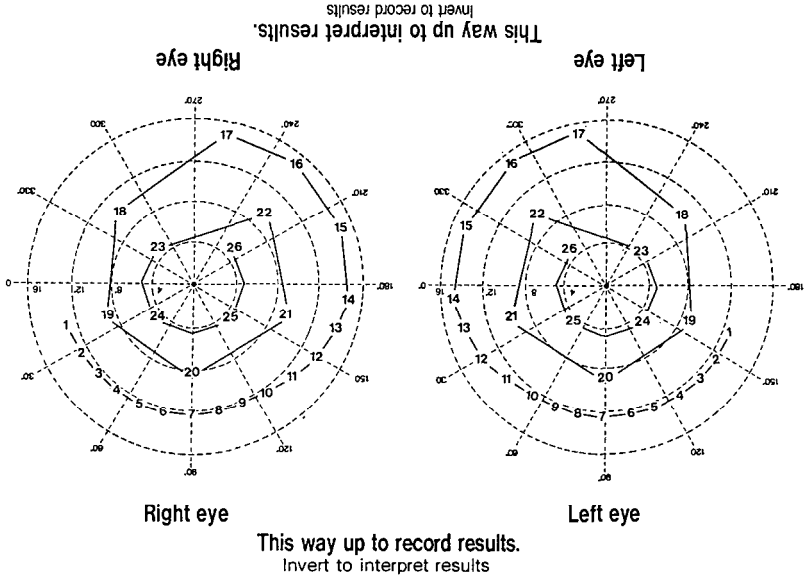

Fig. 1. The chart of the OKP glaucoma screener.

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e.g., a white card on which the fixation points and the single stimulus points are printed in blue ink, and thus might be useful in population studies (Fig. 1).

In this study, we examined normal subjects and glaucoma patients with the OKP glaucoma screener in which examination points are restricted to 26 locations where glaucomatous visual field defects frequently occur, and compared the results with those obtained with Humphrey threshold perimetry.

Subjects and methods

The subjects of this study were 60 eyes of 60 glaucoma patients and 60 eyes of 60 normal subjects. The glaucoma patients consisted of 27 eyes of 27 primary open angle glaucoma (POAG), and 33 eyes of 33 normal tension glaucoma (NTG). They had been followed up at the Glaucoma Service of the Department of Ophthalmology, Gifu University Hospital and Tajimi Municipal Hospital. The diagnostic criteria for NTG were as follows: maximum intraocular pressure equal to or below 21 mmHg, normal open angle, visual field defects corresponding to glaucomatous optic disc atrophy, and no other systemic or ocular diseases which might cause field defects. The normal subjects were determined according to the following criteria: refractive error of less than ±3 diopters in spherical equivalent, corrected visual acuity equal to or better than 0.7, no ocular abnormality found by routine examination, and no history of systemic disease which might bring about field defects. The mean age of the glaucoma patients and the normal subjects was 58.6 ± 12.3 years and 40.0 ± 13.2 years, respectively (Table 1). All subjects were examined with the OKP glaucoma screener and the threshold program central 30-2 of the Humphrey Field Analyzer (HFA 30-2) on the same day. The results of the HFA 30-2 were classified according to the Aulhorn-Greve classification. Furthermore, we examined the subjects using the newly developed program of HFA, which enables us to measure the thresholds of the 26 points located as the OKP test points. We provisionally named this program OKP-HFA.

In order to compare OKP and HFA 30-2 results, we divided the field into four quadrants. When visual field defects detected with HFA were found with OKP in the same quadrants, we called this "agreed". If OKP demonstrated only a part of the defects in, at least, one identical quadrant, we called this "partly agreed". If no field defects were detected by OKP, or when the

Table 1. Clinical background

	Male/Female	*Age (years)*	*Corrected visual acuity*
Glaucoma patients	31/29	58.6±12 3*	≥0.7
Normal subjects	31/29	40.0±13.2*	≥0.7

*mean ±SD

Table 2. The ratio of location agreement

	0-I	*I*	*II*	*III*	*IV*	*V*	*Total*
Agreed	0	1 (14 3)	4 (36.4)	9 (64.3)	6 (54.5)	8 (66.7)	26 (46.7)
Partly agreed	1 (20)	1 (14.3)	3 (27.2)	5 (35.7)	5 (45.5)	4 (33.3)	19 (31.7)
Disagreed	4 (80)	5 (71.4)	4 (36.4)	0	0	0	13 (21.6)
Total	5 (100)	7 (100)	11 (100)	14 (100)	11 (100)	12 (100)	60

Eyes; ( ):%

Table 3. Sensitivity loss demonstrable with OKP (dB)

5th percentile	*50th percentile*	*95th percentile*
7	24	34

defects were located in different quadrants, we called this "disagreed". With HFA 30-2, the stimulus points with a probability symbol of less than 2% were defined as abnormal. Then, we determined the degree of sensitivity loss demonstrable with OKP by means of the program OKP-HFA.

Results

No defects were detected in any of the normal eyes at any examination. Hence, the specificity of OKP was 100%. The ratio of location agreement between OKP and HFA 30-2, which was estimated by combining "agreed" and "partly agreed", was 20% in stage 0-I, 28.6% in stage I, 63.6% in stage II and 100% in stage III or worse. When HFA 30-2 results were taken as the gold standard, and the rates of "agreed" and "partly agreed" were combined, the sensitivity of OKP was 78.4% (Table 2). The 50th and 95th percentile of sensitivity losses demonstrable with OKP were 24 dB and 34 dB, respectively (Table 3).

Discussion

In this study, we found that the specificity of the OKP glaucoma screener was 100%, and its sensitivity was 78.4%. Further, we found that the 95th percentile value of sensitivity loss demonstrable with OKP was estimated to be 34 dB. The OKP glaucoma screener seems to be an effective means of detecting moderately advanced glaucomatous field changes, but seems to be of little help in detecting early field changes accurately. Therefore, the ability of the OKP glaucoma screener to detect glaucomatous visual defects in general is rather limited.

References

1. Damato BE: Oculokinetic perimetry: a simple visual field test for use in the community Br J Ophthalmol 69:927-931, 1985
2. Alvarez E, Damato BE, Jay JL, McClure E: Comparative evaluation of oculokinetic perimetry and conventional perimetry in glaucoma. Br J Ophthalmol 72:258-262, 1988
3. Damato BE, Ahmed J, Allan D, McClure E, Jay JL: The detection of glaucomatous visual field defects by oculo-kinetic perimetry: which points are best for screening? Eye 3:727-731, 1989
4. Damato BE, Chyla J, McClure E, Jay JL, Allan D: A hand-held OKP chart for the screening of glaucoma: preliminary evaluation. Eye 4:632-637, 1990
5. Maeda M, Tomita G, Kitazawa Y: Detection of glaucomatous visual field defects with the oculo-kinetic perimetry glaucoma screener. J Eye 9:819-822, 1992
6. Iwase A: Clinical evaluation of oculo-kinetic perimetry glaucoma screener. J Eye 9:1241-1244, 1992

Computer-assisted moving eye campimetry

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Abstract

Computer-assisted moving eye campimetry (CAMEC) uses a moving fixation target and grey stimuli on a white background to enable the visual field to be examined by means of a standard desk-top computer. The test procedure is designed for patients who cannot cope with conventional oculo-static perimetry. The initial results show that CAMEC is both user-friendly and sensitive. CAMEC may allow automated perimetry to become more widely available than is currently possible with implications for the detection and monitoring of diseases such as glaucoma.

Introduction

The use of a standard computer screen for visual field examination is limited by the small screen size and the lack of an effective method of monitoring the patient's direction of gaze, particularly in children. We have therefore developed a computerized visual field analyzer which overcomes both these obstacles by means of a moving fixation target, which must be successfully maintained within a circle, the circle being moved by the patient using a mouse or joystick[1]. The visual field analyzer, which is called computer-assisted moving eye campimetry (CAMEC), is intended for children as well as adults and therefore includes features designed to maintain interest and cooperation. CAMEC also includes special modules that teach the patient how to perform the examination so that the program may be used in situations where experienced perimetrists are not available.

The aim of this article is to describe CAMEC and to demonstrate its potential by presenting an illustrative result.

Material and methods

CAMEC operates on a standard IBM-compatible computer with an VGA graphics screen and fitted with a head-rest, a joystick, and an audio card for computer speech. In addition, a Microsoft Works spreadsheet is used for designing test strategies and other variables.

When CAMEC is not in use, the computer screen shows a picture of an eye with a printed message to press the button on the joystick to start the examination. When this is done, the computer, by means of pictures, auditory commands and printed phrases, instructs the patient to place the forehead against the head-rest and to cover one eye. Once the patient signals readiness to commence the examination, the computer displays a spot and a circle in different parts of the screen and instructs the patient to move the circle over the spot using the joystick. When this is achieved, the spot starts to meander around the screen and the patient is advised to keep the circle over the spot; this allows the computer to adjust the speed of the spot according to the patient's ability. Once the patient has learned how to track the moving fixation target,

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successive stimuli appear and the patient is instructed to signal awareness of their presence by pressing the button on the joystick. Successful completion of this program indicates that the patient is sufficiently cooperative for CAMEC and the examination begins; otherwise the procedure is aborted and the patient is advised to seek assistance.

A variety of test strategies has been developed. A general purpose examination commences with a screening test, in which 26 points in the central 30 degree field are examined. If any points are consistently missed on retesting, then additional points are tested between seen and missed points. Another program measures the depth of any defect by means of an ascending staircase technique with stimuli of increasing negative contrast (Mutlukan, in press).

By independently adjusting the intensity of the red, green and blue colors of the computer screen through 64 levels for each color, it is possible to have a wide variety of colors and contrast levels; however, we prefer grey stimuli of varying contrast on a white background. A special module allows stimulus color and background to be viewed and calibrated.

When examination of the first eye is completed, the patient is instructed to cover the second eye and to press the joystick button to resume the examination. At the end of the test, the results are displayed on screen, saved on disc for subsequent display or analysis, and printed on paper. A special module allows symbols for up to 16 different stimuli to be designed.

A number of safeguards have been developed to cope with loss of cooperation. If the patient looks away from the fixation target, then the spot escapes from the circle and CAMEC "says" to the patient "please keep the circle over the spot" while the presentation of further stimuli is delayed until cooperation is regained. If the patient attempts to cheat by pressing the joystick button prematurely, then CAMEC "says" "please do not guess" and stimulus presentations are postponed. False positive and negative results are recorded as well as the duration of the examination.

Example

Fig. 1 shows a homonymous quadrantanopia in a six-year-old boy with a head injury, which had been successfully demonstrated with CAMEC at the first attempt. After an initial screening test, additional points were automatically examined between normal and abnormal areas. Goldmann perimetry, performed by an experienced examiner, was unsuccessful. CAMEC allows the use of grey stimuli on a white background, of varying contrast. The software allows the user to define a wide range of stimuli and corresponding symbols.

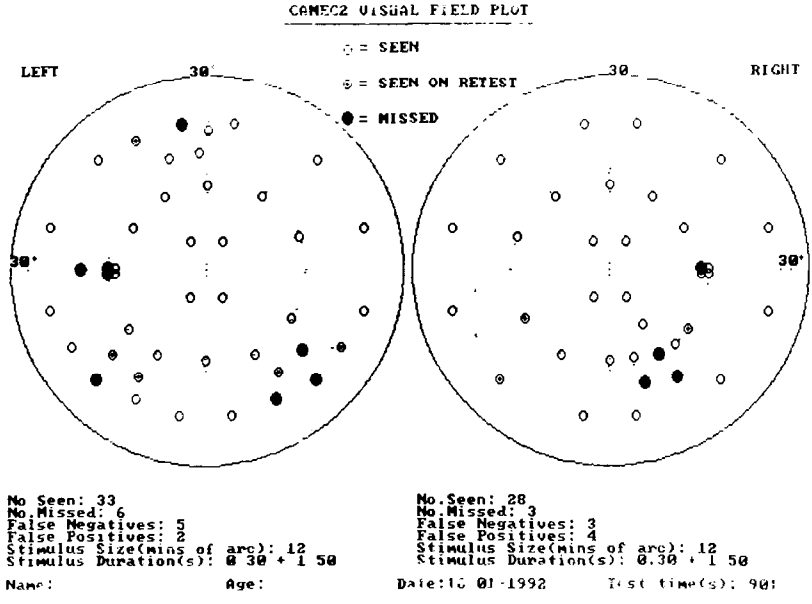

Fig. 1. Homonymous quadrantanopia detected with CAMEC in a six-year-old boy with a head injury, who could not be examined with Goldmann perimetry.

Discussion

The example in this article show that CAMEC produces satisfactory results, despite the use of a standard computer screen and a moving fixation target.

The moving fixation target does not reduce the resolution of the visual field test significantly and enables successful results to be obtained in patients who cannot cooperate with conventional "oculo-static" perimetry. The speed of the fixation target must be well adjusted according to the patient's abilities; otherwise, problems with cheating and fatigue will occur.

The ability to perform accurate automated perimetry on standard desk-top, lap-top, and notebook computers could be useful in two situations in particular. Firstly, CAMEC may provide a practical method of screening for glaucoma and other diseases in places such as family general practice clinics in the community and hospital waiting rooms. For situations where there is insufficient skill for the interpretation of the results, we are working to provide CAMEC with diagnostic capability by using a neural network system. Secondly, CAMEC may enable selected patients with known visual field loss to perform regular automated perimetry, at monthly intervals for example, either in their own home or at the ophthalmic clinic on a non-appointment basis. Such a strategy may allow more rapid detection of visual field loss than is currently possible with restricted clinic visits, especially if suitable statistical methods are used.

In conclusion, by using a moving fixation target and grey stimuli, CAMEC allows sensitive visual field examination to be performed using inexpensive equipment, not only in highly skilled patients, but also in many individuals who cannot be examined conventionally.

References

1. Johnston SC, Damato BE, Evans AL, Allan D: Computerized visual field test for children using multiple moving fixation targets. Med Biol Eng Comput 27:612-616, 1989

Subjective detection of glaucomatous visual field defects using a home TV set

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Abstract

The usefulness of the noise-field test (NFT), which utilizes the noise-field spontaneously generated on a home television screen for subjective perception of visual field defects, was evaluated in 400 eyes of patients with primary open angle glaucoma or normal tension glaucoma and in 300 normal eyes. No subject had ever perceived their field defect. In glaucoma eyes, 359 eyes (89.8%) could perceive abnormality of the noise-field which corresponded with the visual field defects confirmed by static perimetry. In 19 normal eyes, abnormality of the noise-field was perceived. The sensitivity and specificity of the test were 90% and 94%, respectively In the subsequent comparative study between NFT and Tübingen electric campimetry (TEC) performed in 136 eyes with glaucoma and 114 eyes with normal visual fields, the sensitivity of NFT, TEC (fine) and TEC (coarse) was 85.3%, 82.9% and 79.3%, respectively. The specificity was 88.6%, 78.9% and 82.5%, respectively. These results indicate that NFT using a home television set is an excellent method for the subjective perception of visual field defects and will be very useful in glaucoma screening.

Introduction

Glaucoma patients do not usually perceive their field defects until the advanced stages. However, recognition of their visual field defects is important in improving the medical compliance of glaucoma patients. Since 1990, we have reported on the usefulness of the noise-field spontaneously generated on a home television screen for subjective perception of glaucomatous visual field defects (VFD). We have named the test the noise-field test (NFT)[1-6].

We report here the results of the use of NFT in 400 eyes of patients with glaucoma and the results of a comparative study between NFT and Tübingen electric campimetry (TEC), which utilizes the noise-field generated by a computer program on a monitor screen.

Material and methods

Four hundred eyes of 241 primary open angle glaucoma or normal tension glaucoma patients and 300 eyes of 150 ocular hypertensives or normals were examined using NFT. In the comparative study between NFT and TEC, 136 glaucoma eyes and 114 eyes with a normal field were examined. With TEC, two checkered patterns, *i.e.*, fine and coarse, were tested. No glaucoma patients had ever perceived their visual field defects in their daily life or even under the conditions of monocular viewing. The grade of the visual field defects were evaluated by Aulhorn's classification as modified by Greve *et al.*[7]. Ocular hypertensives and normals were confirmed not to have any field defects by the Humphrey Visual Field Analyzer (program 30-2). Age and visual acuity of the subjects are shown in Table 1.

The testing method of NFT has been reported elsewhere[1-6]. Briefly, the noise-field spontaneously generated on a 21-inch television screen (Sony KV-21XBR1, or Victor kk-21, Tokyo) through a non-transmitting channel was utilized. The test field of the screen is a rectangle 34 cm long and 30 cm high, subtending a visual field of 33.7 angle degrees in the horizontal and 26.5 angle degrees in the vertical direction from a distance of 30 cm. As a fixation point, a white spot with a diameter of 5 mm was affixed to the center of the screen.

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Table 1. Age and visual acuity of subjects

	No. of eyes	*Age (years)*	*Visual acuity*
POAG or NTG	400	57.8±12.3	0.7±0.2
OH or normals	300	52.5±12.8	0.8±0.2

Mean ±SD POAG: primary open angle glaucoma; NTG: normal tension glaucoma; OH: ocular hypertensives

The subjects, with one eye occluded, were requested to look at the center of the screen from a distance of 30 cm for three to five seconds, checking to see whether there was an area different from the surround. The test was performed three times for each eye and when the subjects successively perceived any abnormal area on the noise-field, they were asked to draw a picture of that area on paper. The examiners (MA and medical staff) were not aware of the visual fields of the subjects. The test method for TEC was the same as for NFT. Both tests were performed on the same day in different rooms. NFT was performed prior to TEC. Different examiners were used for NFT and TEC and the examiner for TEC was not aware of the results of NFT.

Judgment of the correspondence of the results of NFT with the findings using the Humphrey perimeter program 30-2 was classified into five categories as follows:

1. "good correspondence": the drawn area corresponds to the field defects detected by static perimetry in size and position;
2. "acceptable correspondence": the drawn area corresponds to all or part of the field defects in its position;
3. "poor correspondence": the area corresponds to all or part of the field defects in its position, but another abnormal area is also perceived in the noise-field;
4. "no correspondence": the area is detected incorrectly;
5. no detection": the subject does not perceive any abnormality in the noise-field.

Judgment was performed by the authors and the lowest evaluation was adopted.

Results

In the 400 eyes of patients with glaucoma, 359 eyes perceived an abnormal area corresponding to all or part of the field defects. In the 300 eyes with a normal visual field, 19 eyes perceived an abnormal area on the screen (false positive). The sensitivity and specificity of NFT were calculated as 89.8% and 93.7%, respectively. According to the visual field classification, false negative responses in glaucoma patients were found in 44% and 29% of the eyes with field defects of grades 0 and I, respectively. With grade II, the false negative response was only 7.9%. With grades III, IV and V, all patients could perceive the abnormality in the noise-field corresponding to part of or all their field defects (Table 2).

In the comparative study between NFT and TEC, the detection rate of the field defects was

Table 2. Results of noise-field test in glaucoma and normal or ocular hypertensive (OH) subjects (no. of eyes)

*Classification**	*Correspondence*					*Total*
	good	*acceptable*	*poor*	*none*	*not detected*	
0	13	0	2	2	10	27
I	38	3	9	4	16	70
II	89	8	8	3	6	114
III	58	4	4	0	0	66
IV	50	6	4	0	0	60
V	40	19	4	0	0	63
Total	288	40	31	9	32	400
OH or normals	0	0	0	19	281	300

See text for definition of different grades of correspondence; *Aulhorn's visual field classification modified by Greve *et al.*[7]

always higher with NFT except for grade I visual field defects. With grade I, the sensitivity of NFT was equal to that of TEC (fine). With TEC, the fine checkered pattern had detection rates equal to or higher than the coarse pattern except for grade IV field defects. False positive responses in eyes with a normal visual field on NFT, TEC (fine) and TEC (coarse) were 11.4%, 21.1% and 17.5%, respectively (Tables 3 and 4).

Table 3. Results of noise-field test in 250 eyes: comparative study with Tübingen electric campimetry (no. of eyes)

*Classification**	*Correspondence*					*Total*
	good	*acceptable*	*poor*	*none*	*not detected*	
0	4	0	0	0	3	7
I	5	0	3	0	10	18
II	36	1	5	0	7	49
III	21	2	1	0	0	24
IV	12	1	1	0	0	14
V	18	4	2	0	0	24
Total	96	8	12	0	20	136
OH** or normals	0	0	0	13	101	114

See text for definition of different grades of correspondence; *Aulhorn's visual field classification modified by Greve *et al.*[7]; **ocular hypertension

Table 4. Results of Tübingen electric campimetry in 250 eyes: comparative study with noise-field test (no of eyes)

*Classification**	*Correspondence*									
	good		*acceptable*		*poor*		*none*		*not detected*	
	F[#]	*C*[#]	*F*	*C*	*F*	*C*	*F*	*C*	*F*	*C*
0	2	2	0	0	0	0	2	0	3	5
I	6	4	1	2	1	1	3	3	7	8
II	18	17	9	11	6	4	7	4	9	13
III	10	7	10	12	2	0	2	0	0	5
IV	9	6	0	3	4	5	1	0	0	0
V	10	8	12	13	2	2	0	0	0	1
Total	55	44	32	41	15	12	15	7	19	32
OH** or normals	0	0	0	0	0	0	24	20	90	94

See text for definition of different grades of correspondence; *Aulhorn's visual field classification modified by Greve *et al.*[7]; **ocular hypertension; [#]fine (F) or coarse (C) checkered pattern in TEC

Discussion

The present study shows the usefulness of NFT in the subjective perception of visual field defects in glaucoma. In 1989, Aulhorn *et al.* reported that all 214 visual field defects caused by infrageniculate lesion were perceived, except for the blind spot and congenital defects, by using the noise-field generated by a computer program on a computer monitor screen[8]. Our study confirms their results that pathological field defects can be perceived on a field of flickering small black-and-white random dots. However, in our study not all glaucoma patients could perceive their field defects. Even though all patients with field defects higher than grade III could perceive an abnormal area on the noise-field corresponding to all or part of their field defects, false negative responses were found in 44%, 29% and 7.9% of eyes with field defects of grades 0, I and II, respectively. Even in other glaucoma studies using TEC, developed by Aulhorn, the false negative responses were found to be 8.2% or 45% in the fine checkered pattern and 6.5% or 41.7% in the coarse checkered pattern[9,10]. Although some of these differences in false negative responses could have been caused by the difference in the number of

eyes included in each grade of visual field defects, it is clear that not all glaucoma patients could perceive their field defects in a noise-field generated spontaneously or by a computer program.

To our knowledge, this is the first report in which the reliability of TEC and NFT is compared in the same patients. In this study, the detection rate of glaucomatous visual field defects by NFT was always higher than by TEC in every grade of VFD, except for the grade I field defects in which the sensitivity of TEC (fine) was equal to that of NFT. On the contrary, the specificity of NFT was then lower. The causes for these differences in the assessment of the two test methods are not clear. In the present study, NFT was performed prior to TEC. Since the patients had never perceived their VFD until NFT, and TEC was performed on the patients after they had perceived their VFD by NFT, the order of the examinations was considered to be favorable for TEC.

The differences in the flickering pattern or frequency of the noise between a home television set and a computer monitor might also have influenced the results. In TEC, even though the flickering frequency of luminous intensity of each part of the checkered pattern is random, the size of the checkered pattern is fixed. On the other hand, with NFT, black-and-white dots, which are random in size and flickering frequency, appear on the screen through electric thermal noise.

In conclusion, the results of our study show that the Noise-Field Test using a home TV set has high sensitivity and specificity as a method for subjective perception of the visual field defects in glaucoma.

These results indicate that the noise-field test is a good self-screening method for glaucoma which can be easily performed at home. It is a good method to enable glaucoma patients to realize visual field defects which are difficult to recognize in daily life, even after explanation by an ophthalmologist.

References

1 Shirato S, Adachi M, Hara T: Subjective detection of visual field defects using home TV. Gannka (Ophthalmology) 32:1321-1326, 1990
2. Shirato S, Adachi M, Hara T: Subjective detection of visual field defects using home TV set. Jpn J Ophthalmol 35:273-281, 1991
3. Adachi M, Shirato S: The usefulness of noise-field test as a visual field screening method in primary health care system. Rinsho-gannka (Jpn J Clin Ophthalmol) 46:336-337, 1992
4. Adachi M, Shirato S: Subjective detection of visual field defect using the noise-field on a home TV set in low-tension glaucoma Nihon-gankagakkai-zasshi (Acta Soc Ophthalmol Jpn) 96:492-495, 1992
5. Tagawa I, Adachi M, Shirato S: Precision of noise-field test in subjective detection of early glaucomatous visual field defect. Rinsho-gannka (Jpn J Clin Ophthalmol) 46:455-457, 1992
6. Adachi M, Shirato S: Visual field defects not detected by the noise-field test. Rinsho-gannka (Jpn J Clin Ophthalmol) 46:1307-1311, 1992
7. Greve EL, Langerhorst CT, Van den Berg TTJP: Perimetry and other function tests in glaucoma. In: Cairns JE (ed), Glaucoma, pp 37-77. London: Grune & Stratton 1986
8. Aulhorn E, Köst G: Noise-field campimetry: a new perimetric method (snow campimetry). In: Heijl A (ed) Perimetry Update 1988/89, pp 331-336. Amsterdam: Kugler Publ 1989
9 Sogano S, Maeda M, Matsushita H, Iwase A: Detection of glaucomatous visual field defects with noise-field campimeter. Atarashii-gannka (J Eye) 8:1493-1496, 1991
10 Uyama K, Okuyama S, Matumoto C, Otori T: Evaluation of clinical usefulness of noise-field campimetry in glaucoma patients. Atarashii-gannka (J Eye) 9:1035-1039, 1992

Preliminary report on the use of laptop computer perimetry with a motion sensitivity screening test to detect optic nerve disease in onchocercal communities of rural Nigeria

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Abstract

Following a successful study using laptop computer perimetry with a motion sensitivity screening test (MSST) to detect early glaucoma in the UK, MSST was tried out on rural Nigerian people (largely illiterate) in a randomized controlled trial of annual ivermectin for onchocerciasis, during 1991 and 1992. The aim of this study was to assess the acceptability and reproducibility of MSST as a screening test to detect optic nerve disease and other causes of visual impairment. Three MSSTs each controlled by a Sharp notebook computer with 10″ liquid crystal display were used by trained village helpers Twelve hundred and seventy-four subjects were examined, and 123 (202 eyes) were retested. Results show that there was close inter-observer agreement (78%) and excellent intra-observer agreement (98%). The results show that onchocercal communities had reduced motion sensitivity. The findings on repeating MSST on a sample of only 88 people over one year, show significant improvement from ivermectin: a result which paralle¹s the findings in the whole trial which required three years following 3522 people to prove benefit from ivermectin. The authors conclude that laptop perimetry with MSST has an important value in mass visual function screening from onchocerciases, glaucoma and other causes.

Introduction

Motion sensitivity testing using personal computers has been shown to be useful in measuring glaucomatous visual field loss[1]. Wu *et al.*[2] developed a motion sensitivity screening test (MSST) for mass visual field screening and found that MSST has a high sensitivity and specificity for glaucoma case finding in a hospital based study. More recently, Quigley *et al.*[3] have reported that motion sensitivity test with a laptop computer has a high acceptability in field work. The aim of the present paper is to measure MSST reproducibility as a screening test in rural communities with onchocerciasis in Nigeria. An attempt was also made to find out whether MSST could be used to prove visual benefit from annual ivermectin for controlling onchocerciasis[3].

Methodology

The MSST tests the paracentral field. In onchocercal optic nerve disease the pathogenic process has not been defined, so it could not be assumed that MSST alone would measure central acuity and also peripheral field defects. We therefore combined a computerized visual acuity test (CVAT), a peripheral flash and flicker screening test (PFFST) and MSST into one

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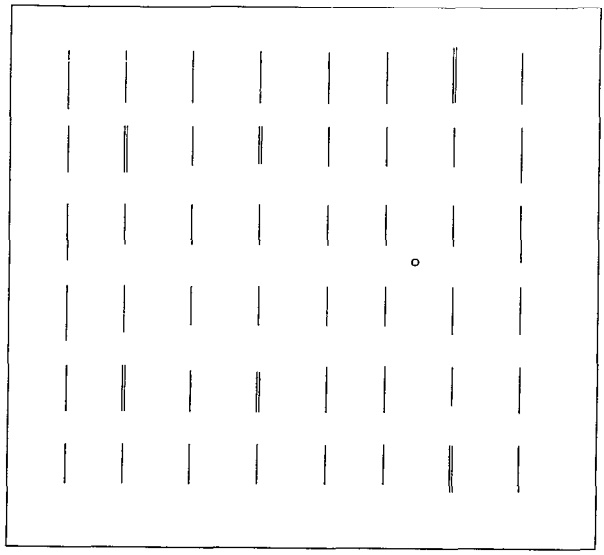

Fig. 1. MSST reference lines on screen arranged around fixation point for right eye. The six tested locations appear as double lines.

system: the Wu-Jones Visual Function Testing System. This has been applied to a substantial sample of individuals in the randomized trial, in parallel with the standard visual function tests and ophthalmic screening examinations[4]. Standard tests were carried out before treatment and after two and three years. MSSTs were performed at the second and third examination. CVATs and PFFSTs were performed at the third examination. This paper gives a preliminary report based on the MSST data. Other data will be published elsewhere.

The MSST is produced on each of three notebook computers with a 10" liquid crystal display (LCD) under control of a 12 mHz Sharp PC6220, using software developed by one of the authors (JW). Contrasts on the three LCDs were calibrated. The display is "paperwhite" triple supertwist technology with backlighting, 16 shades of grey, 640 · 480 pixel resolution, VGA emulation. It weighs only 4.4 pounds and measures 1.4 by 11 by 8.5 inches. With a rechargeable battery package, it can run for three to four hours, making it suitably portable for field work.

The MSST program tested six locations among 48 white reference vertical lines around a fixation circle, corresponding to the central 6 × 8 grid of the HFA 34-2 program (Fig. 1). The size of the vertical lines increases as a function of eccentricity from three pixels to 12 pixels. In a dark room, the maximum illuminance for the reference lines was 413 lux and the illuminance of the background was 200 lux. The contrast was 62% (contrast = (Lmax-Lmin)/(Lmax+Lmin)). The stimulus was presented for a duration of 0.2 seconds. A single amplitude of displacement (four pixels) was tested, which was assumed to be an optimal amplitude for this screening test[5]. The observer was asked to press a button when there was any movement on the screen. If the subject responded within the allowed waiting time, the next presentation was initiated. Each of the test locations were tested seven times. The presentation order for each location was randomized. The initial waiting time for response was 1.75 seconds but it was dynamically modified according to patients' responding time. The limit of waiting time was 2.2 seconds. The time to complete a test in one eye varied from 0.9 to 2.2 minutes for each eye according to response time. The viewing distance from the notebook computer screen was standardized at 40 cm by a chin rest. At the end of each test, the operator was asked to record the test reliability. If the test was unreliable, for instance if the subject stopped responding during the testing, the operator was required to comment.

The results are displayed on the laptop screen and automatically entered onto the hard disc for subsequent transfer to the main computers at base for processing.

Procedure

Testing was sometimes carried out in a school room, but usually MSST was carried out in a village hut. A red light was provided to give dim red light "dark room" conditions to facilitate observation of the patients, movement of other people and recording. Local helpers performed the MSST supervised by a trained worker who was computer literate. They were in charge of data entry, training subjects and pressing the command key to perform MSST. In addition, the helpers were required to monitor subjects' eye movement during the test. MSST provided a checking system to detect data entry error. Home visits with MSST were performed by local helpers under supervision. After introduction of PFFST, the order of the tests changed so that MSST was performed following CVAT and PFFST. With repeats, the testing times were substantially extended to over 20 minutes per eye, so that MSST testing was carried out in conditions of some fatigue.

Intra-observer agreement on MSST was measured by repeating MSST immediately on the same setting. Inter-observer agreement for each subject on MSST was separately measured on two different MSST settings including different computers and different operators but in the same testing room after a five-minute break.

MSSTs were carried out on consenting subjects aged 15 years and over in the Kaduna randomized controlled trial of ivermectin for onchocerciasis, under which all subjects had been taking either ivermectin or placebo annually for three years. MSSTs were performed after standard visual function tests had been carried out by six ophthalmic nurses. It was not possible to perform MSSTs on all those who underwent the nurses' tests, so priority was given to those who failed one or more of the nurses' tests and to a predetermined random sample of the whole trial. This tended to generate a pathology-enriched sample but those subjects who were too blind to test were excluded from the study.

In addition, a population which was not endemic for onchocerciasis (Fatika) with similar ethnic, cultural, educational, geographic and economic backgrounds to the endemic population was examined as a control population. All subjects from the control population had either inter- or intra-observer agreement measured. Approximately 10% of the endemic population were recruited for reproducibility measurement.

Data analysis

Descriptive data analysis was carried out by SPSS[6]. Agreement within and between observers was analyzed using the limits of agreement[7] and intraclass correction coefficient[8]. The choice of the limit of agreement was a matter of correct interpretation of assessing observer variability[9,10]. A plot of the intra-observer agreement against the mean of two observers was produced to illuminate the range of disagreement in the MSST by the retest (Fig. 2). A similar analysis was done for the inter-observer agreement.

The intraclass correlation coefficient is the proportion of the total variability accounted for by the intra- and inter-observer variability. This is useful because the intraclass correlation coefficient is based on comparative results from unstable observers during a psychophysical retest in which the learning effect or fatigue effect could seriously affect the retest results. Thus, a high intraclass correlation coefficient, of say 90%, means that little if any of the variability is due to observer disagreement.

Results

The results given below are preliminary analyses of a total of 1275 individuals (1201 from the endemic population and 74 from the non-endemic population) who were screened by MSST.

For each MSST result, the percent of responses to 36 presentations, from six locations for six retests, was determined. The percentage of motion seen over all six locations for six trials can be varied between 0% (0/36) to 100% (36/36). However, the method of estimating motion sensitivity based on each individual testing point, previously reported[1], will not be given in this paper, because this method is strongly influenced by the fixation status which is questionable in this field study.

One hundred and twelve eyes (71 individuals) were examined twice by three operators each

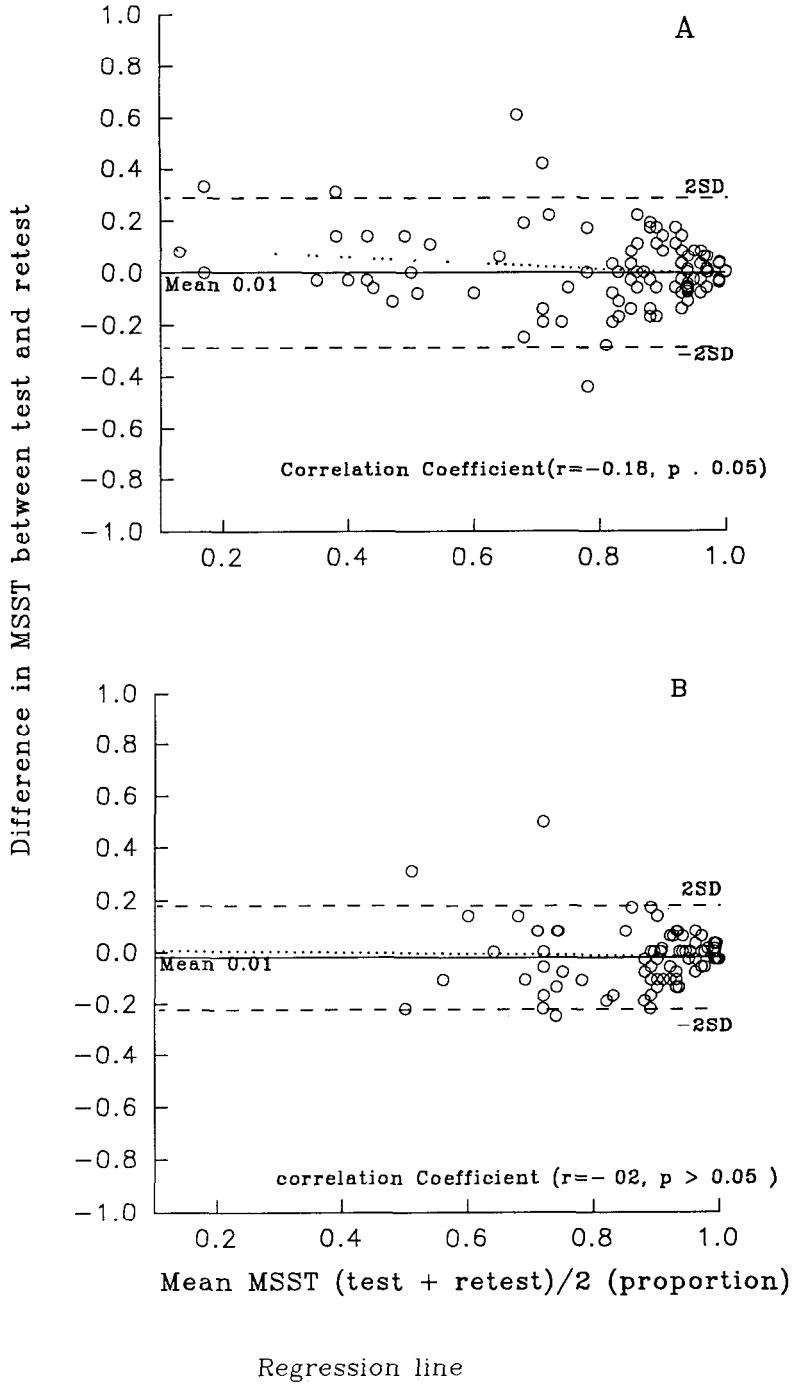

Fig. 2. Range of disagreements in MSST by retesting 40 persons from the control community (Fatika) and 72 from a meso-endemic onchocercal community for intra-observer variation (A) and retesting 92 eyes of 52 persons for inter-observer variation (B).

for intra-observer variation. There were 40 from the control population and 72 from endemic populations. These results are presented in Fig 2. The limits of agreement were from -0.25 to 0.27 in intra-observer agreement (Fig. 2A). The inter-observer agreement, in repeat MSST of 92 eyes of 52 individuals, also showed very good agreement (Fig. 2B). The limits of agreement were from -0.198 to 0.18. The mean differences (test-retest), namely intra- and inter-observation were 0.01 SD 0.13 and -0.02 SD 0.11 as shown in Table 1. For the purpose of British Standard of the test[12], there were six (5.3%) differences of more than 2 SD in intra-observer agreement and three (3.3%) differences of more than 2 SD in the inter-observer agreement. Neither the intra-observer nor inter-observer differences were related to the mean of retest (correlation coefficient $r = -0.026$, $p>0.05$ and $r = -0.181$ $p>0.05$, respectively). The differences were uniform across the whole range of motion sensitivity and were not related to mean. The intraclass correlation coefficients are shown in Table 1.

Table 1. Limits of agreements (LOA) and intraclass correlation coefficients (ICC) of MSST

	Control			*Endemic*			*Total*		
	n	*mean (SD)* *LOA*	*ICC* *%*	*n*	*mean (SD)* *LOA*	*ICC* *%*	*n*	*mean (SD)* *LOA*	*ICC* *%*
Intra-	40	0.01 (0.16) (-0.039, 0.059)	40	72	0.01 (0.12) (-0.017, 0 0377)	90	112	0 01 (0.13) (-0.014, 0 034)	78.9
Inter-	37	-0.02 (0.07) (-0.064, 0.0241)	98	53	-0.02 (0.13) (-0.054, 0.014)	60	90	-0 02 (0.10) (-0.04, 0)	95.5

ICC: $(S^2(X) + S^2(Y)-S^2(D))/(S^2(X) + S^2(Y) + d^2-(S^2(D)/n))$
n: number of subjects; $S^2(X)$ and $S^2(Y)$ are the variances of measures for observers X and Y, respectively. d and $S^2(D)$ are the mean differences and mean variance of differences between measures of both observers, respectively[7]

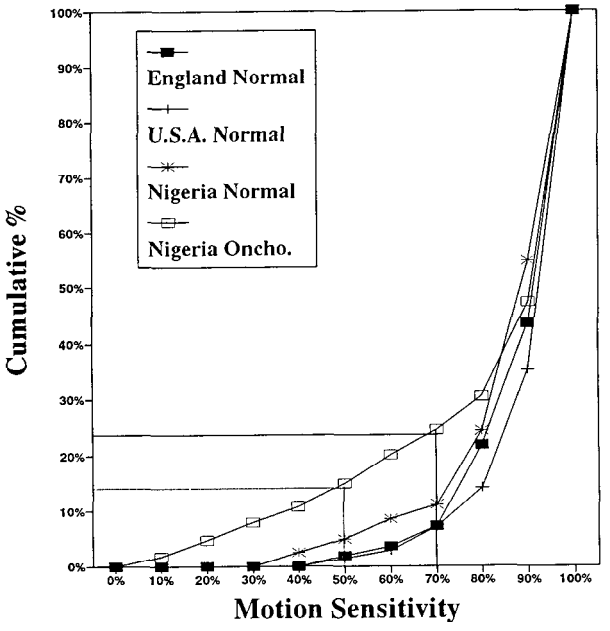

Fig. 3. Cumulative frequency of MSST results in three putatively normal groups and one meso-endemic onchocercal group. English Normal: 91 staff, student and 121 glaucoma patients' spouse volunteers, Institute of Ophthalmology, London. U.S.A. Normal: 74 volunteers for MSST at ARVO Meeting 1991, Sarasota. Nigeria Normal: 74 persons from Fatika (non-endemic for autochthonous onchocerciasis. Similar in ethnic, cultural, geographic, and economic background to the onchocercal communities.) Nigeria Oncho.: 1201 persons from meso-onchocerciasis communities in whom visual failure was due mainly to optic nerve or retinal disease.

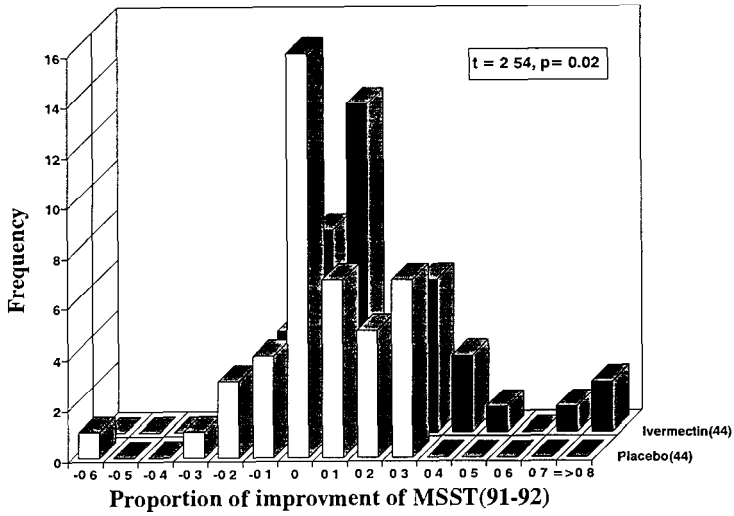

Fig. 4. Proportionate change in MSST after one year compared with initial MSST (91) for left eyes of 44 persons receiving annual ivermectin and 44 persons receiving placebo (MSST1992-MSST1991)/(MSST91).

A total of 1275 individuals underwent the MSST (74 control and 1201 onchocerciasis endemic subjects). Average age in the controls and in the onchocercal populations was 31.2 SE 0.24 and 31.9 SE 0.57 years, respectively. In the control group, the correlation coefficient between MSST and age was -0.50 ($p<0.001$). However, after excluding all cataract cases (five individuals), no significant correlation was found (r = -0.24, $p>0.05$). For the meso-endemic onchocerciasis population in Nigeria, the overall correlation coefficient between age and MSST was -0.21 ($p<0.01$).

The MSST results were plotted as a function of percent of response by each of four populations (Fig 3). If the cut-off criterion of normal motion was set at 50%, 15% of the onchocerciasis endemic population in Nigeria had reduced motion sensitivity, while only 5% was found in the non-endemic Nigerian population. The prevalence of motion sensitivity loss in the sample of the endemic population was three times the rate in this non-endemic population. If the cut-off was selected at 70%, which has been used in clinic[1], 25% of the onchocerciasis endemic population had abnormal MSST.

There were 343 people who had MSST in 1991 in the annual mass ivermectin trial. Of them, 102 individuals were retested in 1992. Because the MSST results from the right eye in 1991 were regarded as "training", the comparison analysis was based only on the 88 individuals whose left eyes had repeats after one year. The result in 88 left eyes examined in 1991 and again in 1992 shows that the placebo-treated group had developed an unmatched "tail" worsening in 1992 and the ivermectin-treated group had developed an unmatched "tail" of improvement (Fig. 4). This improvement from ivermectin is significant (t = 2.54, p=0.02).

Discussion

Because MSST has been fully automated by computer, the operator influence can be minimized. In addition three MSST drivers had the same computer with similar contrast on the LCDs. Therefore, it is not surprising that both intra-observer variability and inter-observer variability were low. However, we expected to see a fatigue effect from the intra-observation group because subjects carried out the MSST test twice without a break. In this case, the motion sensitivity measurements from retest could have been reduced if there was a fatigue effect in optic nerve disease[10]. Also, we expected to see a learning effect if the motion sensitivity is improved in the retest, especially in the inter-observer tests because subjects had experience after the first test and had a break before retesting. Interestingly, our findings did not show any strong evidence of learning effect and fatigue effect in MSST.

Furthermore, the finding that the difference measurements of more than two standard deviations of limit of agreement was less than 5% suggested that MSST has the reproducibility required for a standard test as recommended by British Standards Institution[12].

In our study, it is clear that reduced motion sensitivity in the endemic population cannot be due to low education because the control group with similar education background had almost the same motion sensitivity as more highly educated populations in England and the USA (Fig. 3).

The precise pathology responsible for reduction in MSST will be addressed in subsequent papers but it is of interest that the changes over one year observed in 44 subjects receiving annual ivermectin and 44 receiving placebo show a statistically significant improvement with ivermectin and worsening with placebo (Fig. 3). This is parallel with the results of the whole randomized trial which took three years of following 3522 subjects by standard methods to reach statistical significance: annual ivermectin prevents 80% of optic nerve diseases[3]. The MSST may be reflecting more than the optic nerve pathology and there are methodological and sampling differences in this comparison; but it is clear that MSST has very good potential for cost and time reduction in monitoring and comparing control measures for onchocerciasis.

From the perimetry point of view, this paper shows that the laptop or notebook computer provides great potential to carry out visual field testing by using a software-based visual function test with a low cost computer. The important advantage is that they allow implementation of a whole test in only minutes without knowledge of computers or programming languages[13]. More recently, the new electronic displays, such as liquid crystal display (LCD) in laptop computers or notebook computers, have been shown to have many advantages, in terms of portable flat screen monitor, even contrast, absolutely flicker-free and no radiation[14]. There is, as yet, no report about the application of notebook computers in visual psychophysical tests. In the present study, we demonstrate the preliminary application of this technology to provide an alternative way of developing a portable automated perimeter as a visual field screening test. This is especially important in mass screening or epidemiological study of diseases which commonly produce field loss with preserved macular function, such as onchocerciasis and glaucoma.

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References

1. Fitzke FW, Poinoosawmy D, Ernst W, Hitchings RA: Peripheral displacement thresholds in normals, ocular hypertensives and glaucoma In: Greve EL, Heijl A (eds) Seventh International Visual Field Symposium, pp 447-452. 1986
2. Wu X, Wormald R, Fitzke F, Poinoosawmy S, Subramanian N, Hitchings R: Laptop computer perimetry for glaucoma screening. Invest Ophthalmol Vis Sci (Suppl) 32:810, 1991
3. Quigley H, Sheila W, Beatriz M, Mabaga B, Ptak M: Pilot survey of visual impairment in rural East Africa, with visual field and scotopic tests for glaucoma. Invest Ophthalmol Vis Sci (Suppl) 33:757, 1992
4. Abiose A, Jones BR, Cousens SN, Murdoch I, Cassels-Brown A, Babalola OE, Alexander NDE, Nuhu I, Evans, Ibrahim UF, Mahmood AO: A randomized, controlled trial of annual ivermectin for onchocerciasis: evidence for a reduction in the incidence of optic nerve disease. Lancet 1992
5. Wu, JX: PhD Thesis, University of London, 1993
6. Norusis MJ: SPSS/PC+ V2.0 Base Manual for the IBM PC/XT/AT and PS/2 SPSS Inc 1988
7. Bland JM, Altman DG: Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1:307-310, 1986
8. Jamart J: Assessing observer variability. Br Med J 303:313, 1992
9. Brennan P, Silman A: Statistical methods for assessing observer variability in clinical measures. Br Med J 304:1491-1494, 1992
10. Brennan P, Silman A: Authors' reply. Br Med J 305:313, 1992
11. Enoch JM: Quantitative Layer-by-Layer Perimetry, pp 168-220. Grune & Stratton 1981
12. British Standards Institution: Precision of test methods. I. Guide for the determination and reproducibility of a standard test method (BS 5497, Part I). London: BSI, 1979
13. Wenderoth P: Sofware-based visual psychophysics using Commodore Amiga with Deluxe Paint III. Bec Res Meth Inst Computers 22:383-388, 1990
14. Bosman D: Display Engineering. Amsterdam: North-Holland Publ 1989

A new screening program with the Kowa automated perimeter AP 3000: a peripheral isoptometry and central three-zone program

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Introduction

With the development of automated perimeters, emphasis has been placed on the central visual field in perimetry. In routine evaluation, static perimetry with an automated perimeter is commonly used for central testing, while kinetic perimetry with the Goldmann perimeter is used for peripheral testing. However, for screening, only central static perimetry with an automated perimeter is usually performed. When it is difficult to judge disease severity by the results of this central perimetry alone, an accurate assessment can be made through a combination of both static and kinetic perimetry. When combined with central static testing, peripheral isopters generated by kinetic testing may give important information in understanding changes in the central visual field, as well as the relationship between the central and peripheral visual fields.

The Kowa automated perimeter AP 340, developed in 1986[1], has a program which examines the peripheral visual field by isoptometry. We have developed a new screening program which incorporates isoptometry with central three zone testing in the newer Kowa automated perimeter, the AP 3000, and have investigated its clinical usefulness.

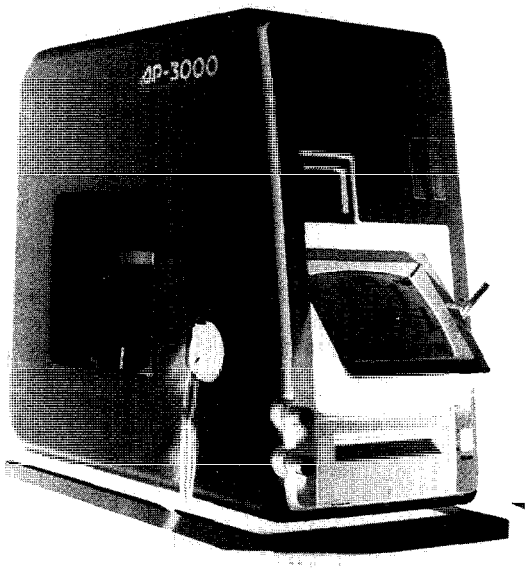

Fig. 1. The Kowa automated perimeter AP 3000. Cupola distance: 300 mm; stimulus size: I-V (same as the Goldmann perimeter); stimulus intensity: 0.1 - 10000 asb (50 - 0 dB); presentation time of stimulus: 0 2 seconds; background luminance: 31.5 asb; fixation target: red LED.

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Subjects and methods

Subjects

Thirty eyes of 24 patients with glaucoma, 20 eyes of 13 patients with neurological disease, and 15 eyes of 12 patients with retinal disease were examined. All patients had visual field changes assessed by the Goldmann perimeter and/or the Humphrey Field Analyzer. In addition, 35 eyes of 20 normal controls were also evaluated.

Methods

Perimetry was performed on all subjects using the new screening program of the Kowa AP 3000 (Fig. 1). With this program, peripheral isoptometry was performed first, followed by central visual field testing. During isoptometry, measurements were performed without a corrective lens, even within the 30° central zone. In addition, testing using the Goldmann perimeter and the Humphrey Field Analyzer programs 30-2 or 24-2 was also performed on each subject.

Averaged isopters and specificity for normal subjects were determined, and the sensitivity and coincidence ratio for patients were calculated. The ability of the screening program to detect visual field changes assessed by the Goldmann perimeter and/or the Humphrey Field Analyzer was used to calculate the sensitivity.

Isopters were compared between the Goldmann perimeter and the AP 3000, and coincidence ratios were calculated at the measured meridians on the AP 3000 (deviation of less than 10° was considered a coincidence) and was expressed as:

(Number of meridians coinciding) / (total number of measured meridians) × 100

The results of central visual field testing with the AP 3000 were compared with those with the Humphrey Field Analyzer. Because a direct comparison could not be made, coincidence ratios were determined by examining the difference in patterns of defects between the two.

Lastly, the examination time of our screening program on normal subjects, and on patients with visual field defects, was also monitored.

Strategy

Isoptometry

A stimulus with a presentation time of 0.2 seconds was intermittently shown centripetally at a rate of 5°/sec. Measurements were made for each meridian, that is both sides of the vertical (85°, 95°, 265°, 275°) and the horizontal (5°, 175°, 185°, 355°) meridians and at 45°, 135°, 225° and 315°. If not seen, the stimulus was not advanced beyond the fixation point towards the contralateral meridian. The same V/4 and I/3 stimuli as used in the Goldmann perimeter were used for isoptometry.

Central three zone test

The central 25° visual field was tested using the three-zone strategy performed with stimuli both at suprathreshold (5 dB brighter than the corresponding age-related normal threshold), and at maximum intensity (0 dB). The stimulus size was the same as size III on the Goldmann perimeter. The 82 test points were radially arranged.

Results

Normal isopters on the AP 3000

Normal subjects were divided into three groups: those younger than 40 years, 40 to 59 years old, and those over 60 years. There were almost no differences between the age groups for the V/4 isopter. For the I/3 isopter, general contraction was found for subjects over 60 years of age, although there was no substantial difference between the two groups younger than 60 (Fig. 2).

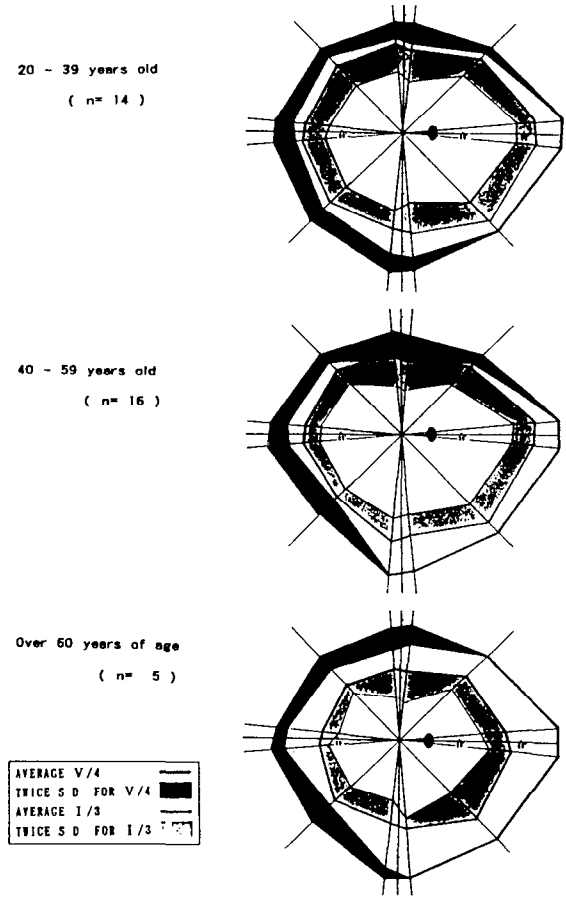

Fig. 2. Normal isopters on AP 3000. The shaded areas indicate twice the standard deviation.

Table 1. Sensitivity of defects and coincidence ratio

Diseases		*Sensitivity*	*Coincidence ratio*		
			V/4	*I/3*	*three-zone*
Glaucoma	(n=30)	100%	93.9± 9.4%	80.3±19 5%	93.3%
stage I-II	(n= 9)	100%	100%	79.6±13.7%	100%
stage III-IV	(n=11)	100%	92.4±12.0%	78 0±25.2%	90 9%
stage V	(n= 6)	100%	90.3± 5.7%	81.9±18.3%	100%
stage VI	(n= 4)	100%	87.5± 7.2%	85.4±12.3%	75.0%
Hemianopsia	(n=14)	100%	95.2± 7.5%	83.3±15.7%	100%
Optic neuritis	(n= 6)	100%	95.8± 6.4%	90 3±10.2%	83.3%
Retinal diseases	(n=15)	100%	87.2±20.2%	85 0±24.6%	97.5%
RP	(n= 9)	100%	81.5±23.8%	84.3±30.5%	100%
ROP	(n= 2)	100%	87.5± 4 2%	87.5± 4.2%	50.0%
others	(n= 4)	100%	100%	85.0±12.3%	80.0%

( ): number of eyes. Stages of glaucoma: Aulhorn's classification modified by Greve. RP: retinitis pigmentosa; ROP: retinopathy of prematurity; others: post-surgical retinal tear, central retinal artery occlusion, triangle syndrome, macular hemorrhage

For the V/4 isopter, there were no abnormalities and the specificity was 100%. For the I/3 isopter, there were abnormal isopters present in four eyes of three subjects with a specificity of 88.6%. In the central visual field, there were no defects and the specificity was 100%.

Sensitivity of defects and coincidence ratio

The sensitivity of defects in all patients was 100% by the screening program since all visual field defects picked up by the Goldmann perimeter and/or the Humphrey Field Analyzer were also found by our screening technique.

The coincidence ratio was 93.9% for the V/4 isopter, 80.3% for the I/3 isopter, and 93.3% for the central three-zone test in glaucoma patients. The same was 93.8% for the V/4 isopter, 85.4% for the I/3 isopter, and 95.0% for the central three-zone test in the neurological disease patients. Finally. in the retinal disease patients, the coincidence ratio was 87.2% for the V/4 isopter, 85.0% for the I/3 isopter, and 87.5% for the central three-zone test (Table 1).

Examples of patients with glaucoma, hemianopsia and flecked retina syndrome are shown in Figs. 3, 4 and 5.

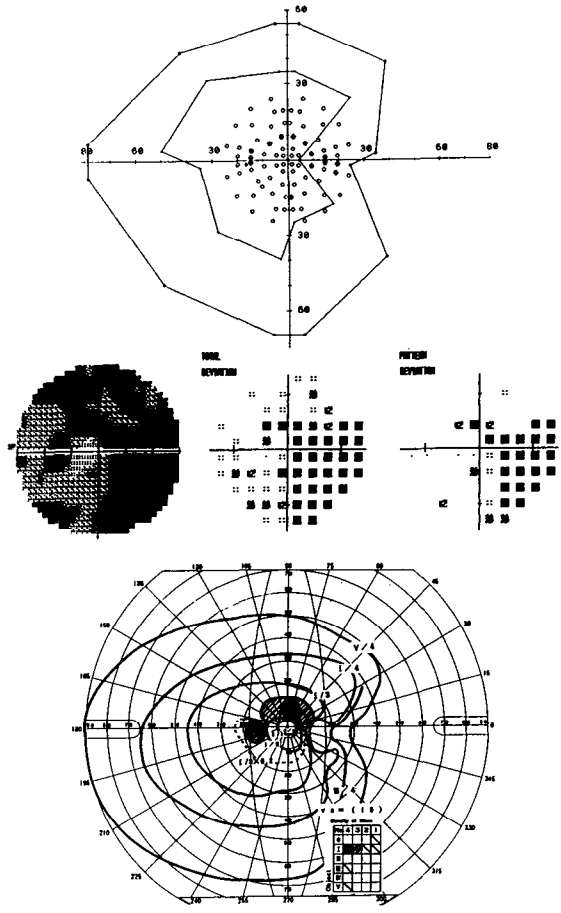

Fig. 3. Visual fields of a patient with glaucoma. Top: AP 3000 the new screening program; center: Humphrey Field Analyzer 30-2; bottom: Goldmann kinetic perimetry. The new screening program detected the superior arcuate and nasal defects found with the Humphrey Field Analyzer and the Goldmann perimeter. The defects were highly coincidental.

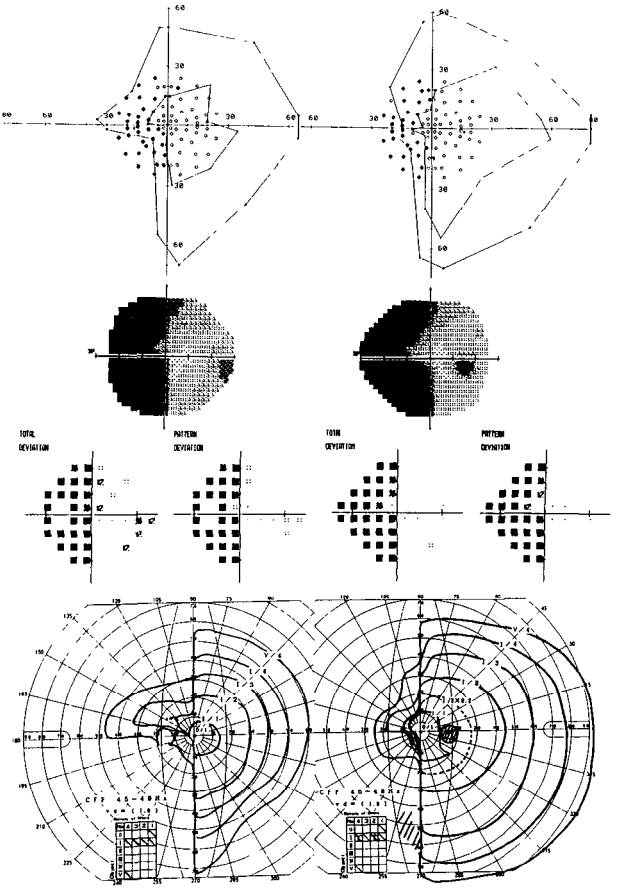

Fig. 4. Visual fields of a patient with a cerebral tumor. Top: AP 3000 the new screening program; center: Humphrey Field Analyzer 24-2; bottom: Goldmann kinetic perimetry. The new screening program detected the hemianopsia with the macular sparing found with the Humphrey Field Analyzer and the Goldmann perimeter. The defects were highly coincidental.

Table 2. Average total examination time

Subjects		*Examination time (min.)*
Normal	(n=20)	6.79±0.55
Glaucoma	(n=30)	11.80±3.14
stage I-II	(n= 9)	9.35±3.71
stage III-IV	(n=11)	11.29±2.52
stage V	(n= 6)	13.13±2.76
stage VI	(n= 4)	16.93±1.69
Neurological diseases	(n=20)	10.70±2.49
hemianopsia	(n=14)	11.08±2.07
optic neuritis	(n= 6)	9.08±2.89
Retinal diseases	(n=15)	12.58±3.64
RP	(n= 8)	14.93±2.22
ROP	(n= 2)	11.22±2.45
others	(n= 5)	10.03±2.94

( ): number of eyes

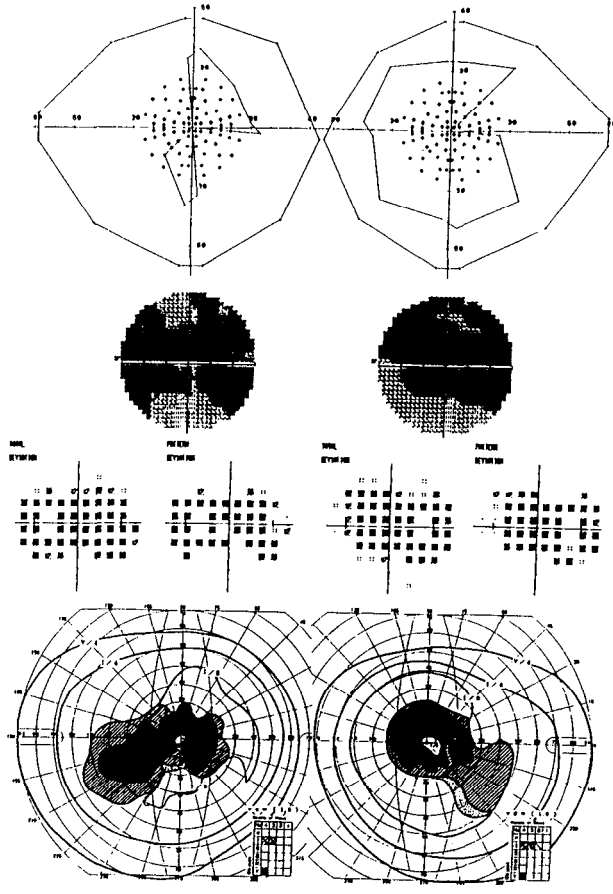

Fig. 5. Visual fields of a patient with a flecked retina syndrome. Top: AP 3000 the new screening program; center: Humphrey Field Analyzer 30-2; bottom: Goldmann kinetic perimetry. The result of the new screening program was highly coincidental with both the results of the Humphrey Field Analyzer and the Goldmann perimeter.

Examination time

The average total examination time for the new screening program was 6.79±0.55 minutes in normal subjects. The examination time gradually increased for glaucoma patients with progression of their visual field changes, and their average time was 11.80±3.14 minutes. This was 10.70±2.49 minutes for patients with neurological diseases, and 12.58±3.64 minutes for patients with retinal diseases (Table 2).

The time required to measure two isopters alone accounted for 54% of the total examination time in normal subjects, 50% in glaucoma patients, and 60% in both neurological and retinal disease patients.

Discussion

Techniques for kinetic perimetry have been recently developed for some automated perimeters[2-7]. These have adopted the same method of continuous presentation of a stimulus as that used in Goldmann perimetry. Our new screening program utilized intermittent static presentation of a stimulus for isoptometry, combined with a central three-zone test. Our goal was

quickly and reliably to identify changes in the whole visual field.

Normal V/4 isopters using our program were almost identical to those obtained with the Goldmann perimeter, except for being narrower at one infero-temporal and two temporal meridians. This is attributed to the fact that the stimulus appears starting only from 70° at the infero-temporal meridian and from 80° at the two temporal meridians, due to instrument limitations.

The size of the I/3 isopter was also the same with our program as with the Goldmann perimeter, however, it had a wider variation when compared to the V/4 isopter. This is probably because the scatter of the isopter in the midperiphery was larger than in the central and the peripheral visual fields[8,9], and because the small I/3 stimulus appears after the larger V/4 stimulus is shown, causing variation in patient response.

With regard to the sensitivity of the screening program, visual field changes were detected 100% of the time by at least one of the isopters or by the central visual field in all cases examined. However, when coincidence ratios were calculated between our program and Goldmann or Humphrey perimetry, the ratio for the I/3 isopter in glaucoma patients was slightly low at 80%, while closer to 100% for the central visual field in patients with glaucoma, neurological diseases and retinal diseases. This may be attributed to the fact that fine changes could not be detected with the I/3 stimulus. On the other hand, larger changes such as a spike or a spurious isopter could be detected when the stimulus was moved along the 12 meridians, because patients tended to move their eyes towards the expected appearance point of the I/3 stimulus after testing by the V/4 stimulus. For this reason, the III/1 stimulus may be preferred to the I/3 stimulus immediately after V/4 presentation in automated isoptometry.

The time required to test eyes with visual field changes ranged from approximately nine to 18 minutes for the total examination, and from five to 11 minutes for isoptometry only. This may be due to the fact that the stimulus for isoptometry was always presented starting from the periphery. Since this program is designed for the purpose of screening, if an abnormality is found by isoptometry, it is better to proceed directly to central threshold testing rather than to continue with the central three-zone test, and to evaluate the combined results of isoptometry with central threshold testing.

Conclusions

1. For the purposes of screening the whole visual field, a new program has been developed using isoptometry by two stimuli, in combination with three zone testing for the central visual field.
2. Using this program, it is possible to evaluate the relationship between peripheral and central visual field changes, and easy to assess the whole visual field.
3. The sensitivity and specificity of this program are satisfactory for the purposes of screening, and therefore it is considered that the program is appropriate for clinical use.
4. The examination time exceeded ten minutes for each eye when a severe visual field defect was present. Therefore, when a visual field change is detected by isoptometry, we recommend halting the central three-zone test and proceeding directly to the central threshold testing, in order to save time.

References

1. Kowa Automatic Visual Field Plotter AP 340 Operation Manual
2. Uchida H, Maeda M, Iwase A, Kitazawa Y: Evaluation of the Humphrey kinetic program. J Eye 8:1319-1322, 1991
3. Lynn JR, Swanson WH, Fellman RL: Evaluation of automated kinetic perimetry (AKP) with the Humphrey Field Analyzer. In: Mills RP, Heijl A (eds) Perimetry Update 1990/1991, pp 433-452. Amsterdam: Kugler Publ 1991
4. Barnebey H, Li Yi, Mills R: Automated peripheral perimetry: kinetic versus suprathreshold static st. In: Mills RP, Heijl A (eds) Perimetry Update 1990/1991, pp 423-431. Amsterdam: Kugler Publ 1991
5. Zingirian M, Gandolfo E, Capris P, Mattioli R: Perikon PCL 90: a new automated perimeter. In: Mills RP, Heijl A (eds) Perimetry Update 1990/1991, pp 403-407. Amsterdam: Kugler Publ 1991
6. William C, Stewart M, Shields B, Ollie AR: Peripheral visual field testing by automated kinetic perimetry in glaucoma. Arch Ophthalmol 106:202-206, 1988

7. Kevin N, Miller M, Shields B, Ollie AR: Automated kinetic perimetry with two peripheral isopters in glaucoma. Arch Ophthalmol 107:1316-1320, 1989
8. Dubois-Poulsen A: New technique for the examination of the peripheral vision. Acta Ophthalmol Jpn 65:1369-1376, 1961
9. Matsuo H, Furuse M, Hara T: Quantitative kinetic perimetry. 1. Threshold gradients for normal eyes. Acta Ophthalmol Jpn 67:1049-1054, 1963

Automated scotopic perimetry in glaucoma

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Abstract

In this study the authors investigated whether automated perimetry under scotopic conditions is useful in the early detection of glaucoma. Twenty-one control eyes, 27 glaucoma suspects, and 23 POAG eyes were examined with (a) standard automatic perimetry (Humphrey 30-2), (b) blue-on-yellow perimetry, and (c) automated perimetry under dark-adapted conditions Adaptation curves were also measured. Comparison of scotopic visual fields with the results of standard automatic perimetry showed large inter-individual differences. Scotopic perimetry showed a 1.4 times larger inter-individual variation in the control group. After correction for this, the mean defect in scotopic perimetry was larger than in standard perimetry in 65% of the POAG eyes and 67% of the suspects. The greater part of this, however, seems due to diffuse loss rather than localized damage. Therefore, it does not seem very useful to assess visual fields under scotopic conditions. Finally, dark adaptation was no slower in the pathological groups than in our control group.

Introduction

It is suggested that mechanisms other than those tested in conventional perimetry are affected earlier or more strongly in glaucoma; see for example the results of blue-on-yellow perimetry[1]. In view of possible similarities between the short wavelength sensitive cone system and the rod system, we investigated in the present study whether scotopic perimetric thresholds are affected in early glaucoma. And, if so, whether the scotopic visual fields are similar to those obtained with blue-on-yellow perimetry. Moreover, it would be interesting to have the three types of visual fields together which are determined by rod thresholds, SWS-cone thresholds, and MWS/LWS cone thresholds (*i.e.,* visual fields from scotopic, blue-on-yellow, and conventional perimetry, respectively).

It has already been shown by other authors that scotopic sensitivity can be reduced in glaucoma[2,3]. It should be noted, however, that in these studies only a diffuse loss was found. In the study of Drum *et al.*[2], a limited number of visual field locations was examined, and no additional localized defects were found under dark-adapted conditions, compared to standard photopic conditions. Quigley *et al.*[3] used whole-field stimulation and therefore no information was obtained on possible localized damage.

A second reason for the division of defects into "localized" and "diffuse" defects is that other factors, such as pupil diameter, have influence on global sensitivity, but not on the size of the localized defects.

We examined glaucomatous eyes and normal eyes with blue-on-yellow perimetry, scotopic perimetry, and conventional automated perimetry. In all three conditions, the central 30 degree visual field was examined. We intended to compare the scotopic results to the blue-on-yellow data, and also to data from conventional perimetry. However, the correlation between scotopic and blue-on-yellow results appeared to be rather poor. Therefore, we will restrict ourselves in this paper to the comparison of results from scotopic perimetry with those from "standard" automated perimetry.

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Subjects and methods

Seventy-one eyes were examined in this study: 21 controls (aged 52.4 ± 14.4 years, mean ±SD), 27 glaucoma suspects (aged 53.8 ± 10.7 years), and 23 eyes with primary open angle glaucoma (POAG) (aged 59.9 ± 13.6 years). Glaucoma suspects had either increased intraocular pressure (IOP >21 mmHg), or a suspected retinal nerve fiber layer, or both, but no visual field defects (standard Humphrey 30-2). POAG patients had relative visual field defects.

Visual fields were assessed in all eyes with two types of perimetry with: *a.* standard automatic perimetry, and *b.* automated scotopic perimetry. In both types the central 30-2 threshold program was used on a Humphrey Field Analyzer. The instrument was equipped with software which allowed the background illumination to be switched off.

With standard automatic perimetry, standard conditions were used: 10 cdm^{-2} bowl illumination, Goldmann size III stimulus.

Scotopic perimetry was performed in a dark room after 30 minutes of dark adaptation. Bowl illumination was switched off, and stimulus intensity was reduced by 4 log units, in order to obtain threshold values (in dB) well within the range of the Humphrey program. Both stimulus sizes III and V were used.

To obtain adaptation curves, threshold was measured every two minutes during the first 20 minutes of dark adaptation. This was done at two locations at 14 degrees of eccentricity, with a user-defined two-point test grid. In patients with visual field defects, one point was located in a healthy area, and the other point in a relative defect.

None of our subjects used miotics.

Results

Visual fields

Some examples are shown in Fig. 1. In the left column, the standard visual field is printed, in the middle column the scotopic visual field with stimulus size III, and in the right column the scotopic visual field with stimulus size V. Data from one subject are shown on each row. Note that inter-individual differences are large when comparing scotopic visual fields with standard perimetric results.

To make it easier to compare both sets of data with each other, they are plotted as deviations from the average of the control group (Fig. 2).

As we were especially interested in the localized defect in scotopic perimetry (as opposed to global defect), the individual diffuse or global reduction in sensitivity was subtracted from each value for each eye. The third highest value in the visual field was used as a measure for "global sensitivity". The corrected visual field was averaged to obtain a "mean defect".

To obtain an overview of the results, the percentages of cases, in which scotopic perimetry yields "better results", *i.e.*, larger mean defects compared to the standard (photopic) mean

Table 1. Numbers of cases with larger mean defects with scotopic perimetry than with standard perimetry: size V (III)

	Total MD (No.)		*Corrected for global sensitivity (No.)*	
POAG	65	(76)	29	(53)
Suspects	67	(67)	50	(54)
Controls	50	(50)	46	(53)

Table 2. Dark adaptation

		Time constant (minutes) (±SD)	*Final threshold (dB) (±SD)*
Controls		5.80±2.36	41.21±2.45
Suspects		6.91±3.30	38.77±4.35
POAG	healthy	5.46±2.13	35.43±3.79
	defect	6.99±3.98	34.09±4.76

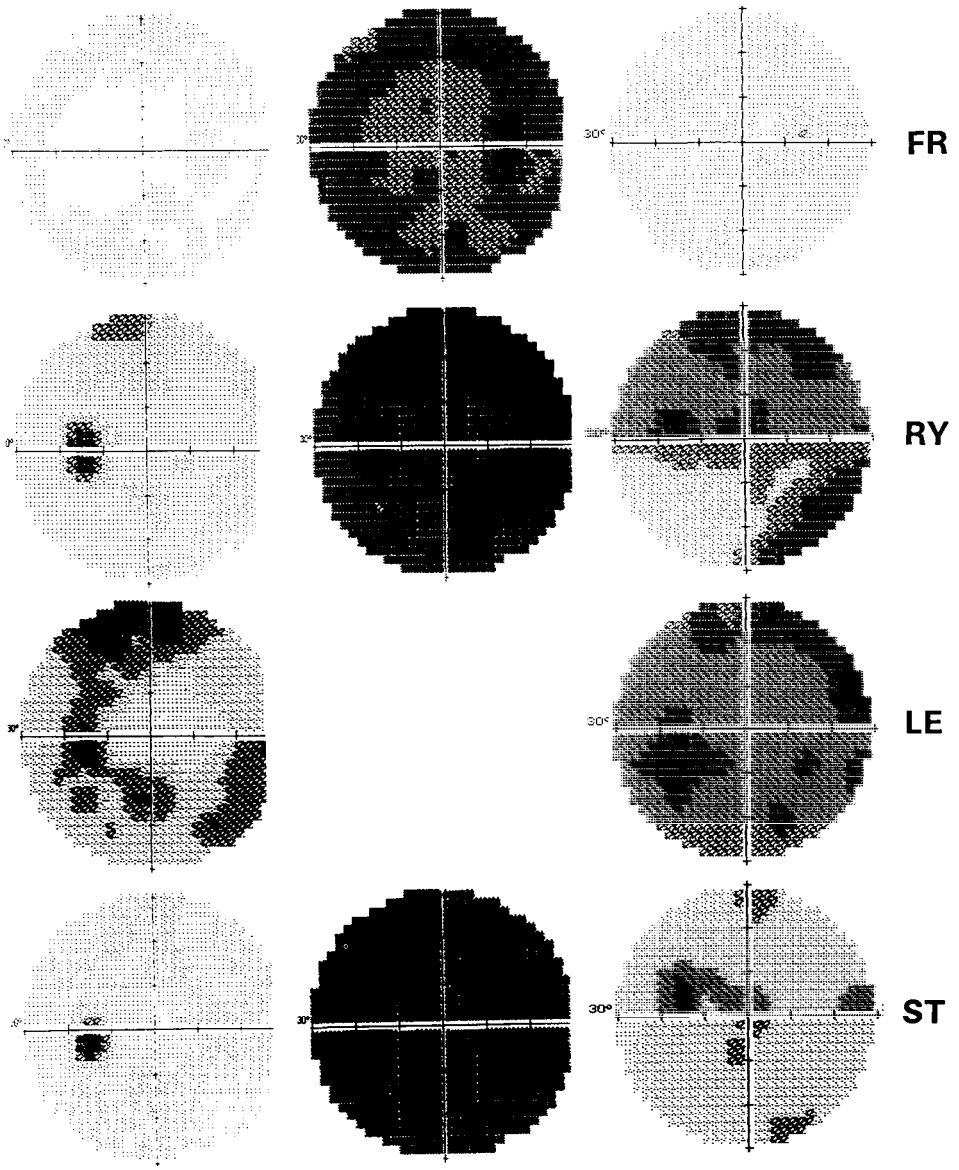

Fig. 1. Visual field print-outs for four subjects. From left to right: results from standard perimetry, scotopic perimetry with stimulus size III, and scotopic perimetry with stimulus size V. FR is a control, RY a normal pressure glaucoma patient, LE a high pressure glaucoma patient, and ST a glaucoma suspect.

defect, are set out in Table 1. It can be noted that the figures for the control group should be approximately equal to 50%. From Table 1 it becomes clear that, although scotopic defects are somewhat larger, this "gain" disappears after correction for global sensitivity (See Table 1, right column).

Dark adaptation

An exponential function was fitted individually to the adaptation data of each eye. The resulting time constants and final threshold levels are averaged among subject groups, and compiled in Table 2. The POAG data were divided into "healthy" and "relatively defect" areas.

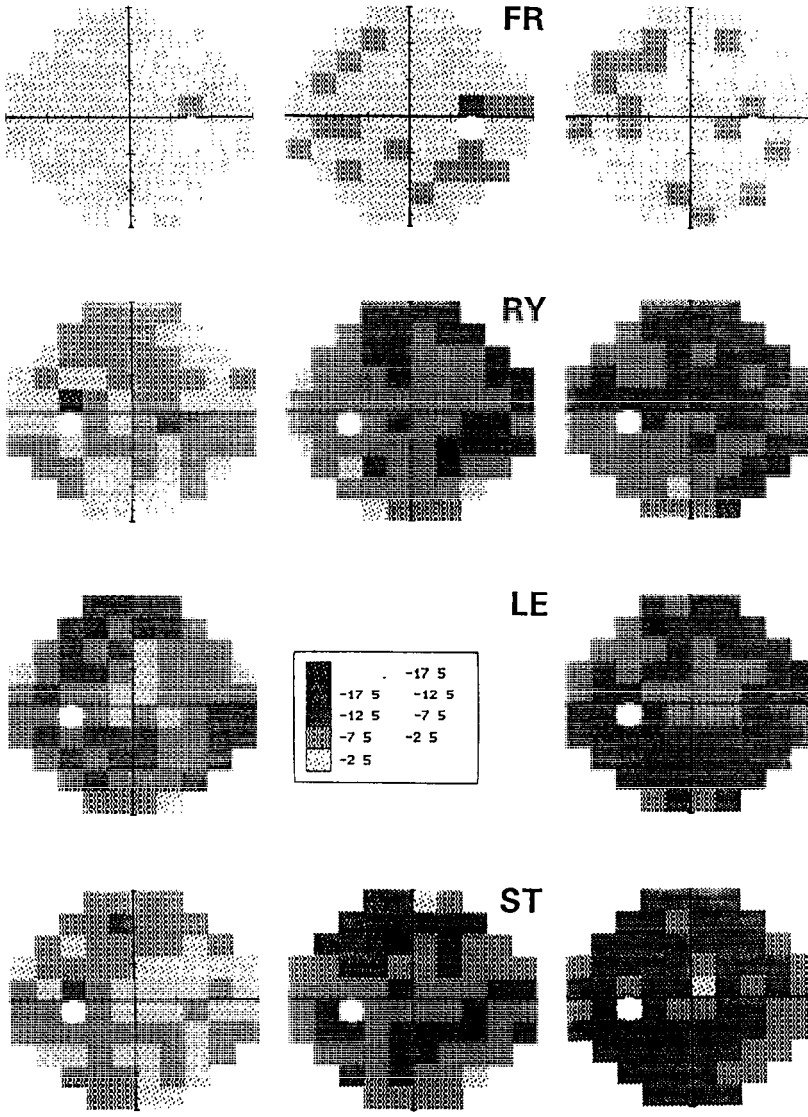

Fig. 2. Deviations from the average of the normal population, for the same subjects as in Fig. 1.

Analysis of variance pointed out that, although time constants in the pathological groups are somewhat larger than in controls, these differences are not statistically significant. The final threshold level is elevated in suspects (p=0.039) and POAG (p<0.002). This elevation correlates well with the measures for "global sensitivity" mentioned in the visual fields section (r^2 = 0.88).

Discussion

Although scotopic visual fields are damaged in early glaucoma, the gain with respect to standard perimetry is mostly due to diffuse or global loss. It can be concluded, therefore, that assessment of the visual field in early glaucoma is not very useful. It is not necessary to perform an entire visual field examination to assess this global reduction. The practical usefulness

becomes even more doubtful when it is pointed out that in our subjects inter-individual fluctuations were larger in scotopic perimetry than in standard perimetry. This makes scotopic defect values in terms of standard deviations of the normal population smaller in comparison to their photopic counterparts.

Finally, dark adaptation was not slower in the pathological groups than in our control group.

References

1 Johnson CA, Adams AJ, Twelker JD, Quigg JM: Age-related changes in the central visual field for short wavelength-sensitive pathways. J Opt Soc Am A5:2131-2139, 1988

3. Drum B, Armaly MF, Huppert W: Scotopic sensitivity loss in glaucoma. Arch Ophthalmol 104:712-717, 1986

3. Quigley HA, Glovinsky Y, Drum B, Jampel HD, Bissett RA: Scotopic Ganzfeld Sensitivity Test for the detection of early glaucoma damage to large (M) retinal ganglion cells. Invest Ophthalmol Vis Sci (Suppl) 2566, 1991

Visibility threshold for dark perimetric stimulus

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Abstract

Dark-on-bright perimetric stimulus is not conventional but may have advantages over luminous stimuli in certain situations Twenty-five glaucomatous eyes with 6/6 vision were examined with the Humphrey Visual Field Analyzer thresholding program 30-2 and computer assisted moving eye campimeter (CAMEC), using static dark stimuli at four different Weber contrast levels of -10, -22, -37 and -76% cdm^{-2} on a cathode ray tube with 10 cdm^{-2} background luminance. The retinal sensitivity levels in terms of Humphrey decibel values required for the awareness of dark stimulus were determined across the central visual field. Ten eyes were also tested with dark stimuli of identical size and contrast on a background of 100 cdm^{-2}. Lower stimulus contrasts and higher background luminance level required higher retinal sensitivity for the detection of dark stimuli. A 66% decrease in dark stimulus contrast required an average of 3.14 Humphrey decibels higher retinal sensitivity for detection. One log-unit increase in the background luminance raised the detection threshold of a low contrast dark stimulus by an average of 0.9 decibel without any effect on the detection threshold of high contrast stimulus. The preliminary results with dark stimuli in this study should allow the development of more sophisticated tests for the detection and follow-up of glaucoma and other visual disorders.

Introduction

The retina has differential sensitivity to both increments and decrements in luminance and these two functions seem to be subserved by parallel "on" and "off" pathways, respectively[1]. These pathways are known to display several asymmetries[2] and it is possible that testing them separately with bright and dark stimuli may facilitate the diagnosis and follow-up of visual loss[3-5].

We investigated the visibility of different contrasts of static dark perimetric stimuli on a cathode ray tube in the central 30 degree visual field in eyes with glaucomatous loss. In this article, we describe the detection thresholds in terms of decibel values for different contrasts of dark stimulus.

Material and methods

Twenty-five glaucomatous eyes (17 right and eight left) of 25 perimetrically experienced patients, 13 male and 12 female, aged between 35 and 82 years (mean 68 years) were included in the study. All tested eyes had 6/6, N5 visual acuity with correction (<±7.00 diopters sph), normal pupil sizes, no media opacities or co-existing abnormalities. The tests were performed with a full aperture near correction.

Conventional perimetry was performed using the Humphrey Visual Field Analyzer program 30-2 with standard parameters. This program tests 76 points in the central visual field. The patients were also examined with computer assisted moving eye campimetry (CAMEC), which is capable of presenting either dark or bright single static stimulus in relation to a moving

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fixation target in the central visual field[6,7]. In summary, the CAMEC technique operates with a desk-top computer (IBM PS/2 30-286) and a 14-inch high resolution cathode ray tube (CRT, IBM 8512). During the test, the patient has to keep a randomly moving fixation spot in a circle using a mouse or joystick. This maneuver forces the patient to look at the fixation target continuously. As long as the fixation spot is kept inside the circle, the stimuli are presented automatically in a seemingly random fashion at predetermined locations in the central visual field, and the patient signals the awareness of the stimulus by pressing the joystick button. Missed presentations are retested, and repeatable misses are recorded as abnormal points. Patient responses are processed, analyzed, printed and saved at the end of the test. For calibration, the luminance of the test stimuli and background are measured at 30 locations using a photometer (Minolta nt-1), and an average luminance (Weber's) contrast is calculated[8]. Although cathode ray tubes usually present topographical luminance non-homogenities which, in our case, was approximately ±20% fluctuation from the mean luminance across the screen, the ratio of the stimulus luminance to the background luminance (contrast) remained constant at different locations and, therefore, Weber's law and stimulus visibility were protected[9]. Four stimulus contrasts of -76, -37, -22 and -10% on 10 cdm^{-2}, and, also two stimulus contrasts of -76 and -22% on 100 cdm^{-2} were selected for single intensity testing with 0.2 seconds stimulus duration. The CAMEC test grid was identical to the test grid of Humphrey thresholding program 30-2. The CAMEC stimulus size was eccentricity compensated with a rectangular surface area of 1.8 mm^2 up to 10 degrees, 3.1 mm^2 between 10 and 20 degrees and 4.9 mm^2 beyond 20 degrees from the fixation. The number of the eyes tested with each contrast and background is given in Table 1. Each test was performed once. The fatigue was prevented by rest periods of ten minutes after each 20-minute examination session. All tests for each individual were completed on the same day.

The Humphrey numeric decibel threshold values, STATPAC total deviation probability (% *P*) values as well as the dark stimulus detection status ("seen" or "missed") for each stimulus contrast at the corresponding points on CAMEC results were processed using a statistical software package (Minitab).

Table 1. The number of glaucomatous eyes tested with each dark stimulus contrast on two different background luminances

Stimulus contrast	*CAMEC (on 10 cdm^{-2})*	*CAMEC (on 100 cdm^{-2})*
-10%	9	-
-22%	25	10
-37%	14	-
-76%	25	10

Results

Humphrey STATPAC evaluation of the decibel threshold values in the 25 glaucoma eyes revealed relative scotomas in 11 eyes (Aulhorn-Karmeyer Classification, Stage 1), small isolated absolute scotomas in ten eyes (Stage 2) and absolute scotomas connected to the blind spot in four eyes (Stage 3)[10]. The global visual field indices and the frequency distribution of the abnormal points identified by STATPAC are summarized in Fig. 1.

The retinal sensitivity levels in terms of Humphrey decibels have been determined in various eccentricities for all contrasts and sizes of dark stimuli as the detection thresholds above which 70% of the "seen" and below which 70% of the reproducible "missed" responses were recorded by CAMEC. The full results from 10 cdm^{-2} and 100 cdm^{-2} are set out in Tables 2 and 3. The retinal sensitivity levels required for the detection of all four contrasts of dark stimuli in the selected sizes were lower than the normal retinal sensitivity values for the mean age group of the study group[11] and, therefore, designed stimuli were supra-threshold (Fig. 2a). Lower contrasts of dark stimuli required higher retinal sensitivity for their detection. Decreasing the stimulus contrast to -10% from -76% on 10 cdm^{-2} background caused an increase in the dark stimulus detection threshold of 2.6-3.5 Humphrey decibels (dB) (at 6 and 28 degree eccentricity, respectively). Increasing the background luminance to 100 cdm^{-2} caused a significant eleva-

tion in the detection threshold for -22% dark stimuli in all eccentricities (mean difference of +0.82 ±0.36 dB, p=0.0068; paired t test) without any effect on the threshold for -76% stimuli (mean difference of 0.06±0.4 dB, p=0.76) (Fig. 2b).

Table 2. The retinal sensitivity levels in terms of Humphrey decibel units above and below which approximately 70% of the "seen" and "missed" CAMEC responses were given for each dark stimulus contrast and size at different eccentricities in 25 glaucomatous central visual fields

Eccentricity and stimulus area	*Stimulus contrast (Weber's)*	*Above which 70% of "seen"*	*Below which 70% of "missed"*	*Average*
6 degrees	-10%	28 7 dB (n= 18)	29.5 dB (n= 14)	29.1 dB (n= 32)
(2 sq mm)	-22%	27 8 dB (n= 74)	26.7 dB (n= 26)	27.3 dB (n=100)
	-37%	27 5 dB (n= 46)	26.3 dB (n= 6)	26.9 dB (n= 52)
	-76%	27.0 dB (n= 89)	26.0 dB (n= 11)	26.5 dB (n=100)
12 degrees	-10%	27.3 dB (n= 34)	27.7 dB (n= 38)	27.5 dB (n= 72)
(3 sq mm)	-22%	26.4 dB (n=114)	26.6 dB (n= 86)	26.5 dB (n=200)
	-37%	26.0 dB (n= 88)	24.5 dB (n= 24)	25.3 dB (n=112)
	-76%	24 8 dB (n=161)	24.0 dB (n= 39)	24 4 dB (n=200)
18 degrees	-10%	25.8 dB (n= 60)	26 7 dB (n=110)	26.3 dB (n=170)
(3 sq mm)	-22%	24.5 dB (n=255)	24.2 dB (n=216)	24.4 dB (n=471)
	-37%	23.9 dB (n=185)	23.7 dB (n= 80)	23.8 dB (n=265)
	-76%	23.2 dB (n=325)	23 3 dB (n=130)	23.3 dB (n=455)
24 degrees	-10%	23 7 dB (n= 50)	25.5 dB (n=130)	24.6 dB (n=180)
(5 sq mm)	-22%	22.8 dB (n=237)	23.8 dB (n=263)	23.3 dB (n=500)
	-37%	22 5 dB (n=192)	23.2 dB (n= 88)	22.8 dB (n=280)
	-76%	21.6 dB (n=355)	20 5 dB (n=125)	21.1 dB (n=480)
30 degrees	-10%	23.5 dB (n= 27)	24 5 dB (n=117)	24 0 dB (n=144)
(5 sq mm)	-22%	22.0 dB (n=133)	22.5 dB (n=251)	22.3 dB (n=384)
	-37%	21 0 dB (n=143)	22.0 dB (n= 97)	21 5 dB (n=240)
	-76%	20.4 dB (n=223)	20.5 dB (n=145)	20.5 dB (n=368)

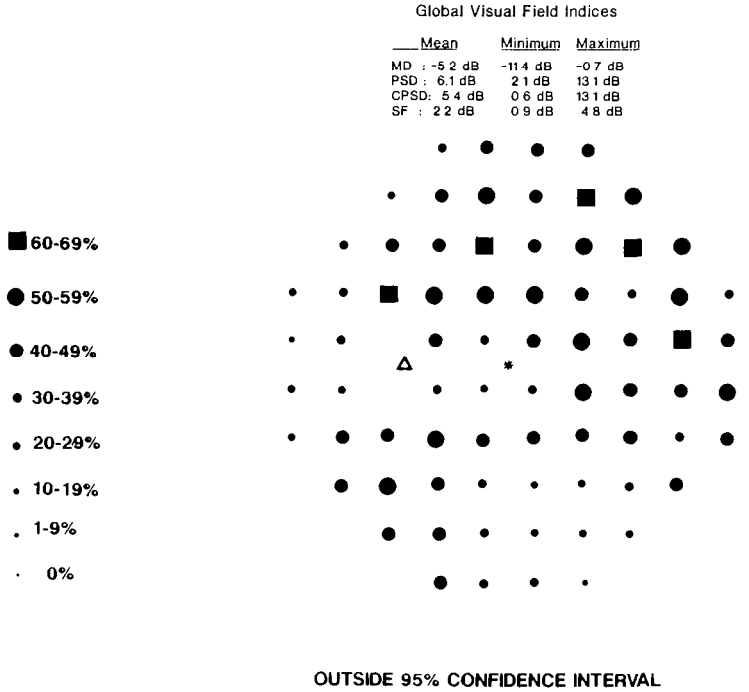

Fig. 1. The global visual field indices and the frequency distribution of abnormal points in the central visual fields of 25 glaucomatous eyes according to Humphrey auto-perimeter thresholding program 30-2 and STATPAC total deviation values (p<5%).

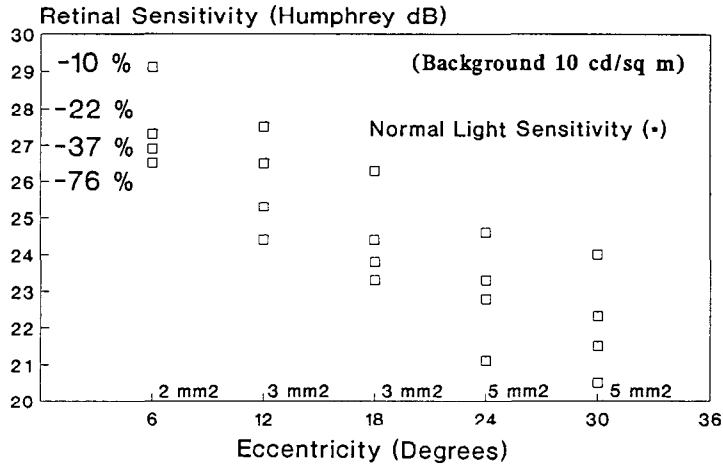

Fig. 2a. Equivalent retinal light sensitivity for dark stimulus detection (n=4805).

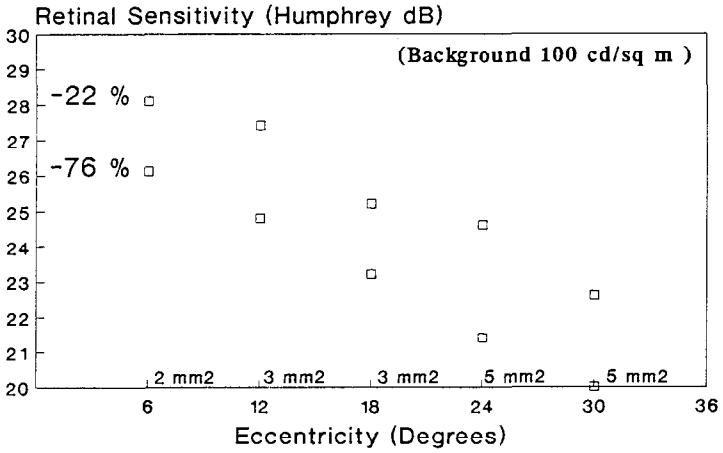

Fig. 2b Equivalent retinal light sensitivity for dark stimulus detection (n=1308).

Fig. 2. The clinical retinal sensitivity levels in terms of Humphrey decibel units above which dark stimuli of different contrasts and sizes become detectable in glaucomatous visual fields of *a.* 25 eyes tested against 10 cdm^{-2} and *b.* ten eyes tested against 100 cdm^{-2} background luminance

Table 3. The retinal sensitivity levels (Humphrey dB) above and below which 70% of the "seen" and "missed" responses were recorded for low (-22%) and high (-76%) contrast dark stimuli in ten glaucomatous visual fields (background luminance: 100 cdm^{-2}

Eccentricity and stimulus area	*Stimulus contrast (Weber's)*	*Above which 70% of "seen"*	*Below which 70% of "missed"*	*Average*
6 degrees	-22%	27 6 dB (n= 21)	28.5 dB (n= 19)	28.1 dB (n= 40)
(2 sq mm)	-76%	26.1 dB (n= 38)	26.1 dB (n= 2)	26.1 dB (n= 40)
12 degrees	-22%	27.6 dB (n= 30)	27.1 dB (n= 50)	27.4 dB (n= 80)
(3 sq mm)	-76%	25.6 dB (n= 62)	24.0 dB (n= 18)	24.8 dB (n= 80)
18 degrees	-22%	25.0 dB (n= 75)	25.3 dB (n=115)	25.2 dB (n=190)
(3 sq mm)	-76%	22.8 dB (n=151)	23.6 dB (n= 39)	23.2 dB (n=190)
24 degrees	-22%	25.1 dB (n= 80)	24.1 dB (n=120)	24.6 dB (n=200)
(5 sq mm)	-76%	19 2 dB (n=161)	23.2 dB (n= 39)	21.4 dB (n=200)
30 degrees	-22%	21.9 dB (n= 52)	23 2 dB (n= 92)	22.6 dB (n=144)
(5 sq mm)	-76%	20.5 dB (n=100)	19.5 dB (n= 44)	22.3 dB (n=144)

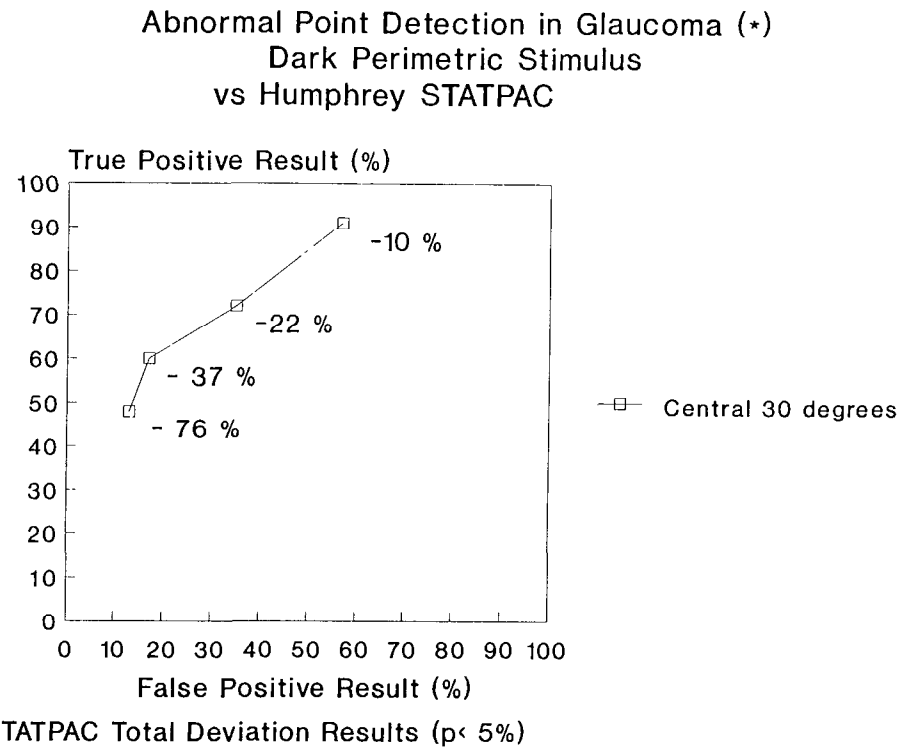

Fig. 3. The frequency of dark stimulus non-visibility at abnormal and normal parts of the glaucomatous visual field defects (true and false positive result rates, respectively) according to stimulus contrast (n=4805).

The sensitivity and the specificity of the CAMEC stimulus parameters in the detection of abnormal and normal points in the visual field was studied further. For that purpose, point-by-point comparisons were made between the Humphrey STATPAC total deviation p values and CAMEC results. All test locations showing significant depression on total deviation plots (p<5%, 2%, 1% and 0.5%) were admitted to represent glaucomatous loss and the remaining locations (inside 95% confidence interval) were considered healthy parts of the visual field. High (-76%) contrast dark stimuli detected the normal and abnormal points in the visual field with 87% (true negatives) and 48% (true positives) accuracy respectively (Fig. 3). The true positive detection rate increased with decreasing dark stimulus contrast, and reached 93%at -10% stimulus contrast. However, the true negative result rate decreased to a minimum of 43% simultaneously.

Discussion

In this study, we demonstrate that the visibility of dark perimetric stimulus, like that of conventional luminous stimulus, is dependent on stimulus parameters such as size, contrast and level of background luminance.

Selecting progressively larger stimuli towards the periphery of the visual field (eccentricity compensation) caused the detection thresholds for dark stimuli to follow the slope of normal hill of vision at all contrast levels.

Lower contrasts of dark perimetric stimulus functioned as weaker stimuli and required higher retinal sensitivity for their detection in the visual field. Therefore, it seems possible that the visual field may be evaluated by presenting successive dark stimuli with increasing or decreasing contrast. An average of 3.14 Humphrey dB change in the dark stimulus detection threshold in response to varying the stimulus contrast from -76% to -10% represents the small dynamic

range of the stimulus sizes used in this study. However, the dynamic range may be varied by altering the stimulus area.

Employing a high background luminance with dark stimulus may provide several advantages over luminous stimuli on a dim background. First of all, the field can be tested under ordinary ambient illumination conditions without needing adaptation periods. Secondly, the inadvertent reflections and glare on the glass surface of CRT, as well as the after-image following brief stimulus presentations, become less of a problem. Thirdly, the opposite contrast polarity (negative; dark-on-bright) may facilitate the diagnosis of visual sensitivity loss undetected by conventional techniques. However, increasing the background luminance seem to necessitate higher retinal sensitivity for the detection of low contrast dark stimuli.

Several alternative explanations may be suggested for that observation. Although the stimulus contrasts were calibrated separately for different backgrounds, it was not possible, because of technical limitations, to measure the luminance of a spot smaller than approximately 1.5 cm in diameter. It is likely that the actual contrast and perceived size of the stimuli were reduced due to increased light scatter into the small stimulus area especially when the background is brighter. Intraocular light scatter and glare may also interfere with the visibility of lower contrasts. An alternative explanation might be the decrease in the ratio of the retinal receptive field excitatory center area to the inhibitory surround area under higher luminance, and the consequent lower contrast gain and stimulus visibility[12]. Therefore, the effect of background onto the visibility of dark stimulus should be taken into consideration in the design and application of tests for different clinical situations.

The lower true positive detection rates with higher contrast (darker gray) stimuli provide further evidence that the dark stimulus becomes more suprathreshold with increasing contrast. However, lower contrasts of suprathreshold dark stimuli have been missed more frequently in the apparently normal parts of the glaucomatous visual fields, causing higher "false positive" rates. The ROC curve (Fig. 3) suggests that the optimum sensitivity and specificity for the stimulus sizes used in this study would have been provided by 30% contrast stimuli with 70% true and 30% false positive rates. The high incidence of false positive results with low contrast stimuli also suggests more extensive visual field involvement to dark stimuli in glaucoma, and may represent false negative (defect remained undetected) results from conventional luminous stimuli. The concepts of differential involvement of "on" and "off" pathways in glaucoma and other neuro-ophthalmic problems, and any diagnostic advantage of employing dark stimuli require further study.

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References

1. Schiller PH: Central connections of the retinal on and off pathways. Nature 297:580-583, 1982
2. Schiller PH: The connections of the retinal on and off pathways to the lateral geniculate nucleus of the monkey. Vision Res 24:923-932, 1984
3. Mutlukan E: Perimetry with dark stimulus and testing off-centre ganglion cells in glaucoma. Mary Hawthorne Essay in Ophthalmology, University of Glasgow, 1991
4. Mutlukan E, Damato BE: The dark perimetric stimulus. Br J Ophthalmol 76:264-267, 1992
5. Mutlukan E, Bradnam M, Keating D, Damato BE: Visual evoked cortical potentials from transient dark and bright stimuli: selective on and off pathway testing? Doc Ophthalmol 80:171-181, 1992
6. Johnston SC, Damato BE, Evans AL, Allan D: Computerised visual field test for children using multiple moving fixation targets. Med Biol Eng Comput 27:612-616, 1989
7. Damato BE, Mutlukan E, McGarvie J, Johnstone S, Keating D, Evans A: Computer assisted moving eye campimetry (CAMEC). This Volume, pp 315-317
8. Westheimer G: The oscilloscopic view: retinal illuminance and contrast of point and line targets. Vision Res 25:1097-2003, 1985
9. Carpenter RHS: Neurophysiology. London: Edward Arnold Publ 1990

10. Aulhorn E, Karmeyer H: Frequency distribution in early glaucomatous visual field defects Doc Ophthalmol Proc Ser 14:75-83, 1977
11. Brenton RS, Phelps CD: The normal visual field on the Humphrey Visual Field Analyzer. Ophthalmologica 193:56-74, 1986
12 Shapley R, Enroth-Cugell C: Visual adaptation and retinal gain controls In: Osborne N, Chader G (eds) Progress in Retinal Research, Vol 3, pp 263-346 Oxford: Pergamon Press 1984

Conversion of normal visual field data between the Humphrey Field Analyzer 640, the Rodenstock Peristat 433 and the Octopus 1-2-3

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Abstract

One hundred and twenty eyes of 120 normal subjects aged from nine to 86 years (mean 43.7 ± 18.9 years, median 44 5 years) were tested with three automated light-sense perimeters: the Humphrey Field Analyzer 640 (HFA), the Rodenstock Peristat 433 (PRT) and the Octopus 1-2-3 (OCT). For the Humphrey Field Analyzer program 30-2 was used, for the Peristat 433 program GL1 and for the Octopus 1-2-3 the standard program G1X. The tests were performed in random order. Subjects were excluded if they had: corrected visual acuity < 0.8, refractive error > ±5 dpt sph or 2 dpt cyl, intraocular pressure > 21 mmHg, media opacities, abnormalities of the fundus, severe ocular trauma or any ocular surgeries in their history, family history of glaucoma or any inheritable ocular diseases, history of poorly controlled hypertension, diabetes mellitus, multiple sclerosis, cerebrovascular attacks, epilepsy or ingestion of any psychopharmaca 24 hours prior to field testing. The pairwise correlation of Mean Sensitivity (MS) of the central visual field for each instrument was highly statistically significant: MS(HFA)/MS(OCT): $r = 0.7076$, $p<0.0001$; MS(PRT)/MS(HFA): $r = 0.7461$, $p<0.0001$; MS(PRT)/MS(OCT): $r = 0.6500$, $p<0.0001$. The results of the present study provide the possibility of converting normal visual field data between the three instruments.

Introduction

Clinical routine perimetry relies on the availability of well-documented normal data acquired according to strict statistical criteria. During the last years, such normal data have been published for some of the instruments which are currently in use: the Humphrey Field Analyzer[1,2], the Octopus[3,4] and the Rodenstock Peristat[5]. These studies were performed on different normal populations and thus do not provide the possibility of comparing normal visual field data between instruments. Thus, aim of the present study was to provide the statistical basis for converting normal data of one perimeter to another and transforming the dB scales which are in use for each instrument. A large number of normal individuals was tested with three automated perimeters which are currently used for routine perimetry: the Humphrey Field Analyzer 640 (program 30-2), the Rodenstock Peristat 433 (program GL1), and the Octopus 1-2-3 (program G1X).

Material and methods

One hundred and twenty eyes of 120 normal subjects aged from nine to 86 years (mean 43.7 ± 18.9 years, median 44.4 years) were included in the present study. Subjects were excluded if they had: corrected visual acuity < 0.8, refractive error > ±5 dpt sph or 2 dpt cyl, intraocular pressure > 21 mmHg, media opacities, abnormalities of the fundus, severe ocular trauma or any ocular surgeries in their history, family history of glaucoma or any inheritable ocular dis-

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eases, history of poorly controlled hypertension, diabetes mellitus, multiple sclerosis, cerebrovascular attacks, epilepsy or ingestion of any psychopharmaca 24 hours prior to field testing.

All subjects were tested with the Humphrey Field Analyzer 640 (HFA; program 30-2), the Rodenstock Peristat 433 (PRT; program GL1) and the Octopus 1-2-3 (OCT; G1X). In order to rule out a possible learning effect in each subject, all tests were performed in random order. In addition, a short introductory learning program was used prior to the standard program for HFA and PRT. No learning program was performed for OCT because for the prototype used in the present study only the standard program G1X and no custom-made short tests were available.

Humphrey Field Analyzer 640

The Humphrey Field Analyzer 640 is an automated projection perimeter with a surround luminance of 10 cdm^{-2}. Program 30-2 which was used for the present study examines 77 points up to 30° including the fovea over a 6° orthogonal grid (Fig. 1, left). Program 30-2 (stimulus size Goldmann III) uses a full-threshold strategy (4/2 dB). The short introductory custom-made learning program tests 13 points up to 25°.

Rodenstock Peristat 433

The Rodenstock Peristat 433 automated perimeter uses yellow-green light emitting diodes (560 nm) which are mounted invisibly behind a diffusing screen (luminance of surround = 10 cdm^{-2}, stimulus diameter 30'). Program GL1 which was used for the present study examines 81 points up to 30° (Fig. 1, middle). Prior to the standard program a short introductory learning program testing 28 points up to 25° was used.

Octopus 1-2-3

The Octopus 1-2-3 perimeter uses a yellow LED-array (592 nm) for stimulus generation. The stimuli are imaged directly into the subject's eye according to the optical principle of an optometer. Luminance of the surround is 10 cdm^{-2}, stimulus size is Goldmann III. The standard program G1X which was available in the prototype instrument of the first generation used in the present study corresponds to the central part of program G1 as described by Flammer and co-workers[6]: 59 points up to 26°, full threshold bracketing procedure, all points are tested twice. The grid of program G1X is shown in Fig. 1, right. For the present study, a prototype instrument of the first generation was available which unfortunately had a calibration error of the stop controlling the surround luminance. Thus, the normal data recorded with this instrument were slightly lower than the normal reference values stored in the machine and were lower than normal data acquired with a correctly calibrated instrument of the second generation. In order to quantify this systematic error another normal value study was performed testing 50 eyes of 50 normal subjects on both the instrument of the first generation and on a correctly calibrated instrument of the second generation. From a preliminary statistical analysis of these data a correction factor was obtained[7] as follows: the mean sensitivity values of the first prototype (MS_1) can be transferred into the corrected values of the second generation system (MS_2)

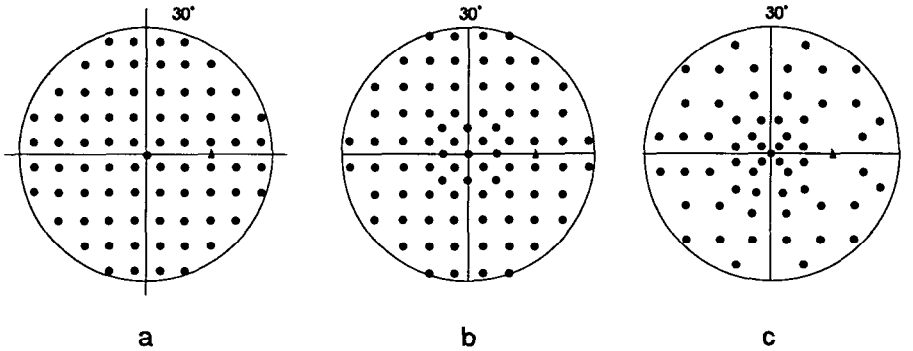

Fig. 1. Test grids of the Humphrey Field Analyzer 640, program 30-2 (left), Rodenstock Peristat 433, program GL1 (middle), and Octopus 1-2-3, program G1X (right).

according to the following approximate formula: $MS_2 = MS_1 + 1.3$ dB. An extensive statistical analysis of these data with calculation of an exact correction factor is in preparation. For the correlation analysis of the present study the uncorrected data were used.

Results

The results obtained for the 120 eyes of our 120 normal subjects were used for calculating age-corrected normal values for each instrument. These normal data will be published in detail elsewhere[8,9]. In the following, the outcome of the pairwise correlation of mean sensitivity indices of the different instruments will be presented. For each visual field the average sensitivity of all tested points was calculated as follows: mean sensitivity MS (HFA) for the Humphrey Field Analyzer, mean sensitivity MS (PRT) for the Peristat 433, and mean sensitivity MS (OCT) for the Octopus 1-2-3. Pairwise correlation between these global indices is shown in Figs. 2, 3 and 4. The correlation coefficients are as follows: MS(HFA)/MS(OCT): $r = 0.7076$, $p<0.0001$; MS(PRT)/MS(HFA): $r = 0.7461$, $p<0.0001$; MS(PRT)/MS(OCT): $r = 0.6500$, $p<0.0001$. The correlation was fairly good and highly statistically significant with correlation coefficients of approximately 0.7. The parameters of the regression lines are summarized in Table 1, they can be used for transforming the dB-scales between the different instruments.

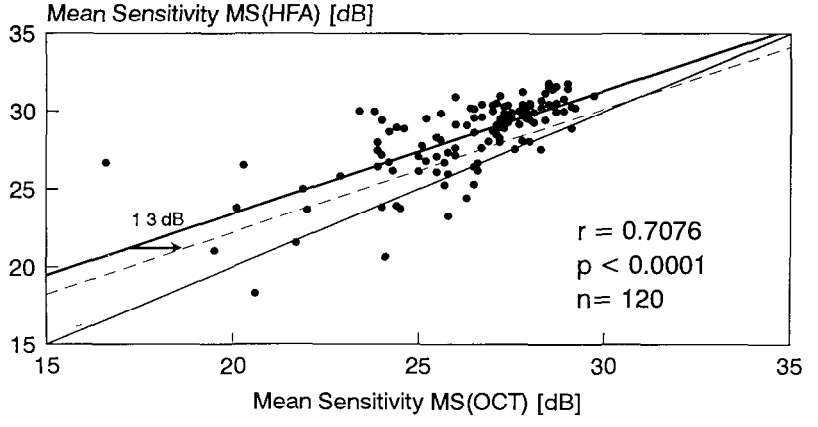

Fig. 2. Correlation of mean sensitivity of the Humphrey Field Analyzer MS (HFA) to mean sensitivity of the Octopus 1-2-3 MS (OCT): $r = 0.7076$, $p<0.0001$. The line indicating equal sensitivity on abscissa and ordinate is included together with the shift of the regression line by an amount of approximately 1 3 dB, due to the calibration error of the Octopus 1-2- 3 of the first generation used in the present study

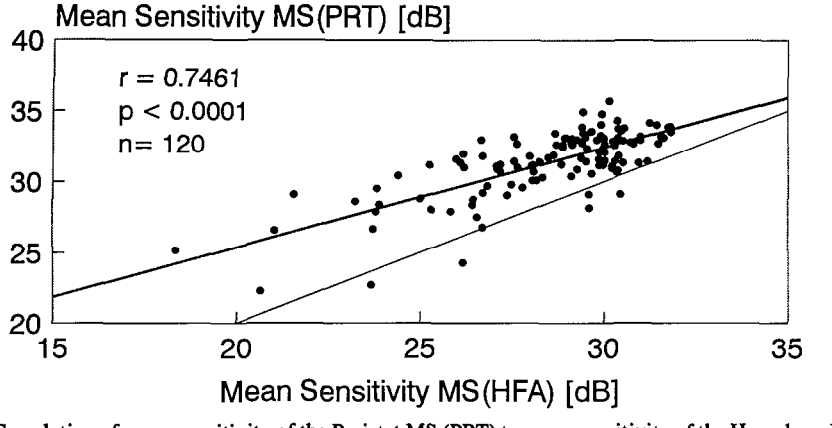

Fig. 3. Correlation of mean sensitivity of the Peristat MS (PRT) to mean sensitivity of the Humphrey Field Analyzer MS (HFA): $r = 0.7461$, $p<0.0001$. The line indicating equal sensitivity on abscissa and ordinate is included.

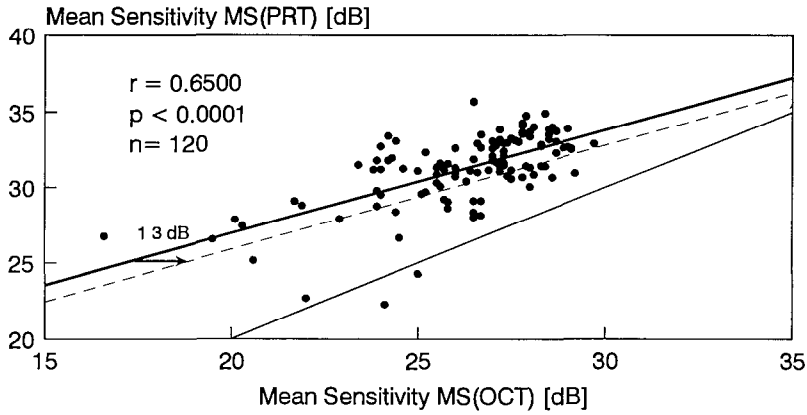

Fig. 4. Correlation of mean sensitivity of the Peristat MS (PRT) to mean sensitivity of the Octopus 1-2-3 MS (OCT): $r = 0\ 6450$, $p<0.0001$. The line indicating equal sensitivity on abscissa and ordinate is included together with the shift of the regression line by an amount of approximately 1.3 dB due to the calibration error of the Octopus 1-2-3 of the first generation used in the present study.

Table 1. Linear regression analysis of the pairwise correlation of the mean sensitivity indices MS (HFA), MS (PRT) and MS (OCT)

MS(HFA)/MS(OCT)	MS(HFA) [dB] = 0.7924 · MS(OCT) [dB] + 7.57
MS(PRT)/MS(HFA)	MS(PRT) [dB] = 0.7029 · MS(HFA) [dB} + 11.31
MS(PRT)/MS(OCT)	MS(PRT) [dB] = 0.6857 · MS(OCT) [dB] + 13.25

As the prototype of the first generation of the Octopus 1-2-3 used in the present study had a calibration error of the surround luminance, the data which are used for the present analysis have to be corrected according to the following approximate formula:

$MS_2 = MS_1 + 1.3$ dB

MS_1 = mean sensitivity, 1st generation

MS_2 = mean sensitivity, 2nd generation

Discussion

The results of the present study provide the possibility of converting normal visual field data between the Humphrey Field Analyzer 640, program 30-2, the Rodenstock Peristat 433, program GL1, and the Octopus 1-2-3, program G1X. In order to demonstrate the shift between the different dB-scales, a line corresponding to equal sensitivity values on both abscissa and ordinate was included in Figs. 2, 3 and 4. In addition, in Figs. 2 and 4 the shift of the regression line due to the calibration error of the Octopus 1-2-3 by an amount of approximately 1.3 dB is indicated. While the difference between HFA and OCT is small and almost negligible when performing the correction of the Octopus scale, there is a considerable shift between the scales of the PRT and the HFA, respectively, OCT. This has to be taken into account when comparing visual field data between these instruments. A more comprehensive statistical analysis of our data including pointwise correlations, correlations of quadrants and ring zones and other global indices together with the reliability parameters is currently in preparation and will be published elsewhere. Further comparative studies with patients showing abnormalities of the visual field are planned in order to verify the dB-scale transformation in the range of lower sensitivity values.

References

1 Heijl A, Lindgren G, Olsson J: Normal variability of static perimetric threshold values across the central visual field. Arch Ophthalmol 105:1544-1549, 1987

2. Iwase A, Kitazawa Y, Ohno Y: On age-related norms of the visual field. Jpn J Ophthalmol 32:429-437, 1988

3. Haas A, Flammer J, Schneider U: Influence of age on the visual fields of normal subjects. Am J Ophthalmol 101:199-203, 1986
4. Hendrich G, Lachenmayr BJ, Vivell PMO: Automatische Perimetrie am Octopus 1-2-3; normales Gesichtsfeld und Erfassung glaukomatoser Gesichtsfelddefekte. Fortschr Ophthalmol (Suppl) 88:145, 1991
5. Vivell PM, Lachenmayr BJ, Schaumberger MM, Zimmermann P, Dietrich H, Mueller AJ: Normal data of the central and peripheral visual field for the Peristat 433. Invest Ophthalmol Vis Sci (Suppl) 33:969, 1992
6. Flammer J, Jenni F, Bebié H, Keller B: The Octopus glaucoma G1 program. Glaucoma 9:67-72, 1987
7. Vivell PMO, Grubwinkler S, Lachenmayr BJ: Das normale Gesichtsfeld am Octopus 1-2-3. Fortschr Ophthalmol (Suppl) 88:226, 1991
8. Dietrich J: Normalwerte für das zentrale Gesichtsfeld am Humphrey Field Analyzer. Thesis, Medical Faculty, Ludwig-Maximilian-University, Munich, in preparation
9. Hendrich G: Automatische Perimetrie am Octopus 1-2-3: normales Gesichtsfeld und Erfassung glaukomatöser Gesichtsfelddefekte. Thesis, Medical Faculty, Ludwig-Maximilian-University, Munich, 1992

Reappraisal of normal values of the visual field using the Octopus 1-2-3

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Abstract

The authors studied the normal values of the visual field in normal subjects using the latest model of the direct projection automated perimeter Octopus 1-2-3. They tested 142 eyes of 142 normal subjects (12-76 years of age) with the standard program G1X using target size 3. The normal subjects had corrected vision of 20/20 or better. Their refraction was less than 3 diopters (D) of spherical error and 2 D of astigmatism. Their intraocular pressure was less than 21 mmHg. Their optical media were clear and their fundi normal. They had neither family history of glaucoma nor systemic diseases likely to affect their visual function. In addition, the authors excluded the test results if their false negative or false positive responses were greater than 10%. The results of the initial examination were also excluded. The mean sensitivity of the normal subjects was found to decrease linearly with age Its age slope was -0.40 dB per decade. The age slope of the sensitivity for each test point increased with eccentricity in the central 30° field. The age slope of the upper field was greater than that of the lower field between 10° and 30° eccentricity. The variation between individuals increased with eccentricity and this increase was more remarkable in old than in young people.

Introduction

Detection of pathological changes in the visual field is based on knowledge of the normal visual field. In perimetry the thresholds are influenced by the conditions of the examination, such as the background luminance, target size, target luminance and target color. The thresholds also depend on such factors as age and experience of the examinee. In addition, the differential thresholds change with the test locations in the visual field.

The Octopus 1-2-3 is a unique automated perimeter with many innovative features. It has a newly developed direct stimulus projection system. Furthermore, some examination conditions of the Octopus 1-2-3, such as background luminance and target color differ from those of other Octopus perimeters[1].

The purpose of this paper was to reappraise the effect of age on sensitivity in normal subjects, and to estimate the age slope at each test point and the variation of normal values between individuals within the central 30° visual field with the use of program G1X of the Octopus 1-2-3.

Subjects and methods

We tested 142 eyes of 142 normal Japanese volunteers ranging in age from 12 to 76 years with a mean age of 44.5 years. All normal subjects in this study had a corrected vision of 20/20 or better. Their refraction was within 3.0 D of spherical error and within 2.0 D of astigmatism. Their intraocular pressure was less than 21 mmHg. Their optical media were clear and their fundi normal. They had no systemic diseases likely to affect their visual functions and no family history of glaucoma. The size of their pupils was larger than 3 mm.

We used the latest model of the Octopus 1-2-3. Using all the stages of the standard program G1X, we measured the thresholds twice at 59 test locations within the central 30° field. We

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determined the static visual field under the background luminance of 31.5 asb using target size 3. When we used correction lenses, we selected a spherical lens so that the examinee could get the clearest view of the cross mark for fixation.

We excluded the test results if false negative or false positive responses were greater than 10%. We also excluded the results of the initial examination to avoid learning effects. To analyze the data for each test location, we converted the results of the left eyes to those of the right eyes.

Results

Table 1 shows the arithmetic means and standard deviations of the global indices, such as mean sensitivity (MS), mean defect (MD), corrected loss variance (CLV) and short-term fluctuation (SF) for each age group.

Table 1. Means and standard deviations of the global indices for each age group of 142 normal subjects

Age	*(mean ± SD)*	*No. of eyes*	*MS*	*MD*	*CLV*	*SF*
12-19	16.2±2.6)	12	28.5±0.6	1.1±0.6	0.8±0.3	1.5±0.2
20-29	(24.6±2.8)	23	28.2±1.2	1.1±1.2	1.6±0.8	1.4±0.2
30-39	(34.9±3.0)	19	27.9±1.3	0.8±1.1	1.8±1.1	1.3±0.2
40-49	(44.9±3.0)	29	27.8±1 0	0.2±1.0	1.9±1.2	1.4±0.2
50-59	(54.9±3.1)	28	27.4±1.1	0.0±1.1	2.2±1.8	1.4±0.2
60-69	(64.3±2.8)	24	26.6±1.3	0.1±1.3	2.2±1.5	1.5±0.3
70-76	(73.3±2.0)	7	25.9±1.6	0.3±1.5	3.1±1.5	1.7±0.5

The mean and the standard deviation of SF of 142 normal subjects was 1.44±0.27 dB. SFs were within 2.0 dB except those of four out of 142 normal subjects (2.8%, maximum: 2.5 dB).

MS decreased linearly with age (Fig. 1). The slope of the decrease with age was -0.40 dB per decade by a linear regression analysis (95% confidence range for the slope was -0.51 to -0.28 dB per decade).

MD, which is the mean decrease from the normal values previously set in the Octopus 1-2-3, was slightly larger in young than in old people (MD = -0.022 × ages + 1.5, by a linear regression analysis). The average MD value of old people was close to 0 dB. Therefore, the thresholds of old people agreed with the values set as normal. The MD values of 15 of 142 normal subjects (10.6%, maximum: 3.5 dB) exceeded 2.0 dB. CLV values of eight of 142 normal subjects (5.6%,

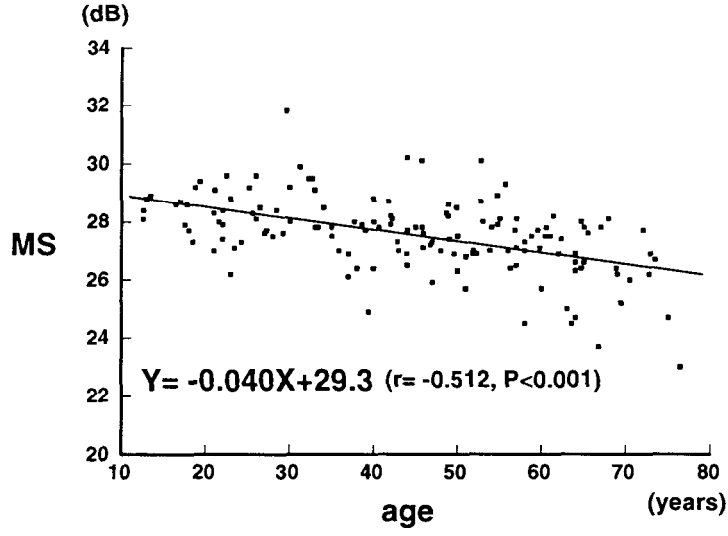

Fig. 1. The relationship between age and mean sensitivity values.

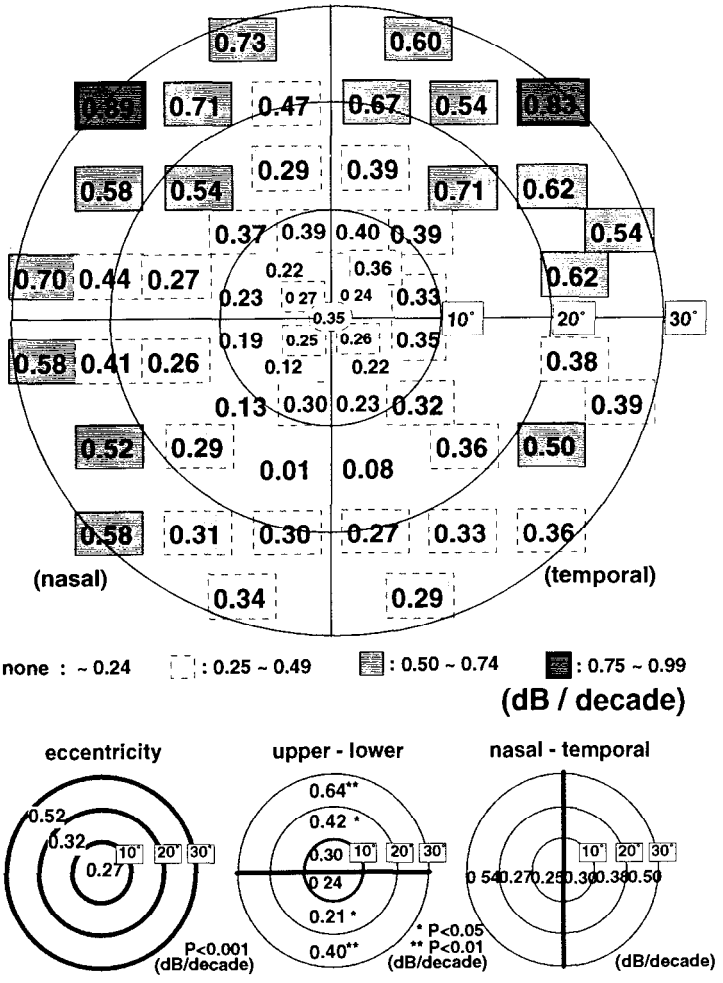

Fig. 2. The age slopes of sensitivity for each test point (dB per decade).

maximum: 8.3 dB^2) exceeded 4.0 dB^2.

To evaluate the effect of age on sensitivity, we calculated the slope of the regression line for each test point (Fig. 2). The sensitivity loss with age varied with the test point. In addition, these age slopes were gentler than those of previous results reported with the use of other automated perimeters[2-5]. The age slopes were gentle especially in the central 20° field and the lower field.

In addition, these slopes were significantly different among 0-10°, 10-20° and 20-10° eccentricity zones ($p<0.001$, by Kruskal-Wallis analysis). The slopes were significantly larger in the upper half than in the lower half of the field between 10° and 30° eccentricity (10-20°: $p<0.05$, 20-30°: $p<0.01$, by Wilcoxon analysis). The difference between the nasal and the temporal half of the field was not significant in any eccentricity zones within the central 30° field.

Thus, we calculated the age-corrected normal values of 50 years of age for the G1X program on the basis of our data of the regression analysis for each test point (Fig. 3).

The standard deviations of the normal sensitivity at each test point were also calculated for each age group (Fig. 4). The variation between individuals was larger in the zone between 20° and 30° than in the central 20° field. The increase of variation with eccentricity was more remarkable in old than in young people.

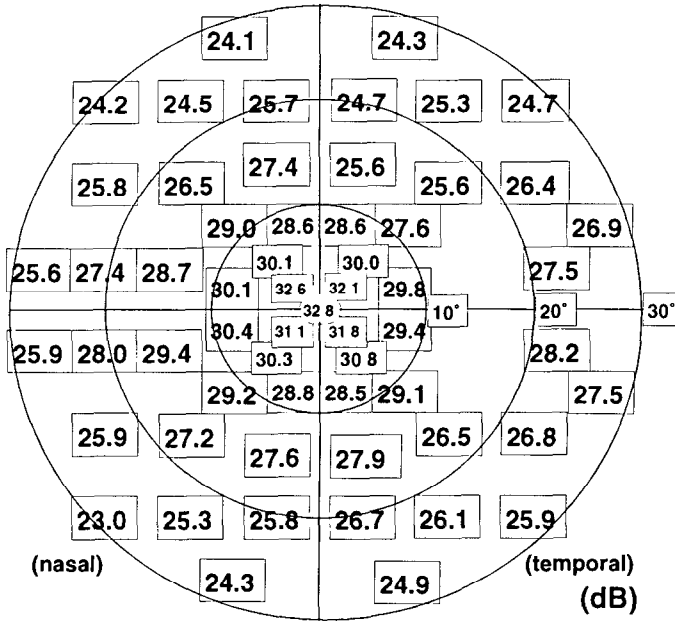

Fig. 3. The age-corrected normal sensitivity values calculated for 50 years of age.

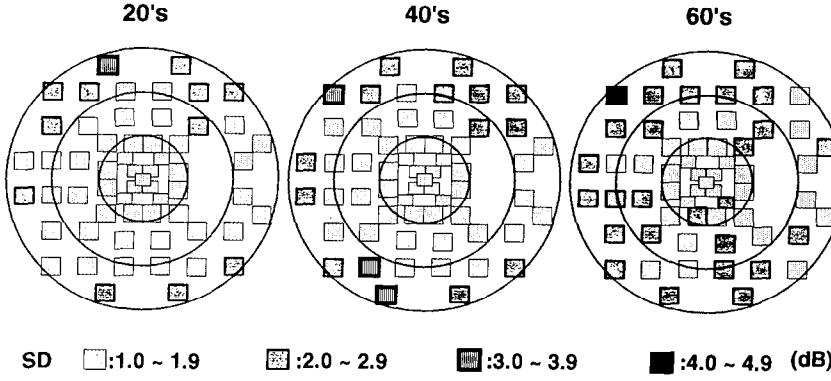

Fig. 4. Standard deviations of sensitivity of normal subjects in the 20s, 40s and 60s.

Discussion

We know that the average of the differential light thresholds decreases with age. Using an automated perimeter, Haas *et al.* found that the linear decrease of the mean sensitivity per decade was -0.58 dB. They tested 203 eyes of 153 normal subjects with the Octopus program JO[2]. Brenton and Phelps tested 102 normal subjects with the Humphrey Field Analyzer and found that the linear decrease was -0.6 dB per decade in the central 30° field[3]. The mean sensitivity of our 142 normal subjects also decreased linearly with age. The slope was, however, -0.40 dB per decade, which was smaller than previous results.

Various factors might be connected with our smaller decrease of sensitivity with age. One of these may be the difference in target color. The stimulus color of the light emitting diode (LED) of the Octopus 1-2-3 is yellow (590 nm). Therefore, the influence of aging of the lens might be less with the Octopus 1-2-3 than with other perimeters which use a white target.

The difference might also be explained by the fact that criteria for our normal subjects were slightly stricter than those described by several authors as far as visual acuity, refractive error and rate of false responses are concerned. We tried to collect reliable data with smaller false

responses. If we included the subjects who had larger refractive errors and decreased visual acuity, the variation of the thresholds between individuals might have been greater. Opacity of the ocular media causes reduction in the visual acuity with age. It is possible that these factors modified our sensitivity values.

In addition, the unique optical system of the Octopus 1-2-3 may have affected the thresholds of young people. Some cases younger than 40 years of age did not have a clear view of the fixation target with the correction lens for distance. This blurring of vision with the far corrected lens may have been caused by the accommodation of the examinee. In these cases we used a spherical lens which gave them a clear view of the cross.

Based on all these results, it is recommended that the normal values set in the latest model of the Octopus 1-2-3 should be modified in the near future.

References

1. Jenni A, Hirsbrunner HP: A comparison of cupola-free perimetry with conventional perimetry: preliminary results. Jpn J Ophthalmol 34:280-290, 1990
2 Haas A, Flammer J, Schneider U: Influence of age on the visual fields of normal subjects Am J Ophthalmol 101:199-203, 1986
3. Brenton RS, Phelps CD: The normal visual field on the Humphrey Field Analyzer Ophthalmologica 193:56-74, 1986
4. Jaffe GJ, Alvarado JA, Juster RP: Age-related changes of the normal visual field Arch Ophthalmol 104:1021-1025, 1986
5. Heijl A, Lindgren G, Olsson J: Normal variability of static perimetric threshold values across the central visual field Arch Ophthalmol 105:1544-1549, 1987

Clinical value of FASTPAC: a comparative study with the standard full threshold method

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Abstract

FASTPAC is a new thresholding algorithm for the Humphrey perimeter which uses 3 dB steps and a single crossing of the threshold It takes less time than the standard Humphrey thresholding protocol. The authors tested four eyes of four ocular hypertensives and 22 eyes of 22 glaucoma patients; all were experienced with and reliable in automated perimetric examinations. On average, FASTPAC took 66% of the time required by the standard method; the time difference was greatest in normal fields, and least in patients with more advanced field loss. Across the spectrum of tested subjects, both mean deviation and short-term fluctuation were significantly larger with FASTPAC compared with the standard method: mean deviation: -6.12 dB *versus* -5.3 dB, $p<0.01$; short-term fluctuation 2.4 dB *versus* 2.0 dB, $p<0$ 05. FASTPAC substantially shortens examination time in eyes with less advanced field defects Further studies are needed to determine its place in clinical practice.

Introduction

FASTPAC is a newly available thresholding algorithm for the Humphrey perimeter; it uses 3 dB steps and a single crossing of the threshold for the purpose of shortening test time[1]. Little is known as to how the results of FASTPAC compare with those of the standard thresholding algorithm, particularly with regard to test time and visual field indices. In order to evaluate FASTPAC clinically, we compared its results with those of the standard algorithm in glaucoma patients.

Patients and methods

Perimetry was performed with a Humphrey Field Analyzer 630 using the standard algorithm (Standard) and FASTPAC with program 30-2. Either Standard or FASTPAC was chosen ran-

Table 1. Clinical backgrounds of enrolled patients

Age (years)	51.0 ± 7
Male/female	16/10
Corrected visual acuity	≥0.7

Table 2. Diagnostic criteria for normal tension glaucoma

1.	Maximum IOP ≤ 21 mmHg
2.	Glaucomatous cupping of the optic disc
3.	Presence of glaucomatous visual field defects corresponding to optic disc changes
4.	A non-occludable open angle
5.	No intracranial or otolaryngological lesion
6.	No history of massive hemorrhage or hemodynamic crisis
7.	No history of corticosteroid therapy

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domly to be the first test, then the other was performed on the same day, and visual field indices were calculated. We examined four patients with ocular hypertension (OH), 15 with primary open angle glaucoma (POAG) and seven with normal tension glaucoma (NTG). The clinical background of the patients is summarized in Table 1. All patients were experienced in automated perimetry, and the reliability of the results was satisfactory (fixation loss, false positive and false negative each were less than 20%). The diagnostic criteria for NTG are listed in Table 2.

Results

Mean global indices found in our clinical sample are shown in Table 3 for FASTPAC and for the Standard full threshold method. Mean deviation (MD) was significantly larger in magnitude with FASTPAC (-6.15±6.71 dB) than with Standard (-5.30±6.98 dB). Short-term fluctuation (SF) was also significantly larger with FASTPAC (2.38±0.89) *versus* Standard (1.96±0.87).

Table 3. Global indices for FASTPAC and for the Standard full threshold method

	Standard	*Fastpac*	*P*
MD	-5.30±6.98	-6 16±6.71	<0.01
SF	1.96±0.87	2.38±0.89	<0.05
PSD	6 69±4.20	6 62±3.57	NS
CPSD	6.10±4.42	5.66±4.08	NS

Mean ± SD; n=26; Wilcoxon's signed-rank test

Neither pattern standard deviation (PSD) nor corrected pattern standard deviation (CPSD) differed significantly between the two thresholding algorithms.

Average testing time for the Standard algorithm was 914.5±140 seconds compared with 597±105 seconds for FASTPAC. Therefore, FASTPAC took 34% less time than Standard. The time difference was significantly greater in eyes with less advanced field defects (Fig. 1).

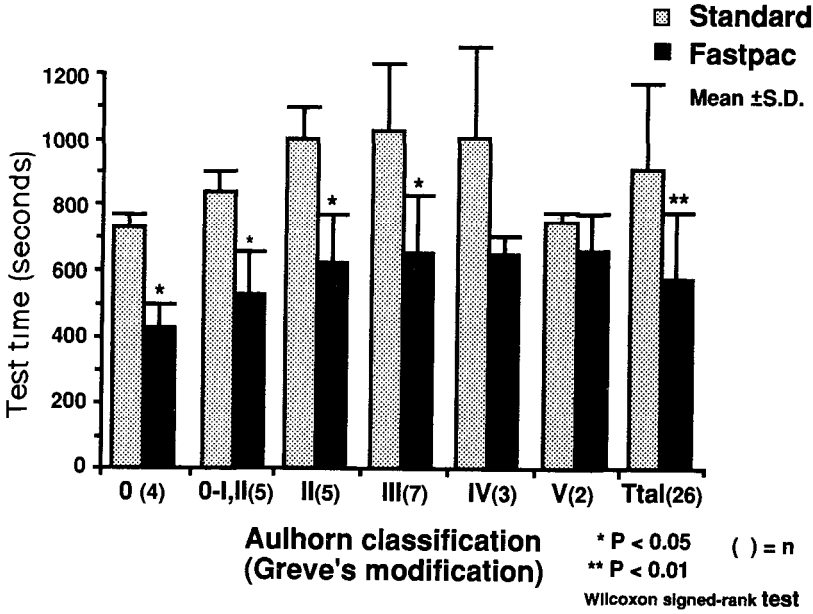

Fig 1. The time difference was significantly greater in eyes with less advanced field defects.

Discussion

FASTPAC makes only one crossing of the threshold, compared to the two crossings used by the Standard threshold algorithm of the Humphrey perimeter. FASTPAC moves in 3 dB steps instead of the Standard method's 4 dB steps followed by 2 dB steps[2]. Hence, it is not surprising that our study revealed that FASTPAC substantially shortened the perimetric examination time in eyes with early to moderate visual field loss. FASTPAC's time advantage was less marked in eyes with more advanced field loss. FASTPAC's MD and SF were significantly different from those of the Standard method.

Automated static threshold perimetry has become the standard care in the diagnosis and management of glaucoma patients, but some patients cannot tolerate long test times, and often produce unreliable test results. FASTPAC measures thresholds in less time than the Standard algorithm of the Humphrey perimeter, although its intra-test variability (SF) is significantly larger than that of the Standard. Heijl has suggested that algorithms using 3 dB steps and single crossing of the threshold are less useful than Standard algorithms in the follow-up of glaucomatous visual fields[3]. The larger fluctuation associated with them interferes with the detection of progressive changes. We believe that FASTPAC offers an advantage which may be very important in patients who cannot tolerate longer procedures. Since the number of patients enrolled in the present study was rather small, further studies are needed to determine the place of FASTPAC in clinical practice.

References

1. STATPAC 2 User's Guide: Allergan-Humphrey, San Leandro, CA 1989
2. FASTPAC User's Guide: Allergan-Humphrey, San Leandro, CA 1991
3. Heijl A: A computer test logics in automatic perimetry Acta Ophthalmol 55:837-853, 1977

STATPAC-FASTPAC comparison in glaucoma

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Abstract

Objective: To compare two different methods (STATPAC and FASTPAC) of measuring retinal sensitivity in glaucoma using the Humphrey Visual Field Analyzer Design: Prospective evaluation at a single visual field examination session of both methods, using the right eye only; half the patients tested with STATPAC first followed by FASTPAC, and vice versa. Subjects: 34 primary open angle glaucoma and three low tension glaucoma patients, seven ocular hypertensive subjects. Setting: Glaucoma clinic. Main outcome measures: Assessment of method differences in global and reliability indices as well as test time.

Results

The sum of the differences between STATPAC and FASTPAC was -1.19 ± 2.37 dB for mean deviation (MD) and 0.97 ± 2.14 dB for corrected pattern standard deviation (CPSD). These differences were just as likely to occur with early or advanced field loss. FASTPAC underestimated MD and CPSD with reference to STATPAC. No difference was seen in short-term fluctuation or in the reliability indices. Test time was reduced by 35% using FASTPAC.

Conclusions

Because FASTPAC only makes a single pass across threshold, it will lead to inaccurate measurement of test point retinal sensitivity. This apparently results in an underestimation in determining true pathology as reflected in MD and CPSD, and will lead to errors in the early detection of visual field defects in ocular hypertension. Intuitively, the inaccuracy in threshold estimation due to using steps of 3 dB will lead to greater long-term fluctuation, and will cause greater difficulty in clinical and statistical monitoring of change in visual fields over time. We do not recommend the use of FASTPAC (in its present form) in high risk ocular hypertensive subjects and glaucoma patients. We suggest that it has a role to play in low risk ocular hypertensives and in screening.

This paper will be published in detail elsewhere.

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Effects of stimulus size on test-retest variability

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Abstract

A major problem with threshold automated perimetry is the high test-retest variability Heijl and colleagues have reported that test points with loss of 8 to 18 dB have a 95% prediction interval that almost exceeds the measurement range of the perimeter (0-40 dB)[1]. To investigate this variability of different sizes of perimetric stimuli, the authors studied three subjects with the Humphrey Visual Field Analyzer using three target sizes: Goldmann sizes I, III and V. They analyzed test points along the horizontal meridian from -30° (nasal) to 30° (temporal) spaced 10° apart. They performed five threshold determinations for each of the three stimulus sizes at each test location. Their results by coefficient of variation show the highest test-retest variability for size I targets and lower variabilities for sizes III and V. Also, there was an increase in variability with increasing eccentricity (decreasing sensitivity), greatest for the smallest targets. The results suggest test-retest variability may be reduced by using large target sizes, especially in less sensitive areas of the visual field.

Introduction

A major problem with threshold automated perimetry is its high test-retest variability[1-6]. The statistical analysis program of the Humphrey Visual Field Analyzer (STATPAC 2) requires a minimum of four visual fields to test for change and is unable to use test points with low sensitivity. For test points with an initial disturbance of greater than 12 dB or a mean deviation greater than -15 dB, the Humphrey STATPAC analysis will verify stability but will not attempt to determine change[7].

Pointwise inter-test variability increases with decreasing sensitivity of the test point[5]. Therefore, areas of visual loss have the highest variability. These regions are therefore the most difficult areas to judge whether change is occurring. To determine the effects of target size on variability, we evaluated the central 30° along the horizontal meridian at 10° intervals to test the hypothesis: test-retest variability is greater with small targets than with large targets.

Subjects and methods

Three highly trained normal subjects participated in the study. Their mean age was 36 ± 7 (range 28-42). The subjects all had normal ophthalmologic examinations and normal conventional automated perimetry. The right eye of each subject was tested. Patients' fixation was monitored by the visual field technician. The testing for each subject was done in one day. Rest breaks were given between each of the 15 trial runs of three minutes.

The test protocol with the Humphrey Visual Field Analyzer used three different target sizes: Goldmann sizes I, III and V. Test points were along the horizontal meridian spaced 10° apart from -60° to 60°(only those from -30° to 30° are analyzed in this report). The foveal threshold was determined both with the other test points and separately. The subject's appropriate near correction was given when necessary for the central 30°. Only the results for the central 30°

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are reported here. Five threshold determinations were performed in each subject at each test location for each of the three stimulus sizes.

The subject's data files were converted to a DIF format with a software conversion program (Humphrey.COM) and imported into a spreadsheet. We calculated the means, standard deviations and coefficients of variation* of each test point of the five trials within subjects. The coefficients of variation for each size at each location were regressed against mean sensitivity.

Results

As expected, the mean sensitivities for the size I targets were the lowest and the size V scores the highest (Fig. 1). Note, in this figure, how the size V target flattens the slope of the island of vision. The standard deviations increase with increasing eccentricity (Fig. 1. error bars) as do the standard deviations plotted as a percentage of the mean (coefficient of variation = CV) (see Fig. 2). When the CV was plotted against the mean threshold sensitivity there was an exponential rise in variability for the size I target (Fig. 3). Of interest was the report of subjects that at maximal visual field eccentricities, small targets were actually perceived as large when the intensity was suprathreshold.

The foveal thresholds were about one dB greater when tested alone compared with the rest of the other test points (Table 1). The coefficients of variation were greatest for the size I and least for the size V target (Fig. 4). The coefficients of variation were greater for the fovea tested with the rest of the group of test locations.

Table 1. Foveal thresholds: the foveal thresholds were tested with other test points and singly

Stimulus	*Fovea included*		*Fovea alone*	
size	*mean*	*standard deviation*	*mean*	*standard deviation*
I	29.7	2.0	28.3	1.0
III	35.0	1.5	35.0	1.0
V	37 9	1.3	38.2	0.8

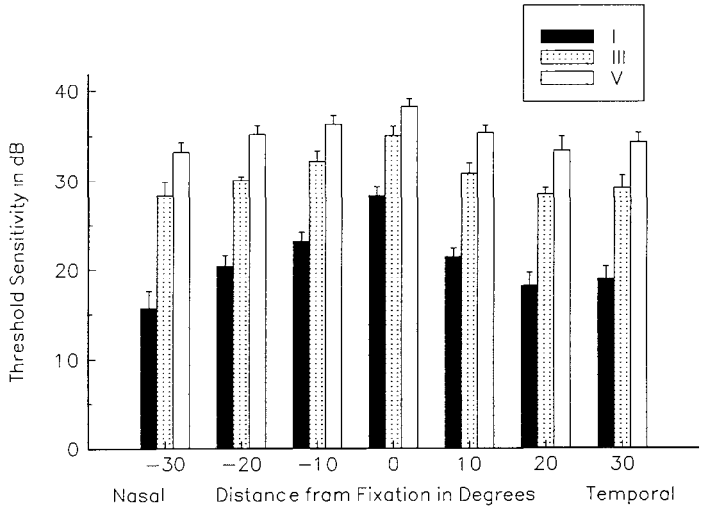

Fig. 1. Mean threshold sensitivity of the right eyes of three subjects for the three test sizes at 13 test locations. Note the steeper slope of the visual island with smaller test sizes (error bars = 1 standard deviation).

* Use of the coefficient of variation, also called the relative standard deviation [(standard deviation * 100) / mean] is not appropriate for comparison of variabilities within target sizes. However, since the hill of vision has such a different shape for each target size, direct comparison of different target size variabilities is like comparing different tests. To allow comparison of the means between the size groups, the coefficients of variation are presented.

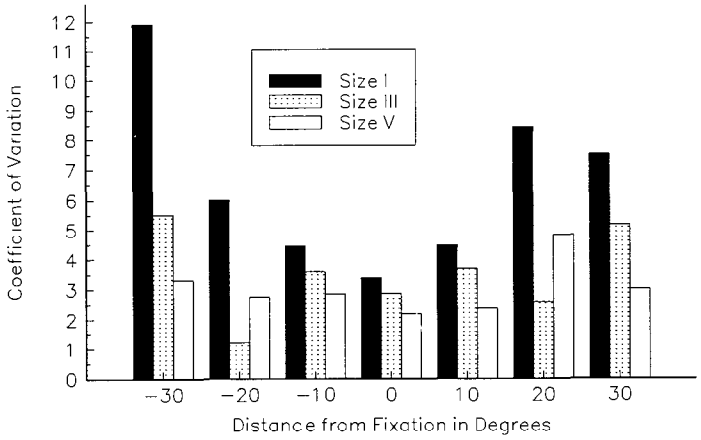

Fig. 2. The coefficient of variation [(standard deviation 1 mean) * 100] for the three subjects. Note the pattern at many locations of the highest variability with size I and the lowest variability with size V.

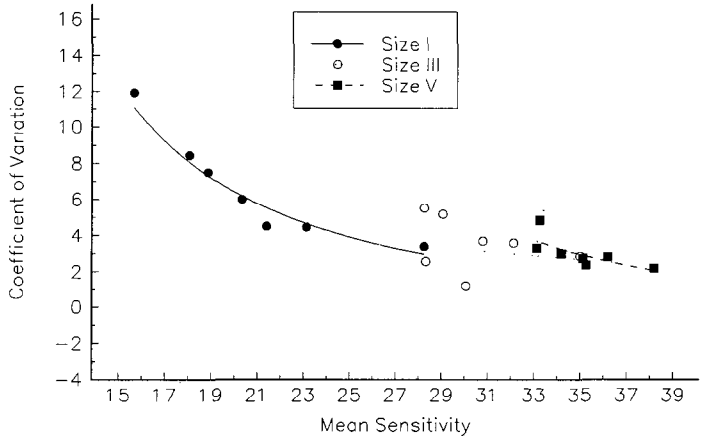

Fig. 3. Exponential curve fit results of coefficient of variation plotted against mean threshold. Mean threshold is the average threshold sensitivity of five repetitions per subject for all locations. Foveal thresholds were tested in isolation.

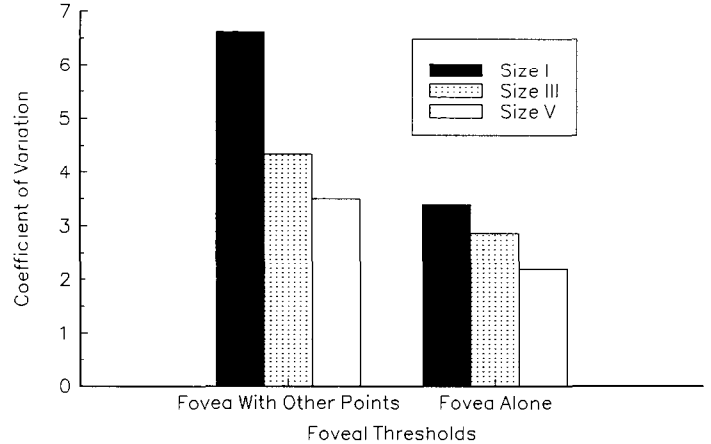

Fig. 4. Coefficients of variation of foveal thresholds tested with other test points and in isolation. Note the higher variability when tested with other points.

Discussion

It is well known that total stimulus power is a function of the luminance and the area of the stimulus[8]. Goldmann simplified this relationship by establishing "equivalent stimulus values"[9]. These values are based on the relationship: increasing target diameter by a factor of two is approximately equal to increasing luminance by one-half log unit. Since the Goldmann target diameters increase by doubling of the diameters (*e.g.*, 1, 2, 4, 8 mm), and the standard intensities differ by one-half log unit, a I_{4e} stimulus is similar in stimulus power to II_{3e}, III_{2e} and IV_{1e} stimuli[10].

Goldmann realized that spatial summation varied across the retina[10]. However, as an approximation for the effect of spatial summation for entire field he estimated the summation coefficient to be 0.8. Sloan reported a gradual increase in the capacity for spatial summation with increasing distance from the fovea[11]. In addition, she showed the relationship is exponential, not linear and therefore not a constant[11]. Fellman *et al.* reported a greater capacity for spatial summation in glaucoma patients compared with normals[12].

Our data also show this effect of spatial summation. The mean sensitivity was highest with size V targets and lowest with size I (Fig. 1). Our results are similar to those of Choplin *et al.* who compared sizes III-V[13], and also Sloan who used sizes 0-V[11]. The higher mean sensitivity is best explained by increased receptive field coverage and resultant spatial summation[14]. This also appears to be the explanation for the findings of Wilensky and Joondeph[15], and Fellman and co-workers[12]. They reported glaucoma patients could detect a size V stimulus in areas of absolute scotomas to the size III target.

Our data demonstrate less variability for large than small targets. This may have practical importance since with light sensitivity threshold automated perimetry using a fixed target size, test-retest variability is a major problem. This variability can seriously confound visual field interpretation. The high intrasubject variability of conventional automated perimetry has been measured in normals by coefficients of variation of 10-20%[3,16]. Unfortunately, this already high variability increases dramatically in areas of visual field damage: the greater the loss of sensitivity, the greater the variability[1,17,18]. It is also significantly increased at the edge of scotomas[19,20]. The CV is much higher in subjects with damaged visual fields (about 37% for a mean sensitivity of 15.8 dB)[21]. CVs of less than 10% are desirable. A test that uses targets with constant luminance and varies size (ring perimetry) has coefficients of variation of 6-8% in normals[22,23] and 4% in patients with damaged visual fields due to idiopathic intracranial hypertension[22].

An explanation for lower variability with a thresholding algorithm that uses size instead of luminance has been proposed[22]. Perception is dependent on the number of receptive fields covered by a target. Receptive fields are more sparse in areas of field damage requiring either a brighter small stimulus or a larger stimulus of the same brightness. For example, a small automated field target covers a few receptive fields and is seen; microfixation shifts occur[24] and on retest the target may now be covering fewer receptive fields and may not now be seen. This effect would be less prominent with a large, dimmer test target because the chance of change in the number of receptive fields covered would be less. Also, a decrease in variability of large stimuli could partly be due to less degradation of the stimulus by refractive error and media opacities. Finally, spatial summation which is greater in the periphery may be acting to reduce variability when large targets are used.

Gilpin and colleagues have also studied the effect of stimulus size on variability. They limited their testing to the central 20°. A custom program was given twice within 20 minutes using five stimulus sizes. They repeated the test three times on other days[25]. They also found higher variability with small target sizes than large sizes.

Of interest was the report of subjects that at maximal visual field eccentricities, small targets were actually perceived as large when the intensity was suprathreshold. Bedell and Johnson have previously noted this observation[26]. It suggests scatter of the target is recruiting large numbers of receptive fields in order to be seen. The prominent effect in the periphery was attributed to peripheral retinal ganglion cells having larger summation areas than central retinal ganglion cells and to optical degradation of the peripheral retinal image.

The results shown in Fig. 3 suggest that much or all of the size effect on variability can be attributed to smaller size causing a decrease in sensitivity. Some of the effect of the larger target size may be to shift the area of the tested visual field from a low sensitivity value to a higher

sensitivity value.

Variability is directly related to the number of visual field loci tested and total visual field area examined[27]. Our data of the foveal threshold are similar - lower variability (and higher sensitivity) with the fovea tested in isolation. In our protocol for the central 30°, only seven points were tested. In addition, it is likely a program that thresholds 76 points in the central 30° would have higher variabilities and possibly a greater effect of differences in target size variabilities.

In conclusion, our results show variability is correlated with target size. The greatest variability is found with the Goldmann size I target. This effect increases exponentially with eccentricity (and corresponding decreased sensitivity). These results are from normal subjects and cannot be directly extrapolated to patients with damaged visual fields. However, the results suggest using a larger target may significantly reduce variability and thus be superior for determining change over time in patients with damaged visual fields.

References

1. Heijl A, Lindgren A, Lindgren G: Test-retest variability in glaucomatous visual fields Am J Ophthalmol 108:130-135, 1989
2. Heijl A, Lindgren G, Olsson J: Normal variability of static perimetric threshold values across the central visual field. Arch Ophthalmol 105:1544-1549, 1987
3. Katz J, Sommer A: A longitudinal study of the age-adjusted variability of automated visual fields. Arch Ophthalmol 105:1083-1086, 1987
4. Lewis RA, Johnson CA, Keltner JL, Labermeier PK: Variability of quantitative automated perimetry in normal observers. Ophthalmology 93:878-881, 1986
5. Werner EB, Petrig B, Krupin T, Bishop KI: Variability of automated visual fields in clinically stable glaucoma patients. Invest Ophthalmol Vis Sci 30:1083-1089, 1989
6. Fankhauser F, Bebié H: Threshold fluctuations, interpolations and spatial resolution in perimetry Doc Ophthalmol Proc Ser 19:295-309, 1982
7. Heijl A, Lindgren G, Lindgren A et al: Extended empirical statistical package for evaluation of single and multiple fields in glaucoma: Statpac 2. In: Mills RP, Heijl A (eds) Perimetry Update 1990/91, pp 303-315. Amsterdam: Kugler Publ 1991
8. Frumkes TE: Classical and modern psychophysical studies of dark and light adaptation. In: Leibovic KM (ed) Science of Vision, pp 172-210. New York: Springer-Verlag 1990
9. Goldmann H: Grundlagen exakter Perimetric. Ophthalmologica 109:57-70, 1945
10. Tate GW, Linn JR: Principles of Quantitative Perimetry, p 17. New York: Grune and Stratton 1977
11. Sloan LL: Area and luminance of test object as variables in examination of the visual field by projection perimetry. Vision Res 1:121-138, 1961
12. Fellman RL, Lynn JR, Starita RJ, Swanson WH: In: Heijl A (ed) Perimetry Update 1988/1989, pp 313-324. Amsterdam: Kugler Publ 1989
13. Choplin MT, Sherwood MS, Spaeth GL: The effect of stimulus size on the measured threshold values in automated perimetry. Ophthalmology 97:371-374, 1990
14. Johnson CA, Keltner JL, Balestrery F: Effects of target size and eccentricity on visual detection and resolution. Vision Res 18:1217-1222, 1978
15. Wilensky JT, Joondeph SC: Variation in visual field measurements with an automated perimeter. Am J Ophthalmol 97:328-331, 1984
16. Parrish RK, Schiffman J, Anderson DR: Static and kinetic visual field testing: reproducibility in normal volunteers. Arch Ophthalmol 102:1497-1502, 1984
17. Flammer J, Drance SM, Fankhauser F, Augustiny L: Differential light threshold in automated static perimetry: factors influencing short-term fluctuation. Arch Ophthalmol 102:876-879, 1984
18. Boeglin RJ, Caprioli J, Zulaf M: Long-term fluctuation of the visual field in glaucoma Am J Ophthalmol 113:396-400, 1992
19. Haefliger IO, Flammer J: Increase of the short-term fluctuation of the differential light threshold around a physiologic scotoma. Am J Ophthalmol 107:417-420, 1989
20. Haefliger IO, Flammer J: Fluctuation of the differential light threshold at the border of absolute scotomas: comparison between glaucomatous visual field defects and blind spots. Ophthalmology 98:1529-1532, 1991
21. Werner EB, Adelson A, Krupin T: Effect of patient experience on the results of automated perimetry in clinically stable glaucoma patients. Ophthalmology 95:764-767, 1988
22. Wall M, Lefante J, Conway M: Variability of high-pass resolution perimetry in normals and patients with idiopathic intracranial hypertension. Invest Ophthalmol Vis Sci 32:3091-3095, 1991
23. Chauhan SC, House PH: Intratest variability in conventional and high-pass resolution perimetry Ophthalmology 98:79-83, 1991

24. Ditchburn RW, Ginsborg SL: Involuntary eye movements during fixation. J Physiol 119:1-17, 1953
25. Gilpin LB, Stewart WC, Hunt HH, Broom CD: Threshold variability using different Goldmann stimulus sizes. Acta Ophthalmol (Copenh) 68:674-676, 1990
26. Bedell HE, Johnson CA: The perceived size of targets in the peripheral and central visual fields. Ophthalmic Physiol Opt 4:123-131, 1984
27. Fujimoto N, Adachi-Usami E: Effect of number of test points and size of test field in automated perimetry Acta Ophthalmol (Copenh) 70:323-326, 1992

Influence of occlusion of the non-tested eye on sensitivity in automated perimetry

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Abstract

Occlusion of the non-tested eye during perimetric examination may influence the sensitivity level of the other eye. Seventeen normal subjects underwent automatic threshold static perimetry tests (Perikon PCL 90) under five different conditions: *1.* binocular vision; *2.* monocular vision with a translucent white paper occluder; *3.* monocular vision with an opaque occluder; *4.* total occlusion with a mirror occluder giving the sensation of seeing the perimetric background; *5.* partial occlusion with the same mirror occluder. Sensitivity in binocular vision was always better than in every monocular condition ($p<0.00001$), due to summation phenomena (ANOVA test). Significant sensitivity improvement ($p<0.001$) was present with the translucent occluder in comparison to the opaque one. Sensitivity with the translucent occluder was not significantly different from the mirror occluder. The simple use of a paper occluder does not create important inhibition phenomena which happens with an opaque occluder and represents a comfortable, practical and hygienic means for eye occlusion in monocular perimetry.

Introduction

Visual field examination is carried out both by manual and automatic methods with monocular vision, occluding the non-tested eye using various means which not only differ among various perimetry centers, but also according to the habits and customs of each examiner.

The occlusion method utilized for the non-tested eye is not only important for the physical and psychological comfort of the patient, who often has to undergo prolonged tests, but also, as has recently been noted[1], for the sensitivity of the eye being tested, since it is influenced by the type of occlusion utilized in the contralateral eye.

The Troxler effect[2], which refers to the sensation of glare in the visual field or of absence of perception during observation of a uniformly illuminated background (like the perimetric bowl) is a well-known phenomenon in perimetry. It occurs when the difference in luminance between the two eyes is greater than 7.5 dB[3]. The use of a translucent occluder for the non-tested eye decreases these phenomena improving the average light sensitivity of the eye being tested by 0.7 dB with respect to that obtained with a black opaque occluder[1].

It is known that binocular vision with respect to monocular vision improves light sensitivity, and this has been demonstrated both in special experimental conditions[4-7] and in modern automated perimetry. In particular, the increased sensitivity of about 1 dB in binocular vision has also been demonstrated in amblyopic eyes[5,6].

Occlusion of the non-tested eye, which gives rise to dissociating phenomena of binocular vision, certainly induces inhibitory phenomena in the eye being tested as well, which can probably cause a phenomenon due to monocular vision inhibition erroneously appearing to be an improvement in binocular vision.

The aim of our investigation is therefore to verify the influence of different types of contralateral eye occlusion on the threshold of the eye being tested, and to evaluate the real presence of sensitivity summation phenomena in binocular vision once the typical inhibition phenomena of monocular examination have been eliminated, in order to identify optimum testing conditions and occlusion in everyday perimetry.

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Material and methods

Seventeen normal subjects with experience in perimetry, aged 21 to 35, underwent a complete ophthalmological examination, including motility test, fusion test and stereoscopic sense (Titmus test). Only subjects within ±1.5 D ametropia were included in the study.

Each subject underwent five perimetric tests carried out in different ways in a randomized order, the same day, with a 15-minute interval between one examination and the other and with five minutes for adaptation at the beginning of each test. The automated projection perimeter Perikon PCL 90 (Optikon, Rome, Italy)[8] was used with standard background illumination (31.5 asb). A custom threshold static program was especially prepared which tested 12 points placed at 5°, 10° and 15° eccentricity along the 45°, 135°, 225° and 315° meridians and the central point.

The five perimetric testing conditions used in the study were as follows:

- Test 1: perimetric examination using binocular vision.
- Test 2: perimetric examination of the left eye in monocular vision using a white opaque occluder for the right eye, which consisted of a simple piece of white paper (80 g), folded into a cone, so as to prevent peripheral vision, create homogenous illumination and prevent perception of the stimuli with the greatest luminance.
- Test 3: perimetric examination of the left eye in monocular vision using a black plastic occluder to occlude the contralateral eye.
- Test 4: perimetric examination in binocular vision with perception only by the left eye, placing a mirror mounted on an experimental frame in front of the right eye. The mirror was fixed on to the bridge of the frame at an angle of 30° with respect to the sagittal plane. In this way the right eye, by means of the mirror, sees the right external part of the perimetric bowl, where no stimulus is presented, but which gives the observer the impression of normal binocular vision.
- Test 5: perimetric examination with binocular vision in the left hemifield and monocular vision in the right hemifield by placing the mirror described above at an angle of 10° with respect to the sagittal plane. In this way the left eye can perceive all stimulus locations, while the right eye can perceive only the stimuli in the right half of the bowl. For the left hemifield, the mirror shows the peripheral part of the perimetric bowl where no stimulus is presented. The subject thus has the impression of binocular vision, which is only true for the right hemifield.

For each test the perimeter gives the threshold values of each of the 13 points tested.

We calculated the average sensitivity of the six points in each hemifield under the five different testing conditions, and carried out an analysis of variance for paired data to compare the results of the right and the left hemifield and total sensitivity of the five different testing conditions.

Results

Table 1 shows the mean sensitivity values of the left eye in the different test conditions (tests 1-4). Table 2 shows the mean sensitivity difference (± SD) in dB, observed in the right eye in the different test conditions (tests 1-4) and its statistical significance. The mean sensitivity value of the right hemifield was significantly greater ($p<0.0001$) than the left one (34.8 ± 1.51 dB) in test 5. These results confirm the better sensitivity of the hemifield in which binocular perception was not obstructed by the mirror device.

Table 1. Mean sensitivity (dB ± SD)

	Right eye	*left eye*
Test 1	no occlusion	36.55 ± 0 77
Test 2	translucent occlusion	35.03 ± 1 01
Test 3	black occlusion	34.30 ± 0.81
Test 4	mirror occlusion	34.83 ± 0.84

Average sensitivity values (± SD) of the left eye in the 17 subjects tested in the four different testing conditions 1, 2, 3 and 4

Table 2.

Test 1 > Test 3	dB 2.2	$p<0.000001$
Test 1 > Test 4	dB 1 7	$p<0$ 000001
Test 1 > Test 2	dB 1.5	$p<0$ 000001
Test 2 > Test 3	dB 0.7	$p<0.001$

Differences (dB) between average sensitivity of the left eye in the four different testing conditions 1, 2, 3 and 4, and their statistical significance (analysis of variance) The comparisons which have not been shown were not statistically significant

Conclusions

Light sensitivity measured by perimetry is influenced by occlusion of the contralateral eye.

With the three types of occlusion used by us, monocular sensitivity was significantly lower than that of binocular vision, with no differences except for occlusion by means of a black occluder, which showed a significantly lower sensitivity (0.7 dB) with respect to that obtained with a translucent occluder. The use of a mirror as a means of preventing binocular vision in perimetric examination, which we do not believe represents a further dissociating method, has provided concordant data in tests 4 and 5. These results support the greater sensitivity of binocular vision, and exclude the possibility of an artifact due to simple inhibitory phenomena by the occluded eye on the tested one.

The sensitivity we found using the translucent occluder was greater than that obtained with the other methods, but this did not reach statistical significance.

The mirror method used in test 5 can obviously not be used in clinical practice due to its encumbrance and because of its practical use only within the 15-20° eccentricity. We believe that the translucent occluder, as well as avoiding the Troxler phenomenon, as demonstrated by Fuhr *et al.*[1], also has other advantages which have emerged from our study:

- it reduces the inhibitory effect on the examined eye to the least possible exact, in a not significantly different way from the conditions of monocular vision without occlusion (mirror device);
- it improves luminous sensitivity by 0.7 dB with respect to the black occluder;
- it keeps retinal adaptation conditions of the non-tested eye practically equal to the contralateral eye, thus making it possible to reduce the adaptation time before testing the second eye;
- it provides an easily realizable means of occlusion with common paper and any kind of adhesive tape, as well as being hygienically better than any occluder for multiple use.

We therefore hope that the method we have proposed may become part of everyday clinical practice. We believe that the occlusion method of the non-tested eye is an important factor which influences the result of a perimetric examination and is often underestimated in clinical practice and in scientific research programs, and should be standardized.

References

1. Fuhr PS, Hershner TA, Daum KM: Ganzfeld blankout occurs in bowl perimetry and is eliminated by translucent occlusion. Arch Ophthalmol 108:983-988, 1990
2. Troxler D: Ueber das Verschwinden gegebener Gegenstände innerhalb unseres Gesichtskreisses. Ophthalmol Bibliothek 2:54, 1804
3. Bolanowsky SJ, Doty RW: Perceptual "blankout" of monocular homogeneous fields (ganzfelder) is prevented with binocular viewing. Vision Res 27:967-982, 1987
4. Zingirian M, Molfino A, Levialdi S, Trillo M: Monocular and binocular responses to liminal and subliminal stimuli. Ophthalmologica 162:41-50, 1971.
5. Fava GP, Capris P, Fioretto M, Gandolfo E: Binocular threshold campimetry in the amblyopic syndrome. Doc Ophthalmol Proc Ser 49:633-637, 1987
6. Fioretto M, Brezzo MV, Fava GP, Gandolfo E: Binocular interaction in normal and amblyopic patients: comparative study with automatic perimetry and VEP. In: Mills RP, Heijl A (eds) Perimetry Update 1990/91, pp 161-163. Amsterdam: Kugler Publ 1991
7. De Palma G, Gandolfo E, Capris P, Semino E, Zingirian M: Confronto tra soglie luminose in visione monoculare e binoculare in soggetti normali e con difetti del campo visivo esaminati con la perimetria computerizzata. Atti 70° Cong Soc Oftalm Italiana, pp 187-194. Rome 1990
8. Zingirian M, Gandolfo E, Capris P, Mattioli R: "Perikon PCL 90": a new automatic perimeter. In: Mills RP, Heijl A (eds) Perimetry Update 1990/91, pp 403-407. Amsterdam: Kugler Publ 1991

Influence of the target size on the sensitivity of the central visual field in patients with early glaucoma

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Abstract

The authors studied the usefulness of the target size 1 in the central 30° visual field in early glaucoma patients. Quantitative static perimetry was carried out using program 32 of the automated perimeter Octopus 201. They examined 70 eyes of 70 normal subjects under the conditions of target sizes 1 and 3. Based on the arithmetic mean and standard deviation of the sensitivity in each test point, the normal sensitivity of each test point for each age group was standardized for target sizes 1 and 3. As a clinical application of the above-mentioned results, quantitative static perimetry was performed in 32 eyes of 32 early glaucoma patients using target sizes 1 and 3. In ten of 32 eyes, target size 1 was more sensitive in detecting glaucomatous visual field defects than target size 3. These results suggested that target size 1 was more sensitive and useful than target size 3 in the diagnosis of early glaucoma

Introduction

Visual field studies with an automated perimeter are very important in the diagnosis and follow-up of glaucoma and glaucoma-suspect patients. These patients have usually been examined using target size 3. So far, only a few papers have reported on the influence of target size 1 on the detectability of early glaucomatous visual field defects[1-3]. We studied the usefulness of target size 1 in the central 30° visual field in early glaucoma patients.

Subjects and methods

Automated static perimetry was performed in 70 eyes of 70 normal subjects and 32 eyes of 32 early glaucoma patients using target sizes 1 and 3 of the automated perimeter Octopus 201. All normal subjects were chosen based on the following criteria:

1. corrected visual acuity equal to or better than 20/20;
2. refractive errors of less than 3 diopters;
3. no systemic or ocular diseases;
4. examinees were well experienced in automated perimetry.

We measured the sensitivity of each test point of program 32 of the automated perimeter Octopus 201 for each age group. Then we compared the results of automated static perimetry in 32 eyes of 32 early glaucoma patients using target sizes 1 and 3. The background luminance of the perimeter was 4 asb and the stimulus duration of the target was 0.1 seconds.

Results

The average sensitivity and standard deviation of each test point of normal subjects in their 40s and 50s using target sizes 1 and 3 are shown in Figs. 1 and 2.

In order to standardize and classify the sensitivity of each test point in normal subjects under

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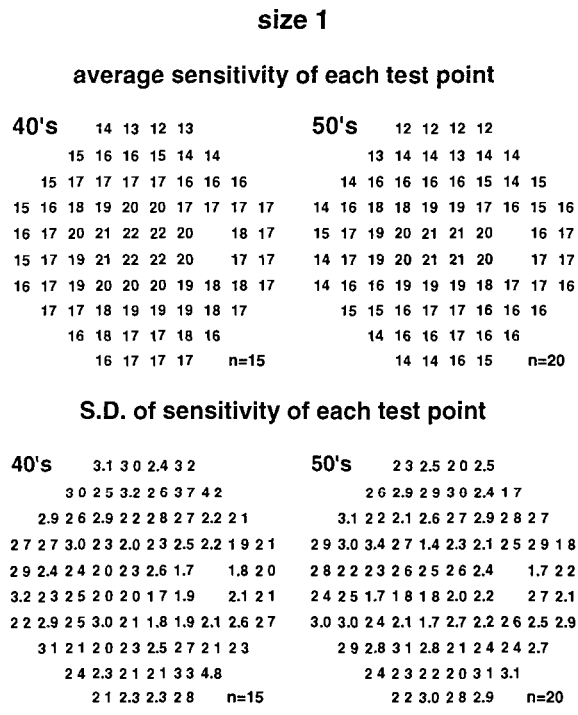

Fig. 1. The average sensitivity and standard deviation of each test point of normal subjects for target size 1 in their 40s and 50s (Octopus program 32).

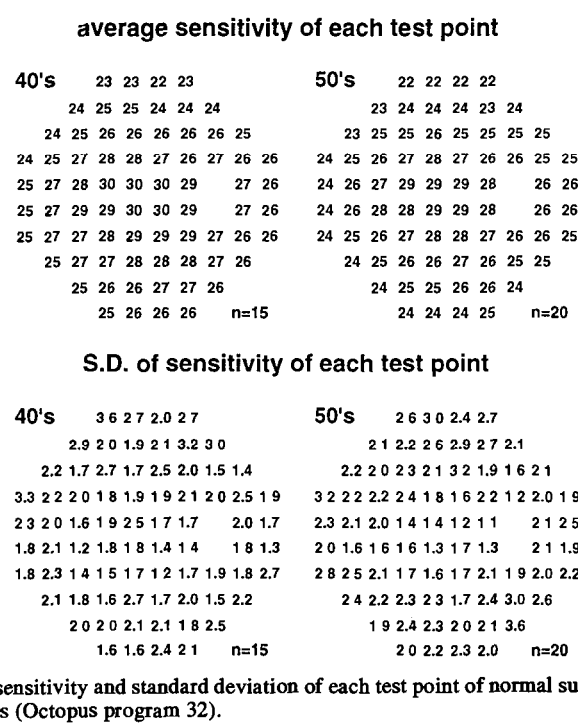

Fig. 2. The average sensitivity and standard deviation of each test point of normal subjects for target size 3 in their 40s and 50s (Octopus program 32).

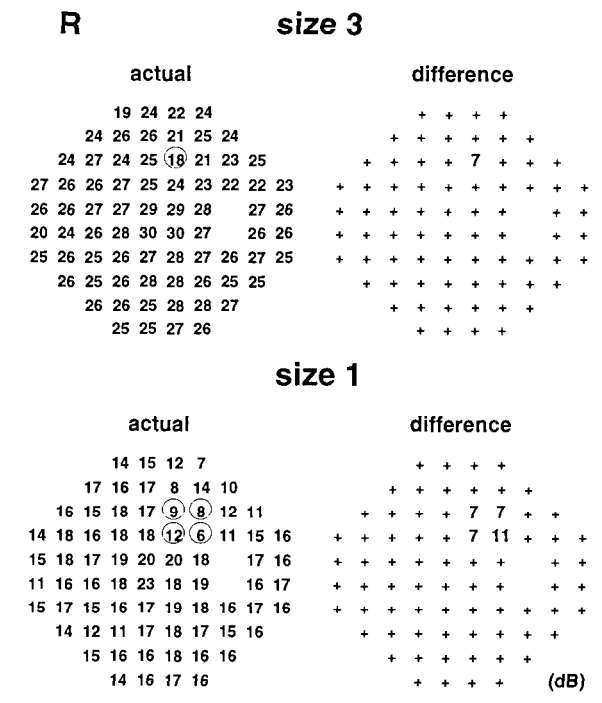

Fig. 3. Actual value tables and difference tables for target sizes 1 and 3 (Case 1).

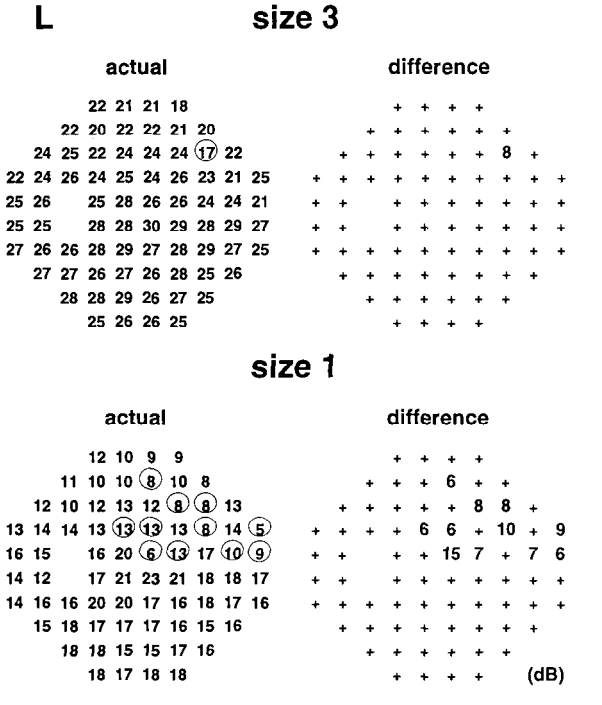

Fig. 4. Actual value tables and difference tables for target sizes 1 and 3 (Case 2).

the conditions of target sizes 1 and 3, we divided the visual field of program 32 into three zones, *i.e.*, within 10°, between 10° and 20° and between 20° and 30°.

Table 1 shows two standard deviations (SDs) of each field zone of the Octopus program 32 for target sizes 1 and 3 in normal subjects. If the sensitivity of each test point was more than "two SDs" lower than the average sensitivity of normal subjects (Figs. 1 and 2), we classified it as the abnormal sensitivity. For example, if the sensitivity of a test point within 10° was 5 dB lower than the average sensitivity of normal subjects in a patient in the 50s using target size 1, we classified it as abnormal.

Table 1. Two SD of each field zone of the Octopus program 32 for target sizes 1 and 3 in each decade of normal subjects

Age group	*Field zone*	*2 SD (dB)*	
		target size	
		1	*3*
20s	-10°	4	2
	10-20°	4	3
	20-30°	4	3
30s	-10°	4	3
	10-20°	4	3
	20-30°	5	4
40s	-10°	4	3
	10-20°	5	4
	20-30°	5	4
50s	-10°	4	3
	10-20°	5	4
	20-30°	5	5
60s	-10°	4	3
	10-20°	5	3
	20-30°	5	4

The automated static fields of patients with early glaucoma were then studied. Case 1 is a 57-year-old female with primary open angle glaucoma. Actual value tables and difference tables of her right eye using target sizes 1 and 3 are shown in Fig. 3. Under the conditions of target size 3, there was only one abnormal test point the sensitivity of which was 7 dB lower than normal sensitivity. However, under the conditions of target size 1, there were four clustered abnormal test points the sensitivities of which were 7 to 11 dB lower than normal sensitivity.

Case 2 is a 51-year-old female with primary open angle glaucoma. Actual value tables and difference tables of her left eye under the conditions of target sizes 1 and 3 are shown in Fig. 4. There was only one abnormal test point the sensitivity of which was 8 dB lower than normal sensitivity using target size 3. Glaucomatous visual field defects were suspected in this location, but it was difficult to make a definite diagnosis. When target size 1 was used, there were many abnormal test points the sensitivities of which were more than 7 dB lower than normal sensitivity in the upper nasal quadrant of her visual field.

Similarly, we examined the visual fields of 32 early glaucoma patients using target sizes 1 and 3. Table 2 shows the comparison of the detectability of glaucomatous visual field defects using target sizes 1 and 3. In ten of 32 eyes, target size 1 was more sensitive in detecting glaucomatous visual field defects than target size 3.

Table 2. Comparison of detectability of early glaucomatous visual field defects between target sizes 1 and 3

Defect (-)	*14 eyes*
Defect (+)	
size 1 > size 3	10 eyes
size 1 ≒ size 3	8 eyes
size 1 < size 3	0 eyes

Discussion

Automated static perimetry is very important in the diagnosis and follow-up of patients with early glaucoma. In manual kinetic perimetry with a Goldmann perimeter, target sizes 1 and 5 have been routinely used in Japan. However, target size 3 is generally used in automated static perimetry.

It is known that the results of visual field studies are influenced by target size in perimetry. We have already reported the usefulness of examining the paracentral visual field with target size 1 in neuro-ophthalmological cases[4]. As reported by Quigley *et al.*, early glaucomatous visual field defects may easily be missed under the conditions of target size 3[5]. Gramer *et al.* reported that the mean threshold values in the diseased areas of the glaucomatous fields were 6-10 dB higher with target size 3 than with target size 1[1]. Fellman *et al.* and Zalta and Burchfield also reported on the influence of the target size on the sensitivity in glaucoma patients using automated perimeters[2,3].

In the present study, we standardized the normal sensitivity for target sizes 1 and 3 based on the arithmetic mean and standard deviation of the sensitivity of each test point for each age in normal subjects. We performed all these calculations manually using Table 1 and a calculator. Since it is a laborious task to calculate the difference between the actual value and the average normal value for each age group, we are planning to develop some software for these calculations.

We also examined patients with early glaucoma using target sizes 1 and 3. Our results suggested that target size 1 was more sensitive and more useful than target size 3 in the diagnosis of early glaucoma.

References

1. Gramer E, Kontic D, Kreiglstein GK: Die computerperimetrische Darstellung glaukomatöser Gesichtsfelddefekte in Abhängigkeit von der Stimulusgrösse. Ophthalmologica 183:162-167, 1981
2. Fellman RL, Lynn JR, Starita RJ, Swanson WH: Clinical importance of spatial summation in glaucoma. In: Heijl A (ed) Perimetry Update 1988/89, pp 313-324. Amsterdam: Kugler Publ 1989
3. Zalta AH, Burchfield JC: Detecting early glaucomatous field defects with the size 1 stimulus and STATPAC. Br J Ophthalmol 74:289-293, 1990
4. Matsumoto C, Uyama K, Okuyama S, Nakao Y, Otori T: The study of the influence of the target size on the pericentral visual field. In: Mills RP, Heijl A (ed) Perimetry Update 1990/91, pp 153-159. Amsterdam: Kugler Publ 1991
5. Quigley HA, Dunkelberger GR, Green WR: Retinal ganglion cell atrophy correlated with automated perimetry in human eyes with glaucoma. Am J Ophthalmol 107:453-464, 1989

Minimized test duration in computerized quantitative layer-by-layer perimetry

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Abstract

On the basis of ideas originally introduced by Enoch, a new computerized design of quantitative layer-by-layer perimetry was developed. In order to optimize testing employing this technique, the test strategy was selected and stimulus parameters were investigated, so as to ensure a minimum test duration while minimizing the variance of the threshold estimate With an optimal stimulus parameter setting, a ten-fold decrease in test duration could be obtained, compared to earlier versions of the technique. This allows the testing of larger field point patterns.

Introduction

Quantitative layer-by-layer perimetry is a psychophysical technique originally developed by Enoch[1]. The technique estimates characteristics of visual integration presumably attributable to specific retinal layers. In the original design of the technique, the total testing of one visual field point lasted approximately 30 minutes[2], which precluded the testing of larger field point patterns.

In order to minimize test duration and thereby enable the testing of larger field point patterns, the test principles of quantitative layer-by-layer perimetry were implemented into the existing hardware environment of the computerized perimeter Humphrey Field Analyzer (HFA)[5]. Optimal stimulus parameters were defined to allow treatment of measured threshold values in a statistical context, and optimally reduce test duration without reducing test reliability[6]. The present paper reports experimental evidence showing that the newly developed version of the technique provides a ten-fold reduction in test duration compared with earlier versions of the technique, thus allowing the testing of larger field point patterns.

Methodology

The psychophysical criterion in quantitative layer-by-layer perimetry is the flashing or not of a small test field I centered on a larger background field II (Fig. 1), the intensity of which is varied until the central flash field can just be seen. Both fields I and II are superimposed onto an adaptive surround field III. By varying the area and configuration of the background field II and determining the threshold of field I in each case, functions describing center-surround interaction can be defined. When the area of background II is varied, a function describing sustained center-surround interaction, probably integrated in the inner retinal layers, can be defined. When the background field is subjected to fast on/off shifts, *e.g.*. produced by a rotating windmill pattern, a function describing transient center-surround interaction, probably integrated in the inner plexiform layer, can be defined.

In the present version of quantitative layer-by-layer perimetry, stimulus parameters were selected optimally so that the test field I flashed with a frequency of 4 Hz, and so that each

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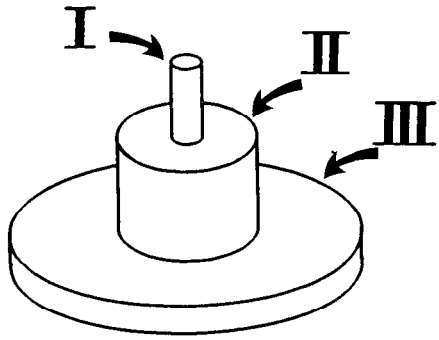

Fig. 1. The three centered and superimposed luminous fields employed in quantitative layer-by-layer perimetry: I. the central flashing test field; II. the variable-intensity background field; III. The adaptive surround field

presentation, consisting of the background field with the centered flashing test field, lasted 1000 msec[6]. With an appropriate staircase bracketing algorithm and repeated threshold determinations in each point, this algorithm allowed a treatment of threshold values in a statistical context, while optimally reducing test duration without reducing test reliability[6]. The present paper reports data of test duration employing this optimal test strategy, to confirm the achievement of a methodology fast enough to allow the testing of larger field point patterns.

Investigations

The evidence presented here is unreported data from a larger test series described in detail elsewhere[6]. In short, 20 normal volunteers (aged 30-56 years) had their right eye tested in a pattern of five points with a spacing of one degree located on the horizontal meridian from degree coordinates (-7.0) to (-3.0). Each test consisted of nine successive sessions with varying stimulus duration. A stimulus duration of 1000 msec was employed in two of the sessions (Nos. 2 and 8) in each test. This stimulus duration was found to be an optimal compromise which ensured minimal test duration and minimal variance of the threshold estimate[6]. The present paper reports data of the duration of tests employing this optimal stimulus duration of 1000 msec, and practical consequences are discussed.

Results

The time required for testing the five visual field points with a stimulus duration of 1000 msec is shown in Fig. 2 for all 20 persons tested. For each person, the solid triangle indicates test duration for the first session, and the solid square test duration for the second session where this stimulus duration was employed. As tested by a paired sign test, there was no significant change in test duration from the first to the second test session with a stimulus duration of 1000 msec. The duration of the sessions ranged from 1.36 to 4.36 minutes, mean 2.33. When all the test sessions with a stimulus duration of 1000 msec were considered together, there was no correlation between session duration and the variance of the threshold estimate as indicated by the root mean square (RMS) of repeated determinations, and no relation between session duration and the threshold level.

Discussion

The results reported in the present paper confirm that the newly developed design of quantitative layer-by-layer perimetry can be used for the testing of larger field point patterns. From the average test duration of 2.33 minutes for the testing of five visual field points with an optimal test strategy[6], a mean duration of approximately half a minute for the testing of one

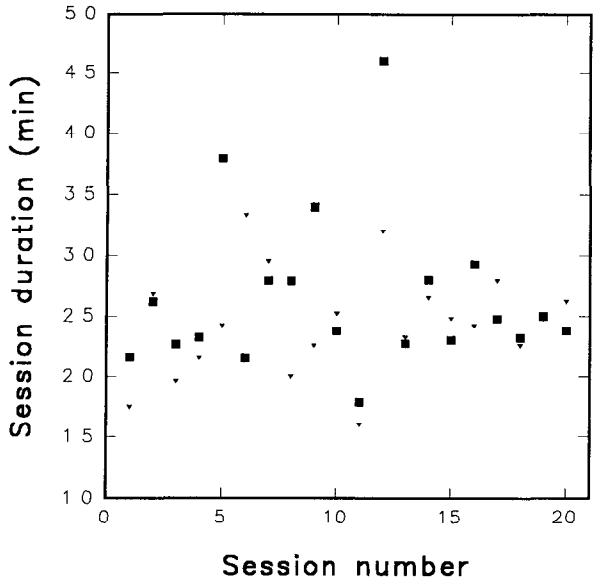

Fig. 2. Duration of sessions with a stimulus duration of 1000 msec (two per test person) in all persons tested. Solid triangles indicate first session and solid squares indicate second session.

visual field point can be calculated. Therefore, depending on how many background areas and configurations one wishes to test, only a few minutes are required for the whole testing of one visual field point. In the earlier version of the technique, the total testing of one field point lasted about 30 minutes[2]. Therefore, the present version of the technique is in theory at least ten times faster, and the testing of larger field point patterns can thus be allowed. The fact that there was no significant difference between the duration of sessions tested early and late in each test indicates that, in terms of session duration, all sessions tested with a stimulus duration of 1000 msec could be considered together in one pool. In this pool of sessions, there was no correlation between session duration and threshold level, and no correlation between session duration and RMS. The session duration reflects the time required for the testing of one field point. The fact that this time was independent of the threshold level may indicate that the initial stimulus level in the test algorithm was sufficiently close to the true threshold level to avoid too much test time being spent in approaching this. Furthermore, the independence of the time required for the testing of one field point and the variance of the threshold level (RMS), may indicate that the variance has been duly minimized by the time-consuming third testing in triple tested points[6].

In conclusion, employing an optimal test strategy for the new computerized design of quantitative layer-by-layer perimetry, the threshold level has been found to increase with increasing test duration[6], and according to the data reported in this paper, independence has been found between the time required for the testing of one field point, the threshold estimate, and the variance of this estimate. This evidence is important for the interpretation of results when the technique is employed in future clinical trials.

Thus, a sound theoretical and experimental basis has been provided for the selected stimulus parameter setting and test strategy in the present version of quantitative layer-by-layer perimetry. It is conceivable that the technique will provide a valuable tool for the study of presumed layer-specific function in future trials on retinal disease.

References

1. Enoch JM, Fitzgerald CR, Campos EC: Quantitative Layer-by-Layer Perimetry: An Extended Analysis. New York: Grune & Stratton 1976
2. Enoch JM: Quantitative layer-by-layer perimetry. Proctor lecture. Invest Opthalmol Vis Sci 17:208-257, 1978

3. Bek T: Quantitative layer-by-layer perimetry adapted to the Humphrey Field Analyzer. I. Design of methodology and instrumentation. Acta Opthalmol 70:470-476, 1992
4. Bek T: Quantitative layer-by-layer perimetry adapted to the Humphrey Field Analyzer. II. Centre-surround interaction produced by sustained surround stimulation. Acta Opthalmol 70:477-481, 1992
5. Bek T: Quantitatave layer-by-layer perimetry adapted to the Humphrey Field Analyzer. III. Centre-surround interaction produced by transient surround stimulation: area characteristics of the transient stimulus pattern. Acta Opthalmol 70:482-488, 1992
6 Bek T: Optimal test strategy for computerized quantitative layer-by-layer perimetry. Accepted for publication in Graefe's Arch Clin Exp Ophthalmol

NON-CONVENTIONAL VISUAL FIELD TESTING

Unilateral intraocular pressure increase: effects on high-pass resolution perimetry and retinal leukocyte velocity

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Abstract

High-pass resolution perimetry was performed in 12 subjects with unilaterally increased intraocular pressure. In all hypertensive eyes the mean resolution threshold was higher than in the opposite normotensive eyes, corresponding to an average reduction in functional neural channels of 42%. Retinal leukocyte velocity was measured using the blue field entoptic phenomenon. In 11 of the 12 subjects the retinal leukocyte velocity was lower in the hypertensive than in the opposite normotensive eye. The reduction in leukocyte velocity was approximately 60%. In eight of nine subjects the side difference in retinal leukocyte velocity persisted for two to six weeks after normalization of intraocular pressure with treatment This finding indicates that deficient function of retinal ganglion cells is accompanied by reduced retinal blood flow velocity, which does not seem to be immediately related to the increase in intraocular pressure.

Introduction

The possibility of a vasogenic origin of glaucomatous optic nerve damage has been debated for a long time[1]. It is presently possible to measure the retinal circulation in humans using techniques such as computer-simulated blue field entoptic phenomenon[2] and laser Doppler velocimetry[3]. The former method relies on the patient's comparison of the perceived leukocyte motion over the perimacular retina[4] with a simulated picture on a computer screen, where the velocity of the moving spots is known. Grunwald[5] observed lower leukocyte velocities in eyes with glaucomatous visual field loss and Sponsel *et al.*[6] found a significant correlation between leukocyte velocity and visual function in subjects with glaucoma or ocular hypertension.

High-pass resolution perimetry[7] relies on acuity measurements in the 30-degree central visual field and has been shown to be a sensitive test for glaucomatous damage[8-10]. The typical finding in early glaucoma is a rather uniform increase of mean resolution threshold[11].

The aim of the present study was to find out whether abnormalities in retinal leukocyte velocity and high-pass resolution perimetry could be demonstrated in subjects with unilaterally increased intraocular pressure. By using the opposite, normotensive eye as a control, the sensitivity of the measurements would be enhanced since the inter-individual variability would be by-passed.

Material and methods

Retinal leukocyte velocities were measured using a simplified set-up based on the principle described by Riva and Petrig[2]. The patient viewed the entoptic phenomenon in a Mira Entoptoscope and compared the leukocyte velocity to that of moving spots on the screen of an Amiga 500 computer. The software allowed the examiner to adjust the velocity of the simulated particles in nine discrete steps or arbitrary units (AU). Step No. 6 (AU 6) was designed to approximate the normal population mean, reported to be 0.79 to 1.02 mm/s[12]. The increase of one step

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Table 1. Measurement values from the examined subjects

Patient No.	*Hypertensive eyes*				*Normotensive eyes*			
	IOP mmHg	*MRT dB*	*RBF AU*	*FC-q %*	*IOP mmHg*	*MRT dB*	*RBF AU*	*RBF-diff AU*
1	24	7.4	5	-	12	4.6	6	1
2	30	3.9	5	68	20	3.2	6	1
3	25	3.8	2	70	17	3.0	3	1
4	26	6.0	5	69	16	5.2	6	1
5	20	3.9	5	52	13	1.9	6	1
6	26	7 8	4	-	17	6.6	5.5	1.5
7	27	3.9	1	74	10	3.8	4	3
8	25	5.3	4	54	16	3.9	6	2
9	34	6.5	4	50	21	4.9	5	1
10	24	4 2	5	68	18	1.8	5	0
11	31	5.5	6	23	15	2.2	7	1
12	32	4.0	5	50	16	2.2	6	1

IOP: intraocular pressure (mmHg): MRT: mean resolution threshold of the 50 tested locations within the 30-degree central visual field, tested by the high-pass resolution perimeter; FC-q: functional channel quotient (hypertensive eye/normotensive eye); RBF: retinal capillary blood flow velocity: RBF diff: difference in RBF between normotensive and hypertensive eyes; dB: decibels; AU: arbitrary units of capillary flow velocity, a side difference of one AU implied that the lower velocity is 50% of the higher

implied a doubling of the velocity and *vice versa*. The step size was deliberately made large in order to make the examination easy for the patients.

The high-pass resolution perimetric system has been described elsewhere[7,13].

Twelve subjects, seven females and five males aged 40 to 82 years (mean 67, SD 10), were included in the study, the selection criterion being a difference in intraocular pressure between the eyes of at least 6 mmHg. The IOP range in the normotensive eyes was 10 to 21 (mean 16, SD 3) and in the hypertensive eyes 18 to 34 (mean 27, SD 5) mmHg. All subjects had a visual acuity of 0.67 (20/30) or better and normal ophthalmological findings except for glaucomatous optic disc changes in eight of the 12 hypertensive eyes. All subjects were otherwise healthy and used no drugs which could be assumed to influence the measurements. Nine subjects were examined also after antiglaucoma treatment.

Results

In 11 of the 12 subjects the retinal leukocyte velocity was lower in the hypertensive eye than in the opposite normotensive eye (p=0.01, Wilcoxon test). Velocities ranged from 1 to 6 AU in the hypertensive (mean 4.3, SD 1.4) and from 3 to 7 AU (mean 5.5, SD 1.1) in the normotensive eyes. Thus, the inter-individual variation was quite large. Mean velocity for 11 age-matched normal controls was 6 AU, SD 0.6.

Mean resolution thresholds from the hypertensive eyes were higher than in the contralateral eyes in all 12 tested subjects (p=0.01, Wilcoxon test) and ranged from 3.8 to 7.8 dB (mean 5.2, SD 1.5) in the hypertensive and from 1.9 to 6.6 dB (mean 3.6, SD 1.5) in the normotensive eyes. Reference values from the age-matched normal controls were 3.8 ± 0.7 dB. The calculated mean side difference in functional neural channels was 42%. In the normal reference group the corresponding number was 8%.

Nine subjects were re-examined two to six weeks after normalization of IOP (mean 18, SD 3 mmHg) with treatment: betaxolol three subjects, propine two subjects, timolol one subject, timolol + laser trabeculoplasty one subject, pilocarpine + betaxolol + laser trabeculoplasty one subject and trabeculectomy one subject. Eight subjects showed the same side difference in retinal leukocyte velocity as before treatment. One subject, treated with betaxolol, showed equal velocities in both eyes.

Discussion

In the present study reduction of retinal leukocyte velocity and functional neural channels was observed in the hypertensive eyes of subjects with unilateral IOP increase, when the opposite, normotensive eye in the same individual was used as a control. The observed reduction in retinal leukocyte velocity persisted for at least two to six weeks after normalization of IOP in eight of nine treated subjects.

Blood flow can be maintained despite reduced velocity by an increase in the diameter of the retinal vessels, according to Poiseuille's law. However, the vessels in glaucomatous eyes have been reported to be constricted rather than dilated[14,15]. When changes in blood flow are induced by breathing oxygen or carbon dioxide, the vessel diameter and flow velocity increases and decreases in symmetry[11]. Moreover, changes in capillary diameter, which would be relevant to the findings in the present study, have not been reported. Thus, reduction in leukocyte velocity can be assumed to reflect a reduced blood supply to the inner retina. This, however, does not necessarily imply anoxia in the tissue. Slowing down the blood flow has been shown to increase oxygen delivery because molecules have more time to diffuse out of the capillaries[16].

From the measurements in this and other studies[6,17], it is not possible to judge whether the changes in retinal microcirculation are a cause or consequence of the retinal neuron damage in glaucoma. An experiment which might give some information on this would be to measure the retinal leukocyte velocity after an artificial increase of the metabolic demand in the inner retina. Increased flow velocity under such circumstances would indicate the presence of a reserve circulatory capacity, making circulatory insufficiency unlikely as primary reason for ganglion cell loss. Enhanced uptake of radio-labeled deoxyglucose in the inner retina after stimulation with flickering light, indicating increased metabolic demand, has been demonstrated in animal experiments[18].

Strangulation of the inflow arteries, *e.g.*, at the level of the lamina cribrosa, could result in a reduced capillary leukocyte velocity. In normal subjects the leukocyte velocity has been shown to increase by some 40% with hypercapnia, induced by carbon dioxide breathing[11]. Obstruction of arteries would be expected to diminish this response. No experiments of this kind seem to have been performed in glaucoma patients but Grunwald *et al.*[17] observed impaired ability of the retinal circulation to autoregulate, when the perfusion pressure was changed.

In the study by Sponsel *et al.*[6], the retinal velocity reduction correlated much better with abnormalities in contrast sensitivity than with visual field defects, demonstrated using the Henson and the Humphrey perimeters. In contrast to these methods, high-pass resolution perimetry allows the calculation of the number of functional neural retino-cortical channels[13], in the present context equivalent to the number of functioning retinal ganglion cells. In the present study, mean reduction in both leukocyte velocity and number of functional channels was of the same order of magnitude: 60 and 42%, respectively. Yet, six of the 12 tested subjects showed mean resolution thresholds within the normal range and the reduction of functional channels could be demonstrated only by comparison with the opposite, normotensive eye.

In conclusion, increased intraocular pressure seemed to be accompanied by loss of retinal ganglion cells and reduced retinal blood supply. Normalization of IOP did not seem to improve retinal circulation, at least not within a period of two to six weeks.

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References

1. Hayreh SS, Revie IHS, Edwards J: Vasogenic origin of visual field defects and optic nerve changes in glaucoma. Br J Ophthalmol 54:461-472, 1970
2. Riva CE, Petrig B: Blue field entoptic phenomenon and blood velocity in the retinal capillaries. J Opt Soc Am 70:1234-1238, 1980
3. Riva CE, Grunwald JE, Sinclair SH: Laser Doppler velocimetry study on the effect of pure oxygen breathing on retinal blood flow. Invest Ophthalmol Vis Sci 24:47-51, 1983

4. Sinclair SH, Azar-Cavanagh M, Soper HA, Tuma RF, Mayrovitz HN: Investigation of the source of the blue field entoptic phenomenon. Invest Ophthalmol Vis Sci 30:668, 1989
5. Grunwald JE: Retinal hemodynamics in open-angle glaucoma. In: Lambrou GM, Greve EL (eds) Ocular Blood Flow in Glaucoma, pp 147-149. Amsterdam: Kugl Publ 1988
6. Sponsel WE, DePaul KL, Kaufman PL: Correlation of visual function and retinal leucocyte velocity in glaucoma. Am J Ophthalmol 109:49-54, 1990
7 Frisén L: High-pass resolution targets in peripheral vision. Ophthalmology 94:1104-1108, 1987
8. Wanger P, Persson HE: Pattern-reversal electroretinograms and high-pass resolution perimetry in suspected or early glaucoma. Ophthalmology 94:1098-1103, 1987
9. Dannheim F, Abramo F, Verlohr D: Comparison of automated conventional and spatial resolution perimetry in glaucoma. In: Heijl A (ed) Perimetry Update 1988/89, pp 383-392. Amsterdam: Kugler Publ 1989
10. Airaksinen J, Tuulonen A, Välimäki J, Alanko HI: High-pass resolution perimetry and retinal nerve fiber layer in glaucoma. Acta Ophthalmol 68:687-689, 1991
11. Martin-Boglind LM, Wanger P: Computer-assisted evaluation of the results from high-pass resolution perimetry: a knowledge-based system. In: Mills RP, Heijl A (eds) Perimetry Update 1990/91, pp 297-301. Amsterdam: Kugler Publ 1991
12. Fallon TJ, Maxwell D, Kohner EM.:Retinal vascular autoregulation in conditions of hyperoxia and hypoxia using the blue field entoptic phenomenon. Ophthalmology 92:701-705, 1985
13. Frisén L: Acuity perimetry: estimation of neural channels. Int Ophthalmol 12:169-174, 1988
14. Jonas JB, Nguyen XN, Naumann GOH: Parapapillary retinal vessel diameter in normal and glaucomatous eyes. Part 1. Invest Ophthalmol Vis Sci 30:1599-1603, 1989
15. Jonas JB, Naumann GOH: Parapapillary retinal vessel diameter in normal and glaucomatous eyes. Part 2. Invest Ophthalmol Vis Sci 30:1604, 1989
16. Riva CE, Pournaras CJ, Tsacopoulos M: Regulation of local oxygen tension and blood flow in the inner retina during hypoxia. Am J Physiol 214:592-598, 1986
17 Grunwald JE, Riva CE, Stone PA, Keates EU, Petrig BL: Retinal autoregulation in open-angle glaucoma. Ophthalmology 91:1690-1694, 1984
18. Sperber GO, Bill A: The 2-deoxyglucose method and ocular blood flow. In: Lambrou GN, Greve EL (eds) Ocular Blood Flow in Glaucoma, pp 73-80. Amsterdam: Kugler Publ 1988

Spatial distribution of age effects in high-pass resolution perimetry

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Introduction

It is well known that perimetric performance normally deteriorates with age. This is true also for high-pass resolution perimetry (HRP)[1], which is a novel technique that determines resolution thresholds in the visual field[2,3]. The spatial distribution of aging effect over the HRP visual field has recently been studied[4]. It was found that resolution thresholds expressed in decibels (dB, 0.1 $\log_{10}$ unit) rose more in central than in peripheral test positions. The differences were small, however, and their significance was not systematically analyzed.

The theory behind HRP[2] states that resolution thresholds directly reflect the spatial distribution of functioning retinal ganglion cells: minimum angles of resolution (MAR) are held to be directly proportional to ganglion cell separations. This proportionality applies only to thresholds expressed in absolute terms (*e.g.*, minutes of arc) and not to the commonly used dB notation.

The present study analyzes age-related HRP threshold changes in various field locations, using both types of threshold scaling. The aim of the study was to see whether HRP, with its foundation in resolution theory, could provide new information about the aging effects on a neuronal level.

Subjects and methods

Visual fields from 157 normal subjects were analyzed. Ages varied between 18 and 83 years. Subjects were referred to one of three age groups (Table 1). All subjects underwent a careful neuro-ophthalmological examination that revealed no ophthalmological or neurological pathology affecting vision. No subject had ametropia exceeding ±5 diopters. None had previous experience with HRP and only first-time, first-eye examinations were included.

Perimetry was performed with the Ophthimus Ring perimeter version 2 (HighTech Vision, Malmö, Sweden) according to the manufacturer's instructions. The test measures resolution thresholds in 50 visual field locations within the central 30 degrees horizontally, 20 degrees superiorly, and 25 degrees inferiorly (Fig. 1). The test targets have the shape of rings and the measured parameter is the smallest visible ring size. Thresholds are expressed in dB and also in minutes of arc stroke width, where stroke width is defined as the width of the bright core of the ring target[5]. In contrast to conventional perimeters, the reference point for the dB scale is in the low-stimulus end, *i.e*, a high dB value corresponds to a high threshold.

Thresholds in 18 test points located in a sector bordered by the upper and lower 45 degrees meridians in the nasal visual field were analyzed (Fig. 1). This field sector was chosen because

Table 1. Characteristics of the three subject groups

Age group	*Age range*	*Mean*	*No. of subjects*
1	18-39	28.4	58
2	40-61	50.8	56
3	62-83	71.4	43

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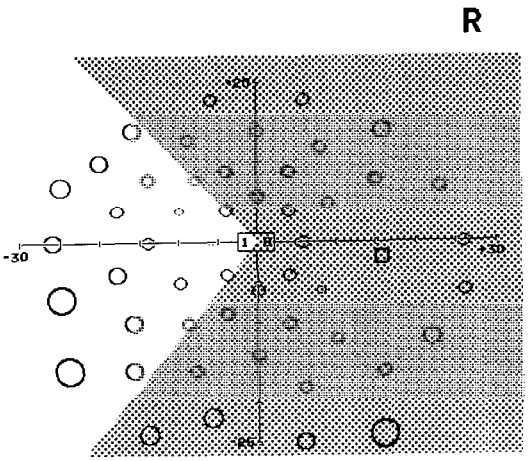

Fig. 1. Print-out from Ophthimus Ring perimeter showing spatial distribution of test points. The non-shaded sector field area (delineated by the upper and lower 45° meridians) was used for the present analyses.

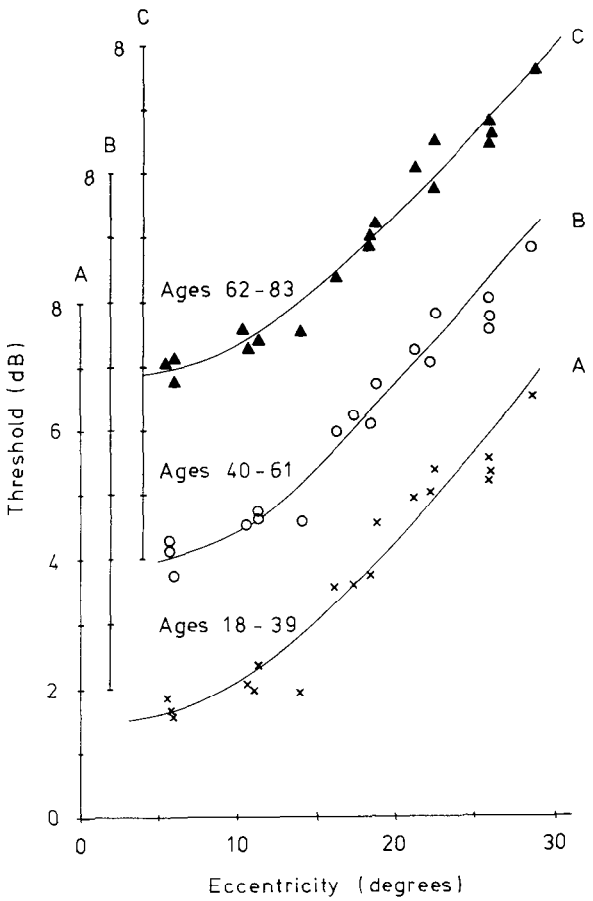

Fig. 2. Mean high-pass resolution thresholds in dB plotted against test point eccentricity for the three age groups The data are best fitted by the equations: y = -3.853 + 4.505 * exp (0.029*x) in A; y = -3.888 + 4.938 * exp (0.027*x) in B; and y = -0.476 + 2.632 * exp (0.039*x) in C.

the slope of the normal hill of vision in this area is approximately constant. The eccentricity of each test point was calculated as the polar distance (in degrees) from the center of fixation.

Statistical analyses were made using Systat (Evanston, IL). The level of significance was set to p=0.05.

Results

Mean thresholds were calculated for each of the 18 test points in each of the three age groups, in dB as well as in min arc stroke width. In Fig. 2, mean thresholds in dB are plotted against eccentricity for the three age groups. The data were best fitted by exponential equations. It can be seen that age changes were slightly more pronounced in the central compared to the peripheral visual field.

A similar plot for mean thresholds expressed in min arc is shown in Fig. 3. Again, the relations between mean thresholds and eccentricity were best described by exponential functions.

To analyze the aging effects, mean thresholds for all test positions in age groups 2 and 3, respectively, were plotted against the corresponding values in age group 1. Fig. 4 shows the result for the dB values. If thresholds in the different age groups were equal, all observations should center around the 45-degree dotted line (regression coefficient 1.0). It was found that regression coefficients were similar for the two comparisons (0.970 and 0.932, respectively).

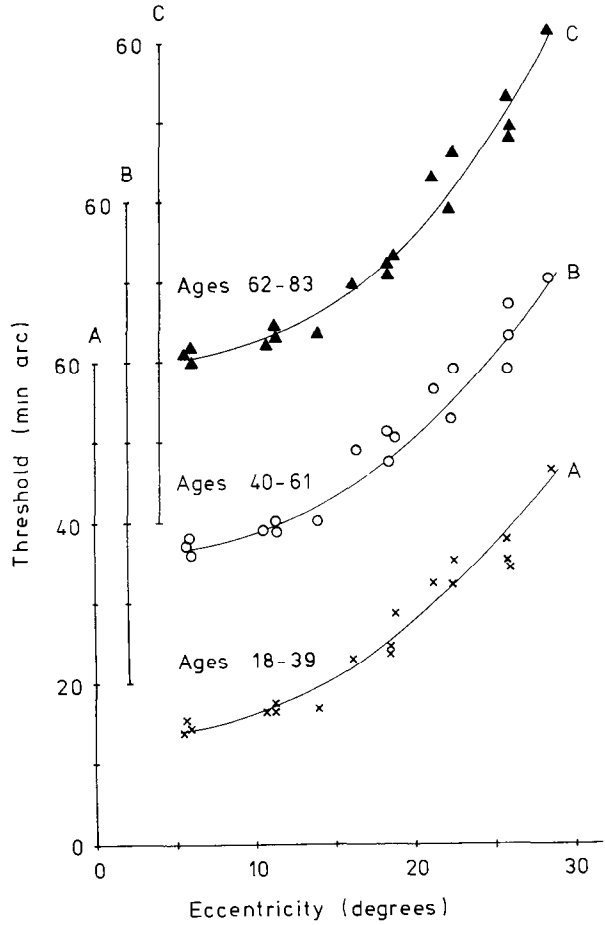

Fig. 3. Mean high-pass resolution thresholds in min arc plotted against test point eccentricity for the three age groups. The data are best fitted by the equations: y = 4.693 + 6.521 * exp (0.063*x) in A; y = 7.645 + 5.895 * exp (0.068*x) in B; and y = 14.349 + 3.529 * exp (0.090*x) in C.

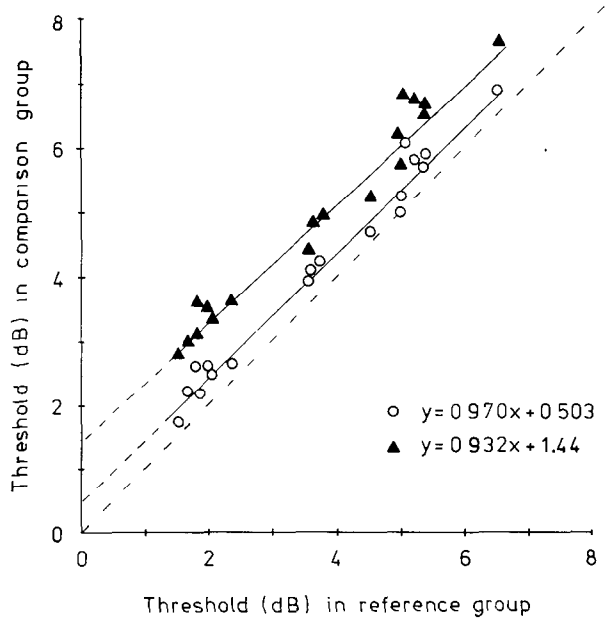

Fig. 4. Mean high-pass resolution thresholds in dB for age groups 2 and 3, respectively, plotted against the value for the corresponding test position in age group 1. Inset: equations for the two regression lines.

There was no statistically significant difference between the two and none was significantly different from 1.0. The intercepts were significantly different from zero ($p<0.005$). Thus, the two regression lines were closely parallel and neither went through the origin. For MAR results, on the other hand, both age group comparisons were characterized by linear relations through the origin, but with different regression coefficients (1.059 and 1.272, respectively) (Fig. 5). Both were significantly different from 1.0 ($p<0.05$ and $p<0.005$, respectively). The difference

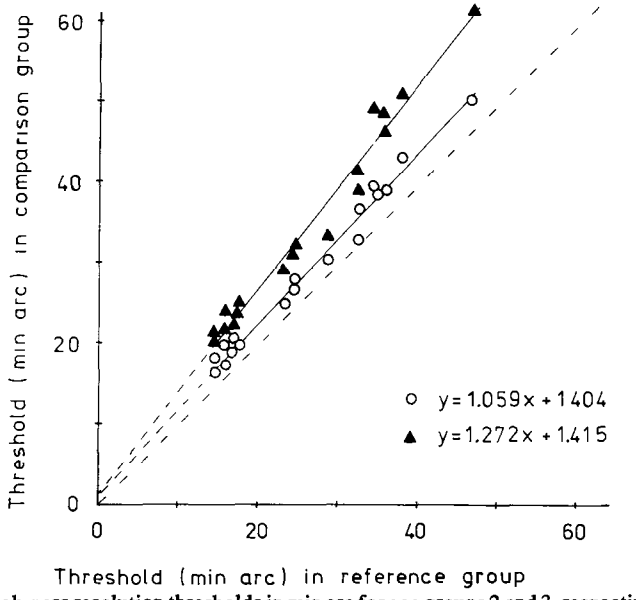

Fig. 5. Mean high-pass resolution thresholds in min arc for age groups 2 and 3, respectively, plotted against the value for the corresponding test position in age group 1. Inset: equations for the two regression lines.

between the regression coefficients was statistically significant ($p<0.005$). Intercepts were not significantly different from zero. In summary, MAR in age groups 2 and 3 was directly proportional to MAR in age group 1, while no such simple relation could be shown for threshold values expressed in dB.

These results were confirmed by a similar analysis of test points in a superior visual field sector.

Discussion

The present study design, exploiting relative threshold changes, avoids some common pitfalls in the comparison between sensory and retinal physiology, such as perimetric training effects and spatial uncertainty effects[6].

For HRP thresholds expressed in minutes of arc, the result of the present study can be interpreted as follows: the separation between functional ganglion cells (as derived from HRP measurements) increases with age. The increase is proportional to the original ganglion cell separation in the young retina. Conversely, linear ganglion cell density decreases with age, again with a constant fraction. Across the retina, ganglion cells are lost in proportion to their original number.

This result is in good agreement with current histological knowledge. Gao and Hollyfield[7] studied retinal aging effects histologically. It can be calculated from these authors' results that relative reduction in ganglion cell density between the ages of 20 and 60 years was similar in the perifoveal region and in the equator zone. In the perifoveal zone the reduction was about 16% (their Fig. 11) and in the equator zone about 22% (their Fig. 2E). A direct numerical comparison with the present result is difficult because perimetric measurements reflect function not only in the retina but in the whole retinocortical neuronal chain. There is no reason to believe that aging effects are unique to pregeniculate neurons and aging effects seen in perimetry must therefore reflect both pre- and postgeniculate cell loss[1]. Present HRP data suggest that functional ganglion cell separation was 27.2% (Fig. 5, inset) higher in age group 3 compared to group 1 (mean age 71.4 and 28.4 years, respectively). Linear cell density is the reciprocal of cell separation and was therefore 1/1.272 or 78.6% lower in age group 3. If, for simplicity's sake, we assume a quadratic ganglion cell packing, this corresponds to a functional ganglion cell density over area in age group 3 that was 0.786^2 or 61.8% of that of age group 1. The reduction of functional ganglion cells between age groups 1 and 3 thus was 38.2%. However, for reasons mentioned above this is an overestimation. As a first approximation it may be assumed that one-half of the observed perimetric age effect is caused by postgeniculate cell loss, the other half by ganglion cell loss. With this assumption, the decrease in HRP thresholds between age groups 1 and 3 corresponds to a loss of 21.5% of ganglion cells ($(1-N)*(1-N)=0.618$, where N is the proportion of lost neurons). Although the age groups in the present study are not identical to those of Gao and Hollyfield[7], the estimate of age-derived ganglion cell loss in the two studies is very similar. A comparison with data from histological optic nerve axon counts is also warranted. Frisén pooled data from seven different axon counts[1]. From the data in his Fig. 1, it can be calculated that between the ages 28.4 and 71.4, 17.4% of optic nerve axons are lost. This figure is also in good agreement with the present result.

When HRP thresholds were transformed to a decibel scale, interpretation of the results became more difficult. Comparisons between age groups (Fig. 4) could not be analyzed in anatomical or physiological terms. However, the present results confirm previous findings that the aging effect in HRP (with thresholds expressed in decibel) is somewhat more pronounced in the central compared to the peripheral visual field[4] (Fig. 4).

Several studies analyzing age effects in conventional perimetry (measuring differential light sensitivity) have been published. Haas *et al.*[8] demonstrated a linear decrease in overall sensitivity with increasing age using the Octopus perimeter. Furthermore, they found the loss of sensitivity to be non-uniformly distributed over the visual field: the most pronounced losses occurred in the central and peripheral field while the pericentral area was relatively spared. Consequently, an alteration of the shape of the hill of vision occurs with advancing age. Heijl *et al.*[9] presented a similar study using the Humphrey Field Analyzer. They found a general loss of sensitivity with increasing age and also a steepening of the normal hill of vision.

In studies of the spatial distribution of age effects in conventional perimetry, thresholds were

expressed in the decibel scale. The reference point of this scale is machine-specific. Therefore, results from different instruments are not directly comparable. Furthermore, the measured thresholds have no simple relation to anatomical or physiological factors. It is not known whether an age-dependent decrease in central field sensitivity of, say, 1 dB is equivalent to the same change in the peripheral field. The lack of understanding of the normal sensory physiology of conventional perimetry prevents an analysis of underlying aging mechanisms. Recent empirical work suggests, however, that differential light thresholds relate to calculated ganglion cell density according to an exponential function for a given contrast and stimulus size, at least for certain background illumination levels[10,11].

The present results add further support to the notion that age-related decline in perimetric sensitivity depends primarily on neuronal, and not on optical, factors[12].

References

1. Frisén L: High-pass resolution perimetry and age-related loss of visual pathway neurons. Acta Ophthalmol 69:511-515, 1991
2. Frisén L: A computer-graphics visual field screener using high-pass spatial frequency resolution targets and multiple feedback devices. Doc Ophthalmol Proc Ser 49:441-446, 1987
3. Frisén L: High-pass resolution perimetry: recent developments. In: Heijl A (ed) Perimetry Update 1988/89, pp 369-375. Amsterdam: Kugler Publ 1989
4. House P, Schultzer M, Drance S, Douglas G: Characteristics of the normal central visual field measured with resolution perimetry Graefe's Arch Clin Exp Ophthalmol 229:8-12, 1991
5 Frisén L: High-pass resolution perimetry: evidence for parvocellular neural channel dependence. Neuro-Ophthalmology 12:257-264, 1992
6. Lindblom B, Westheimer G: Spatial uncertainty in stereoacuity tests: implication for clinical vision test design. Acta Ophthalmol 70:60-65, 1992
7. Gao H, Hollyfield JG: Aging of the human retina: differential loss of neurons and retinal pigment epithelial cells. Invest Ophthalmol Vis Sci 33:1-17, 1992
8. Haas A, Flammer J, Schneider U: Influence of age on the visual fields of normal subjects. Am J Ophthalmol 101:199-203, 1986
9. Heijl A, Lindgren G, Olsson J: Normal variability of static perimetric threshold values across the central visual field. Arch Ophthalmol 105:1544-1549, 1987
10. Frisén L: High-pass resolution targets in peripheral vision Ophthalmology 94:1104-1108, 1987
11. Lindblom B: Effects of laser-induced retinal lesions on perimetric thresholds. Doc Ophthalmol 79:241-252, 1992
12. Johnson C, Adams AJ, Lewis RA: Evidence for a neural basis of age-related visual field loss in normal observers. Invest Ophthalmol Vis Sci 30:2056-2064, 1989

Sensitivity of conventional light sense perimetry and ring perimetry to artificial media opacities and manifest glaucoma: a comparative study

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Abstract

The authors studied the influence of blurring by artificial media opacities on conventional light sense perimetry and resolution perimetry. Light sense perimetry was performed using the G1 program of the Octopus 1-2-3 perimeter, resolution perimetry was performed with the "ring" test, version 2.20, High-Tech-Vision Inc., designed by Frisén Six levels corresponding to a visual acuity of between 1.6 and hand motion were tested in ten eyes of ten healthy subjects. With both perimeters the mean defect increased with decreasing visual acuity. At good visual acuities (1.2-1.6) no changes were found in either resolution perimetry or light sense perimetry At acuity levels of 0.8 and below the decrease in sensitivity with the ring perimeter was much more pronounced than with the light sense perimeter. At the level of hand motion, there were only absolute scotomas with the ring perimeter while with the Octopus 1-2-3 a baseline sensitivity was still detectable The ring perimeter, at least its currently available version giving an absolute scotoma at mean scores >14 dB, is obviously more sensitive to media opacities than the Octopus 1-2-3. This may be of clinical importance if both perimetric methods are combined, for example, during the follow-up of glaucoma patients Thus, the influence of media opacities on visual field results may be filtered out.

Introduction

Computer-assisted light sense perimetry is an established method in the diagnosis and follow-up of different ophthalmologic diseases. It determines the differential light thresholds ("intensity thresholds"), *i.e.*, the ability of an eye to percept light stimuli in the presence of a constant background illumination. Usually the central 30° of the visual field are examined.

In the 1980s Frisén developed a new kind of perimetry, the so-called ring perimetry. This kind of perimetry determines the spatial resolution in the central 30° of the visual field, *i.e.*, the ability to resolve fine details at constant contrast[1,2].

The stimulus used by ring perimetry is a ring-shaped optotype of variable size (Fig. 1). One of the most interesting features of ring perimetry is the correlation of results with morphological findings, *i.e.*, the number of intact retinocortical channels[3,4]. Further advantages are short test duration and multiple feedback mechanisms.

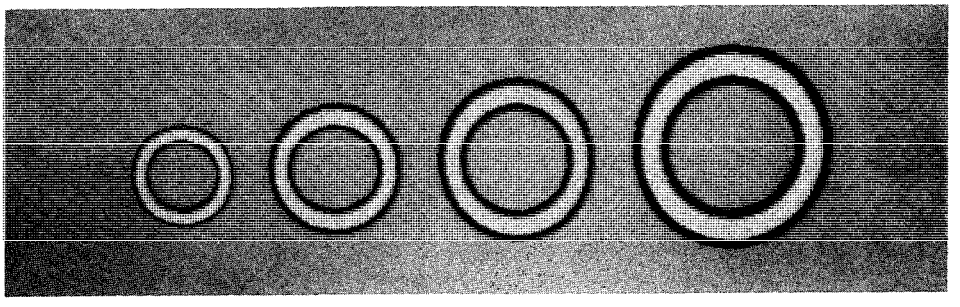

Fig. 1. Ring-shaped optotypes as they are used in ring perimetry

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In clinical practice, for example during the follow-up of glaucoma patients, both light sense and ring perimetry are biased by other ocular diseases such as media opacities, which may interfere with the glaucomatous changes. This makes interpretation of the visual field findings difficult. The effect of media opacities on light sense perimetry is well described[5-8].

The effect of media opacities on ring perimetry was described by Hölzl *et al.*[9], who investigated the influence of diffusor foils between the visual acuity levels 1.0 and 0.07.

In the present study we examined the influence of artificial media opacities on the results of ring and light sense perimetry. Furthermore, we compared these results to 14 eyes at different stages of manifest glaucoma. The clinical consequences will be discussed.

Methods

Ten eyes of ten healthy subjects (aged 22-38 years, mean 28 years) were included in this study. Refractive error ranged from -2.0 to +1.0 diopters. Visual acuity was better than 1.25 (Landolt rings). Exclusion criteria were any known pathology of the eyes, astigmatism of >1 dpt and systemic diseases. If both eyes of a subject met the inclusion criteria, one was selected by a random list.

Different Bangerter foils (characterized as "visual acuity of 1.0, 0.4, 0.2, 0.1, 0") were mounted in front of the correcting lenses.

Light sense perimetry was performed using program G1 of the Octopus 1-2-3[10]. This light sense perimeter measures the differential light thresholds at 59 locations within the central 30° visual field. Refractive error was corrected with spherical glasses in steps of 1, 2, 3, etc. diopters. For further evaluation, we chose the parameters mean sensitivity (MS) and loss variance (LV).

Ring perimetry was performed using the "ring" test (version 2.20) of the Ophthimus ring perimeter (High-Tech-Vision Inc.). This device determines spatial resolution thresholds by means of ring optotypes of different sizes, ranging from 0.8 to 20 square degrees. Further details have been described elsewhere[11].

The same correcting lenses as those of the Octopus 1-2-3 were used. For further evaluation we chose the parameters mean score (ring size) and local defect (LD). A normal result obtained by ring perimetry is shown in Fig. 2.

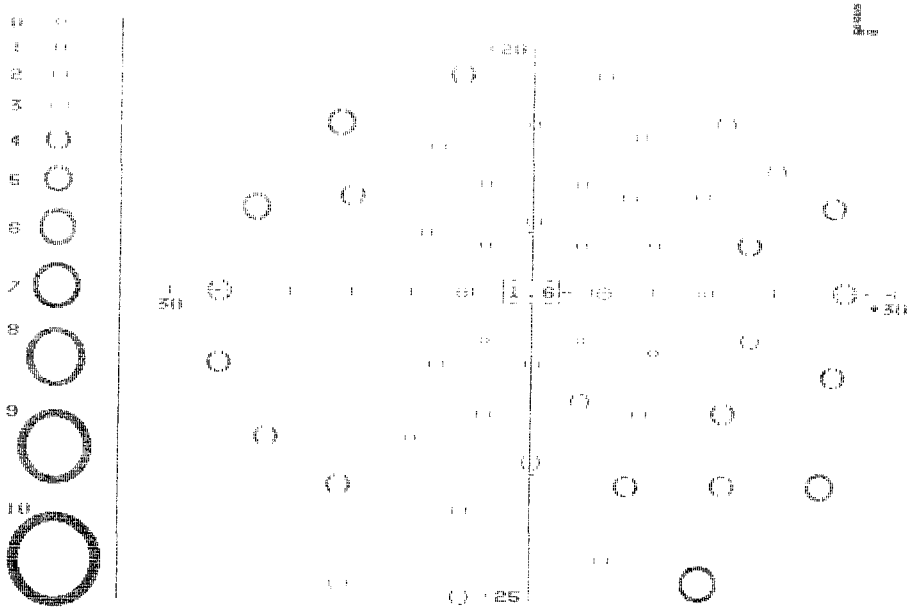

Fig. 2. Print-out of a normal visual field obtained with the ring perimeter. The minimal ring sizes seen are determined at 50 test locations in the central visual field. Fovea and blind spot are excluded from examination. Eleven of 15 possible ring sizes are shown on the left side.

Results

Mean values of visual acuity and the visual field parameters are shown in Table 1. The parameters describing local deviations remained constant at different blurring levels. This shows that sensitivity was reduced uniformly at all test locations. In Fig. 3 mean sensitivities and mean scores are shown as a function of the blurring level.

Table 1. Mean visual acuity and visual field parameters dependent on the blurring level

Bangerter foil	*Visual acuity*	*Mean sensitivity*	*LV*	*Mean score*	*LD*
None	1.57	29.7 ±0.73	3.13	2.38±0.67	0.802
1.0	1.2	29.38±0.56	3.24	2.45±0.77	0.779
0.4	0.79	28.45±0.78	3.55	3.56±0.76	0.712
0.2	0.42	23.84±0.76	3.06	6.4 ±0.59	0.658
0.1	0.07	19.3 ±0.54	3.39	10.02±0.45	0.708
0	0.005	6.07±1.61	7.1	>14	-

LV: loss variance; LD: local defect

Scaling of both ordinates ranged between the normal values (corresponding to a mean score of 2.38 dB and a mean sensitivity of 29.7 dB, respectively) and absolute scotomas (mean score >14 and stimulus brightness <0 dB, respectively). Thus, a decrease in sensitivity was evaluated with regard to the perimeter's measuring range.

With both perimeters, sensitivity decreased with decreasing visual acuity. At good visual acuities (1.2-1.6), no changes were found in either kind of perimetry. At acuity levels below 1.2, sensitivity decreased more with the ring perimeter than with the light sense perimeter. At the level of hand motion vision, there were only absolute scotomas with the ring perimeter while with the Octopus 1-2-3 a baseline sensitivity was still detectable (corresponding to 20% of the measuring range). A decrease of more than 1/3 of the measuring range was obtained with the ring perimeter at a visual acuity of >0.4, but with the light sense perimeter only at visual acuities below 0.1.

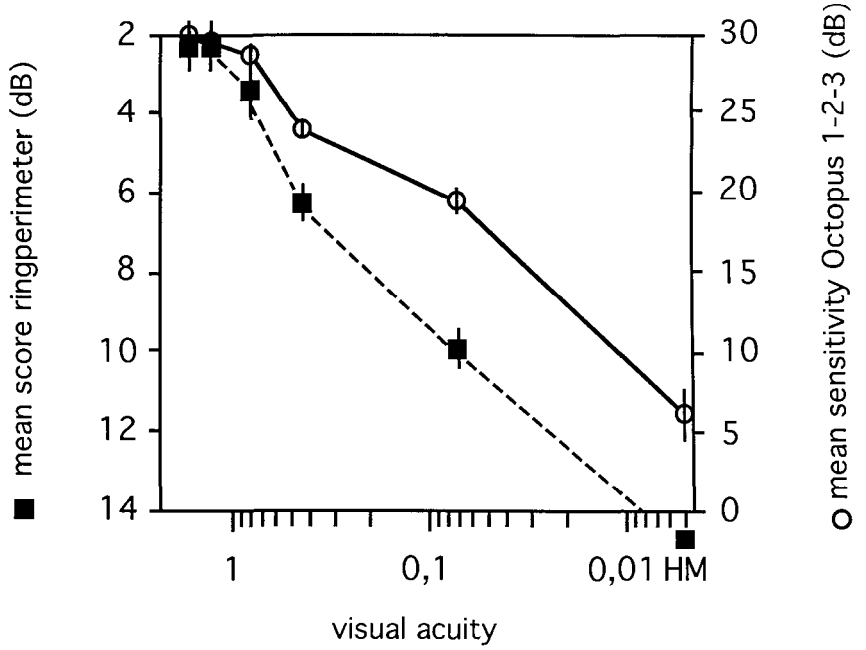

Fig. 3. Sensitivity (■: mean score; o: light difference sensitivity) as a function of blurring by artificial media opacities. Mean values of ten healthy subjects, standard deviations vertical bars. HM: hand motion.

Discussion

Our results show, that the ring perimeter of Frisén is more sensitive to artificial media opacities than the Octopus 1-2-3 within the measuring range of each device. It is important to note the restriction "within the measuring range of each device", since a suitably chosen change in the definition of the absolute scotoma with one of the devices may abolish the effect. Although our results may be of interest in the clinical application of both devices, they should not be interpreted as higher irritability of resolution perimetry in general.

A similar correlation between light sense perimetry and blurring was shown by Gleissner *et al.*[5], who used the Humphrey Field Analyzer. Hölzl *et al.*[9] demonstrated a linear correlation between the mean scores of the ring perimeter and the so-called reduced luminance factor, reflecting the blurring power of the Bangerter foils. Due to methodological differences, these studies do not allow a direct comparison of both perimeters. Their sensitivity values are similar to but slightly higher than ours.

The different influence of media opacities on both perimeters may be useful for clinical purposes. Plotting the mean sensitivities against the mean scores at each blurring level leads to the result shown in Fig. 4. Since the correlation is high ($r^2 = 0.97$), the mean score of resolution perimetry can be predicted from a given value of mean sensitivity and *vice versa*.

Furthermore, Fig. 4 shows the relationship between mean score and mean sensitivity in 14 eyes at different stages of manifest glaucoma. Obviously the correlation between resolution perimetry and light sense perimetry in glaucoma patients may also be approximated by a linear regression (although the correlation coefficient is smaller than in normal subjects). The slope of the regression line, however, seems to be clearly different from that produced by media opacities, at least within the measured range which contains only established glaucoma, not ocular hypertension or very early stages of glaucoma. Therefore, one cannot conclude that the ring perimeter is less sensitive than the Octopus 1-2-3 in detecting early glaucomatous damage. Wanger and Persson reported that sensitivity of ring perimetry in early glaucoma is even higher than that of conventional light sense perimetry[12]. The different regression lines found in glaucoma patients and in subjects with media opacities may help the ophthalmologist in the follow-up of patients suffering from both cataract and established glaucoma: If a progressive visual field loss is found during the longitudinal monitoring of such a patient, it may be at-

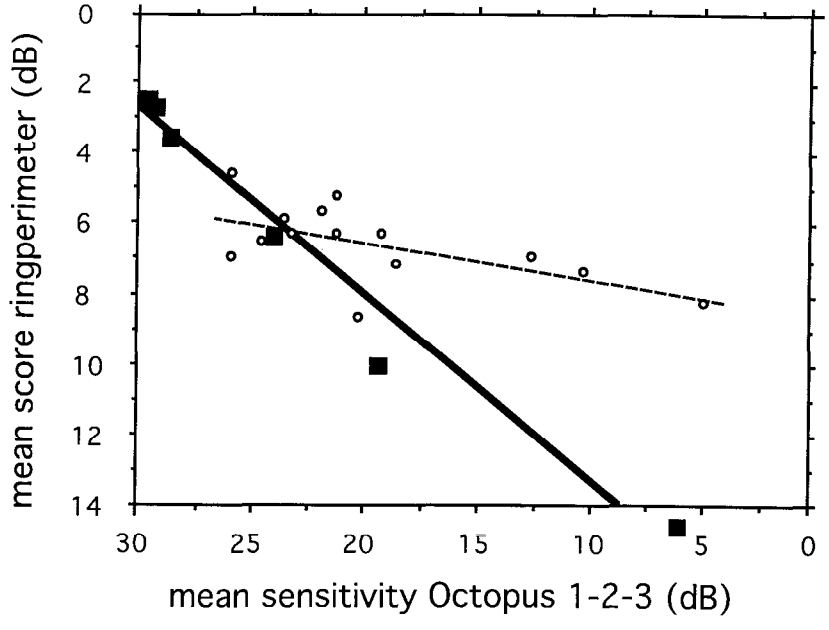

Fig. 4. Correlation of mean score (ring perimeter) with mean sensitivity (Octopus 1-2-3) at different blurring levels (■) and at different stages of glaucomatous damage (o). Regression curves: Blurring: $y = -0.54x + 19.03$; $r^2 = 0.97$ (if absolute scotoma = 15 dB). Glaucoma: $y = -0.1x + 8.59$; $r^2 = 0.35$.

tributed to cataract if it is more pronounced in resolution perimetry than in light sense perimetry and, *vice versa*, it may be attributed to glaucoma if it is more pronounced in light sense perimetry.

References

1. Frisén L: High-pass resolution targets in peripheral vision Ophthalmology 94:1104-1108, 1987
2. Frisén L: A computer graphics visual field screener using high-pass spatial frequency resolution targets and multiple feedback devices Doc Ophthalmol Proc Ser 49:441-446, 1987
3. Frisén L: Acuity perimetry: estimation of neural channels. Int Ophthalmol 12:169-174, 1988
4. Frisén L: High-pass resolution perimetry; evidence for parvocellular neural channel dependence Neuro-Ophthalmology 12:257-264, 1992
5. Gleissner M, Lachenmayr BJ: Lichtsinn- und Flimmerperimetrie: Einfluss von Fehlrefraktion, artifiziellen Medientrübungen und Pupillenweite. Fortschr Ophthalmol 89:162-165, 1992
6. Heuer DK, Anderson DR, Feuer WJ, Gressel MG: The influence of decreased retinal illumination on automated perimetric threshold measurements. Am J Ophthalmol 108:643-650, 1989
7. Heuer DK, Anderson DR, Knighton RW, Feuer WJ, Gressel MG: The influence of simulated light scattering on automated perimetric threshold measurements. Arch Ophthalmol 106:1247-1251, 1988
8. Urner U, Müller M: Das Verhalten von Visus, Gesichtsfeld und Kontrastempfindlichkeit unter dem Einfluss einer simulierten Katarakt. Klin Mbl Augenheilk 192:122-129, 1988
9. Hölzl MJ, Lachenmayr BJ, Vivell PMO: Einfluss von Fehlrefraktion und artifiziellen Medientrübungen auf die Sehschärfenperimetrie. Fortschr Ophthalmol 88:875-880, 1991
10. Flammer J, Jenner F, Bebié H, Keller B: The Octopus glaucoma G1 program Glaucoma 9:67-72, 1987
11. Frisén L: Vanishing optotypes: new type of acuity test letters. Arch Ophthalmol 104:1194-1198, 1986
12. Wanger P, Persson HE: Pattern reversal electroretinograms and high-pass resolution perimetry in suspected or early glaucoma Ophthalmology 94:1098-1103, 1987

A comparative study between high-pass resolution perimetry and differential light sensitivity perimetry in glaucoma patients

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Abstract

High-pass resolution perimetry (HRP) is considered to estimate the number of functioning retinal ganglion cells. To evaluate clinical validity of HRP, the authors investigated the correlation between HRP and differential light sensitivity perimetry (Humphrey Field Analyzer 630, HFA) in 43 eyes of 27 primary open angle glaucoma and 85 eyes of 51 normal tension glaucoma patients. In a total of 128 eyes, both functional channels (FC) and global deviation (GD) of HRP were significantly correlated with MD (r=0.73, p<0.01; r=-0.71, p<0.01, respectively). Also, local deviation (LD) of HRP was significantly correlated with CPSD (r=0.78, p<0 01). These correlations tended to be higher in eyes with more advanced field changes compared with those with less changes (r=0.66, p<0.01 *versus* 0 35, p<0.01 for FC and MD; r=0.69, p<0.01 *versus* 0.39, p<0.01 for LD and CPSD). These results indicate that HRP may be useful for evaluation of glaucomatous visual field abnormalities. The observed discrepancies between the two different methods in early stage glaucoma may be attributable to differences in physiological factors tested with these methods.

Introduction

Differential light sensitivity (DLS) perimetry is widely used for detection and evaluation of glaucomatous visual field abnormalities. However, several disadvantages have been pointed out concerning DLS perimetry. First of all, it takes a long time for patients to be tested. Secondly, this perimetry has large test variability[1]. And thirdly, correlations between the test results of DLS perimetry and the state of the visual system are not clear[2,3].

On the other hand, high-pass resolution perimetry (HRP), which was developed and introduced by Frisén, is a new method for visual field evaluation that determines spatial resolution threshold[2-5]. In this system, test variability was reported to be low[6]. Also, test time is short (usually five to six minutes per eye). Furthermore, HRP is thought directly to reflect the number of functioning retinal ganglion cells[3,4].

Concerning the comparative study between HRP and DLS perimetry, several investigators have reported a good overall agreement between HRP and DLS results[7-10], but their relationships in different degrees of glaucoma damage have not yet been examined.

In this study, we compared the results of HRP with those of DLS perimetry in primary open angle glaucoma (POAG) and normal tension glaucoma (NTG) in order to evaluate the clinical validity of HRP.

Subjects and methods

One hundred and twenty-eight eyes of 78 patients with glaucomatous optic disc abnormalities consisting of POAG and NTG patients were enrolled in this study, and were followed up at the Glaucoma Clinic of the Department of Ophthalmology, Gifu University Hospital, Japan. The POAG group consisted of 43 eyes of 27 patients, whose ages ranged from 27 to 72 years (mean 52.0 years; standard deviation 12.5 years), including 17 men and ten women, with elevated IOP (≥ 22 mmHg). The NTG group consisted of 85 eyes of 51 patients, whose ages ranged from 14 to 73 years (mean 52.4 years; standard deviation 14.4 years), including 20 men and

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31 women, with normal IOP (≤ 21 mmHg). All patients had a visual acuity of 0.7 or better and a refractive error equal to less than 5 diopters.

High-pass resolution perimetry was performed with the Ophthimus system version 2.0 (HighTech Vision, Malmö, Sweden). In this system, using ring-shaped, spatially high-pass filtered targets with variable sizes, presented on a computer monitor, resolution thresholds of 50 locations are measured within the central 30 degrees of the visual field. Each ring had a bright core and dark borders with a space-average luminance equal to the background (20 cdm^{-2}). Within-target contrast was 0.25. This system provides several statistical indices. Global deviation (GD) and local deviation (LD) are equivalent to mean deviation and pattern standard deviation measured in conventional perimetry, respectively. Also, functional channels (FC) is a unique index estimating the number of functioning retinal ganglion cells, which is expressed as a percentage of the normal average. Normal ranges of these three indices are 0±0.64 dB, 0.66±0.10 dB, and 100±18%, respectively. The reliability is graded as good, dubious, or poor. In this study, only the results with "good" reliability were analyzed.

DLS perimetry was performed with program central 30-2, using a Humphrey Field Analyzer 630 (Allergan-Humphrey, San Leandro, CA) (HFA). In this study, only the results with false positive, false negative and fixation loss of less than 20% were analyzed. These two perimetric examinations were performed within two weeks.

A total of 128 eyes were classified into "early stage" and "advanced stage" eyes according to the results of HFA. "Early stage" eyes were defined as eyes with either one or both of p values of mean deviation (MD) and corrected pattern standard deviation (CPSD) calculated by the STATPAC 2 equal to or greater than 5%. "Advanced stage" eyes were defined as eyes with p values of both MD and CPSD less than 5%.

In this study, Pearson's correlation coefficient values were calculated between FC and MD, GD and MD, and LD and CPSD in five groups, that is, all eyes, POAG eyes, NTG eyes, "early stage" eyes and "advanced stage" eyes.

Results

Relationship between FC and MD

In a total of 128 eyes, 43 POAG eyes and 85 NTG eyes, FC was significantly correlated with MD (r=0.73, ;<0.01; r=0.82, p<0.01; r=0.68, p<0.01, respectively) (Fig. 1). In 53 "early stage" eyes, FC was significantly correlated with MD (r=0.35, p<0.01). Also, in 75 "advanced stage" eyes, FC was significantly correlated with MD (r=0.66, p<0.01) (Fig. 2).

Relationship between GD and MD

In all eyes, POAG eyes and NTG eyes, GD was significantly correlated with MD (r=-0.71, p<0.01; r=-0.82, p<0.01; r=-0.66, p<0.01, respectively) (Fig. 3). In "early stage" eyes, GD was

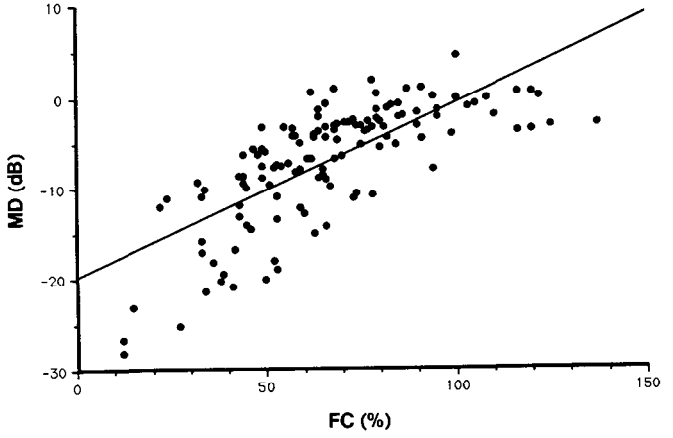

Fig. 1. Relationship between FC and MD in a total of 128 eyes.

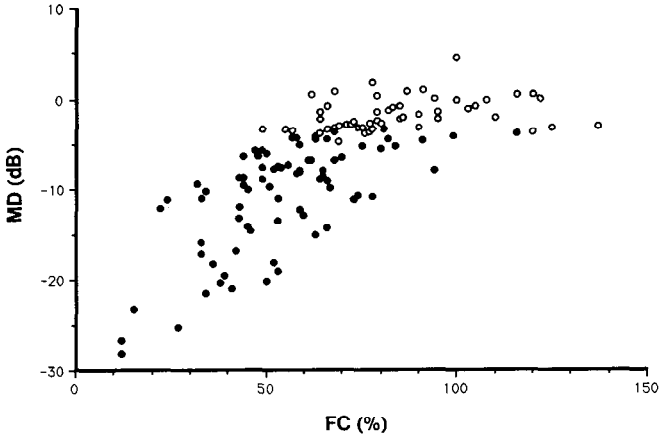

Fig. 2. Relationship between FC and MD in "early stage" eyes (53 eyes; open circles) and "advanced stage" eyes (75 eyes; closed circles).

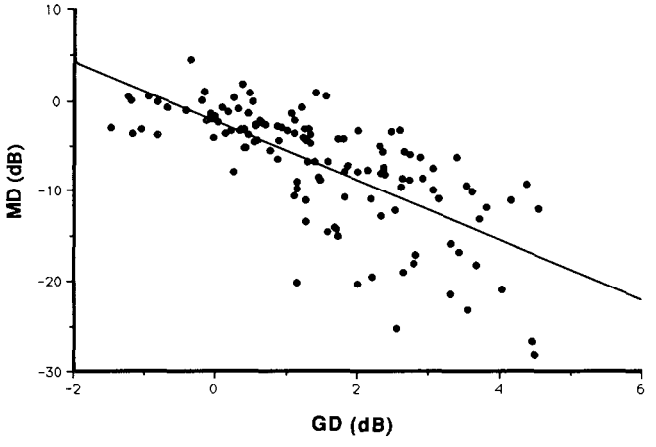

Fig. 3. Relationship between GD and MD in a total of 128 eyes.

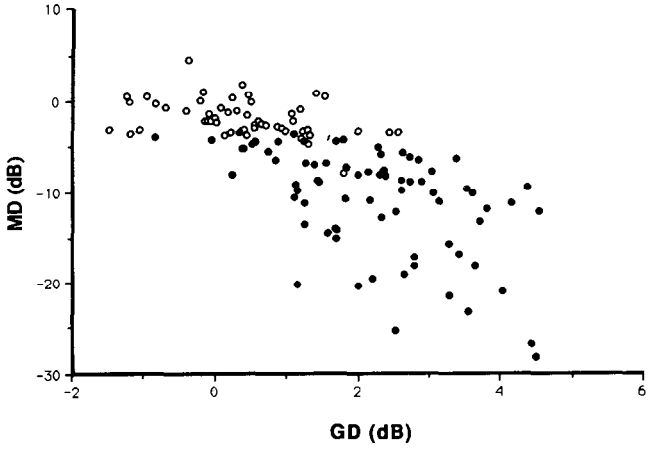

Fig. 4. Relationship between GD and MD in "early stage" eyes (53 eyes; open circles) and "advanced stage" eyes (75 eyes; closed circles).

significantly correlated with MD (r=-0.39, p<0.01). Also, in "advanced stage" eyes, GD was significantly correlated with MD (r=-0.53, p<0.01) (Fig. 4).

Relationship between LD and CPSD

In all eyes, POAG eyes and NTG eyes, LD was significantly correlated with CPSD (r=0.78, p<0.01; r=0.75, p<0.01; r=0.78, p<0.01, respectively) (Fig. 5). In "early stage" eyes, LD was significantly correlated with CPSD (r=0.39, p<0.01). Also, in "advanced stage" eyes, LD was significantly correlated with CPSD (r=0.69, p<0.01) (Fig. 6). The correlation coefficient values are summarized in Table 1.

Table 1 Correlation coefficient values between indices of HRP and HFA

		FC versus MD	*GD versus MD*	*LD versus CPSD*
POAG and NTG	(n=128)	0.73*	-0.71*	0.78*
POAG	(n= 43)	0 82*	-0 82*	0 75*
NTG	(n= 85)	0.68*	-0.66*	0.78*
Early stage	(n= 53)	0.35*	-0.39*	0.39*
Advanced stage	(n= 75)	0.66*	-0 53*	0 69*

*p<0.01

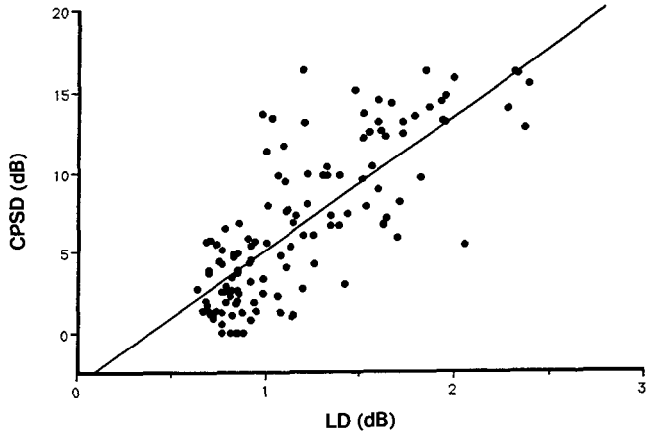

Fig 5. Relationship between LD and CPSD in a total of 128 eyes.

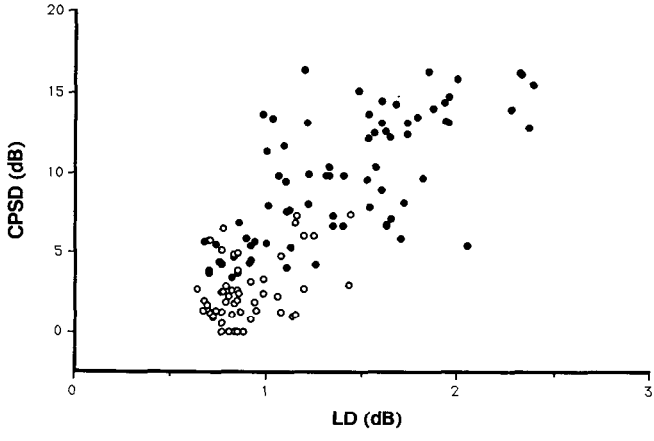

Fig. 6. Relationship between LD and CPSD in "early stage" eyes (53 eyes; open circles) and "advanced stage" eyes (75 eyes; closed circles).

Discussion

Most test targets measuring visual resolution have two different thresholds associated with acuity targets: one for detection and one for resolution. The detection threshold is usually lower than the resolution threshold[2]. In contrast, the HRP target has closely similar thresholds in detection and resolution. In HRP, because extrafoveal minimum angles of resolution are thought to be directly proportional to local ganglion cell separations, an estimate of the total number of ganglion cells within the test area can be calculated, using resolution threshold levels and previously published data of normal retinal ganglion cell counts[3,4].

There are several reports on comparative studies between HRP and DLS perimetry. Wanger and Persson[7] suggested that mean resolution threshold of HRP appeared to be more sensitive compared with Digilab 750 apparatus in patients with suspected or early glaucoma, because HRP showed abnormalities in higher percentage of eyes than with Digilab 750 apparatus. Dannheim and co-workers[8] compared the Octopus G1 program with HRP in open angle glaucoma including suspects and found significant correlation between mean sensitivity of the Octopus and mean threshold sizes of HRP. Sample and co-workers[9] reported that HRP and HFA agreed on an abnormality of 67%, and when the defect was present in both tests, HRP showed a 92% agreement with HFA by comparing the results of HRP with those of HFA in normal eyes, eyes with ocular hypertension, and eyes with POAG. In contrast, Lachenmayr and co-workers[10] reported that HRP was less sensitive in detecting glaucoma compared with DLS perimetry.

In this study, we investigated the relationship between indices of HRP and DLS perimetry in POAG and NTG eyes. Furthermore, differences between early stage eyes and advanced stage eyes were studied.

Summarizing the results, significant correlation was found between FC and MD, GD and MD, and LD and CPSD in POAG and NTG, respectively. Also, these correlations tended to be higher in eyes with more advanced field changes compared with those with less changes. The scattergram between FC and MD appears to suggest that MD might be insensitive to early FC decrease in early stage eyes, including those with small visual field defects.

In conclusion, HRP may be useful for evaluation of glaucomatous visual field abnormalities. The observed discrepancies between the two methods in early stage glaucoma may be attributable to differences in physiological factors tested with these methods.

Acknowledgement

We would like to thank Dr. L. Frisén, Department of Ophthalmology, University of Göteborg, Sweden, for his helpful comments.

References

1. Heijl A, Lindgren G, Olsson J: Normal variability of static perimetric threshold values across the central visual field. Arch Ophthalmol 105:1544-1549, 1987
2. Frisén L: High-pass resolution targets in peripheral vision Ophthalmology 94:1104-1108, 1987
3. Frisén L: Acuity perimetry: estimation of neural channels. Int Ophthalmol 12:169-174, 1988
4. Frisén L: High-pass resolution perimetry: recent developments. In: Heijl A (ed) Perimetry Update 1988/1989, pp 369-375. Amsterdam: Kugler Publ 1989
5. Frisén L: A computer-graphic visual field screener using high-pass spatial frequency resolution targets and multiple feedback devices. Doc Ophthalmol Proc Ser 49:441-446, 1987
6. Douglas GR, Drance SM, Mikelberg FS, Schulzer M, Wijsman K: Variability of the Frisén ring perimeter. In: Heijl A (ed) Perimetry Update 1988/1989, pp 197-198. Amsterdam: Kugler Publ 1989
7. Wanger P, Persson HE: Pattern-reversal electroretinograms and high-pass resolution perimetry in suspected or early glaucoma. Ophthalmology 94:1098-1103, 1987
8. Dannheim F, Abramo F, Verlohr D: Comparison of automated conventional and spatial resolution perimetry in glaucoma. In: Heijl A (ed) Perimetry Update 1988/1989, pp 383-392. Amsterdam: Kugler Publ 1989
9. Sample PA, Ahn DS, Lee PC, Weinreb RN: High-pass resolution perimetry in eyes with ocular hypertension and primary open-angle glaucoma. Am J Ophthalmol 113:309-316, 1992
10. Lachenmayr BJ, Drance SM, Douglas GR, Mikelberg FS: Light-sense, flicker and resolution perimetry in glaucoma: a comparative study. Graefe's Arch Clin Exp Ophthalmol 229:246-251, 1991

High-pass resolution perimetry: comparison between mean dB score and neural capacity in glaucoma diagnosis and follow-up

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Abstract

High-pass resolution perimetry (HRP) measures the resolution threshold at 50 locations within the 30-degree central visual field. In the current study two HRP measurements of overall visual field function: mean dB score and neural capacity, were compared in normal subjects, patients with ocular hypertension and newly diagnosed, treated glaucoma patients, followed for two years. The correlation between mean dB score and neural capacity at the first examination ranged from 0 91 to 0.99 in the examined groups After two years' follow-up of the 53 treated glaucoma patients, 26 visual fields were classified as improved, 13 as unchanged and 14 as deteriorated, when mean dB scores were used Using neural capacity, the corresponding numbers were 20, 18 and 15. The choice of statistic measurement influenced the evaluation of treatment in 12/53 (23%) of these early stage glaucoma patients.

Introduction

One of the major uses of perimetry is for glaucoma diagnosis and follow-up of glaucoma treatment. High-pass resolution perimetry (HRP) has been reported to be a sensitive method for the detection of optic nerve damage in early glaucoma[1] and is regarded as useful in glaucoma management[2], but there are no data regarding the findings in follow-up of treated glaucoma patients.

Several factors are known to influence the visual fields; in resolution perimetry the age-related effect corresponds to a threshold increase of 0.02 dB/year[3,4] and the learning effect has been reported to be up to 0.6 dB[5,6]. The effects of antiglaucoma eye drops were found to be negligible in a single-dose study[7].

The HRP system provides two measurements of overall visual field function: mean dB score, which is calculated from log target sizes, and neural capacity, which uses the inverted MAR values, reflecting retinal ganglion cell density and giving greater weight to the most central visual field[9].

The aim of the current study was to find out to what extent the use of these different measurements would influence what was concluded from the perimetric examination.

Material and methods

The mean dB score and neural capacity statistics were compared in 25 normal subjects, age-matched with 15 subjects with ocular hypertension and 53 patients with glaucoma, examined three times at one-year intervals.

The high-pass resolution perimeter (Ophthimus™, HighTech Vision SCI, Malmö, Sweden) used in the study is described elsewhere[8]. Briefly, it consists of a personal computer with a second graphics card, controlling the stimulus display monitor. Program version 1.0 was used.

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The test targets were high-pass spatially frequency filtered ring-shaped targets, with a space-average luminance equal to the background (20 cdm^{-2}). Target stroke sizes ranged from 10 min of arc (0 dB) to 162 min of arc (12 dB) Within the target the contrast was 0.25.

The difference in visual field findings between the first examination and the examination after two years in the ocular hypertensive and glaucoma groups was also evaluated using both statistical measures.

The findings from a single examination were defined as normal when the value of the studied statistics fell to within ± two standard deviations from the age-corrected population mean. The conclusions from the repeated visual field examinations were defined as follows: threshold change within the 95% confidence interval around the median value in the untreated ocular hypertensive group was regarded as learning effect[5,6]. Threshold decrease above this range was designated improvement and threshold change below the range deterioration.

Results

There was a strong correlation (normal subjects r=0.99 (n=25), ocular hypertension r=0.94 (n=15), glaucoma r=0.91 (n=53)) between the two measurements in a single examination. The

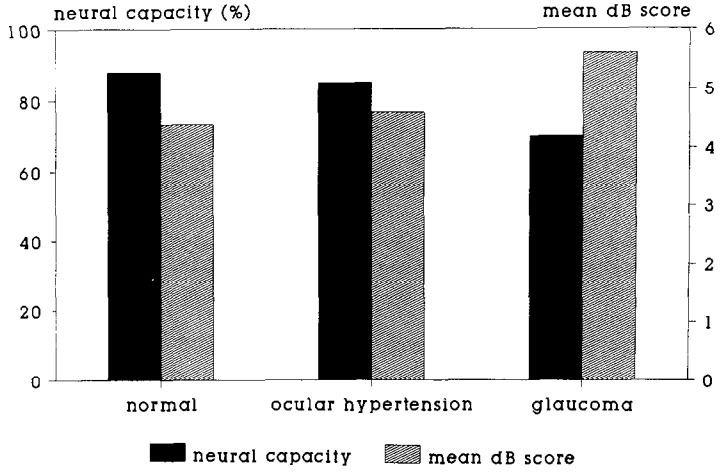

Fig. 1. Perimetric findings from one examination in normal subjects (n=25), ocular hypertension (n=15) and glaucoma (n=53) patients

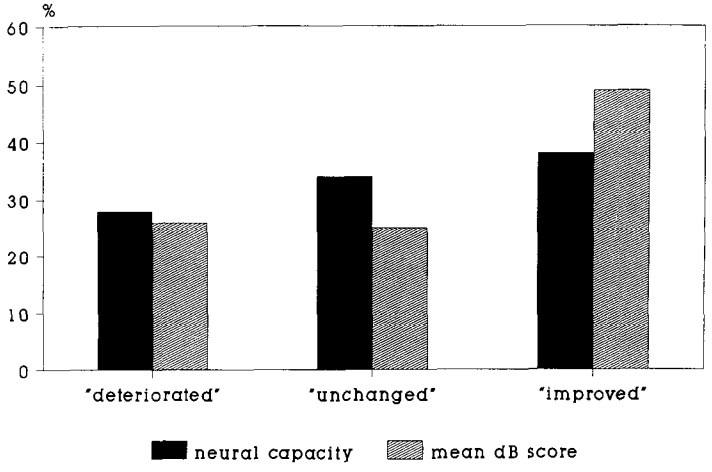

Fig. 2. Perimetric changes during follow-up of treated glaucoma patients (n=53): conclusions based on the differences between first and third examination two years later.

average of mean dB scores were 4.37±0.7 dB (normal subjects), 4.37±0.9 dB (ocular hypertension) and 5.61±1.2 dB (glaucoma). Corresponding values for neural capacity were 88±15%, 90±19% and 69±19% in the respective groups (Fig. 1). In four patients with glaucoma, the mean dB score was slightly abnormal while the neural capacity was normal. In all other subjects evaluation of mean dB score and neural capacity led to the same conclusion.

Regarding the difference between two examinations in the same individual, the two measurements led to different conclusions in 12/53 glaucoma patients (23%) and 1/15 ocular hypertensive patients (7%) (Fig. 2). The deviations in the glaucoma group were mostly due to improved mean dB score in patients with unchanged neural capacity (eight patients). Two patients showed the reverse finding and two patients appeared unchanged with regard to mean dB score, but deteriorated in neural capacity. One ocular hypertensive subject showed improvement in neural capacity and unchanged mean dB score (Table 1).

Table 1 Mean dB score and neural capacity change (medians and confidence intervals) between examination one and three

	Ocular hypertension	*Glaucoma*
Number of patients	15	53
Mean dB score (dB)	0.48	1.14
Confidence intervals	0.0-0.84	0.76-1.7
Neural capacity (%)	12	15
Confidence intervals	0-19	8-21

Discussion

The findings from the current study indicate that the choice of statistics influenced the conclusion from HRP in glaucoma follow-up in 23% of 53 patients studied. Mean dB score indicated improvement more often than neural capacity. In the evaluation of results from a single examination using HRP, the statistics compared appeared to be practically equivalent.

In differential light sense perimetry weighting the indices used for inter-individual fluctuation in the midperiphery did not lead to any difference in visual field evaluation[10]. In HRP the variability is low and neither dependent on thresholds nor on eccentricity[11]. The neural capacity statistic is more sensitive than mean dB score to change in the most central part of the visual field. Due to the higher density of ganglion cells in this part of the retina, one dB threshold increase in the central retina means a greater loss of ganglion cells than one dB threshold increase in the peripheral part where the ganglion cell separation is greater. The observation that mean dB score improved more in treated glaucoma patients may reflect the well-established fact that glaucoma usually affects the paracentral region more than the most central part of the visual field in the early stage of the disease. Hence, the mean dB score measure may be appropriate in glaucoma follow-up.

In conclusion, the two indices of overall visual field function in high-pass resolution perimetry, neural capacity and mean dB score, give practically equivalent information when one examination is evaluated. During follow-up of treated glaucoma patients, mean dB score changed towards threshold decrease, *i.e.*, improved function, somewhat more often than neural capacity.

References

1. Wanger P, Persson HE: Pattern-reversal electroretinograms and high-pass resolution perimetry in suspected or early glaucoma. Ophthalmology 94:1098-1103, 1987
2. Sample PA, Ahn DS, Lee PC, Weinreb RN: High-pass resolution perimetry in eyes with ocular hypertension and primary open-angle glaucoma. Am J Ophthalmol 113:309-316, 1992
3. Martin-Boglind LM, Wanger P: Computer-assisted evaluation of the results of high-pass resolution perimetry: a knowledge-based system. In: Mills RP, Heijl A (eds) Perimetry Update 1990/91, Proceedings of the IXth International Perimetric Society Meeting, pp 297-301. Amsterdam: Kugler Publ 1991
4. Frisén L: High-pass resolution perimetry and age-related loss of visual pathway neurons. Acta Ophthalmol 69:511-515, 1991

5. Martin-Boglind LM and Wanger P: The influence of feedback devices, learning and cheating on the results of high-pass resolution perimetry. In: Heijl A (ed) Perimetry Update. Proceedings of the VIIIth International Perimetric Society Meeting 1988/89, pp 393-398. Amsterdam: Kugler Publ 1989
6. Drance SM, Douglas GR, Schultzer M, Wijsman CS: The learning effect of the Frisén ring perimeter. In: Heijl A (ed) Perimetry Update. Proceedings of the VIIIth International Perimetric Society Meeting 1988/89, pp 199-201. Amsterdam: Kugler Publ 1989
7. Martin-Boglind LM, Graves A, Wanger P: The effect of topical antiglaucoma drugs on the results of high-pass resolution perimetry. Am J Ophthalmol 111:711-714, 1991
8. Frisén L: A computer graphics visual field screener using high-pass spatial frequency resolution targets and multiple feedback devices. Doc Ophthalmol Proc Ser 49:441-446, 1987
9 Frisén L: Acuity perimetry: estimation of neural channels. Int Ophthalmol 12:169-174, 1988
10. Funkhouser A, Fankhauser F: The effects of weighting the "mean defect" visual field index according to threshold variability in the central and midperipheral visual field. Graefe's Arch Clin Exp Ophthalmol 229:228-231, 1991
11 Chauhan BC, House PH: Intratest variability in conventional and high-pass resolution perimetry. Ophthalmology 98:79-83, 1991

Resolution theory and high-pass resolution perimetry (HRP)

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Abstract

A major goal of HRP is to produce a subject-oriented index of the state of the visual system, capable of replacing the machine-oriented indices used in conventional perimetry. Realization of this goal demands demonstration of a close quantitative agreement between HRP test results and a suitable anatomical parameter. This report reviews resolution theory, with emphasis on a recent, statistical model of resolution. This model implies that resolution in peripheral vision is directly proportional to retinal receptive field (ganglion cell) separation, with different proportionality factors for different contrast levels The model appears to link anatomical data and HRP results successfully. Comparable magnitudes of variability and age-related changes also attest to HRP's validity.

Introduction: resolution theory

Every ophthalmologist knows von Helmholtz's decree that the minimum requirement for discrimination of two point sources is that their retinal images are separated by one cone diameter[1]. Non-ophthalmologists, however, have long depended on a more versatile concept that centers on faithful representation of regular patterns, *e.g.*, sinusoidal gratings, by regular detector arrays. The limit of performance, the so-called Nyquist limit, is expressed here in spatial frequency terms: the maximum number of cycles subtended per angular degree that can be faithfully represented is exactly one-half of the detector spatial frequency (Fig. 1). For higher frequencies, the array cannot record all details ("undersampling"). The output will be an "alias" of lower frequency, and resolution "spurious". Orientation and motion reversals may also occur.

The spatial frequency approach has considerable advantages because it is well suited for mathematical analysis. However, by replacing von Helmholtz's twin point sources with peak-to-peak distance in a sinusoidal grating, the two models can be seen to be very closely related.

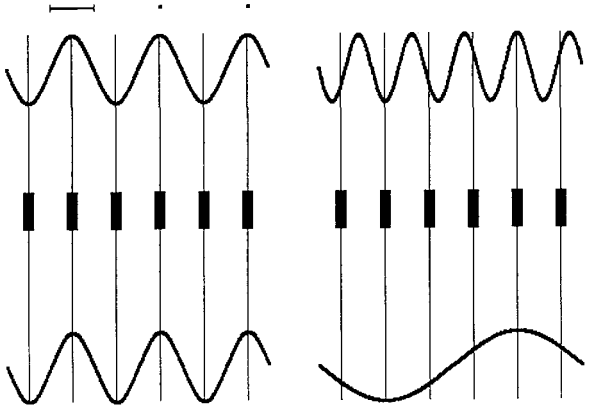

Fig. 1. Scheme of a detector array and its representation of a sinusoidal grating. Left: maximum resolvable spatial frequency. Horizontal bar represents MAR, while squares symbolize limit of two-point discrimination. Right: spurious resolution of a grating of higher frequency.

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The following presentation concentrates on the spatial frequency approach, complemented with the classical clinical concept of minimum angle of resolution, MAR. For the optotypes used for acuity measurements, definition of MAR is straightforward: it is the stroke width of the smallest resolvable target. The corresponding detail in a grating is half a cycle, *i.e.*, a light or a dark band. Hence, an optotype with a stroke width of 1′ corresponds, at least in principle, to a grating with a spatial frequency of 30 cycles (*i.e.*, 30 pairs of light and dark stripes) per degree.

Statistical aspects of resolution

In biological settings there are several problems associated with classical resolution theory. The most important is that resolution cannot be observed directly but must be inferred from the subject's responses to target presentations. Because subjective responses are influenced by a very large number of independently varying factors, *e.g.*, attention, time since the last blink, arterial pulse phase, and photon statistics, repetition is likely to give a different result. In fact, threshold target spatial frequency is a stochastic variable. This is easily shown by repeatedly presenting a target of adjustable spatial frequency to, say, the fovea. Each presentation is begun at an unresolvable level and frequency is smoothly reduced until the subject signals resolution. Several presentations define a distribution of target frequencies for which resolution is first reported. Threshold target frequency (or its logarithm) usually shows a normal distribution (Fig. 2).

Because resolving capacity varies from moment to moment, any given target within the range of variation will not always be resolvable. In fact, presentation of a target in the high frequency range will rarely happen to coincide in time with a high resolving capacity. However, much of the time, resolving capacity will equal or exceed the level required for targets from the low frequency range, so these will be resolved more often. Lythgoe[2] pioneered quantitative experiments of this kind. Recording the fraction of successful attempts at resolution as a function of target frequency, Lythgoe showed that the *probability of resolution* varies with target frequency according to a sigmoid frequency-of-seeing curve.

Because target frequency (or a transform) is normally distributed, the probability to report resolution is exactly defined by the parameters μ (mean) and σ (standard deviation) of frequency-of-seeing curves. Resolution is commonly defined as that target frequency which is resolved with a certain, fixed probability P, *e.g.*, 0.5. Actually, any P value can be selected: none is more natural than another, and none corresponds to the Nyquist limit. However, one argument supporting $P(0.5)$ is that statistical tools like probit analysis[3] are weighted in its favor (Fig. 3).

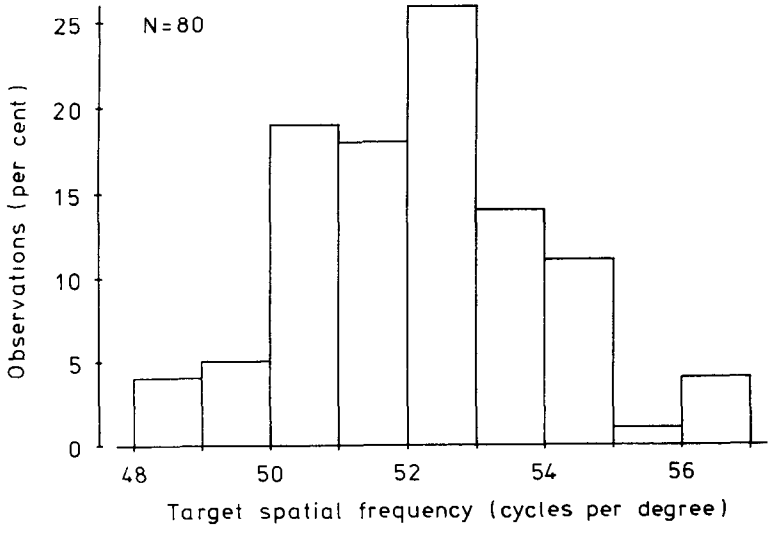

Fig. 2. Distribution of sinusoidal grating frequencies at which resolution was reported on 80 sliding, on-axis presentations in a normal subject. Contrast was 0.9.

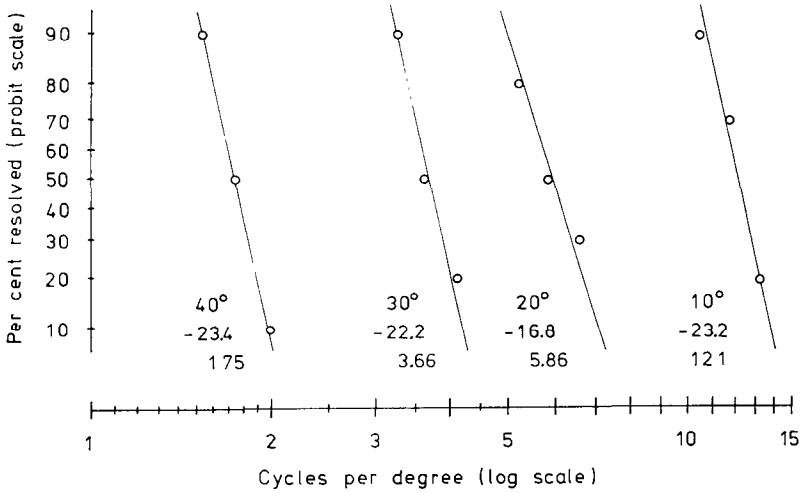

Fig. 3. Frequency-of-seeing data from a normal subject at four locations on nasal meridian, using interference fringes at maximum contrast. Vertical axis uses probit scale to linearize response function: 0 and 100% are undefined on this scale. Inset: locations, slopes, and μs. Data from reference 32

A ratio model of resolution

The statistical shortcomings of the classical model recently have prompted development of another model. This so-called ratio model proposes that *the probability to report resolution is determined solely by the ratio of target spatial frequency to detector spatial frequency.* The only requirement is that target frequency (or a transform) is normally distributed[4]. As already indicated, this is known to be the case.

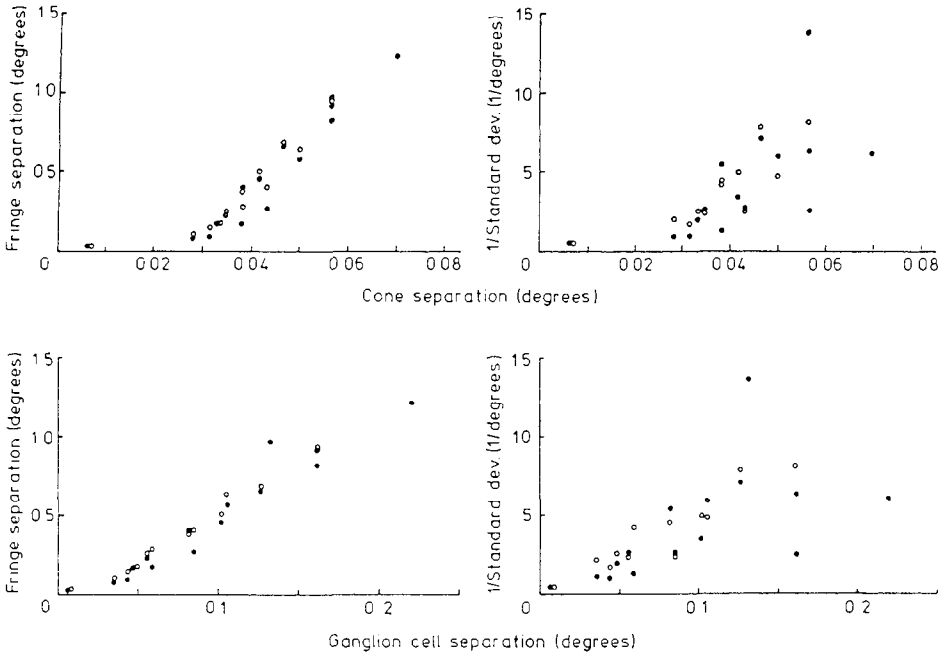

Fig. 4. Relationship between inverse of μ and σ (left and right columns, respectively) of interferometric resolution measurements on horizontal meridian of two normal eyes, and average normal cone and ganglion cell separations (upper and lower rows, respectively) in corresponding locations. Reproduced with permission[4].

The ratio model is perhaps best explained by returning to frequency-of-seeing curves. Remember that each *P* level corresponds to a unique target spatial frequency. Because detector frequency is constant, it follows that *each P level corresponds to a unique ratio of target frequency to detector frequency*. Accordingly, μ and σ correspond to fixed ratio values. A change in detector frequency will force changes in μ and σ but, under otherwise constant conditions, these will still correspond to the same ratios. Therefore, μ and σ are exactly proportional, but for stochastic deviations, to detector frequency. Consequently, for resolution measurements on sets of detector arrays, *e.g.*, different locations in the visual field (Figs. 3 and 4), or measurements at different times on dynamically changing arrays, *e.g.*, benign macular edema, frequency-of-seeing curves should be parallel, and plots of μ and σ *versus* detector frequency, should be linear through the origin. This has proved to be the case in both types of studies[4,5]. The same relationship has been shown to apply to clinical visual acuity measurements and post-mortem counts of optic nerve axons in optic atrophy from various causes[6]. Together, these completely different types of studies indicate that the operation of unidentified concomitant variables is highly unlikely. Meeting the gold standard of validation by precise measurements of both resolution and detector parameters in corresponding retinal locations in normal and abnormal human eyes, is a utopia, of course.

No claim is made that the ratio model is exactly true. However, until a better model emerges, the ratio model seems capable of serving many needs. No refuting evidence is presently known.

The magnitudes of the target/detector frequency ratios are not specified for any level of probability of resolution. However, for the special case of high background luminance and maximum contrast, where performance is best, ratios may well approach the Nyquist limit. In MAR and detector spacing terms, this equals unity (Fig. 1). Note that the ratio model, unlike the classical counterpart, is equally applicable to low background and submaximal contrast levels.

Nature of resolution

Surprisingly perhaps, the actual nature of resolution is not at all clear. In biological settings, resolution cannot be directly observed, of course, but has to be studied from subjects' responses. Hence, resolution is by necessity operationally defined. Different subjects are likely to apply different criteria for resolution, and these need not at all agree with classical aspects[7]. One example is that some humans in certain circumstances can resolve gratings with spatial frequencies up to 1.5 times their measured (parafoveal) cone Nyquist limits[8].

Retinal detector arrays

At photopic light levels there are two detector arrays that set upper bounds on neural resolution. For the fovea, there can be little doubt that cone density is of paramount importance[9]. Outside some 5-10° of eccentricity, retinal ganglion cells are much less numerous than cones, forcing several cones to converge on single ganglion cells, to form receptive fields. There can be little doubt that it is spatial densities of receptive fields that set neural limits for resolution in peripheral vision[9,10]. Analytically, receptive fields can be equated with ganglion cell bodies. However, center-to-center distance must be no larger than effective receptive field radius. Otherwise, "spatial averaging" will impair resolution.

Determination of spatial frequencies of cones and ganglion cells is associated with several problems. In most instances, these parameters have to be assessed from post-mortem cell counts, and in eyes other than those in which resolution was measured. Detailed analyses of factors such as tissue deformations, cell classifications, packing patterns, displacement, neural projection targets, and projections into visual space, have been presented by others[11,12], so there is no need to go into detail here. However, it is already clear on these grounds that stringent application of the classical model of resolution is a most difficult task. In most instances, what can be done is limited to demonstrating some degree of parallelism between resolution and detector measurements. The ratio model offers a more stringent test, by demanding proportionality through the origin, both for μ and σ. At the same time, it is much less demanding concerning array parameters. For example, exact knowledge of detector packing patterns is not required: as long as the pattern remains unchanged, linearity through the origin will apply.

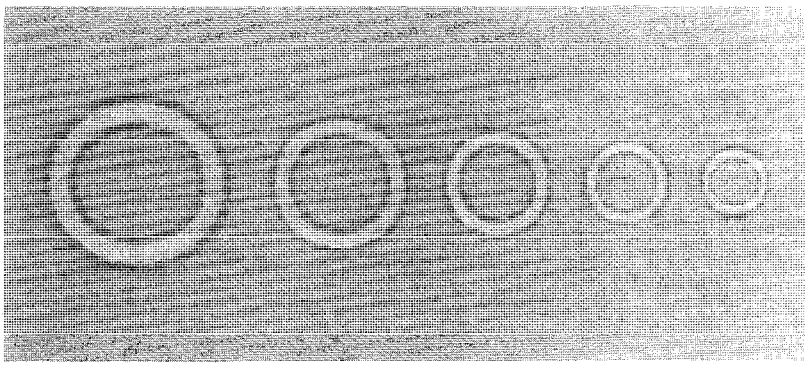

Fig. 5. Set of HRP test targets View figure from various distances to see how targets falling below resolution limit invisibly melt into background.

Optical considerations

The eye's optical system is well known to exhibit many types of imperfections. In the present context, the crucial question is whether optical quality normally sets an upper bound on resolving capacity. Again, there is little point here in going into historical or other details: it suffices to note that modern studies tend to refute this possibility[9,13,14].

High-pass resolution perimetry does not employ sinusoidal gratings but discrete ring-shaped targets of different sizes[15] (Fig. 5). Each target has a bright core bordered by dark annuli: space-average luminance is equal to that of the background. This arrangement makes for a very near coincidence of detection and resolution thresholds[16], and leaves little room for aliasing. This is a requisite for practicable resolution perimetry. Reasons for selecting a ring shape include its relative immunity to astigmatism and its lack of orientation selectivity[17,18].

Each HRP target contains a spectrum of spatial frequencies. Therefore, stimulus value is best designated in MAR terms, *i.e.,* the width of the bright core[18]. For equivalence, detector parameters should be designated in center-to-center separation terms, *i.e.,* inverted spatial frequency.

HRP validations

HRP has been validated in the following ways:

1. μ and σ of frequency-of-seeing curves have been obtained from normal subjects at each 10° off axis on the main visual field meridians. Plotting results against reported ganglion cell separations in corresponding locations, direct proportionality seems to apply[17,19] (Fig. 6).
2. Because resolution changes with different rates along different meridians, the above results cannot be explained by the operation of an unidentified factor related to eccentricity.
3. The studies just described employed three different contrast levels (0.10, 0.25, and 0.50). Results obeyed the ratio model for all contrasts, with a monotonous decrease in direction coefficients with increasing contrast.
4. Extrapolating different-contrast results to the 1.0 level[19], and regressing μ on ganglion cell separation, produces a regression coefficient of about 1.2. Under the admittedly equivocal assumption that gainful employment of all ganglion cells should produce a unit value (the Nyquist limit), the observed result suggests that a subset of ganglion cells with a separation 1.2 times larger than that of the overall ensemble, should suffice to uphold resolution at the 1.0 contrast level. Relative to the full ensemble, this subset comprises 1/1.2 cells per unit of length, and $(1/1.2)^2$ cells per unit area, *i.e.,* approximately 70% of all ganglion cells. This is close to the expected proportion of the so-called parvocellular class of ganglion cells, or 80%. Experimental studies indicate that this is the class which serves resolution tasks[20,21]. This seems to be proportionately represented throughout the visual system[22]. Magnocellular and unclassified ganglion cells, which comprise some 10% each, are obviously much too few to uphold resolution at high contrast. Further, magnocellular cells specialize in low contrasts, at low spatial and high temporal frequencies.

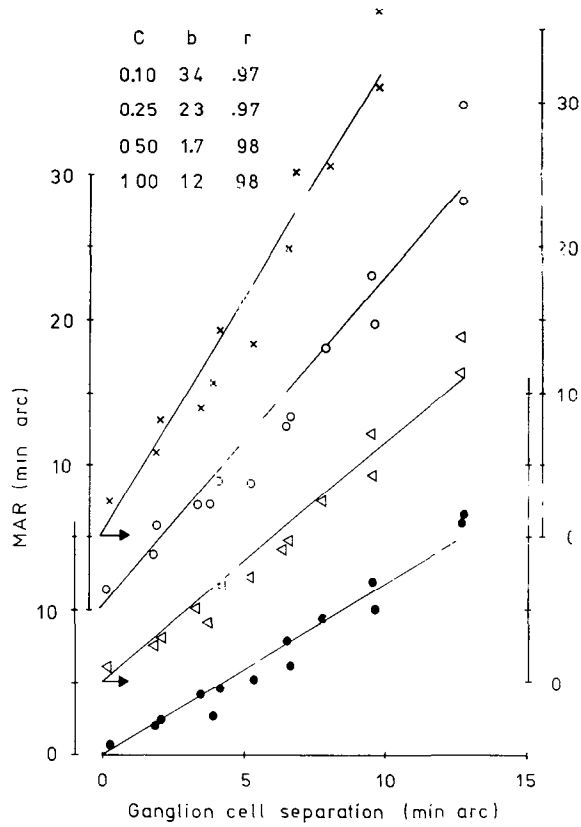

Fig. 6. Relationship between HRP MARs at different contrast levels in a normal subject, and average normal ganglion cell separations in corresponding locations. MAR was obtained at each 10° of eccentricity on the main meridians, out to 50° (temporally, 80°) for contrast levels 0.1, 0.25, and 0.5, and extrapolated to the 1.0 level, and plotted against ganglion cell separations in the same locations. Plots are shifted vertically for clarity. Inset: contrast levels (C), and regression (origin constraint) and correlation coefficients (b, r). Based on data from reference 19.

5. The normal, age-related decline in clinical HRP results correlates very well with postmortem axon counts in human optic nerves of different ages[23] (Fig. 7).
6. Therapeutic photocoagulation in diabetic retinopathy raises HRP thresholds in exact proportion to the destroyed area[24].

Other attempts to validate HRP include the demonstration of statistically significant correlations with optic nerve head and retinal nerve fiber layer parameters in subjects with glaucomatous damage of different severity[25,26]. Unfortunately, it is presently not well understood how these funduscopic parameters relate to actual damage to ganglion cells.

Estimating retinocortical neural channels by HRP

The direct proportionality that characterizes HRP measurements and linear density of retinal ganglion cells can be applied in reverse, *i.e.*, to estimate the spatial density of functional ganglion cells from HRP measurements[27]. Interpretation is straightforward in normal eyes and in eyes in which ganglion cells have been damaged or disconnected from contact with higher centers: such lesions will obviously cause increased separation between remaining, functional ganglion cells, resulting in subnormal resolution. However, abnormal HRP results often arise from other causes. For example, thresholds will be raised also by optical faults and by destruc

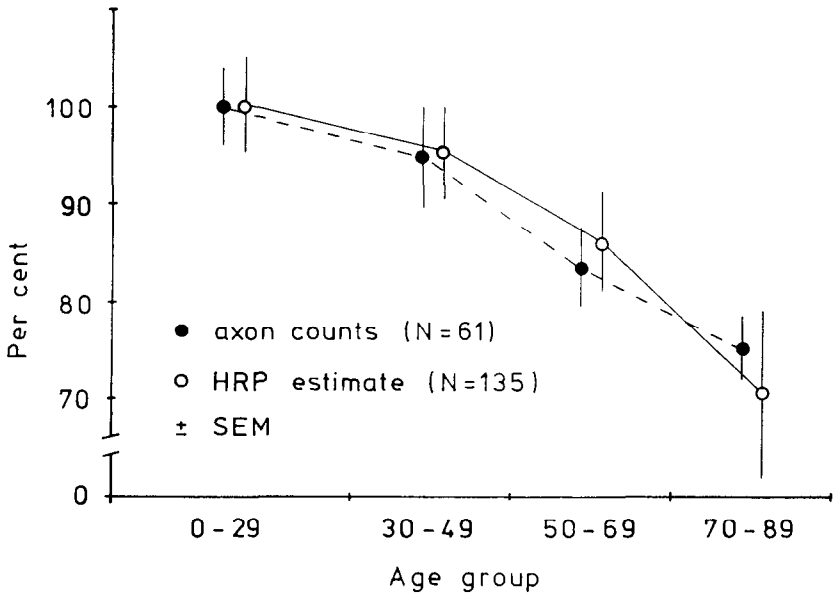

Fig. 7. Age-related changes in neural channel numbers as reflected by compiled optic nerve axon counts and by HRP measurements. The latter are influenced by both infra- and suprageniculate changes with age; the plot shows the estimated infrageniculate contribution Based on data from reference 23.

tion or dysfunction of other neural elements in the visual system. This potential problem can be managed by the concept of *functionally equivalent loss of retinocortical neural channels*[28].

Here, a retinocortical neural channel is defined with reference to a ganglion cell and its associated receptive field, plus the ganglion cell's axon, and the axon's extension to the striate cortex. It is submitted that damage anywhere along this chain is indistinguishable from damage to the ganglion cell itself, from the perceptual resolution point of view. It is further submitted that optical and other preretinal causes of threshold elevations can be viewed in the same way, and that their magnitudes can be expressed as the functionally equivalent loss of ganglion cells. This offers a unified solution to the problem of expressing severity of all the various pathogenetic mechanisms that may raise perimetric thresholds, both in isolation and in combination[28].

When evaluating results of clinical HRP, it would be cumbersome to scrutinize the estimated number of neural channels in each of the 50 tested locations: a summarizing index is more convenient. A simple solution is to calculate the sum of neural channels over all locations, and to express the sum as a percentage of the age-corrected, average normal sum.

An interesting question is whether neural channels should be calculated over area (*e.g.*, channels/degree^2) or over distance (channels/degree). While the former alternative perhaps is intuitively preferable, and indeed was incorporated as a "Functional Channels" index in Version 1 of Ophthimus® Ring Perimetry, it has the disadvantage that the squaring procedure raises variability considerably, without actually adding diagnostic information. Version 2 introduced the linear measure "Neural Capacity", decreasing age-corrected coefficients of variation (CV, 100 × SD/mean) for normal subjects from more than 30% to 18%. Both versions used Oppel's ganglion cell data for reference[11]. The new Version 3 dispenses with ganglion cell data altogether, using only normal HRP resolution results for reference. This move is a logical consequence of the well-defined relationship, and also circumvents the presently unsolved problem of exactly defining array parameters in the retinal region where the neural limitation of resolution changes from cones to ganglion cells. CV remains 18%, which is closely similar to the CV of microscopic counts of optic nerve axons[22] but larger than those of ganglion cell counts[11,12] (Fig. 8).

Clinical experience indicates that subjects seem to differ with respect to how prone they are to respond to near-threshold targets. Some subjects seem prepared to respond to apparently very weak percepts while others seem to need to be quite sure before committing themselves.

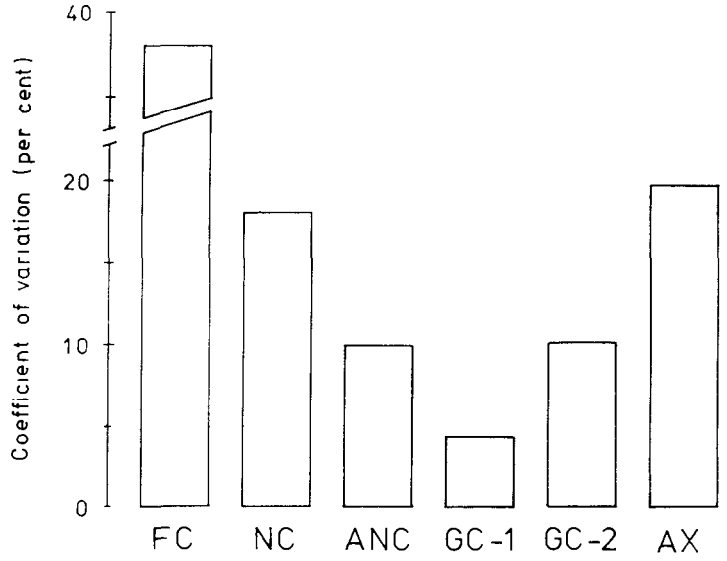

Fig. 8 Coefficients of variation for ganglion cell indices. FC: Ophthimus Functional Channels; NC: Ophthimus Neural Capacity; ANC: NC adjusted for criterion; GC-1: Oppel's microscopic cell counts[11]; GC-2: Curcio and Allen's cell counts[12]. AX: compiled optic nerve axon counts[23]

Expressed in sampling terms, some subjects may accept undersampling, while others demand different degrees of oversampling. Lacking techniques for measuring ganglion cell separations *in vivo*, this proposal remains conjectural. Nevertheless, the concept can be tried empirically, in an attempt to reduce variability between individuals. The procedure, which can be viewed as a normalization of proportionality factors, estimates an individual adjustment factor termed a relative criterion level[29]. Its application to the neural capacity index reduces the latter's CV to about 10% (Fig. 8).

An important aspect of the neural capacity estimates is that they inherently are heavily weighted in favor of the central visual field. Therefore, central field threshold elevations influence the neural capacity index much more than the same changes in peripheral locations. Conventional perimetry differs strongly in this respect, having essentially uniform weights across the visual field.

Concluding remarks

While there seems to be a good case for aiming to estimate functional retinocortical neural channels in perimetry, and HRP appears to manage this task, there are some situations where pure resolution measurements are not optimal. One concerns the non-uniform weighting mentioned above. Uniform weights may be advantageous for evaluations which basically go back to pictorial "Hill of Vision" concepts. Therefore, Ophthimus Ring perimetry calculates "Global Deviation" and "Local Deviation" indices from $\log_{10}$ (target size). This is done also for a "Form Index" that depends on an extended isopter concept for assessing the shape of the "Hill of Vision"[30].

An interesting aspect of the ratio model of resolution is that a threshold target on average involves a constant number of detectors: the number of detectors required to resolve a threshold target in the central field is the same as that in a more peripheral location, the only difference being that the central detectors normally are spread over a much smaller area. The actual number of activate detectors is not known but it is likely that it is its very constancy which explains why HRP variability is largely independent of both threshold level and test location[31]. Conventional perimetry has quite the opposite properties.

Acknowledgement

The author has a proprietary interest in the Ophthimus Vision Test System but not in the design principles.

References

1 Von Helmholt H: Handbuch der physiologischen Optik, 3rd edn, pp 29-41 Hamburg: Voss 1911
2. Lythgoe RJ: The measurement of visual acuity. Med Res Counc (GB) Spec Rep Ser 173:1-85, 1932
3. Finney DJ: Probit Analysis, 3rd edn. Cambridge University Press 1971
4. Frisén L, Frisén M: A simple relationship between the probability distribution of visual acuity and the density of retinal output channels Acta Ophthalmol 54:437-444, 1976
5. Frisén L, Frisén M: Micropsia and visual acuity in macular edema: a study of the neuroretinal basis of visual acuity. Graefes Arch Klin Exp Ophthalmol 210:69-77, 1979
6. Frisén L, Quigley HA: Visual acuity in optic atrophy: a quantitative clinicopathological study. Graefe's Arch Clin Exp Ophthalmol 222:71-74, 1984
7. Thorn F, Schwartz F: Effects of dioptric blur on Snellen and grating acuity. Optom Vis Sci 67:3-7, 1990
8. Williams DR, Coletta NJ: Cone spacing and the visual resolution limit. J Opt Soc Am A 4:1514-1523, 1987
9. Anderson SJ, Mullen KT, Hess RF: Human peripheral spatial resolution for achromatic and chromatic stimuli: limits imposed by optical and retinal factors J Physiol 442:47-64, 1991
10. Merigan WH, Katz LM: Spatial resolution across the macaque retina Vision Res 30:985-991, 1990
11. Oppel O: Untersuchung über die Verteilung und Zahl der retinalen Ganglienzellen beim Menschen. Graefes Arch Klin Exp Ophthalmol 172:1-22, 1967
12 Curcio CA, Allen KA: Topography of ganglion cells in human retina. J Comp Neurol 300:5-25, 1990
13. Thibos LN, Walsh DJ, Cheney FE: Vision beyond the resolution limit: aliasing in the periphery. Vision Res 27:2193-2197, 1987
14. Jennings JAM, Charman WN: Off-axis image quality in the human eye. Vision Res 21:445-455, 1981
15. Frisén L: A computer graphics visual field screener using high-pass spatial frequency resolution targets and multiple feedback devices. Doc Ophthalmol Proc Ser 49:441-446, 1987
16. Frisén L: Vanishing optotypes: new type of acuity test letters. Arch Ophthalmol 104:1194-1198, 1986
17. Frisén L: High-pass resolution targets in peripheral vision. Ophthalmology 94:1104-1108, 1987
18. Frisén L, Nikolajeff F:L Properties of high-pass resolution perimetry targets Acta Ophthalmol (in press)
19. Frisén L: High-pass resolution perimetry: evidence for parvocellular channel dependence. Neuro-Ophthalmology 12:257-264, 1992
20. Merigan WH, Katz LM, Maunsell JHR: The effects of parvocellular lateral geniculate lesions on the acuity and contrast sensitivity of macaque monkeys. J Neurosci 11:994-1001, 1991
21. Schiller PH, Logothetis NK, Charles ER: Role of the color-opponent and broad-band channels in vision. Vis Neurosci 5:321-346, 1990
22. Livingstone MS, Hubel DH: Do the relative mapping densities of the magno- and parvocellular systems vary with eccentricity? J Neurosci 11:4334-4339, 1988
23. Frisén L: High-pass resolution perimetry and age-related loss of visual pathway neurons. Acta Ophthalmol 69:511-515, 1991
24. Lindblom B: Effects of laser-induced retinal lesions on perimetric thresholds. Doc Ophthalmol 79:241-252, 1992
25. Airaksinen PJ, Tuulonen A, Välimäki J, Alanko HI: Retinal nerve fiber layer abnormalities and high-pass resolution perimetry. Acta Ophthalmol 68:687-689, 1990
26. Tomita G, Maeda M, Sogano S, Kitazawa Y: An analysis of the relationship between high-pass resolution perimetry and neuroretinal rim area in normal-tension glaucoma. Acta Ophthalmol (in press)
27. Frisén L: Acuity perimetry: estimation of neural channels. Int Ophthalmol 12:169-174, 1988
28. Frisén L: Visual acuity and visual field tests: psycho-physical vs pathophysical objectives. In: Kennard C, Rose FC (eds) Physiological Aspects of Clinical Neuro-Ophthalmology, pp 3-26. London: Chapman and Hall 1988
29. Frisén L: Perimetric variability: importance of criterion level. Doc Ophthalmol 70:323-330, 1989
30. Frisén L: A shape statistic for visual field evaluation: utility in minor optic neuropathy. Neuro-Ophthalmology 9:347-354, 1989
31. Chauhan BC, House PH: Intratest variability in conventional and high-pass resolution perimetry. Ophthalmology 98:79-83, 1991
32. Frisén L, Glansholm A: Optical and neural resolution in peripheral vision. Invest Ophthalmol 14:528-536, 1975

The normal visual field in light-sense, flicker and resolution perimetry

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Abstract

One hundred and thirty eyes of 130 normal subjects aged from nine to 86 years (mean 43.7 ± 19.0 years, median 45.0 years) were tested with the Humphrey Field Analyzer 640 (program 30-2), the automated flicker perimeter according to Lachenmayr[1-3] and the resolution perimeter according to Frisén[4-6]. The flicker perimeter program used in the present study examines 93 locations in the central visual field of up to 40°, the ring perimeter 50 points up to 30°. Subjects were excluded if they had: corrected visual acuity <0.8, refractive error >±5 dpt sph or 2 dpt cyl, intraocular pressure >21 mmHg, media opacities, abnormalities of the fundus, severe ocular trauma or any ocular surgery in their history, family history of glaucoma or any inheritable ocular diseases, history of poorly controlled hypertension, diabetes mellitus, multiple sclerosis, cerebrovascular attacks, epilepsy or ingestion of any psychopharmaca 24 hours prior to field testing. The statistical analysis of the data shows a highly significant pairwise correlation between global visual field indices: mean sensitivity (MS) for the Humphrey Field Analyzer, mean flicker frequency (MF) for the flicker perimeter and mean ring score (MR) for the ring perimeter. The correlation coefficients are as follows: MF/MS: r=0.5320, p<0.0001; MR/MF: r=-0.2753; p=0.0015; MR/MS: r=-0.5935, p<0 0001. The results of the present study provide the statistical basis for converting normal data between the three different perimetric procedures. There is, however, a tremendous amount of scatter in the comparison of normal data, and this is especially true when looking at the comparison of flicker *versus* resolution perimetry. Despite the fact that all subjects were normals recruited according to very strict inclusion criteria, a high sensitivity in one perimetric modality does not necessarily imply a high sensitivity in another

Introduction

Light-difference sensitivity is the threshold criterion of routine clinical perimetry. During the last years perimetric procedures have been developed to test more sophisticated psychophysical threshold criteria, *e.g.*, temporal transfer[1-3,7,8], spatial transfer[4-6,9], or color vision[10-12]. Temporal threshold criteria as used in flicker perimetry have been shown to be of interest for early detection of glaucomatous damage[1-3] and are largely independent from factors affecting retinal image quality, *e.g.*, refractive defocus or media opacities[13]. The technique of Frisén[4-6] for testing a spatial threshold criterion provides a very short perimetric test of the central visual field.

A prerequisite for the clinical application of new perimetric techniques is the acquisition of large-scale age-corrected normal data. As the different techniques use completely different threshold criteria, their normal values are not comparable. For clinical application, however, it would be helpful to have the possibility to convert normal data between different perimetric procedures. Although normal data were collected for some of those new techniques, there is no study which tested the same normal population with different perimetric methods.

The aim of the present study was to establish age-corrected normal data for three different perimetric techniques, including conventional light-sense perimetry using the Humphrey Field Analyzer, automated flicker perimetry according to Lachenmayr[1-3], and resolution perimetry

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according to Frisén[4-6]. The special purpose of the study was to provide the statistical basis for converting normal data between these three instruments.

Material and methods

Normal subjects

One hundred and thirty eyes of 130 normal subjects aged from nine to 86 years (mean 43.7 - 19.0 years, median 45.0 years) were included in the present study. The subjects were excluded if they had: corrected visual acuity <0.8, refractive error >±5 dpt sph or 2 dpt cyl, intraocular pressure >21 mmHg, media opacities (slit-lamp), any relevant abnormalities of the fundus (indirect ophthalmoscopy in mydriasis), severe ocular trauma or any ocular surgery in their history, a family history of glaucoma or any inheritable ocular diseases, a history of poorly controlled hypertension, diabetes mellitus, multiple sclerosis, or cerebrovascular attacks in their history, epilepsy or ingestion of any psychopharmaca 24 hours prior to field testing. If both eyes of a subject fulfilled the inclusion criteria, one eye was selected randomly. For each individual all visual field tests were performed in random order using an introductory learning program for each procedure. In this way a systematic learning effect could be ruled out. The following perimetric procedures were used:

Light-sense perimetry

Light-sense perimetry was performed with the Humphrey Field Analyzer 640 using program 30-2. This program tests 77 points up to 30° over a 6°-rectangular grid using a full threshold strategy (Fig. 1, left). Prior to the standard program, a custom-made learning program including 13 locations in the central visual field up to 25° was performed.

Flicker perimetry

Automated flicker perimetry according to Lachenmayr[1-3] uses flicker fusion frequency (FFF) as a threshold criterion. Yellow light-emitting diodes (530 nm) of 1° diameter serve as stimuli (mean luminance of stimulus and surround = 50 cdm^{-2}). The modulation of the stimulus is rectangular with a superimposed Gaussian on- and offset in order to rule out possible edge effects. For the present study, a grid testing 93 points of up to 40° of eccentricity in the central visual field was used (Fig. 1, center). The frequency values were transformed from the linear cps/Hz-scale into a logarithmic dB-scale according to the following formula: FFF in dB = 20 × log FFF in cps/Hz. A short introductory learning program testing 13 locations in the central visual field up to 25° was used prior to the standard program.

Resolution perimetry

Resolution perimetry was performed with the system of Frisén[4-6] using high-pass spatial frequency-filtered ring targets ("vanishing optotypes"). The standard program used in the present study examines 50 test locations in the central visual field (Fig. 1, right). As testing time

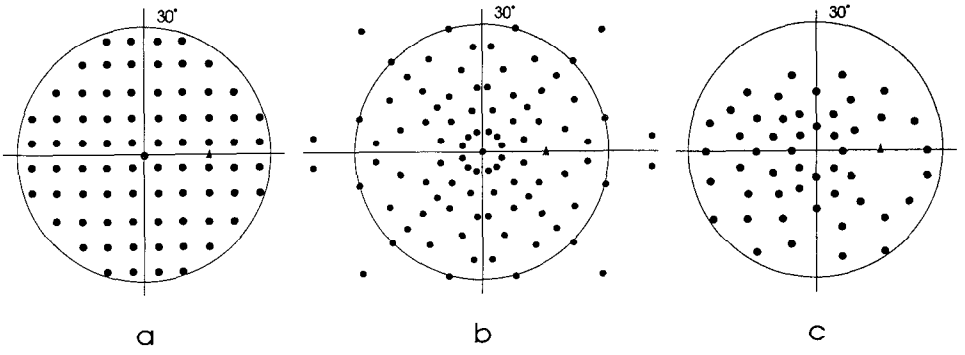

Fig. 1 The test grids of the Humphrey Field Analyzer, program 30-2 (left), the automated flicker perimeter according to Lachenmayr[1-3] (center) and the resolution perimeter of Frisén[4-6] (right).

is short compared to the other perimetric procedures used in the present study, the standard program was run twice for each subject instead of using a special introductory learning program.

For the statistical analysis of the data, which was performed with SPSS software, left eyes were projected onto the grid of a right eye and processed together with the results obtained for right eyes.

Results

The data obtained for the three perimetric techniques were used for the calculation of age-corrected normal values. These normal data will be published separately[14-16]. In the following, the pairwise correlation of global sensitivity values will be presented. For each visual field mean sensitivity indices were calculated as follows: mean sensitivity (MS) for the Humphrey Field Analyzer, mean flicker frequency (MF) for the flicker perimeter and mean ring score (MR) for the ring perimeter. The calculation of these indices was performed by averaging all individual measured points in each visual field. The pairwise correlation of MS, MF and MR is shown in Figs. 2, 3 and 4. The correlation between global indices is highly statistically

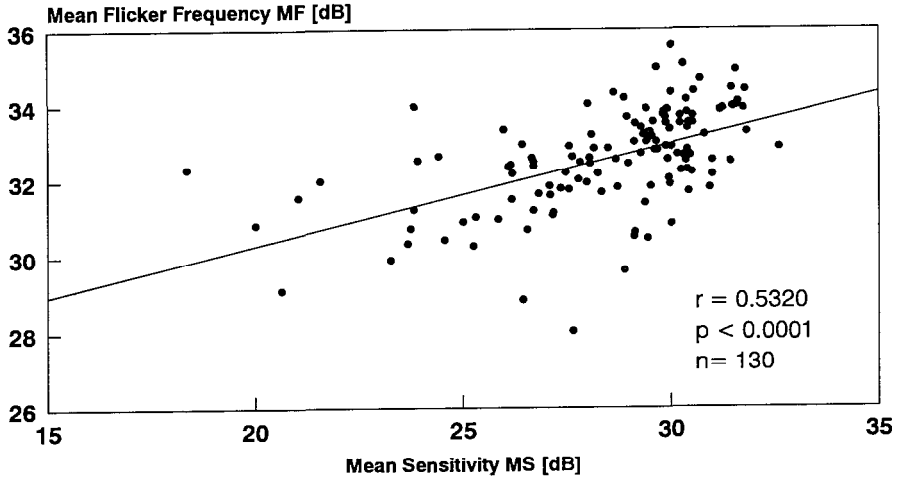

Fig. 2. Correlation of mean flicker frequency (MF) of the flicker perimeter to mean sensitivity (MS) of the Humphrey Field Analyzer (n=130): r=0.5320, p<0.0001.

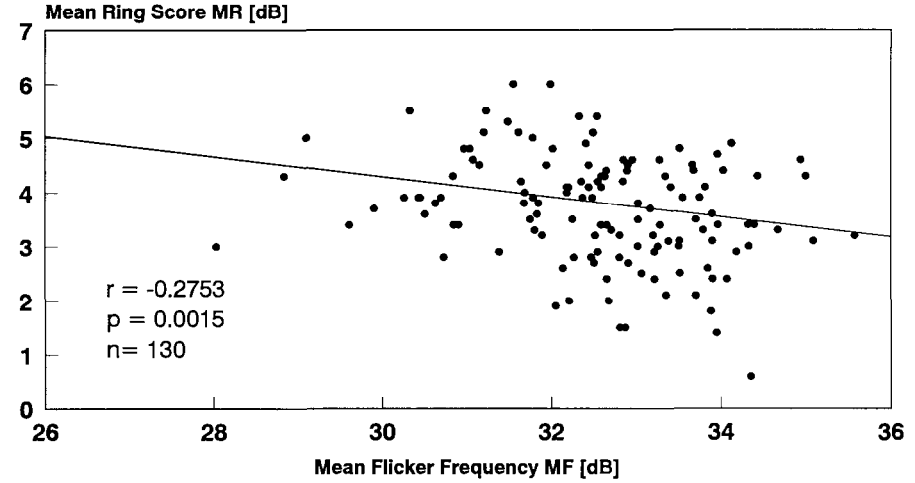

Fig. 3. Correlation of mean ring score (MR) of the resolution perimeter to mean flicker frequency (MF) of the flicker perimeter (n=130): r=-0.2753, p=0 0015

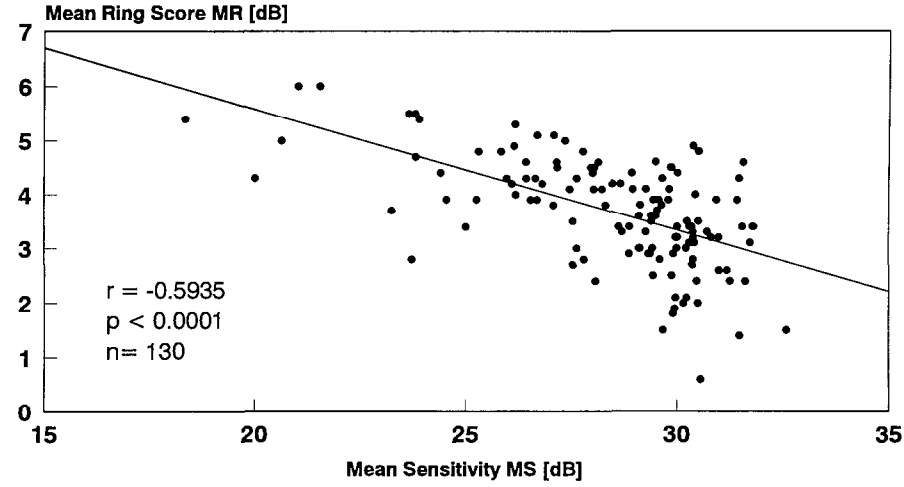

Fig. 4. Correlation of mean ring (MR) score of the resolution perimeter to mean sensitivity (MS) of the Humphrey Field Analyzer (n=130): r=-0.5935, p<0.0001.

significant, the correlation coefficients are as follows: MF/MS: r=0.5320, p<0.0001; MR/MF: r=-0.2753; p=0.0015; MR/MS: r=-0.5935, p<0.0001. While the correlation of MF/MS and MR/MS is fairly good, the correlation of MR/MF is rather poor. In a first step a simple linear regression analysis was performed which seems appropriate when looking at the underlying data distributions: the parameters of the regression lines are presented in Table 1.

Table 1. Linear regression analysis of the pairwise correlation between the global visual field indices mean sensitivity (MS) (Humphrey Field Analyzer), mean flicker frequency (MF) (flicker perimeter) and mean ring score (MR) (ring perimeter)

MF/MS:	MF [dB] = 0 2677	MS [dB] + 24.94
MR/MF:	MR [dB] = -0.2068	MF [dB] + 10.41
MR/MS:	MR [dB] = -0.2243	MS [dB] + 10.07

Discussion

The results of the present study provide the possibility of converting normal visual field data between the Humphrey Field Analyzer, the automated flicker perimeter according to Lachenmayr[1-3] and the ring perimeter of Frisén[4-6]. The correlation is fairly good for the comparison between, respectively, ring, flicker perimeter and Humphrey Field Analyzer. The correlation is poor, however, when comparing the ring perimeter with the flicker perimeter. This could be due to the fundamental differences between these two perimetric procedures: flicker perimetry uses a temporal threshold criterion which is very resistant to disturbing factors, *e.g.*, refractive defocus or slight media opacities which might even be present in normal older subjects[13]. The threshold criterion of the ring perimeter, however, is strongly prone to such artefacts[17-19]. Thus, slight local deviations of refraction in the visual field which are not accessible to routine measurement or slight media opacities might have an influence on the thresholds of resolution perimetry without showing any influence on the thresholds of flicker perimetry. This could explain the large amount of scatter when comparing the normal data of the ring perimeter and the flicker perimeter. When performing a conversion of normal visual field data between light-sense, flicker and resolution perimetry, as used in the present study, these differences of pairwise correlation have to be taken into account. It is interesting to see that despite the fact that all subjects were normals recruited according to very strict inclusion criteria, a high sensitivity in one perimetric modality does not necessarily imply a high sensitivity in another. The influence of age obviously is different for different perimetric threshold criteria. Further statistical analysis of our data will help us to learn more about these differential age effects.

References

1. Lachenmayr B: Analyse der zeitlich-räumlichen Übertragungseigenschaften des visuellen Systems: Ein neuer Weg zur Frühdiagnose von Netzhaut- und Sehnerverkrankungen? Thesis, Medical Faculty, Ludwig-Maximilian-University, Munich 1988
2. Lachenmayr B, Rothbächer H, Gleissner M: Automated flicker perimetry versus quantitative static perimetry in early glaucoma. In: Heijl A (ed) Perimetry Update 1988/89. Proceedings of the VIIIth International Perimetric Society Meeting Vancouver 1988, pp 359-368. Amsterdam: Kugler Publ 1989
3. Lachenmayr BJ, Drance SM, Chauhan BC, House PH, Lalani S: Diffuse and localized glaucomatous field loss in light-sense, flicker and resolution perimetry. Graefe's Arch Clin Exp Ophthalmol 229:267-273, 1991
4. Frisén L: A computer-graphics visual field screener using high-pass spatial frequency resolution targets and multiple feedback devices. Doc Ophthalmol Proc Ser 49:441-446, 1987
5. Frisén L: Acuity perimetry: estimation of neural channels. Int Ophthalmol 12:169-174, 1988
6. Frisén L: High-pass resolution perimetry. In: Heijl A (ed) Perimetry Update 1988/1989. Proceedings of the VIIIth International Perimetric Society Meeting Vancouver 1988, pp 369-375. Amsterdam: Kugler Publ 1989
7. Faubert J, Balazsi AG, Overbury O, Brussell EM: Multi-flash campimetry and other psychophysical tests in chronic open angle glaucoma. Doc Ophthalmol Proc Ser 49:425-432, 1987
8. Casson EJ, Johnson CA, Quigg JM: Visual field analysis of flicker sensitivity in early glaucoma and ocular hypertension. Invest Ophthalmol Vis Sci (Suppl) 31:191, 1990
9. Phelps CD, Blondeau P, Carney B: Acuity perimetry: a sensitive test for the detection of glaucomatous optic nerve damage. Doc Ophthalmol Proc Ser 42:359-363, 1985
10. Hart WM, Burde RM: Color contrast perimetry: the spatial distribution of color defects in optic nerve and retinal diseases. Ophthalmology 92:768-776, 1985
11 Hart WM, Hartz RK, Hagen RW, Clark KW: Color contrast perimetry. Invest Ophthalmol Vis Sci 25:400-413, 1984
12. Sample PA, Weinreb RN: Color perimetry for assessment of primary open-angle glaucoma. Invest Ophthalmol Vis Sci 31:1869-1875, 1990
13. Lachenmayr B, Gleissner M: Flicker perimetry resists retinal image degradation. Invest Ophthalmol Vis Sci 33:3539-3542, 1992
14. Dietrich J: Normalwerte für das zentrale Gesichtsfeld am Humphrey Field Analyzer Thesis, Medical Faculty, Ludwig-Maximilian-University, Munich (in preparation)
15. Angstwurm K: Flimmerperimetrie bei Sehnerv- und Sehbahnläsionen. Thesis, Medical Faculty, Ludwig-Maximilian-University, Munich (in preparation)
16. Bachmayer B: Sehschärfeperimetrie nach Frisén: Normales Gesichtsfeld und Erfassung von Gesichtsfelddefekten bei Netzhaut-, Sehnerv- und Sehbahnerkrankungen Thesis, Medical Faculty, Ludwig-Maximilian-University, Munich, 1993
17. House PH, Drance SM, Schulzer M, Wijsman K: The effect of refractive blur on the visual field using the ring perimeter. Acta Ophthalmol 68:87-90, 1990
18. Hölzl M, Lachenmayr B, Vivell PMO: Einfluss von Fehlrefraktion und artifiziellen Medientrübungen auf die Sehschärfeperimetrie. Fortschr Ophthalmol 88:875-880, 1991
19. Meyer JH, Funk J: Einfluss artifizieller Medientrübungen auf die Sehschärfeperimetrie nach Frisén und die konventionelle Lichtsinnperimetrie. Ophthalmologe (Suppl 1), 89:73, 1992

Automated flicker perimetry using the Octopus 1-2-3

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Abstract

Using the Octopus 1-2-3 and its remote interface and software, the authors developed a strategy for automated static flicker perimetry in the central 30° visual field on an IBM personal computer. Catch trials for the false-positive and the false-negative answers were included to evaluate the cooperation of the patient. The short-term fluctuation was also tested to examine the reliability of flicker perimetry. Using this program, the authors studied the static flicker fusion fields of 100 normal subjects and 36 patients with early glaucoma. The profile of the normal static flicker fusion field was almost flat under our examination conditions. The flicker fusion threshold decreased slightly with age. In 97% of the normal subjects, the catch trials of our automated flicker perimetry were less than 15%, indicating that patient reliability was almost as good as that of Octopus perimetry. Automated static flicker perimetry was able to detect early glaucomatous visual field defects which had not been clearly recognized with Octopus perimetry.

Introduction

Optic nerve fiber damage in early glaucoma often remains undetected with traditional perimetric techniques. Based on the results of histopathological studies of glaucomatous optic nerve damage in human eyes, Quigley reported that 40% of the optic nerve fibers were already damaged when 10 dB loss was found in the central 30° visual field[1]. It is thus very important to develop a more sensitive perimetric method for detecting early glaucomatous visual field loss.

Flicker perimetry, which measures the critical fusion frequency (cff) at each test point in the visual field, is a classical psychophysical technique. Many manual methods of static and kinetic flicker perimetry have already been reported[2-7]. It is known that flicker perimetry is more sensitive than light threshold perimetry for detecting early glaucomatous visual field defects[4,5,8]. However, the examiner and the patients need to have ample experience for manual flicker perimetry. Therefore, manual flicker perimetry has not been widely used for clinical investigations.

Using the Octopus 1-2-3 automated perimeter and its remote software package, we developed a practical strategy for automated flicker perimetry to measure the critical fusion frequency within the central 30° visual field. In this study, we studied the static flicker fusion field of normal subjects and patients with early glaucoma using automated static flicker perimetry.

Subjects and methods

The static flicker fusion field was examined using the Octopus 1-2-3 and its remote interface and software package. Target size 3 and a maximum target luminance of 4000 asb were used with the background luminance of 31.5 asb. The duration of each stimulus was one second. A new strategy for automated flicker perimetry was developed and programmed on an IBM personal computer.

Fig. 1 shows the pattern and waveform of the flicker stimulus and an arrangement of the test

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points for static flicker perimetry. The arrangement of the test points was almost the same as that used in the Octopus standard program No. 38. The double circled points were measured twice randomly in order to calculate the short-term fluctuation. A bracketing method was used to measure cff at each test point. The flicker frequency was varied in steps of 10 Hz initially and then in steps of 5 Hz after the patient's response changed from "yes" to "no" or from "no" to "yes". The location of the target presentation was randomized. Patients were asked to press a button only when they noticed flickering anywhere in their visual field. Catch trials for false-positive and false-negative responses were also utilized to evaluate the correctness of the patient's response. If the patient responded to the presentation of a target which was not flickering, it was counted as a false-positive response. If the patient did not respond to the presentation of a target of 5 Hz which was projected at a test location where positive responses had already been given, it was counted as a false-negative response. Fixation was controlled by the video camera of the Octopus 1-2-3.

Normal subjects

We studied the static flicker fusion fields of 100 eyes of 100 normal subjects; nine eyes of nine subjects aged ten to 19 years, 14 eyes of 14 subjects aged 20 to 29 years, 13 eyes of 13 subjects aged 30 to 39 years, 28 eyes of 28 subjects aged 40 to 49 years, 19 eyes of 19 subjects aged 50 to 59 years, 15 eyes of 15 subjects aged 60 to 69 years, and two eyes of two subjects aged 70 to 79 years. All these normal subjects had a corrected vision better than 20/20. Their refraction was within ±3.0 D (sphere) and -2.0 D (cylinder). The size of the pupils was larger than 3.0 mm. The optical media and the fundi were normal. A short tutorial program for flicker perimetry was carried out before the measurements.

Clinical cases

Measurement was carried out in a total of 58 eyes of 36 subjects; 51 eyes of 32 patients with primary open angle glaucoma, five eyes of three patients with low tension glaucoma, and two eyes of one patient with secondary glaucoma. The stages of their visual fields were between stage 0 and stage 2 according to Aulhorn's classification. Examination of the flicker field using our automated flicker perimeter and examination of the automated static field using program No. 32 of the Octopus 201 were carried out within two months.

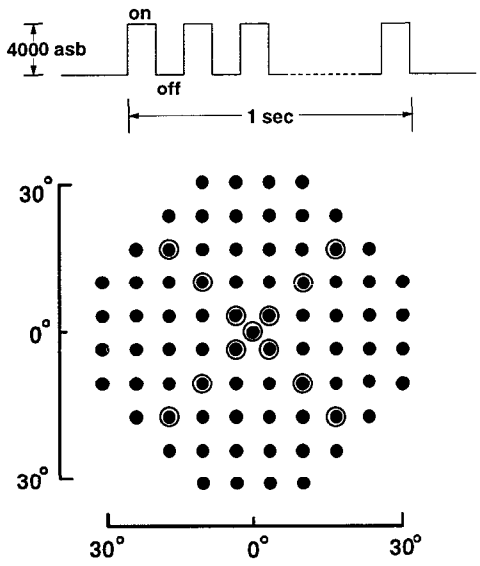

Fig. 1. A wave form of flicker stimulus and an arrangement of the test points for automated static flicker perimetry. Circled test locations were measured twice.

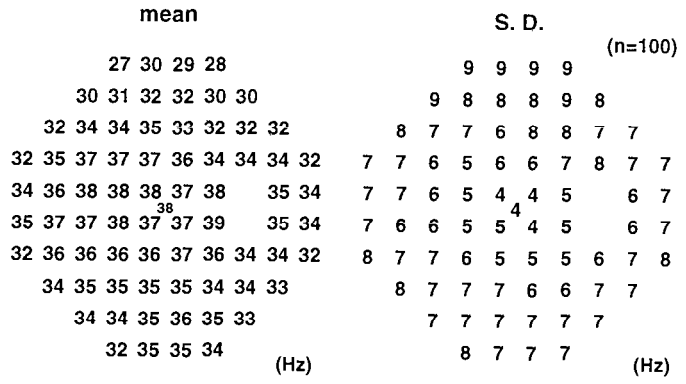

Fig. 2. Arithmetic means and standard deviations of the static flicker fusion fields of 100 normal subjects.

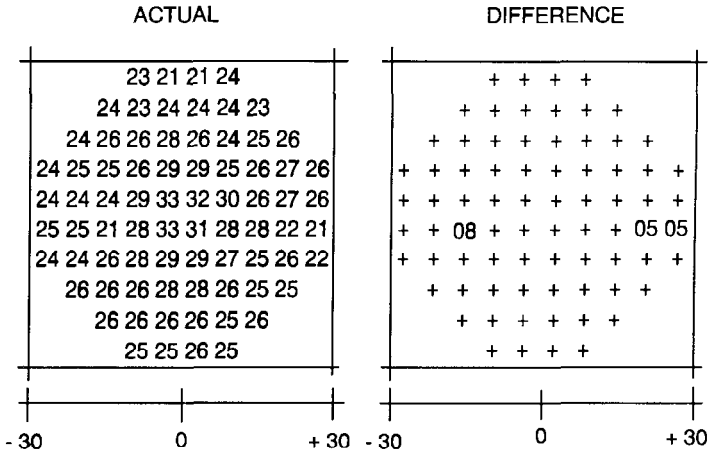

Fig. 3. Actual value and difference tables of the left eye of a 39 year-old male with low tension glaucoma (Case 1). (Octopus 201, program 32).

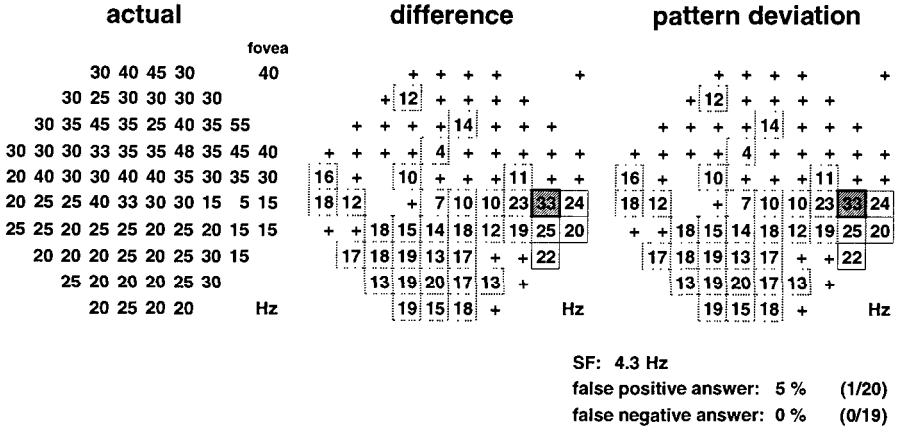

Fig. 4. Actual value table, difference table and pattern deviation of a flicker fusion field (Case 1). The symbol "+" in the difference table and pattern deviation table shows that the flicker sensitivity of the test point is within normal range. The figure with gray shading indicates the difference of flicker sensitivity from the age-related normal value.

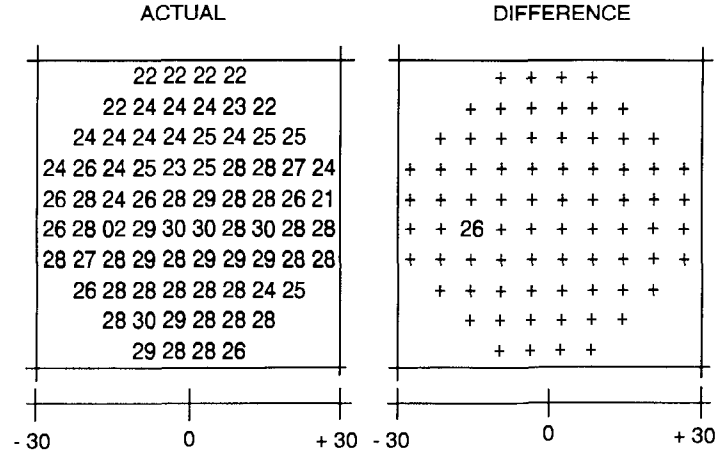

Fig. 5. Actual value table and difference table of the left eye of a 50 year-old female with primary open glaucoma (Case 2). (Octopus 201, program 32).

Results

Normal subjects

Fig. 2 shows arithmetic means and standard deviations of the normal static flicker fusion fields. The profile of the static flicker fusion field was almost flat under our examination conditions. The standard deviations of the normal flicker fusion field became larger towards the periphery. The standard deviations of the larger flicker fusion threshold were almost twice as large as those of the differential light threshold. The mean value of cff decreased with age (-1 Hz/decade).

In most of the normal subjects, the catch trials of our automated flicker perimetry were less than 10%. The short-term fluctuation of the flicker fusion threshold was almost twice as large as that of the differential light threshold in normal subjects.

Clinical cases

Case 1 was a 39-year-old male with low tension glaucoma in both eyes. The intraocular pressure of both eyes was 15 mmHg. The cup/disc ratio of his right eye was 0.8 and that of his left eye 0.6. His right eye showed advanced glaucomatous visual field defects. His left eye showed an atypical small depression in the lower nasal visual field when the Goldmann per-

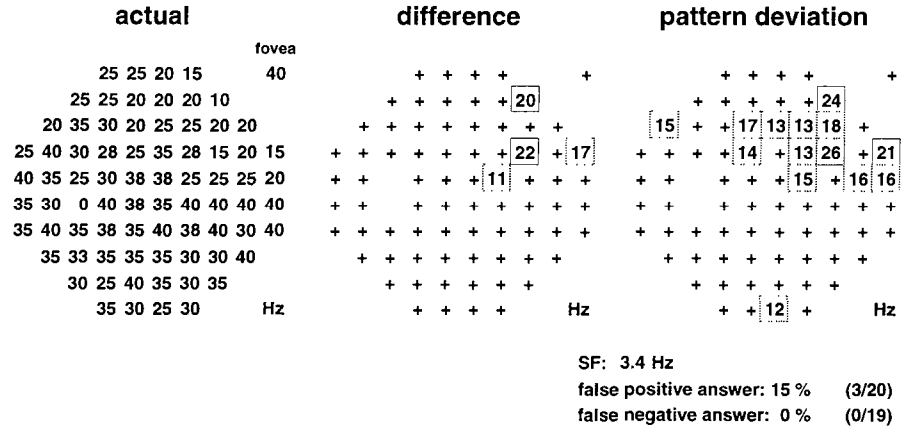

Fig. 6. Actual value table, difference table and pattern deviation of the flicker fusion field (Case 2).

imeter was used. Fig. 3 shows the actual value table and the difference table of his left eye obtained with program No. 32 of the Octopus 201. The difference table shows a small decrease in sensitivity in his lower nasal field. Fig. 4 shows the actual value table, the difference table and the pattern deviation of his flicker field. If actual measured values were higher than the age-related normal mean values minus 2 SDs, they were judged as normal. Pattern deviation was also analyzed using the same formula as the Humphrey STATPAC. The nasal step was clearly detected by automated flicker perimetry.

Case 2 was a 50-year-old female with primary open angle glaucoma. The intraocular pressure of her right eye was 17 mmHg and that of her left eye 22 mmHg. The cup/disc ratio of her right eye was 0.3 and that of the left eye 0.7. Her red free fundus photograph of the left eye showed a nerve fiber bundle defect in the lower temporal retina.

Fig. 5 shows the actual value table and the difference table of her left eye obtained with program No. 32 of the Octopus 201. No glaucomatous field defects were detected by Octopus perimetry when target size 3 was used. Fig. 6 shows the actual value table, the difference table and the pattern deviation of her flicker fusion field. The nasal step was clearly detected by automated flicker perimetry.

Comparison of the detectability of early glaucomatous visual field defects between automated flicker perimetry and Octopus perimetry revealed the following results. In two eyes, both flicker perimetry and Octopus perimetry were normal. In 37 eyes, flicker perimetry was more sensitive than Octopus perimetry. In ten eyes, flicker perimetry had almost the same sensitivity as Octopus perimetry. In nine cases, flicker perimetry was less sensitive than Octopus perimetry.

Discussion

After the clinical report of Philips in 1933, many studies have been made on flicker perimetry[2-8]. However, flicker perimetry has not been accepted as a common diagnostic method. The problems of flicker perimetry were mainly due to the difficulty of examination both on the part of the examiners and of the patients. We reported on a method of manual static flicker perimetry using the Goldmann perimeter and the target fixating panel[5-7]. This manual flicker perimeter could detect early glaucomatous visual field defects which had not been detected by Octopus perimetry. However, this method required the examiner to have ample experience and knowledge of flicker perimetry. In this study, we developed a strategy for automated flicker perimetry using the Octopus 1-2-3. Our automated flicker perimeter is similar to standard automated perimetry and does not require special expertise of the examiner. In order to estimate the reliability of the examination, we programmed an algorithm to obtain catch trials and short-term fluctuation.

A relatively large standard deviation in the flicker fusion fields of normal subjects was also a problem in flicker perimetry[5,6]. The standard deviation and short-term fluctuation of the flicker fusion threshold were almost twice as large as those of the differential light threshold. Occasionally it was difficult for some normal subjects and patients to judge whether the target was flickering or not. This may have been one of the main reasons why the standard deviation of the flicker fusion threshold was larger than that of the differential light threshold. In this study, if an actual measured value minus the 2 SDs was bigger than the age-related normal arithmetic mean in each test point, it was judged as normal. Using these criteria, our automated flicker perimetry could detect early glaucomatous visual fields defects which had not been clearly recognized by Octopus perimetry.

In the past, large target sizes such as Goldmann V or IV were used for flicker perimetry to elevate the highest level of the dynamic range of the flicker fusion fields. It is important to secure the same dynamic range of the static flicker fusion field within the central 30° field in order to detect glaucomatous visual field defects. However, the spatial resolution is decreased if we use a large target size. In this study, we used the standard target size 3 and a target luminance of 4000 asb with a background luminance of 31.5 asb. The dynamic range of the flicker field became larger due to the increase in the target luminance and the background luminance. Under our examination conditions, we could obtain a dynamic range wide enough for flicker perimetry in the 30° visual field.

Recently, Lachenmayr *et al.* reported that flicker perimetry has a high sensitivity for detect-

ing glaucomatous visual field defects, using his own automated flicker perimeter[8]. In their study, the arrangement of the test points was not the same as that of traditional automated perimetry. In our study, we used the Octopus 1-2-3 and we programmed one of our test points in the center in addition to those of program No. 32, enabling us to compare the results of flicker perimetry with those of Octopus perimetry at exactly the same test points.

In a recent histopathological study, it was found that large optic nerve fibers were selectively damaged in early glaucoma[9]. This suggests that the magnocellular pathway is the first to be damaged. It is well known that the magnocellular pathway is more sensitive to high contrast and high temporal resolution. Since cff has temporal transfer properties, it seems to be one of the most suitable stimulus to detect early glaucomatous visual field defects.

References

1. Quigley HA, Dunkelberger GR, Green WR: Retinal ganglion cell atrophy correlated with automated perimetry in human eyes with glaucoma. Am J Ophthalmol 107:453-464, 1989
2 Phillips G: Perception of flicker in lesions of the visual pathways. Brain 56:464-478, 1933
3 Miles PW: Flicker fusion fields. III. Findings in early glaucoma. Arch Ophthalmol 43:661-677, 1950
4 Nakabayashi M: Studies on flicker fusion fields by Iso-frequency method. Folia Ophthalmol Jpn 10:845-856, 1959
5. Uyama R: A clinical study of reliability of flicker perimetry in early glaucomatous eyes. Med J Kinki Univ 12:557-592, 1987
6 Uyama K, Matsumoto C, Uyama R, Otori T: Central static flicker fusion field in normal subjects. Jpn J Clin Ophthalmol 43:1863-1867, 1989
7. Uyama K, Nakao Y, Otori T, Matsumoto C, Uyama R: Central static flicker fusion field in neuro-ophthalmological affections. Jpn J Clin Ophthalmol 44:1317-1322, 1990
8 Lachenmayr B, Rothbächer H, Gleissner M: Automated flicker perimetry versus quantitative static perimetry in early glaucoma. In: Heijl A (ed) Perimetry Update 1988/1989, pp 359-369. Amsterdam: Kugler Publ 1989
9 Quigley HA, Sanchez RM, Dunkelberger GR, L'Hernault ML, Baginski TA: Chronic glaucoma selectively damages large optic nerve fibers Invest Ophthalmol Vis Sci 28:913-920, 1987

Luminance threshold flicker perimetry in primary open angle glaucoma, ocular hypertension and normal controls: the effect of flicker frequency

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Abstract

The authors used a prototype automated flicker perimeter of their own design to investigate the effect of stimulus flicker frequency on retinal sensitivity. The following groups of subjects were studied; glaucoma patients (n=11), ocular hypertensives of "high risk" (n=10)[1] and two groups having ocular hypertension at "low and intermediate" risk, one of subjects having at least four years of follow-up (n=10) and the other of subjects in whom the diagnosis was made less than six months prior to the study (n=11), and normal controls (n=10). Differential light sensitivity flicker perimetry was carried out for one eye of each subject at 5, 10, 15, 20, and 25 Hz at ten locations of 1° in the arcuate and nasal regions of the central 25° of the visual field using a 4-2 dB staircase.

The glaucoma patients had significantly reduced sensitivities for all frequencies, the most significant reduction occurring at 15 Hz ($p<0.001$) Significant reductions in sensitivity for a 10 Hz stimulus were detected for the high risk ocular hypertensives ($p<0.02$) and the low risk ocular hypertensives of more than four years' follow-up ($p<0.05$). Reductions in sensitivity for a 15 Hz stimulus were detected for the high risk ocular hypertensives ($p<0.02$).

The authors' results confirm the presence of flicker visual field defects in glaucoma. In addition they identify a frequency related reduction in sensitivity for both glaucoma patients and ocular hypertensives At present the ocular hypertensive patients in this study show no abnormalities demonstrable by conventional automated static perimetry (Humphrey Visual Field Analyzer, program 24-2) These findings may represent the earliest of perimetric deficits in patients with glaucomatous optic neuropathy

This work will be reported in full elsewhere.

References

1. Yablonski ME, Zimmerman TJ, Kass MA, Becker B: Prognostic significance of optic disk cupping in ocular hypertensive patients Am J Ophthalmol 89:585, 1980

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Temporal modulation perimetry in glaucoma and ocular hypertension

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Abstract

Temporal modulation perimetry (TMP) measures modulation sensitivity to 2, 8 and 16 Hz sinusoidal flicker at 44 locations in the central 30° visual field. To establish the efficacy of this method in detecting and following early glaucomatous visual field loss, the authors obtained longitudinal measurements with standard automated perimetry (white on white or W/W perimetry) and TMP on 53 ocular hypertensive eyes (OH) and 25 early glaucoma patients (EG). Overall, the EG group showed equally reduced sensitivity to all frequencies. The OH group showed a slight increase in sensitivity on average, reflecting the fact that both abnormally high sensitivities and abnormally low sensitivities were measured in the visual fields of some patients. For EG and OH eyes which showed progression on W/W perimetry, the results indicate that TMP defects were initially larger than the W/W defects. Seventy-six percent of EG eyes showed reliable 16 Hz TMP deficits over the three years while 71% of the OH eyes which remained stable did not show reliable evidence of defects with 16 Hz TMP. The consistency of the location of TMP defects between the first and third year of the study was generally equivalent to or better than the consistency of W/W defects. Defects measured with 8 and 16 Hz showed the most consistency and also were more likely to overlap with each other than with 2 Hz defects. These results suggest that TMP produces consistent evidence of localized defects across three years of testing and can precede the onset or progression of defects in standard automated perimetry.

Introduction

Flicker deficits have been reported to occur in patients with glaucoma and those at risk of developing glaucoma[1-11]. A number of studies have examined sensitivity for a range of flicker frequencies and have reported that the largest sensitivity losses occur at higher flicker frequencies in both ocular hypertensives and most patients with glaucoma[1-5]. However, most of these studies have consisted of central measures of flicker sensitivity, whereas the initial evidence of vision loss due to glaucomatous damage usually occurs in the mid-periphery. Several investigators have obtained measurements of flicker sensitivity throughout the visual field in glaucoma patients and have reported localized sensitivity losses in these patients, but these methods do not report results for a range of frequencies[6-11]. Thus, it is not clear whether sensitivity losses in the peripheral visual field of glaucoma patients will be greater for higher frequencies. Furthermore, few perimetry studies to date have reported the results for ocular hypertensives, nor have these investigations made longitudinal measurements to determine the consistency of the sensitivity losses and how they are associated with changes in glaucomatous visual field loss. Such investigations are essential to determine the efficacy of flicker perimetry for the detection and follow-up of early glaucomatous damage.

We have developed a technique, temporal modulation perimetry (TMP), for obtaining local estimates of flicker sensitivity for 2, 8 and 16 Hz at 44 locations in the central 30° visual field. Using TMP, we have obtained longitudinal measurements of flicker sensitivity in both ocular

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hypertensive and glaucoma patients. These measurements allow us to determine whether the flicker sensitivity changes that occur in the visual fields of these patients are greater at a particular frequency and whether they are consistent across time. By comparing the results of TMP to concurrent measurements with standard automated perimetry (white on white or W/W perimetry), we can also investigate the relationship between the results of TMP and W/W perimetry in individual eyes. Finally, by classifying the tested eyes by whether or not the W/W visual fields exhibit change and comparing the TMP results for these groups, we can determine whether TMP can predict the onset or progression of glaucomatous damage in W/W perimetry. This paper presents an overview of these results.

Methods

Temporal modulation perimeter

We measured temporal modulation sensitivity for 2, 8 and 16 Hz sinusoidal flicker at 45 locations in the central 27° radius visual field (11 per quadrant plus fovea). Forty-five 2×2 LED arrays of 2° diameter were mounted at 5° intervals within a standard 30 cm perimetry bowl illuminated at 100 cdm^{-2}. The LED arrays were covered with a diffusing material and recessed behind the bowl in opaque tubes to avoid illumination by the background and obtain maximum test contrast. Test stimuli consisted of sinusoidal flicker beginning and ending at 0° phase, modulated around an average luminance of 100 cdm^{-2}. Test stimuli were presented for 1 sec with a randomized onset delay within a 2-sec interval.

Procedure

A modified binary search procedure adapted for perimetry (MOBS) was used to measure temporal modulation contrast sensitivity[12]. Prior to testing, subjects were shown examples of high and low contrast test flicker at all three frequencies in both foveal and peripheral locations. They were instructed to respond with a button press each time one of the test lights in their field of view appeared to flicker. During the test session, the LEDs in all test locations were continuously illuminated at the same level as the background (100 cdm^{-2}). Presentations for three staircases, one for each frequency, were randomly interleaved for each location. The starting point for each staircase was also randomized so that half the initial presentations were above threshold and half below. The location of presentations was also randomly chosen on each trial for all peripheral stimuli (foveal measurements were obtained separately at the beginning of the test). During each trial, one of 44 test lights (chosen randomly from the set of unresolved points) was modulated at one of three frequencies. A tone indicated when the response button had been pressed. No indication was given as to when a trial was initiated and subjects were required to maintain steady central fixation throughout testing. Fixation was monitored continuously by video camera.

Each session lasted approximately 25 minutes and consisted of 700-800 presentations with approximately 5% of the presentations divided evenly between false positive and false negative catch trials. Brief rest periods were provided throughout the test procedure as needed.

Subjects were evaluated concurrently on W/W perimetry using the 30-2 test strategy on the Humphrey Visual Field Analyzer, which obtains sensitivity measures at 76 locations in the central 30° radius of the visual field. A size III test target (0.43°) and a 31.5 cdm^{-2} background were used for W/W testing.

Subjects

As part of a five-year prospective study, we evaluated both eyes of 31 ocular hypertensives and 16 patients with early glaucomatous visual field loss. Informed consent was obtained from all subjects before testing commenced.

Subjects were evaluated with TMP and W/W perimetry for the final three years of the study. Details of the inclusion criteria for the patients are given elsewhere[13,14]. Patients were included if they had a clinical diagnosis of either ocular hypertension or glaucoma and intraocular pressures of greater than 21 mmHg OU (off medication). Ocular hypertensive (OH) subjects were included if they had normal W/W visual fields at the outset of the study, while early glaucoma

(EG) subjects were included if they had evidence of early glaucomatous W/W visual field loss in one or both eyes. Both eyes of such patients were classified as EG.

Analyses

Group values: Of those tested, 12 EG patients (24 eyes) and 22 OH patients (44 eyes) were over the age of 60 (60 to 85 years). Average data from these eyes in the first year of the study are reported here. Comparisons are made with the average results for 24 older normal eyes and 26 younger normal eyes.

Individual fields: For longitudinal analysis of individual results and within-patient comparisons of TMP and W/W perimetry, the results of 53 OH eyes and 25 EG eyes are used. These results are compared to 95 and 99% confidence limits established from the TMP results for 62 normal eyes.

TMP versus W/W perimetry: To determine the efficacy of TMP for detecting and predicting glaucomatous visual field loss, we subdivided our OH and EG groups into eyes that did or did not demonstrate progression on W/W perimetry. Based on clinical evaluation and STATPAC II indices from the W/W visual fields over five years of testing, five OH eyes (from five OH patients) were judged to have demonstrated reliable evidence (over two years) of the onset of glaucomatous visual field defects. The results for these eyes have been analyzed together as OH Progressed, while visual fields for the remaining 48 OH eyes (27 patients) were analyzed as OH Stable. Similarly, based on five years of data, seven EG eyes (from six patients) were judged to have exhibited reliable (over two consecutive years) progression. The results for six of these eyes (five patients) are presented here as EG Progressed (one eye was excluded due to unreliable TMP fields). Results for the remaining 19 EG eyes (11 patients) were analyzed as EG Stable.

To facilitate comparisons between TMP and W/W perimetry, which use different test configurations, we analyzed all visual fields with the nerve fiber bundle (NFB) pattern[15]. For each eye, sensitivity values for all locations within each of the eight NFB areas covering the superior and inferior arcuate regions were averaged. Previous studies have demonstrated that this spatial analysis is a sensitive indicator of early glaucomatous visual field loss in W/W perimetry[16]. Fig. 1 shows how the locations tested in each form of perimetry are averaged in the NFB pattern.

Results for individual patients were compared with 95% and 99% confidence limits for the NFB pattern (based on age-matched data from 62 normal subjects[16]). For each eye, the number of abnormal (beyond the confidence limits in either direction) NFB areas for 2, 8, and 16 Hz TMP and W/W perimetry were determined for each of the three years. The amount of overlap in defect location was determined for TMP and W/W perimetry across years and for 2, 8 and 16 Hz frequencies within one year.

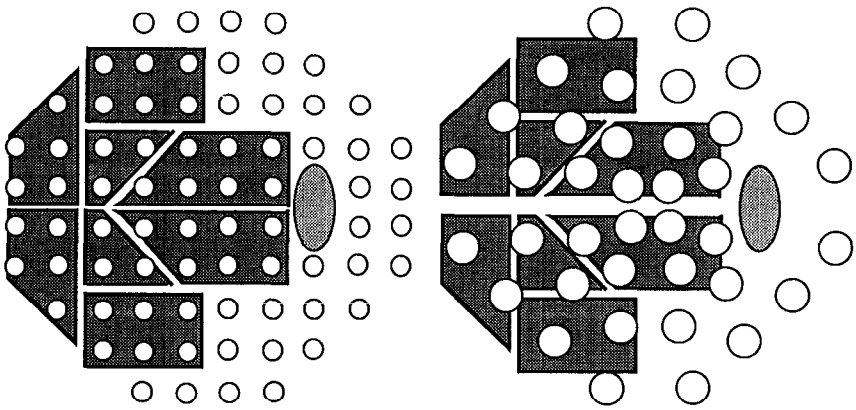

Fig. 1. A representation of the eight nerve fiber bundle (NFB) areas used to analyze and compare individual TMP and W/W perimetry results. For each field, the results for test locations within the boundaries of each darkened area are averaged together to produce one sensitivity value.

Results

We have previously[17] reported that, on average, EG eyes show reduced sensitivity to 2, 8 and 16 Hz TMP throughout the visual field and OH eyes show a slight increase in sensitivity. Table 1 shows how the group averages for OH and EG eyes compared with the results of age-matched, older normal eyes (ONL). The sensitivity differences in decibels between the average results for the normal group and the OH and EG groups are given for 2, 8 and 16 Hz, along with the pooled standard error of the mean. Positive values represent a reduction in average sensitivity, while negative values represent an increase in sensitivity. The average reduction in flicker sensitivity in the EG group is approximately equal for all frequencies, while the OH group shows an increase in sensitivity at all frequencies, particularly for 16 Hz. This reflects the fact that, as we have reported previously, OH eyes appear to exhibit both high and low-sensitivity abnormalities in the peripheral visual field[18]. The lack of a frequency-specific reduction in sensitivity does not result from the inability of the test to demonstrate different amounts of sensitivity reduction across frequency. This is shown in the comparison of the younger (YNL) and older (ONL) normal groups given in the same table which clearly indicates that larger sensitivity reductions occur at 16 Hz than at the other testing frequencies for older normals.

Table 1. Differences in mean sensitivity at 20°

Comparison groups	*2 Hz TMP*	*8 Hz TMP*	*16 Hz TMP*
YNL *versus* ONL	1.5±0.4 dB	2.1±0.4 dB	3.4±0.4 dB
ONL *versus* EG	2.9±0 5 dB	2 3±0.6 dB	2.1±0.7 dB
ONL *versus* OH	-0.6±0 4 dB	-0.6±0.4 dB	-1.3±0.5 dB

Fig. 2 presents the results of comparing the number of abnormal NFB areas obtained with W/W perimetry and 2, 8 and 16 Hz TMP for the four groups of eyes: OH Progressed, OH Stable, EG Progressed and EG Stable. The difference in the number of abnormal areas in TMP and W/W perimetry is shown for the first and third year of the study. A positive difference indicates that there were more abnormal NFB areas measured with TMP than with W/W perimetry. Note that in the two groups that progressed, the extent of the TMP defect is larger than the W/W defect at 8 and/or 16 Hz in the first year. By the third year, the defects in W/W perimetry are on average the same size as, or larger than, the TMP defects. In the OH Stable group the TMP defects are larger than the W/W defects. This is primarily due to the fact that few W/W defects exist in this group, and TMP defects are more frequent. In the EG Stable group, the W/W defects are larger than the TMP defects in the first year and slightly smaller in the third year. This is mainly due to the fact that the average size of the W/W defect decreased in this group from the first to last year of the study, while the size of the TMP defects remained constant.

Fig. 3 compares the amount of longitudinal overlap in the location of abnormal NFB areas obtained with W/W perimetry and TMP. Data are presented for comparisons between measurements obtained in the first and third year with TMP and W/W perimetry for the four groups. The amount of overlap has been normalized for the absolute size of the defect by dividing by

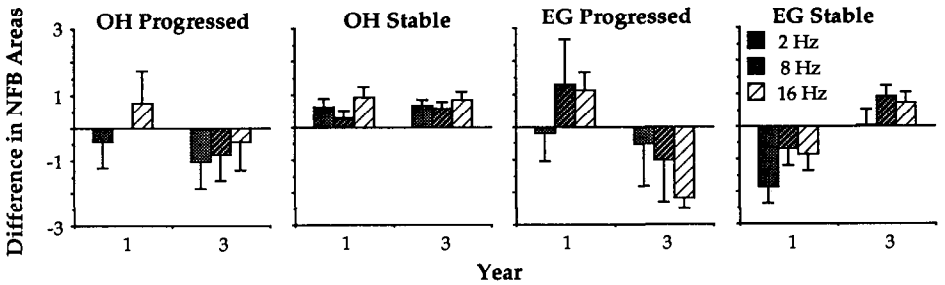

Fig. 2. The average difference between the number of abnormal NFB areas obtained with 2, 8 and 16 Hz TMP and W/W perimetry for each eye. Each panel shows the results for one of the four groups of patients described in the text: OH Progressed, OH Stable, EG Progressed and EG Stable. Standard error bars are given for each value.

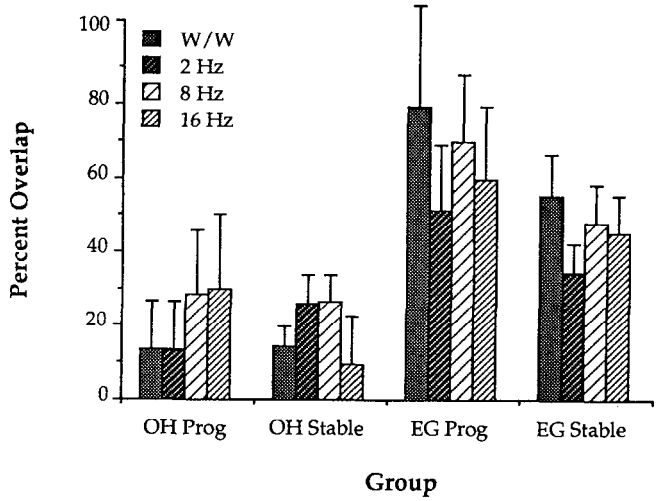

Fig. 3 The average percentage of overlap between the location of defects measured in the first and third year of the study for W/W perimetry and 2, 8 and 16 Hz TMP. Average percentages are shown for the four groups of patients described in the text: OH Progressed, OH Stable, EG Progressed and EG Stable The values shown are based on the number of abnormal NFB areas in year 1 that are also abnormal in year 3 for each eye. These values are then normalized by dividing by the number of overlapping areas by the total number of abnormal areas in year 3 and reported as a percentage. Standard error bars are given for each value.

the number of abnormal NFB areas measured in the third year for each individual. In all groups the amount of overlap for all TMP frequencies is similar to that for W/W perimetry. In the OH groups, TMP is slightly more consistent than W/W perimetry, reflecting the fact that the TMP defects occur earlier and are larger than W/W defects in the same OH eyes. The consistency in the location of defects is somewhat better for 8 and 16 Hz than for 2 Hz TMP, demonstrating

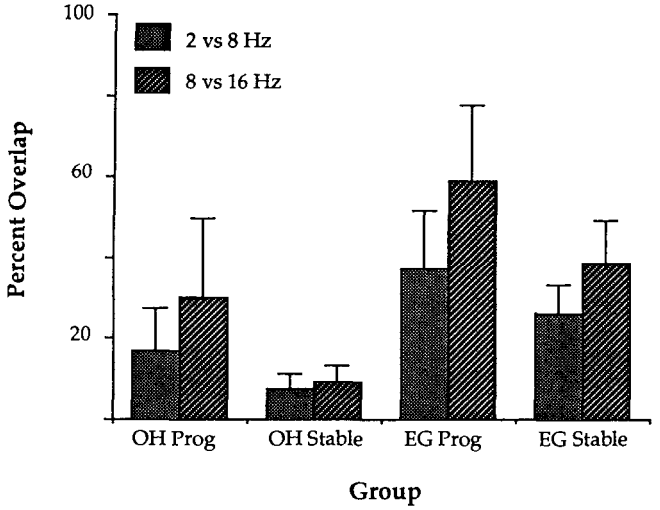

Fig. 4. The average percentage of overlap between the location of defects measured with different TMP frequencies. The two comparisons shown for each of the four patient groups are 2 *versus* 8 Hz TMP and 8 *versus* 16 Hz TMP For the 2 *versus* 8 Hz comparison, the values are calculated by determining the number of NFB areas that are abnormal on 2 Hz TMP and are also abnormal on 8 Hz TMP. These values are then normalized for each individual by dividing by the number of 8 Hz TMP defects and reported as a percentage. The results for the 8 *versus* 16 Hz comparison are derived in a similar fashion and also normalized by dividing by the number of 8 Hz TMP defects. Data from the first year of the study are reported. Standard error bars are given for each value.

that, while defects occur at all frequencies, the information obtained with 8 and 16 Hz is more consistent.

In Fig. 4, we show the average extent of overlap between defects measured with 2, 8 and 16 Hz TMP for the four groups. The percent of overlap between 2 and 8 Hz is compared with the percent of overlap between 8 and 16 Hz. These values have been normalized for absolute defect size by dividing by the number of 8 Hz defects in each case. Data from the first year of the study are shown. Note that, although the amount of overlap varies considerably for the groups, the overlap between the locations of 8 and 16 Hz defects is consistently greater than the overlap between 2 and 8 Hz. This suggests that the results at these two frequencies may be more closely associated than the results of 2 and 8 Hz.

An overall comparison of TMP and W/W perimetry over the three years of the study is presented in Table 2. The results for 16 Hz TMP are presented alone, since this frequency has been demonstrated to be consistent across years and to produce the largest defects in the initial year in the Progressed groups. The results for 2 and 8 Hz TMP are similar. For this analysis, the EG Progressed and Stable groups have been combined to produce a single group of all eyes demonstrating defects in W/W perimetry at the outset of the study. The OH Progressed group is presented separately as a group that demonstrated the onset of W/W defects during the study and the OH Stable group represents a group that has not yet demonstrated any consistent abnormalities on W/W perimetry. The OH Stable may contain individuals who will go on to develop glaucomatous damage in the future, as well as those who will not. For each group, we present the number of eyes that demonstrated consistent TMP defects over three years. This we define as having at least one abnormal NFB area on two out of three years of testing. Note that 76% of the EG group and 60% of the OH Progressed group demonstrate consistent abnormalities on 16 Hz TMP, reflecting the sensitivity of the test. While this number is low compared to other reports for central flicker measures[1,2], it reflects the stringent requirement that defects be consistent over three years. Seventy-one percent of the OH Stable eyes showed no evidence of abnormalities on 16 Hz TMP. This value provides an indication of the specificity of the test. However, some abnormal TMP results would be expected in this group, since it includes eyes that may soon demonstrate damage on W/W perimetry and may already be demonstrating TMP abnormalities. This is supported by the fact that the TMP defects are more consistent over time in this group than the W/W defects, as well as being larger. It should be noted also that, of the 14 eyes that did show abnormalities at 16 Hz, 10 of them (71%) consistently demonstrated abnormally high sensitivities to flicker. The number of high-sensitivity abnormalities was much lower in the other groups (12% of the abnormal 16 Hz TMP fields in the EG group and 1 TMP field in the OH Progressed group), suggesting that the high-sensitivity abnormalities mainly occur in the OH Stable group.

Table 2. Comparison of reliable field defects over three years

16 Hz TMP	*EG*	*OH Progressed*	*OH Stable*	*Total*
Abnormal	19	3	14	36
Normal	6	2	34	42
Total	25	5	48	78

Discussion

Group results

We have demonstrated that, at 20°, there is no greater sensitivity loss at 16 Hz than at any other frequency for the EG eyes. This finding, which has been reported previously[16], is at variance with the previous findings of a greater sensitivity reduction in glaucoma patients to foveally presented high frequency flicker. This may be due to the peripheral nature of the flicker measurements, or to the use of an age-matched control group for comparison. In addition, analysis of the individual results does reveal that 8 and 16 Hz TMP do have some advantages over measures taken at 2 Hz in terms of the consistency and size of the defects.

Individual results

Our results show that TMP defects, particularly for 8 and 16 Hz, are larger than W/W defects on initial testing in the OH and EG eyes that progressed. This suggests that TMP defects can precede impending W/W defects. TMP results are also at least as consistent across time as W/W defects and the 8 and 16 Hz test frequencies produce the largest, most consistent defects.

TMP versus W/W perimetry

Table 2 shows that TMP can successfully detect eyes that demonstrate W/W defects, as well as distinguishing OH fields that will go on to develop glaucoma in the near future from those that are stable. The sensitivity measure is not as high as that reported by Tyler *et al.* (76% *versus* 90%) for central flicker testing, but the specificity is much higher (71% *versus* 31%)[2]. These results may both be due in part to the requirement that defects be consistent over two out of three years to be considered abnormal on TMP.

Specificity might be increased by excluding high-sensitivity defects, since these mainly occur in the OH Stable group, but that would also exclude one of the OH Progressed eyes, reducing sensitivity. High-sensitivity defects are as consistent as low-sensitivity defects and may reflect an earlier form of damage than localized losses in flicker sensitivity. Further investigations will help to determine the role of high-sensitivity defects in the diagnosis and follow-up of glaucoma.

As a technique, TMP is very promising. It provides consistent results and can predict the onset or progression of W/W perimetry in many cases. Furthermore, it is an easy task for patients to perform, with less spatial uncertainty than W/W perimetry. Individual examples of the predictive capacity for both OH and EG eyes have been shown previously[18]. Furthermore, others have demonstrated that this technique, unlike W/W and resolution perimetry, is not susceptible to the presence of blur or cataract[19,20]. TMP is also easier to administer than another promising new form of perimetry, blue-on-yellow perimetry, as it does not require additional testing to provide individual corrections for lens density[13,14]. With further study to optimize the parameters of TMP, this technique may prove to be an effective diagnostic tool in the early detection of the onset and progression of glaucomatous visual field loss.

References

1 Tyler CW: Specific deficits of flicker sensitivity in glaucoma and ocular hypertension. Invest Ophthalmol Vis Sci 100:135-146, 1981
2. Tyler CW, Stamper RL, Hawker N: Predicting progression to glaucomatous field loss with the temporal visuogram. Noninvasive Assessment of the Visual System, 1992 Tech Digest Ser 10:82-85, 1992
3. Faubert J: Retinal geniculate pathways and the spatio-temporal properties of the human visual system in normal, aging and glaucomatous vision. Ph.D. dissertation, Concordia University, Montreal Quebec, Canada, 1991
4. Tytla ME, Trope GE, Buncic JR: Flicker sensitivity in treated ocular hypertension. Invest Ophthalmol Vis Sci 97:36-43, 1990
5. Breton ME, Wilson TW, Wilson R, Spaeth G, Krupin T: Temporal contrast sensitivity loss in primary open angle glaucoma and glaucoma suspects. Invest Ophthalmol Vis Sci 32:2931-2941, 1991
6. Lachenmayr BJ, Rothbächer H, Gleissner M: Automated flicker perimetry versus quantitative static perimetry in early glaucoma. In: Heijl A (ed) Perimetry Update 1988/1989. Proceedings of the VIIIth International Perimetric Society Meeting, Vancouver 1988, pp 359-368, Amsterdam, Kugler Publ 1989
7. Lachenmayr BJ, Drance SM, Chauhan BC, House PH, Lalani S: Diffuse and localized glaucomatous field loss in light-sense, flicker and resolution perimetry Graefe's Arch Clin Exp Ophthalmol 229:267-273, 1991
8. Lachenmayr BJ, Drance SM, Douglas GR, Mikelberg FS: Light-sense, flicker and resolution perimetry in glaucoma: a comparative study. Graefe's Arch Clin Exp Ophthalmol. 229:246-251, 1991
9. Brussell EM, White CW, Faubert J, Dixon M, Balazsi GA, Overbury O: Multi-flash campimetry as an indicator of visual field loss in glaucoma. Am J Opt Phys Optics 63:32-40, 1986
10. Faubert J, Balazsi AG, Overbury O, Brussell EM: Multiflash campimetry and other psychophysical tests in chronic open angle glaucoma. Doc Ophthalmol Proc Ser 49:425-432, 1987

11. Faubert J, Balazsi AG, Muermans M, Brussell EM, Kasner OP: Multiflash campimetry and optic nerve structure in early chronic open angle glaucoma. In Heijl A (ed) Perimetry Update 1988/1989. Proceedings of the VIIIth International Perimetric Society Meeting, Vancouver 1988, pp 349-358, Amsterdam: Kugler Publ 1989
12. Johnson CA, Shapiro L: A comparison of MOBS (modified binary search) and staircase test procedures in automated perimetry. Noninvasive Assessment of the Visual System, 1989 Tech Digest Ser 7:84-87, 1989
13 Adams AJ, Johnson CA, Lewis RA: S cone pathway sensitivity loss in ocular hypertension and early glaucoma has nerve fiber bundle pattern. In: Drum, Moreland, Serra (eds) Proceedings of the 10th Symposium of the International Research Group on Colour Vision Deficiencies. pp 535-542. Dordrecht: Kluwer Academic Publ 1991
14. Johnson, CA, Adams AJ, Casson EJ: Blue on yellow perimetry: a five year overview. This Volume, pp 459-465
15 Sommer A, Duggan C, Auer C, Abbey H: Analytic approaches to the interpretation of automated threshold perimetric data for the diagnosis of early glaucoma. Trans Am Ophthalmol Soc 83:250-267, 1985
16. Casson EJ, Johnson CA, Quigg JM: Comparison of flicker perimetry and standard perimetry in early glaucoma and ocular hypertension: local visual field changes. ARVO abstracts Invest Ophthalmol Vis Sci 32:1104, 1991
17. Casson EJ, Johnson CA, Nelson-Quigg JM: Visual field analysis of flicker sensitivity in early glaucoma and ocular hypertensives. ARVO abstracts Invest Ophthalmol Vis Sci 31:191, 1990
18. Casson EJ, Johnson CA, Shapiro LR: Longitudinal analysis of temporal modulation perimetry in early glaucoma and comparison with white-on-white and blue-on-yellow perimetry. ARVO abstracts. Invest Ophthalmol Vis Sci 33:1384, 1992
19. Tyler CW: Analysis of normal flicker sensitivity and its variability in the visuogram test. Invest Ophthalmol Vis Sci 32:2552-2560, 1991
20. Gleissner M, Lachenmayr BJ, Angstwurm K: Influence of cataract on thresholds in automated light-sense- and flicker-perimetry. ARVO abstracts. Invest Ophthalmol Vis Sci 33:965, 1992

The influence of pre-receptoral absorption on blue/yellow automated perimetry

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Abstract

Blue/yellow perimetry attempts to isolate the SWS (short wavelength sensitive) or blue sensitive pathway by the use of a blue stimulus on a high luminance yellow background. An increase in SWS increment thresholds has been demonstrated prior to any such increase by conventional perimetry particularly in ocular hypertension and glaucoma. The contribution of pre-receptoral absorption to the attenuation of SWS increment thresholds, particularly that of macular pigment, has received relatively little attention. The aim of the study was to determine the effect of lenticular absorption (LA) and macular pigment absorption (MPA) on the SWS perimetric profile in the normal eye. A Humphrey Field Analyzer 630 adapted for blue/yellow perimetry was further modified for the assessment of LA and MPA. The sample comprised ten normal young subjects and ten normal elderly subjects. One eye of each subject was randomly assigned. All subjects were experienced in automated perimetry and had been previously trained in the psychophysical techniques employed LA was assessed by obtaining scotopic threshold measurements at 15° eccentricity for stimuli to which rhodopsin is equally sensitive (*i.e.*, 410 and 560 nm). The difference in threshold between these two wavelengths was taken as a measure of LA. MPA was assessed by comparing green cone sensitivity at the fovea and parafovea. The difference in log parafoveal and log foveal sensitivity to a 460 nm stimulus relative to a value of zero at 570 nm can be taken as a measure of the maximum MPA. The group mean lens optical density relative to 460 nm was found to be 0 41 log unit (SD 0.04) and 0.53 log unit (SD 0.05) for the young and elderly groups, respectively The group mean macular pigment optical density relative to 460 nm for the young group was 0.48 log unit (SD 0.24) at the fovea. MPA could not be assessed in the elderly group due to insufficient dynamic range and an inability to reliably discriminate the 460 nm flicker end point. The magnitude and variation of LA and MPA demands that these factors must be taken into account in the assessment of blue/yellow perimetry in both the young and elderly eye.

Introduction

Blue/yellow perimetry has received considerable attention due to the earlier detection of visual field loss than the standard white-on-white perimetric routine particularly in ocular hypertension[1] and glaucoma[2]. The technique attempts to isolate the short wavelength sensitive (SWS) cone response by the use of a blue stimulus on a high luminance yellow background[3]. The yellow background is designed to saturate the red and green cones and simultaneously to suppress rod activity. In addition, a blue stimulus is employed preferentially to stimulate the SWS cones.

However, the influence of pre-receptoral absorption factors, namely the yellow pigment within the crystalline lens[4] and the macular pigment[5], on SWS increment thresholds has received relatively little attention. In particular, the magnitude of attenuation of the SWS perimetric profile by the macular pigment is unknown. Such information is necessary if physiological variation in pre-receptoral absorption is to be distinguished from disease related SWS increment threshold loss.

The aim of the study was to determine the effect of lenticular absorption (LA) and macular pigment absorption (MPA) on the SWS perimetric profile in the normal eye.

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Methods

Sample

The sample comprised ten normal young subjects (three males and seven females), with a mean age of 24.49 years (SD 3.37) and a visual acuity of 6/6 or better and ten normal elderly subjects (six males and four females), with a mean age 72.00 years (SD 3.86) and a visual acuity of 6/9 or better. For the assessment of LA a larger sample comprising 12 normal young subjects (mean age 23.91, SD 3.05) and 23 normal elderly subjects (mean age 70.82, SD 7.64) was recruited. Volunteers for both groups had a distance refractive error not greater than -3.50 DS and ±2.50 DC. All subjects were experienced perimetric observers with normal central fields (HFA Program 30-2) and had been previously trained in the psychophysical techniques employed in the study. Further inclusion criteria included an intraocular pressure of less than 21 mmHg, an absence of any marked lenticular opacity, normal fundi and normal color vision. Exclusion criteria included the use of contact lenses or any topical eye treatment, a past history of eye disease, a positive family history of glaucoma in a first degree relative, systemic conditions with known ocular involvement including diabetes, neurological or psychiatric illness and systemic medication with known CNS effects. One eye of each subject was randomly assigned. Natural pupils were used for all investigations. For all tests the distance refractive correction was employed, together with the appropriate near addition in the elderly group. All investigations were performed by a single experienced perimetrist (CH). The assessments of LA, MPA and blue/yellow perimetry, each lasted approximately 45 minutes and were undertaken on separate days.

HFA 630 modifications

Various modifications were made to a Humphrey Field Analyzer (HFA) 630 in order to assess LA, MPA and blue/yellow perimetry. Lamp housings were mounted on either side of the HFA close to the intrinsic background sources to provide an even (±2% within 30° of fixation) high intensity adapting field. Both housings were designed to facilitate the easy interchange of background filters and consisted of an ELE/ELT 80 Watt/30 Volt tungsten halogen bulb, an infrared filter and a diffusing filter. Cool air was drawn over the housings via ducting to dissipate heat. In addition, a removable filter holder was attached to the projector arm of the HFA to facilitate the easy interchange of stimulus filters. The intrinsic background illumination was extinguished using 5.3 software for all investigations. A concave mirror positioned behind the stimulus bulb was employed to raise the light output by a factor of 1.6 without forfeit of the intrinsic calibration system. Before switching on the HFA 630 a matt black deflector angled at 30° to the horizontal, sloping away from the stimulus bulb, was placed in front of the mirror. The deflector was removed when the calibration procedure was complete. Consequently, no readjustment of the HFA calibration occurred since the instrument was unaware of the increase in stimulus intensity. The calibration of all background and stimulus filters was achieved using an LMT L1003 photometer.

Pre-receptoral absorption

LA can be assessed by measuring thresholds to 410 nm (HPW 11 nm) and 560 nm (HPW 9 nm) narrowband 100 msec stimuli outside the macula lutea after dark adapting the subject for 30 minutes. Any difference in scotopic sensitivity between the two stimuli can be assumed to be due to LA since the rhodopsin action spectrum exhibits equal absorption at 410 nm and 560 nm and any influence due to the macular pigment has been avoided[6].

A red filter was positioned over the fixation spot to preserve dark adaptation and blocking material was used to reduce the leakage of light from the stimulus bulb. The resultant luminance of the background was <0.009 cdm^{-2}. Fixation was monitored using an infrared illumination system which comprised a 20 Watt/12 Volt tungsten halogen bulb mounted behind a Schott RG830 black light filter encased in a steel tube. The whole assembly was mounted within the perimeter and adjusted so that infrared radiation was reflected off the bowl surface and then onto the subject. A Goldmann size V stimulus was presented from above threshold three times at 15.5° eccentricity in each of the four quadrants. The use of the 560 nm narrowband filter

permitted a dynamic range of 2.45 log units and a 0.24/0.12 log unit double crossing of threshold was employed. Mean pupil sizes were 5.8 mm (SD 1.1) for the young group and 5.35 mm (SD 0.8) for the elderly group.

The "standard observer" data of Norren and Vos[6] were used to calculate individual lens optical densities using the equation:

$$OD_{lens} = OD_{stand} * (X/0.90)$$

where OD_{lens} is the individual lens optical density at a given wavelength, OD_{stand} is the mean "standard observer" optical density at a given wavelength, X is the measured difference in log relative sensitivity between the 410 nm and 560 nm stimuli and 0.90 is the mean "standard observer" density difference between the 410 nm and 560 nm stimuli. This method assumes that the rhodopsin action spectrum is invariant[7], that the absorption of light per unit path length remains constant during life while the lens thickness increases[4] and that any difference in sensitivity at 15.5° eccentricity between the 410 nm and 560 nm stimuli is due predominantly to absorption by the crystalline lens[8].

MPA can be assessed by measuring green cone sensitivity for 460 nm (HPW 9 nm) and 570 nm (HPW 9 nm) narrowband 1.3 secs stimuli. The difference in log parafoveal (*i.e.*, 10°) and log foveal (and 5.5°) sensitivity to the 460 nm stimulus relative to a value of zero at 570 nm can be taken as a measure of the maximum MPA[9,10].

A 460 cdm^{-2} red central field of 26° diameter was employed to adapt the red cones. This was produced by the combination of filtered light (Schott RG645 filter transmitting wavelengths above 630 nm) from a supplementary 250 Watt tungsten halogen projected light source suspended above the subject's head and from the two lamp housings. Subjects were adapted to the red field for three to four minutes prior to testing. Detection by the rods and blue cones was excluded by determining flicker sensitivity for a 25 Hz Goldmann size V stimulus. The flicker wheel was mounted between the stimulus bulb and the aperture plate of the HFA and incorporated an automatic reset mechanism to ensure that the stimulus light path was clear when not in use. Both stimuli were presented three times from below threshold at the fovea, at 5.5° and at 10° eccentricity respectively along the 45° and 225° meridians. The use of the 570 nm narrowband filter permitted a dynamic range of 2.62 log units and a 0.26/0.13 log unit double crossing of threshold was employed. Mean pupil sizes were 4.0 mm (SD 0.6) for the young group and 3.45 mm (SD 0.8) for the elderly group.

Individual macular pigment optical densities relative to 460 nm were calculated using the equation:

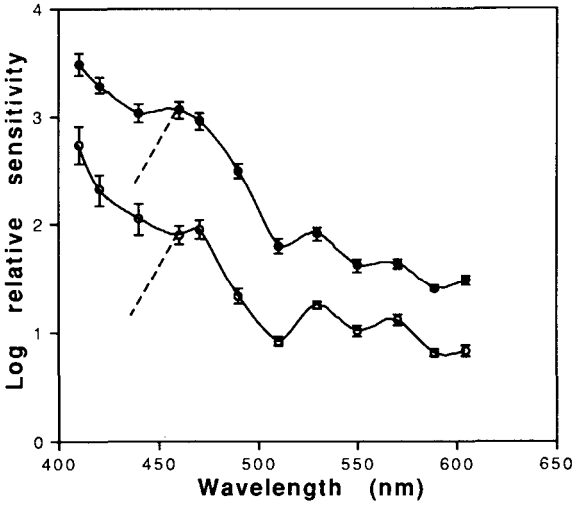

Fig. 1. Group mean ITSS functions after correction for pr -receptoral absorption for the young group (n=10) on the 330 cdm^{-2} background. Open circles: 21° eccentricity on the 225° meridian; closed circles: foveal presentation; dotted line: interpolated SWS component. The error bars represent two standard errors of the mean.

$$OD_{mac} = (\log S_{p460} - \log S_{f460}) + (\log S_{f570} - \log S_{p570})$$

where OD_{mac} is the individual macular pigment optical density at 460 nm, $\log S_{p460}$ and $\log S_{f460}$ are the measured parafoveal and foveal 460 nm log relative sensitivities respectively, while $\log S_{f570}$ and $\log S_{p570}$ are the measured foveal and parafoveal 570 nm log relative sensitivities. The technique assumes that green cone spectral sensitivity does not vary with eccentricity except for the influence of MPA, that macular pigment is absent at 10° eccentricity[11] and that MPA is negligible for wavelengths above 560 nm[12].

Perimetry

For blue/yellow perimetry a 330 cdm^{-2} yellow background was generated by the introduction of Schott OG530 filters (transmitting wavelengths above 500 nm) into the filter holders of the two lamp housings. The choice of stimulus filter was based on increment threshold spectral sensitivity (ITSS) functions previously derived on the 330 cdm^{-2} yellow background for the ten young subjects. The group mean ITSS function exhibited an SWS peak at approximately 460 nm for both foveal and extrafoveal stimuli after correction for pre-receptoral absorption (Fig. 1). Therefore, a 460 nm narrowband (HPW 9 nm) filter was employed for blue/yellow perimetry, which permitted a dynamic range of 0.84 log unit. SWS increment thresholds were assessed for each subject three times at each of nine locations along the 45° and 225° meridians (0°, 5.5°, 10°, 15.5° and 21°) using a custom threshold program. Stimuli were initially presented from below threshold using a 0.08/0.04 log unit double crossing of threshold. The last seen stimulus value was taken as threshold. A 200 msec Goldmann size V (1.724°) stimulus was employed. Mean pupil sizes were 3.8 mm (SD 0.4) for the young group and 2.9 mm (SD 0.3) for the elderly group.

Results

Fig. 2 illustrates the influence of both LA and MPA on the blue/yellow perimetric profile in the normal eye. LA resulted in an overall depression of the blue/yellow perimetric profile, while MPA accounted for a localized loss centered at the fovea. The combined effect of LA and MPA at the fovea was to attenuate the group mean SWS increment threshold in the young group by 0.89 log unit. As might be expected the gradient of the blue/yellow hill of vision was found to be steeper in the elderly group than in the young group.

Fig. 3 illustrates the variation in lens optical density relative to 410 nm as a function of age. A random quadrant variation in lens optical density was exhibited but the group mean maximum variation was found to be smaller than one standard deviation (Table 1). The group mean lens optical density relative to 460 nm was found to be 0.41 log unit (SD 0.04) and 0.53 log unit (SD 0.05) for the ten young and ten elderly subjects, respectively.

Table 1. Group mean lens optical density (log units relative to 410 nm) and standard deviation as a function of quadrant for the young (<30 years) and elderly (>55 years) groups

	Superior temporal	*Inferior temporal*	*Inferior nasal*	*Superior nasal*
Young (n=12)	1.97 (SD 0.23)	1.83 (SD 0.22)	2.02 (SD 0.38)	2.06 (SD 0.35)
Elderly (n=23)	2.50 (SD 0.30)	2.56 (SD 0.33)	2.63 (SD 0.32)	2.65 (SD 0.31)

The group mean macular pigment optical density relative to 460 nm for the young group was 0.48 log unit (SD 0.24, median 0.56) at the fovea, 0.02 log unit (SD 0.17) at 5.5° on the 45° meridian and 0.03 log unit (SD 0.17) at 5.5° on the 225° meridian. Foveal values for macular pigment optical density in the young group ranged from 0.12 log unit to 0.77 log unit. Macular pigment optical density could not be measured in the elderly group due to insufficient dynamic range and an inability to reliably discriminate the 460 nm flicker end point.

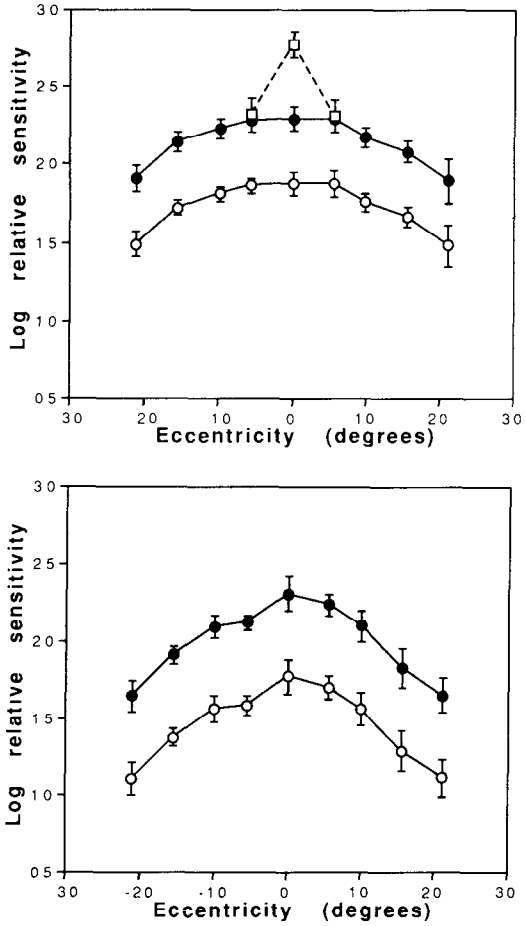

Fig. 2. Group mean SWS perimetric profiles along the 45° and 225° meridians. Upper graph: young group Lower graph: elderly group; open circles: profile prior to correction for LA and MPA; closed circles: profile after correction for LA; open squares: profile after correction for LA and MPA. A +ve eccentricity is the temporal meridian and a -ve eccentricity is the nasal meridian.

Discussion

The magnitude and variation of LA demands that this factor must be individually corrected for in the assessment of the blue/yellow perimetric profile in both the young and elderly eye. The results are comparable with previous perimetry based assessments of lens optical density[3,13]. Interestingly, Sample *et al.*[3] derived a "standard" lens optical density of 0.42 log unit relative to 440 nm which was used to correct all other optical densities relative to this baseline value. This compares favorably with the results of the young group mean lens optical density of 0.41 log unit relative to 460 nm found in this study. Previous studies have noted that a 1.0 log unit variation in lens optical density relative to 400 nm at any given age is not unusual[6]. Similar variation in lens optical density relative to 410 nm was found in this study (Fig. 3).

The magnitude and variation of MPA in the sample of ten young subjects demonstrated that perimetric SWS increment thresholds at the fovea can be influenced by up to 0.77 log unit. Therefore, any attenuation of SWS foveal thresholds cannot necessarily be attributed to a disease process unless MPA is assessed on an individual basis. Alternatively, SWS increment thresholds within 5° of fixation (*i.e.*, the central five points of the HFA 30-2 program) should be ignored if MPA assessment is not undertaken. Previous estimates of the peak (*i.e.*, 460 nm)

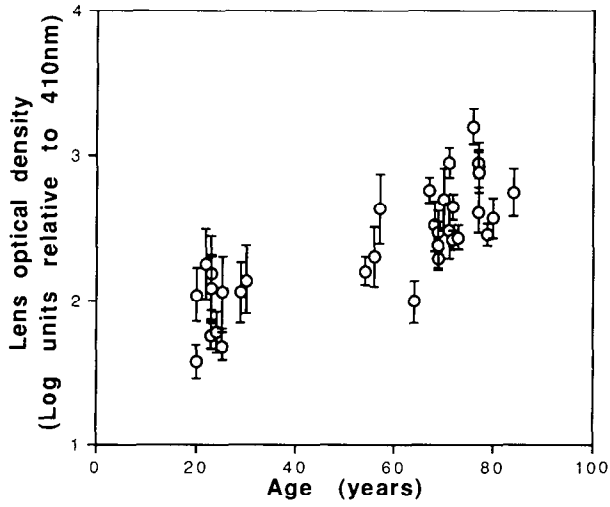

Fig 3 Lens optical density as a function of age for 35 normal observers.

foveal optical density of macular pigment have ranged from 0.32 log units to 0.87 log units[9,14-16]. Furthermore, psychophysical studies have noted that large between subject variations can occur[10,14,16]. For example, Pease *et al.*[10] used a similar technique to this study and found a mean foveal optical density at 460 nm of 0.77 log units (SD 0.31) for 27 normal observers, with a range of individual densities from 0.21 log unit to 1.22 log units. A more recent study[15] has demonstrated an almost perfect agreement between the absorbance spectrum of liposome-bound carotenoids and the psychophysical derived spectrum of macular pigment and as a result has given added significance to studies which use psychophysical measures of macular pigment optical density. The measurement error of the MPA assessment, as shown by the magnitude of the group mean standard deviation, was found to be high. This can be attributed to the previously documented large between subject variation in MPA[10], to involuntary physiological eye movements and to the complexity of the measurement.

The magnitude and variation of LA and MPA demands that these factors be taken into account in the assessment of blue/yellow perimetry in both the young and elderly eye.

References

1 Brandt JD, Johnson CA, Casson EJ, Adams AJ, Shapiro LR: The prognostic efficacy of blue-on-yellow perimetry in ocular hypertension: a five year prospective longitudinal study Invest Ophthalmol Vis Sci (Suppl) 33:1384, 1992
2. Johnson CA, Casson EJ, Adams AJ, Shapiro LR, Brandt JD: Progression of glaucomatous visual field loss over five years: a comparison of white-on-white and blue-on-yellow perimetry. Invest Ophthalmol Vis Sci (Suppl) 33:1384, 1992
3. Sample PA, Weinreb RN: Color perimetry for assessment of primary open-angle glaucoma. Invest Ophthalmol Vis Sci 31:1869-1875, 1990
4 Mellerio J: Light absorption and scatter in the human lens. Vision Res 11:129-141, 1971
5. Nussbaum JJ, Pruett RC, Delori FC: Historic perspectives: macular yellow pigment: the first 200 years. Retina 1:296-310, 1981
6. Norren DV, Vos JJ: Spectral transmission of the human ocular media. Vision Res 14:1237-1244, 1974
7. Alpern M: A note on the action spectrum of human rod vision. Vision Res 27:1471-1480, 1987
8. Weale RA: The lenticular nucleus, light and the retina. Exp Eye Res 53:213-218, 1991
9. Pease PL, Adams AJ: Macular pigment difference spectrum from sensitivity measures of a single cone mechanism. Am J Optom Physiol Opt 60:667-672, 1983
10 Pease PL, Adams AJ, Nuccio E: Optical density of human macular pigment. Vision Res 27:705-710, 1987
11. Snodderly DM, Auran JD, Delori FC: The macular pigment. II. Spatial distribution in primate retinas. Invest Ophthalmol Vis Sci 25:674-685, 1984

12. Bone RA, Landrum JT, Tarsis SL: Preliminary identification of the human macular pigment. Vision Res 25:1531-1535, 1985
13. Johnson CA, Adams AJ, Lewis RA: Evidence for a neural basis of age-related visual field loss in normal observers. Invest Ophthalmol Vis Sci 30:2056-2064, 1989
14. Vos JJ: Literature review of human macular absorption in the visible and its consequences for the cone receptor primaries. Institute for Perception, RVO-TNO, IZF 1972-17, Soesterberg, The Netherlands 1972
15. Bone RA, Landrum JT, Cains A: Optical density spectra of the macular pigment in vivo and in vitro. Vision Res 32:105-110, 1992
16. Hammond BR, Fuld K: Interocular differences in macular pigment density. Invest Ophthalmol Vis Sci 33:350-355, 1992

Blue-on-yellow perimetry: a five-year overview

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Abstract

For the past five years, the authors have conducted a prospective investigation of blue-on-yellow perimetry in comparison to standard white-on-white automated perimetry in young, middle-aged and older normal subjects, ocular hypertensives and patients with early glaucomatous visual field loss. This paper provides a general overview of the findings from this study. The results of this study indicate that: *1.* blue-on-yellow perimetry deficits precede glaucomatous visual field loss for standard white-on-white automated perimetry; *2.* blue-on-yellow deficits predict which ocular hypertensives will develop glaucomatous visual field loss within three to five years; *3.* blue-on-yellow deficits are larger than those observed with standard white-on-white automated perimetry; and *4* the procedure can be successfully implemented on existing commercial automated perimeters for routine clinical use.

Introduction

Previous results from our laboratory and from other investigators indicate that short wavelength sensitivity losses are more prevalent in patients with ocular hypertension and early glaucoma than sensitivity deficits obtained with standard white-on-white (W/W) automated perimetric procedures[1-6]. In addition, these studies indicate that short wavelength sensitivity losses appear to have both diffuse and localized components[2,7], that short wavelength sensitivity deficits typically encompass a larger visual field area than those found with standard automated perimetry[2,3,6,7], that there is considerable but not complete overlap between short wavelength sensitivity losses and visual field deficits obtained for standard W/W perimetry[3], and that localized short wavelength sensitivity losses in ocular hypertension and glaucoma correspond to nerve fiber bundle patterns[4,5] in a manner similar to localized glaucomatous visual field defects found with standard W/W automated perimetry.

We have recently completed a prospective five-year study of young, middle-aged and older normal subjects, ocular hypertensives and patients with early glaucomatous visual field loss in one or both eyes. All participants were followed annually with standard W/W perimetry and blue-on-yellow perimetry. In the present paper, we provide an overview of our findings from this study and describe the advantages and disadvantages of blue-on-yellow perimetry as a clinical diagnostic tool for ocular hypertension and glaucoma.

Methods

All visual field sensitivity measurements were obtained with a modified Humphrey Field Analyzer, an automated perimeter whose stimulus properties and test strategies have been de-

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scribed previously[8]. For this investigation, we used the program 30-2 test strategy, which obtains sensitivity measures according to a staircase procedure at 76 locations in the central 30 degrees radius of the visual field[8]. The pattern of test stimuli is a grid of 76 locations, with 6-degree horizontal and vertical spacing between points that bracket fixation and the horizontal and vertical meridians.

To allow measurements of short wavelength sensitive mechanisms, auxiliary background illumination was added to the Humphrey Field Analyzer to provide a yellow adaptation field of 200 cd/m^2 in the perimeter bowl. This was accomplished by means of two light boxes (Kodak 80 watt ELS projector bulb, heat-absorbing glass, opal diffusing glass, Schott OG530 yellow filter, fans and housing) mounted on each side of the perimeter next to the original background light sources. The output of the two light boxes was balanced to provide uniform illumination of the perimeter bowl. A blue filter (OCLI 500 nm cutoff filter) was placed over the stimulus projection system. In previous investigations[8], we have demonstrated that these test conditions provide approximately 1.5 log units (15 dB) of isolation of the short wavelength sensitive pathways throughout the central 30 degrees of the visual field. These modifications to the Humphrey Field Analyzer allowed us to perform standard automated perimetry testing (white-on-white (W/W)) and blue-on-yellow perimetry testing (B/Y) using the same device and test procedures. A parts list and instructions for modifying the Humphrey Field Analyzer are available from the first author upon request.

Pre-retinal ocular media absorption of short wavelength light was measured for each eye to separate short wavelength sensitivity reductions due to ocular transmission losses from those related to glaucomatous damage to nerve fibers. This was accomplished by measuring dark-adapted scotopic thresholds (15 degrees eccentricity in the superior visual field) for a short wavelength (450 nm) and a long wavelength (656 nm) stimulus using a modified Tübinger perimeter. Three interleaved threshold measurements were obtained for the short and long wavelength stimuli and the results were averaged. Calculations of ocular media transmission loss for short wavelength light were obtained using the procedure described by Van Norren and Vos[9], which assumes that the shape of the rhodopsin curve is invariant, and that differences in dark-adapted spectral sensitivity can be attributed entirely to pre-retinal media absorption.

A total of approximately two hours of testing was performed for each subject on an annual basis for five years. W/W and B/Y tests each required approximately 15 minutes per eye, and ocular media absorption measurements required a total of approximately 20 minutes for both eyes. The remainder of the two-hour test period was spent on visual acuity and IOP measures in both eyes, a brief clinical history and brief rest periods between tests.

To establish normative values for both the W/W and B/Y tests, we evaluated both eyes of 62 normal control subjects (33 males, 29 females). Twenty normal subjects were in a 20-39 year old age group, 22 were in a 40-59 year old age group and 20 were in a 60-78 year old age group. Inclusion criteria for the normal control subjects consisted of a best-corrected visual acuity of 20/40 or better in both eyes, an intraocular pressure (IOP) of less than 20 mmHg in both eyes, refractive errors of less than 5 diopters spherical equivalent and 3 diopters cylinder, a normal eye examination, a normal visual field according to W/W visual field testing, no history of ocular or neurologic disease or surgery, no history of diabetes or other systemic diseases, no history of taking any medications known to affect visual field sensitivity or color vision. For each of the three age groups, the 95% and 99% confidence limits were individually established for the W/W and B/Y tests at each of the 76 stimulus locations. The B/Y data were individually corrected for ocular media transmission losses measured for each eye. These data were used to compare each patient's test results to normative values for their particular age group. By using 95% and 99% normal confidence limits as a basis for evaluating patient data, it was possible to conduct a direct comparison of the performance of the W/W and B/Y test results for early detection of glaucomatous damage. A detailed description of the ocular media, B/Y and visual field characteristics of the normal population has been presented in a previous publication[8].

Both eyes of 38 ocular hypertensive patients were examined. Ocular hypertensives had to meet the same inclusion criteria as the normal control subjects, with one exception: IOP in both eyes had to be greater than 21 mmHg. Both eyes of 22 patients with early glaucomatous visual field loss in one or both eyes were also tested. Eligibility criteria for the early glaucoma patients were the same as for the ocular hypertensives, except that they had early visual field loss in one or both eyes. All of the B/Y test results from patients were also individually corrected for

ocular media transmission losses in each eye. The W/W and B/Y test results for each ocular hypertensive eye were compared to the normal population characteristics for their age group (20-39; 40-59 or 60-78 years of age) at each of the 76 visual field locations and a determination was made as to whether the values were beyond the 95% and/or 99% confidence limits for that age group. By comparing individual patient data to the characteristics of their normal age group for each test, we were able to take into account the effects of normal age-related sensitivity losses, differences in the rate of age-related sensitivity losses for the two tests, and differences in the between-subjects variation for the W/W and B/Y perimetry tests.

Results

All the 76 ocular hypertensive eyes had standard white-on-white automated perimetry tests for the year 1 baseline measures. Nine of the 76 ocular hypertensive eyes had abnormal blue-on-yellow perimetry results at baseline. Over the five years of the study, five ocular hypertensive eyes developed early glaucomatous visual field loss on standard white-on-white automated perimetry. All five of them had abnormal blue-on-yellow perimetry deficits in year 1. None of the ocular hypertensive eyes with normal blue-on-yellow visual fields in year 1 developed glaucomatous visual field loss for standard white-on-white automated perimetry over the five-year period. Individual examples of longitudinal test results have been presented previously[5,11,12]. The examples reveal that the location of subsequent visual field abnormalities for standard white-on-white automated perimetry is predicted by the earlier blue-on-yellow deficits as well. Based on these results, blue-on-yellow perimetry has a sensitivity of 100% and a specificity of 94% for predicting which ocular hypertensives will develop glaucomatous visual field loss within a five-year period.

Seven of the eyes with early glaucomatous visual field loss for standard white-on-white automated perimetry at baseline demonstrated clear evidence of progression of visual field loss over the five years of the study. The remaining early glaucoma eyes did not demonstrate a clear indication of progressive visual field loss. In each of the eyes with progressive visual field loss, the blue-on-yellow abnormalities were much more extensive at baseline. Moreover, individual examples which have been presented previously[5,10,12] revealed that the progression of standard white-on-white automated perimetry deficits extended into areas that had abnormal blue-on-

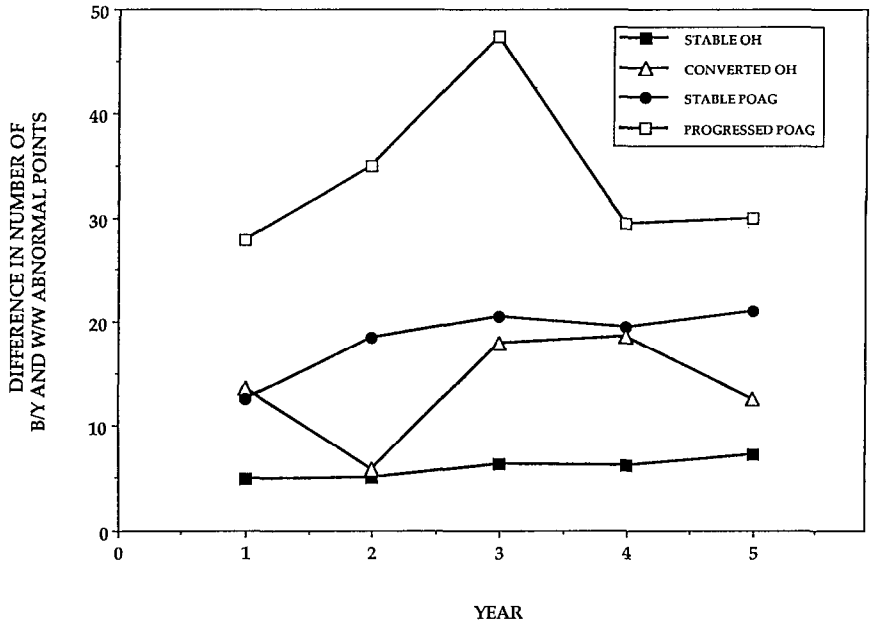

Fig. 1.

yellow sensitivities in earlier years. A general summary of the ocular hypertensives and early glaucomas which remained stable and those which progressed is shown in Fig. 1.

Fig. 1 presents the difference between the average number locations on the blue-on-yellow and standard white-on-white tests which were below normal limits for the 71 ocular hypertensive eyes which remained stable, the five ocular hypertensive eyes which developed visual field loss, the seven early glaucoma eyes which exhibited progression of visual field loss, and the remaining early glaucoma eyes which did not demonstrate consistent evidence of progressive visual field loss. Note that all four groups tend to show an increase in the number of blue-on-yellow abnormalities relative to the number of white-on-white deficits over the five years of the study. This suggests that progression of glaucomatous loss for blue-on-yellow testing is more rapid than for standard white-on-white testing. Note also that the four groups of patients are stratified vertically in Fig. 1. That is, the losses noted for blue-on-yellow testing are proportionately greater than those for standard white-on-white automated perimetry as the overall amount of glaucomatous damage increases. Both these findings, in conjunction with previous results, indicate that blue-on-yellow perimetry is able to detect initial glaucomatous damage and progression of existing glaucomatous damage at a much earlier stage than standard white-on-white automated perimetry.

A useful clinical diagnostic procedure should demonstrate high sensitivity and specificity, good reliability and reproducibility, and should be robust in the face of variations in test conditions. As discussed above, blue-on-yellow perimetry has been shown to have high sensitivity and specificity. Previous studies[3] have established that blue-on-yellow perimetry has long-term variability that is similar to standard white-on-white automated perimetry and only slightly greater (10-15%) inter- and intra-individual short-term variability. Although it is affected by the transmission properties of the lens, the results shown below indicate that blue-on-yellow perimetry is quite resistant to blur.

Fig. 2 demonstrates that blue-on-yellow perimetry is quite resistant to the effects of blur. For this observer, standard white-on-white sensitivity measures decreased by approximately 11 dB for the fovea and 8 dB for the periphery (20 degrees eccentricity, inferior temporal oblique meridian) over a span of 8 diopters of blur. Foveal and peripheral blue-on-yellow sensitivity measures decreased by only about 1-2 dB over this same range of blur. Part of the reduced susceptibility of blue-on-yellow perimetry to blur is due to the use of a larger target (Size V instead of Size III), and part of it is due to the poor resolution properties of the short-wavelength-sensitive pathways[13].

Fig. 3 demonstrates that blur can actually have a small beneficial effect for blue-on-yellow perimetry by increasing the amount of isolation of short-wavelength-sensitive mechanisms by

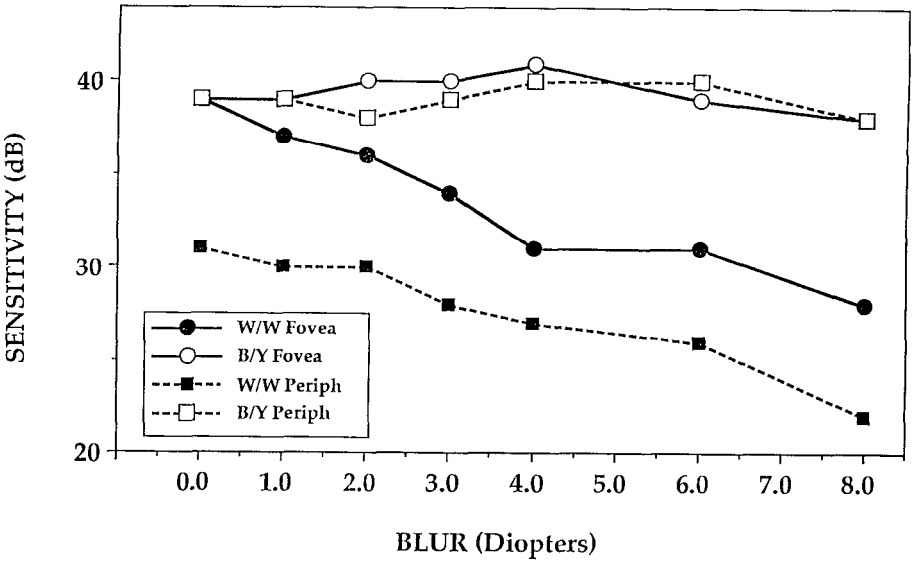

Fig. 2

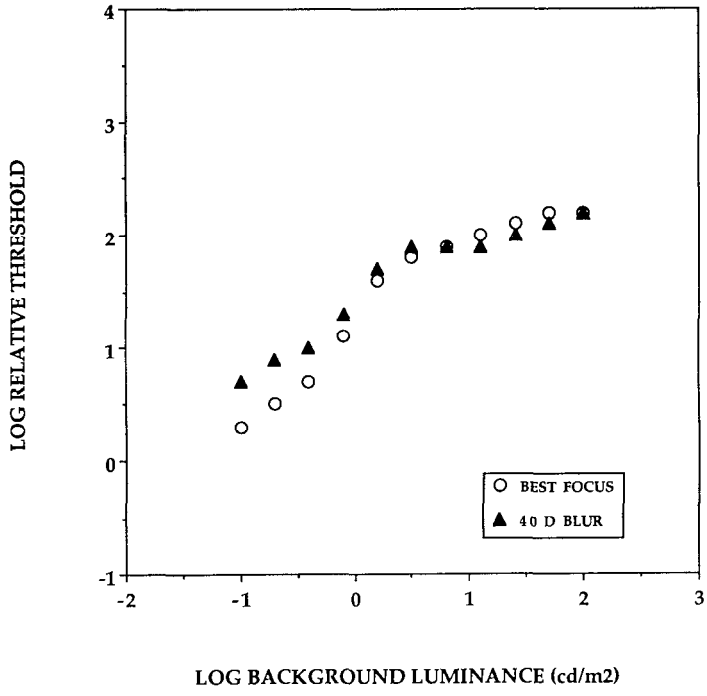

Fig. 3.

0.2 to 0.3 log units (2-3 dB). A threshold *versus* intensity (tvi) curve is presented in Fig. 3, where the threshold (the inverse of sensitivity) for the Size V blue target is plotted as a function of luminance of the yellow background. At low background luminances, threshold is determined by the pi_4 (middle-wavelength-sensitive or "green") mechanism, whereas at high background luminances threshold is determined by the pi_1 (short-wavelength-sensitive or "blue") mechanism. Note that there is an elevation of threshold (reduced sensitivity) by the introduction of 4.0 D of blur when the pi_4 mechanism is responsible for threshold detection, but that 4.0 D of blur has little or no effect when the pi_1 mechanism is responsible for threshold detection. This serves to increase the amount of isolation of short-wavelength-sensitive mechanisms by a small amount.

Discussion and conclusions

Our five-year prospective evaluation of young, middle-aged and older normal control subjects, ocular hypertensives and patients with early glaucomatous visual field loss has permitted us to make a thorough comparison of blue-on-yellow perimetry to standard white-on-white automated perimetry. Based on this experience, it is now possible to provide an overview of the relative advantages and disadvantages of blue-on-yellow perimetry. For the disadvantages, we have also indicated potential methods of resolving existing problems with blue-on-yellow perimetry.

Advantages of blue-on-yellow perimetry

1. The greatest advantage of blue-on-yellow perimetry is its ability to predict the development and location of glaucomatous visual field loss in ocular hypertensives. Our current findings indicate a sensitivity of 100% and a specificity of 94% in the ability of blue-on-yellow perimetry to predict which ocular hypertensives will develop glaucomatous visual field loss within a five-year period.

2. Blue-on-yellow perimetry is able to predict the location of impending progression of visual field loss in patients with early glaucomatous visual field deficits.
3. In patients with early glaucomatous visual field loss, the size and extent of blue-on-yellow perimetry deficits are considerably larger than those obtained with standard white-on-white automated perimetry. This makes it easier to detect early abnormalities and distinguish them from random variations.
4. Blue-on-yellow perimetry is quite resistant to blur, exhibiting only slight decreases in sensitivity to large amounts of blur. Part of this is due to the large Size V stimulus, and part of it is due to the poor acuity and resolution properties of the short-wavelength-sensitive pathways.
5. Blue-on-yellow perimetry can be performed using the same target presentation patterns and test strategies normally used by the Humphrey Field Analyzer. Only a few minor modifications are needed, and the Humphrey Field Analyzer can still be used for normal white-on-white testing.

Disadvantages of blue-on-yellow perimetry

1. Although the long-term variability of blue-on-yellow perimetry is essentially the same as for standard white-on-white automated perimetry, the short-term inter- and intra-subject variability of blue-on-yellow perimetry is approximately 10-15% greater than for standard white-on-white automated perimetry. This means that a larger deviation from average normal values is required to exceed criterion probability levels or confidence limits for blue-on-yellow perimetry than for standard white-on-white automated perimetry. Refinement of existing test strategies may help to reduce the short-term variability of blue-on-yellow perimetry.
2. Since the current implementation of blue-on-yellow perimetry represents a minor modification of the Humphrey Field Analyzer, the dynamic range of stimulus values is more restricted than for standard white-on-white automated perimetry. This is because the OCLI blue stimulus filter reduces the stimulus intensity by 13 dB. A more extensive modification of the Humphrey Field Analyzer to permit greater stimulus intensity levels can provide a solution to this problem.
3. Age-related yellowing of the human lens reduces the amount of light reaching the retina, especially for short-wavelength (blue) light. This further reduces the dynamic range of blue-on-yellow perimetry. In addition, it is necessary to measure the amount of short wavelength transmission loss produced by the lens in order to determine the amount of short wavelength sensitivity loss that is due to optical factors from that which is due to early glaucomatous pathology. These measures must be obtained for each eye, since there are large individual variations in lens density among individuals and some asymmetries between two eyes of the same individual, especially in older age populations. The procedures to do this are rather time consuming, and can take nearly as long as the perimetry test. We are currently evaluating a video-based method of rapidly (one to two seconds) measuring lens transmission properties, and are also exploring the use of analysis procedures to separately analyze localized blue-on-yellow deficits, since lens transmission losses produce diffuse overall reductions in short wavelength sensitivity.

In view of the success of our initial five-year investigation of blue-on-yellow perimetry, we are presently conducting a large-scale five-year prospective evaluation of blue-on-yellow and standard white-on-white perimetry in 250 ocular hypertensive patients to provide a more definitive assessment of the sensitivity and specificity of blue-on-yellow perimetry and its clinical performance characteristics.

References

1. Sample PA, Weinreb RN: Color perimetry for assessment of primary open-angle glaucoma. Invest Ophthalmol Vis Sci 31:1869-1875, 1990
2. Johnson CA, Adams AJ, Lewis RA: Automated perimetry of short-wavelength sensitive mechanisms in glaucoma and ocular hypertension: preliminary findings. In: Heijl A (ed) Perimetry Update 1988/89, pp 31-37. Amsterdam: Kugler Publ 1989

3. Johnson CA, Adams AJ, Lewis RA: Patterns of early glaucomatous visual field loss for short wavelength sensitive pathways. ARVO abstract. Invest Ophthalmol Vis Sci 30:56, 1989
4. Adams AJ, Johnson CA, Lewis RA: S cone pathway sensitivity loss in ocular hypertension and early glaucoma has nerve fiber bundle pattern. In: Drum, Moreland, Serra (eds) Proceedings of the 10th International Research Group on Colour Vision Defiencies, pp 535-542. Dordrecht: Kluwer Academic Publ 1991
5. Johnson CA, Adams AJ, Casson EJ, Nelson-Quigg JM: Can short wavelength sensitivity losses predict the development of glaucomatous visual field defects? In: Noninvasive Assessment of the Visual System, 1991 Technical Digest Ser 1:2216-2219, 1991
6. Sample PA, Weinreb RN: Progressive color visual field loss in glaucoma. Invest Ophthalmol Vis Sci 33:2068-2071, 1992
7. Hart WM, Silverman SE, Trick GL, Nesher R, Gordon MO: Glaucomatous visual field damage: luminance and color-contrast sensitivities. Invest Ophthalmol Vis Sci 31:359-367, 1990
8. Johnson CA, Adams AJ, Twelker JD, Quigg JM: Age related changes of the central visual field for short wavelength sensitive (SWS) pathways. J Opt Soc Am 5:2131-2139, 1988
9. Van Norren D, Vos JJ: Spectral transmission of the human ocular media. Vision Res 14:1237-1244, 1974
10. Johnson CA, Casson EJ, Adams AJ, Shapiro LR, Brandt JD: Progression of glaucomatous visual field loss over five years: A comparison of white-on-white and blue-on-yellow perimetry ARVO abstract Invest Ophthalmol Vis Sci 33:1384, 1992
11. Brandt JD, Johnson CA, Casson EJ, Adams AJ, Shapiro LR: The prognostic efficacy of blue-on-yellow perimetry in ocular hypertension: a five year prospective longitudinal study. ARVO abstract Invest Ophthamol Vis Sci 33:1384, 1992
12. Johnson CA, Adams AJ, Casson EJ: Short-wavelength-sensitive perimetry (SWSP) can predict which glaucoma suspects will develop visual field loss. In: Parel JM (ed) Ophthalmic Technologies II, Proc. SPIE 1644, pp 230-236, 1992
13. Swanson WH: Clinical assessment of short-wavelength-sensitive cone acuity. In: Noninvasive Assessment of the Visual System, 1991. Technical Digest Ser 1:66-69, 1988

Learning effects in blue-yellow perimetry

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Abstract

The existence of learning and fatiguing effects in conventional white-on-white perimetry is well documented during an examination, between eyes at a given visit and between visits. These effects vary with retinal location. The use of blue-on-yellow stimuli to selectively isolate short-wavelength sensitive (SWS) mechanisms has been shown to be of benefit in the early detection of retinal disease. The influence of similar learning and fatiguing effects in blue-on-yellow perimetry is unknown. This study investigated the effect of repeated perimetric examination on SWS thresholds. Forty-four normal subjects (20 young (mean 25.53 years SD 4.09), and 24 old (mean 69.13 years SD 8.56)) were sub-divided into those who were experienced in conventional white-on-white perimetry and those who were naive to any form of perimetric technique. Perimetry was performed using a modified Humphrey Field Analyzer 630 on three consecutive days and after one week Both eyes were examined at each session, the right eye was always examined first. All groups showed an overall, but variable improvement in global mean sensitivity irrespective of degree of training. Younger trained subjects exhibited a mean 0.29 log unit improvement. Improvement was less for the second eye tested and untrained groups showed less improvement for the second eye than trained No eccentricity effect was evident. Unweighted short-term fluctuation declined by up to 0.85 log units. Clinical perimetric examination of SWS mechanisms in the detection of early disease must consider the degree of perimetric experience in the validation of recorded results.

Introduction

The performance of many psychophysical tests has been shown to improve as the subject becomes familiar with the task[1]. Within-test, between-eye and between-visit learning effects in white-on-white automated perimetry are well documented both in normal subjects[2,3] and in glaucomatous patients[4-6]. The effect is eccentricity dependent being more pronounced in the periphery[2,3,5].

Recently, SWS stimuli (*i.e.*, blue stimuli on a high luminance yellow background) have been shown to be useful as an early indicator of glaucomatous damage, yielding defects which often precede the presence of visual field defects recorded by conventional white-on-white perimetric stimuli[7-10].

It is not known whether SWS perimetry, which is biased towards chromatic channels, exhibits similar or different learning and fatiguing characteristics to that of white-on-white perimetry which is based upon the luminance channels. It is unclear, for example, whether different criteria dependent processes are in operation between the two types of stimuli. In addition, the extent to which the learning effect is present in SWS perimetry for patients already experienced in white-on-white perimetry is also unknown. Furthermore, it is not known whether a differential learning effect is present between white-on-white and SWS thresholds in patients naive to any type of automated perimetry.

The aim of the study was to compare potential improvement in performance after repeated SWS perimetric examination as a function of age between a group of normal subjects experienced in white-on-white perimetry and a group naive to any form of perimetric examination.

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Methods

The sample comprised 44 clinically normal volunteers: 20 subjects aged 20-34 years (mean 25.53 years SD 4.09) and 24 between 50 and 85 years (mean 69.13 years SD 8.56). Each age group stratified such that one half had previous experience of conventional white-on-white perimetry but were naive to blue-on-yellow perimetry, and one half were naive to any form of automated perimetry. Inclusion criteria consisted of a corrected visual acuity of at least 6/9, distance refractive correction of <-5 D sphere and <±3 D cylinder, no history of ocular disease or trauma, no neurological history or systemic disease, no systemic medication known to influence the visual field and normal color vision assessed by the Farnsworth-Munsell 100-hue test. All subjects experienced in conventional white-on-white automated perimetry had undergone at least six previous automated perimetric full threshold examinations.

All visual field examinations were performed with a modified Humphrey Field Analyzer 630. The central field was examined with program 30-2 using a blue (Goldmann size V 1.728°) stimulus (OCLI blue dichroic filter, transmitting wavelengths below 475 nm and above 650 nm)) on a yellow background (Schott OG530, transmitting above 500 nm). The bowl illumination consisted of ELE/ELT 80W/30V tungsten halogen bulbs mounted either side of the perimeter housing behind infra-red and diffusing filters. Cooling fans were added to dissipate heat produced from the bulbs. The background luminance was 330.2 cdm^{-2}, a level suggested for achieving isolation of the SWS pathway[11]. The stimulus projection system produced a maximum stimulus luminance for the blue target of 865.21 cdm^{-2}. A 3.94/1.97 log unit double bracketing technique was used. The combination of filters achieves 1.2 log units of SWS isolation out to the periphery[12]. Calibration of stimulus and background was undertaken with an LMT L1003 photometer.

Perimetry was performed on three consecutive days and also at ten days after the initial examination. Each eye was examined at each visit and the right eye was always examined before the left. In order to minimize fatiguing effects, rest periods were given at five to seven minute intervals during each examination, and a further break of at least five minutes was also given between eyes. Each volunteer regardless of perimetric experience was given the same instructions in order to minimize any possible operator bias.

Global mean and median sensitivities were calculated for each eye for each visit. Changes in sensitivity were calculated between visits for each eye and between eyes for both the untrained and trained as a function of age group. The unweighted short-term fluctuation (SF) was calculated for each eye at each visit using the ten standard stimulus locations used for determination of the conventional weighted SF.

Additionally, each field was divided into four annular rings of increasing eccentricity[13]. Mean and median sensitivities were calculated for each zone. The inner region, zone 1, consisted of 12 stimulus locations, zone 2 of 18 locations, zone 3 of 20 locations and the far peripheral zone 4 of 24 locations. Differences in sensitivity between visits within each zone for each eye were calculated for each group of subjects.

Results

The results are listed in Tables 1 and 2. The mean sensitivity (MS) was lower and the unweighted SF higher for the older age group. MS was greater in the untrained than trained groups irrespective of age. The exact reason for this is unclear. It is possibly due to subtle differences in the sample characteristics such as motivation. All groups showed evidence of improvement in performance from days 1 to 10, particularly between days 3 and 10. In general, the improvement was greater in the first (*i.e.*, right) eye.

The young trained group, paradoxically, showed the greatest increase in MS over days 1 to 10. The untrained groups generally showed less improvement than the trained groups.

The unweighted SF improved with repeated examination for both trained and untrained subjects across both age groups. In general the improvement was less in the second eye for all groups and greater for the untrained group.

Table 1. Global median, mean MS (SE)(log units) and unweighted short-term fluctuation (SF)(log units) for each eye at each perimetric examination

		Day 1		*Day 2*		*Day 3*		*Day 10*	
Young trained									
MS	R	2.39		2.45		2.52		2.65	
		2.34	(0.08)	2 46	(0.05)	2.52	(0.08)	2.63	(0.05)
	L	2.40		2.40		2.53		2.61	
		2.39	(0.06)	2 43	(0.07)	2.54	(0.07)	2.60	(0.05)
SF	R	1.55		1.18		1.48		1.26	
		1.70	(0.13)	1.17	(0.14)	1.58	(0.21)	1.33	(0.14)
	L	1.30		1.22		1.55		1.44	
		1.48	(0.20)	1.26	(0.14)	1.52	(0.14)	1.43	(0 11)
Young untrained									
MS	R	2.63		2 64		2.58		2 67	
		2.52	(0.08)	2.65	(0.05)	2.65	(0 05)	2.68	(0.07)
	L	2.57		2.59		2.60		2.65	
		2.51	(0.07)	2 63	(0.05)	2.60	(0.05)	2 55	(0.12)
SF	R	2.05		1 67		1.41		1.22	
		2.11	(0.24)	1.46	(0.17)	1.35	(0.11)	1.31	(0.10)
	L	1.18		1.18		1.26		1.26	
		1.33	(0.14)	1.24	(0.08)	1.42	(0.13)	1.34	(0.14)
Old trained									
MS	R	1.81		1.73		1.72		1.84	
		1 77	(0.11)	1.76	(0 11)	1.76	(0.11)	1.92	(0.11)
	L	1.71		1 65		1.68		1 95	
		1.70	(0.10)	1.73	(0.11)	1.68	(0.11)	1.88	(0.11)
SF	R	1.64		1.58		1.67		1.61	
		1.83	(0.15)	1.67	(0.11)	1.69	(0.15)	1.80	(0.12)
	L	1.76		1.76		1.91		1.58	
		1.90	(0.19)	1.82	(0.12)	1 87	(0 11)	1.56	(0.13)
Old untrained									
MS	R	1.99		2.02		2.05		2.03	
		2.00	(0.15)	2.09	(0.13)	2.09	(0.13)	2.11	(0.14)
	L	1.99		2.04		2.00		2.12	
		2.04	(0.15)	2.03	(0 11)	2.03	(0.14)	2.08	(0.16)
SF	R	2.10		1.95		1.79		1.18	
		2.14	(0.21)	1.98	(0.11)	1.74	(0.12)	1.29	(0.10)
	L	1.90		1.55		1.61		1.34	
		1.98	(0.17)	1.48	(0.18)	1.83	(0.20)	1.58	(0.23)

Table 2. Difference in global median MS and unweighted SF for days 10-1, 10-3 and 3-1. Positive value represents an increase and negative values a decrease in log units

		Day 10-1	*Day 10-3*	*Day 3-1*
Young trained				
MS	R	0.26	0.13	0.13
	L	0.21	0.08	0.13
SF	R	-0.29	-0.22	-0.07
	L	0.14	-0.11	0.25
Young untrained				
MS	R	0.04	0.09	-0.05
	L	0.08	0.05	0.03
SF	R	-0.83	-0.19	-0.64
	L	0.08	0.00	0.08
Old trained				
MS	R	0.03	0.12	-0.09
	L	0.24	0.27	-0.03
SF	R	-0.03	-0.06	0.03
	L	-0.18	-0.33	0.15
Old untrained				
MS	R	0.04	-0.02	0.06
	L	0.13	0.12	0.01
SF	R	-0.92	-0.61	-0.31
	L	-0.56	-0.27	-0.29

Discussion

The influence of prior experience on sensitivity both within and between tests has clear relevance in the interpretation of the visual field. All psychophysical methods of assessing visual function are contaminated by the observer's response characteristics, whether this is span of attention, level of experience or fatiguing. Fatiguing has been shown to occur in perimetric examination in normals[14-16], in ocular hypertension[17] and in glaucoma[18,19]. The outcome is therefore influenced by the degree to which a patient learns the given technique and secondly by the decline in performance due to fatigue. The resultant component thus depends on the level of experience of the observer.

The minimal increase in MS for the untrained groups was less than expected and could be due to the presence of fatiguing effects counteracting the impact of learning, to the higher baseline sensitivity of the untrained groups negating the learning component or to a complex interaction of these factors. Indeed, the trained and untrained young groups exhibited similar final MSs at day 10. All groups exhibited a reduction in the short-term fluctuation. The improvement in performance of the trained group may result from the acquisition of new skills required for the detection of blue-on-yellow stimuli or may result from a regression of the experience of white-on-white stimuli. Indeed, such a regression over an average period of nine months has been reported previously[19]. The learning effect is considered to be a cognitive or judgmental process and is unrelated to any neural interaction of color discrimination[20]. Learning associated with color vision testing is believed to be due to the familiarity with the test rather than to the color itself[1].

References

1 Aspinall PA: Some methodological problems in testing visual function. Mod Prob Ophthalmol 13:2-7, 1974
2 Wood JM, Wild JM, Hussey MK, Crews SJ: Serial examination of the normal visual field using Octopus automated projection perimetry: evidence for a learning effect. Acta Ophthalmol 65:326-333, 1987
3. Heijl A, Lindgren G, Olsson J: The effect of perimetric experience in normal subjects. Arch Ophthalmol 107:81-86, 1989
4 Werner EB, Adelson A, Krupin T: Effect of patient experience on the results of automated perimetry in clinically stable glaucoma patients. Ophthalmology 95:764-767, 1988
5 Wild JM, Dengler-Harles M, Searle AET, O'Neill EC, Crews SJ: The influence of the learning effect on automated perimetry in patients with suspected glaucoma. Acta Ophthalmol 67:537-545, 1989
6. Werner EB, Krupin T, Adelson A, Feitl ME: Effect of patient experience on the results of automated perimetry in glaucoma suspect patients. Ophthalmology 97:44-48, 1990
7. Johnson CA, Adams AJ, Lewis RA: Automated perimetry of short-wavelength mechanisms in glaucoma and ocular hypertension. In: Heijl A (ed) Perimetry Update 1988/89, pp 31-37. Amsterdam: Kugler Publ 1989
8. Johnson CA: Progression of glaucomatous visual field loss over five years: a comparison of white-on-white and blue-on-yellow perimetry. Invest Ophthalmol Vis Sci (Suppl) 33:1389, 1992
9. Sample PA, Weinreb RN: Color perimetry for assessment of primary open-angle glaucoma. Invest Ophthalmol Vis Sci 31:1869-1875, 1990
10 Sample PA, Weinreb RN: Progressive color visual field loss in glaucoma. Invest Ophthalmol Vis Sci 33:2068-2071, 1992
11. Yeh T, Smith VC, Pokorny J: The effect of background luminance on cone sensitivity functions. Invest Ophthalmol Vis Sci 30:2077-2086, 1989
12. Hudson C, Wild JM: Increment threshold spectral sensitivity functions on coloured backgrounds: implications for color perimetry 1992. (submitted for publication)
13. Flanagan JG, Moss ID, Hudson C, Wild JM, Prokopich L. Whitaker D, O'Neill EC: Evaluation of FASTPAC: a new strategy for threshold estimation with the Humphrey Field Analyzer. Graefe's Arch Clin Exp Ophthalmol (in press)
14. Heijl A: Time changes of contrast thresholds during automated perimetry. Acta Ophthalmol 55:696-708, 1977
15. Johnson CA, Adams CW, Lewis RA: Fatigue effects in automated perimetry. Appl Opt 27:1030-1037, 1988
16. Searle AET, Shaw DE, Wild JM, O'Neill EC: Within and between learning and fatigue effects in normal perimetric sensitivity In: Mills RP, Heijl A (eds) Perimetry Update 1990/91, pp 533-537. Amsterdam: Kugler Publ 1991

17. Langerhorst CT, Van den Berg TJTP, Veldman E, Greve EL: Population study of global and local fatigue with prolonged testing in automated perimetry. Doc Ophthalmol Proc Ser 49:657-662, 1987
18. Heijl A, Drance SM: Changes in differential threshold in patients with glaucoma during prolonged perimetry. Br J Ophthalmol 67:512-516, 1983
19. Wild JM, Searle AET, Dengler-Harles M, O'Neill EC: Long-term follow-up of baseline learning and fatigue effects in the automated perimetry of glaucoma and ocular hypertensive patients. Acta Ophthalmol 69:210-216, 1991
20. Breton ME, Fletcher DE, Krupin T: Influence of serial practice on Farnsworth-Munsell 100-Hue scores: the learning effect Appl Opt 27:1038-1044, 1988

Color visual fields: a five-year prospective study in suspect eyes and eyes with primary open angle glaucoma

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Introduction

Current clinical methods for assessment of visual fields in eyes with primary open angle glaucoma may not show sensitivity loss until a considerable number of retinal ganglion cells have atrophied[1]. Histopathologic evidence has indicated damage primarily to cells with larger optic nerve fibers[2], M cells, which project to the magnocellular layers of the lateral geniculate nucleus, and possibly a subset of P cells which have large fibers projecting to the parvocellular layers. The latter most likely project from ganglion cell "on-centers" which handle inputs from short-wavelength sensitive cones and have cell bodies which are approximately 50% larger than those handling middle and long-wavelength cone inputs[3]. This may explain why several investigators have found significant deterioration of short-wavelength sensitivity in eyes with primary open angle glaucoma[4-7]. Color visual fields show more extensive deficits than standard fields in eyes with glaucoma[8]. Additionally, color visual fields show progressive loss sooner than standard fields[8], and color visual fields show deficits in suspect eyes when standard fields are normal[6]. Finally, color fields identify early functional loss in suspect eyes at greatest risk for developing primary open angle glaucoma[9]. We present here results from a five-year longitudinal study of color visual fields in glaucoma (n=100) and glaucoma suspect eyes (n=55), compared to a normative database of 100 eyes. We conclude that the results found in earlier studies are substantiated in this large cohort, and we add information on the nature and extent of the loss at the time glaucoma is diagnosed. We give here a brief summary of results which will be reported in detail elsewhere[10].

Material and methods

Visual fields

Both standard and color visual fields were obtained on a Humphrey Visual Field Analyzer, model 620, using program 24-2. Color visual fields are described below. Standard visual fields refer to traditional white stimulus, white background automated perimetry. Procedures for standard and color fields were identical. As previously reported, we modified the perimeter to provide a bright yellow background of 89.0 cdm^{-2}, which would produce a retinal illuminance of approximately 2.8 log photopic trolands[4,6]. This background is within the range for best isolation of the short-wavelength mechanism.

We have found the stimulus to be critical in successful isolation of the short-wavelength mechanism. And we have previously reported the rationale and psychophysical evidence for our selection of a 440 nm stimulus near the peak of the short-wavelength cone response[6].

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Modifications to the field analyzer allowed a 3.0 log unit range of usable intensities.* Two additional parameters which enhance isolation of the short-wavelength sensitive mechanisms are a large diameter stimulus (Goldmann V, 1.8°), and a stimulus duration of 200 msec. Each color visual field was corrected for lens density using a previously described and validated procedure[11].

Diagnosis

All eyes had a complete ophthalmologic examination and subjects were optimally refracted for all tests. Subjects with ocular pathology other than increased intraocular pressure or optic nerve head abnormalities, a history of congenital color vision loss, pupil diameters less than 3 mm, or ocular surgery, were excluded from the study. Only those having intraocular pressures of less than 21 mmHg, normal optic nerve heads, normal standard visual fields, and no family history of glaucoma were included in the normal group. Suspect patients exhibited questionable optic nerve heads and/or intraocular pressures exceeding 24 mmHg on at least two occasions, but no standard visual field loss. Primary open angle glaucoma was diagnosed in eyes with intraocular pressure exceeding 24 mmHg on at least two occasions, and either characteristic glaucomatous optic disc appearance or visual field loss or both. One eye was selected randomly for each subject.

Subjects

One hundred normal control eyes were included in the normative database for color visual fields. Fifty-five suspect eyes were evaluated, 25 of which had been followed for at least one year (range 12-37 months). One hundred eyes with primary open angle glaucoma were included.

For some comparisons, subjects were matched for both age and lens density.

Analysis

Differences in mean log threshold and number of defective points between groups were evaluated using analysis of variance. A p value of less than 0.05 was considered significant.

To analyze localized *versus* diffuse components of the fields, we used the glaucoma hemifield test as proposed by Åsman and Heijl[12,13].

Results

Comparison of standard and color visual fields

Short-wavelength sensitive color visual fields showed increased sensitivity and specificity when compared to standard visual fields on the same eyes using the glaucoma hemifield test and as reported elsewhere[14]. Additionally, both short-term and long-term fluctuation were comparable to that found on standard visual fields[14].

Differences among subject groups

The mean relative threshold in dB for the three groups at each of the 53 color visual field locations was calculated. There were significant differences between normal and glaucoma eyes throughout the visual field ($p<0.001$) and between normal and suspect eyes in the superior nasal quadrant ($p<0.05$). These results are consistent with those we reported earlier for ten normal, 14 suspect, and 16 glaucoma eyes[6]. Suspect mean values are intermediate between the glaucoma and normal sample at many visual field locations.

*Modifications described in reference 2 are those used for all data reported here. However, we have recently improved on these modifications, without altering the stimulus and background configurations. This information is available from Dr. Sample.

Progression of color visual field loss

We have previously reported that color fields show progression of sensitivity loss prior to evidence for progression on standard fields in eyes with primary open angle glaucoma[8]. The ability to detect early change is also noted in suspect eyes[9].

Early diagnosis

One aspect of color visual fields which has become apparent as our study population grew, was the diffuse component to the visual field loss. This diffuse loss cannot be accounted for by cataract. The results of the glaucoma hemifield test confirmed this.

Discussion

In light of the mounting evidence that color visual fields are more sensitive to early diagnosis and more effective for monitoring progressive loss in patients with ocular hypertension and primary open angle glaucoma, accurate methods for analyzing the fields need to be developed. The glaucoma hemifield test has been shown to improve the sensitivity and specificity of diagnosis of glaucoma based on standard fields[13]. This was found for color fields, as well. Employing this test in color visual fields showed a number of eyes with diffuse loss which cannot be accounted for by cataract as all fields are corrected for lens density. This diffuse loss cannot be accounted for by age as the analysis takes this into account. It might be accounted for by undiagnosed disease processes other than glaucoma, however, all individuals had complete medical and ophthalmological examinations and been diagnosed as glaucoma based on generally accepted criteria. For these reasons, it is likely that the diffuse component is due to reduced function of short-wavelength mechanisms in glaucoma. This diffuse component has been described previously[7,9]. The implication of this result may be that the test provides very early evidence of disease. This suggestion was supported by our data on suspect eyes, which showed that 3% had only this diffuse component, and that early color fields showed localized loss which progressed to include much of the visual field by the time of diagnosis of glaucoma. Continued long-term follow-up of a larger group of suspect eyes is planned and should help to determine the prevalence of these patterns.

References

1. Quigley HA, Dunkelberger GR, Green WR: Studies of retinal ganglion cell atrophy correlated with automated perimetry in human eyes with glaucoma Am J Ophthalmol 107:453-464, 1989
2. Glovinsky Y, Quigley HA, Dunkelberger GR: Retinal ganglion cell loss is size dependent in experimental glaucoma. Invest Ophthalmol Vis Sci 32:484-491, 1991
3. De Monasterio FM: Asymmetry of on- and off-pathways of blue-sensitive cones of the retina of macaque. Brain Res 166:39-48, 1979
4. Sample PA, Weinreb RN, Boynton RM: Blue-on-yellow color perimetry ARVO Abstracts. Invest Ophthalmol Vis Sci (Suppl) 27:159, 1986
5. Johnson CA, Adams AJ, Lewis RA: Automated perimetry of short-wavelength sensitive mechanisms in glaucoma and ocular hypertension: preliminary findings. In: Heijl A (ed) Perimetry Update 1988/89, pp 31-37. Amsterdam: Kugler Publ 1989
6. Sample PA, Weinreb RN: Color perimetry for assessment of primary open angle glaucoma. Invest Ophthalmol Vis Sci 31:1869-1875, 1990
7. Hart WM, Silverman SE, Trick GL, Nesher R, Gordon MO: Glaucomatous visual field damage: luminance and color contrast sensitivities. Invest Ophthalmol Vis Sci 31:359-367, 1990
8. Sample PA, Weinreb RN: Progressive color visual field loss in glaucoma. Invest Ophthalmol Vis Sci 33:2068-2071, 1992
9. Sample PA, Taylor JDN, Martinez GA, Lusky M, Weinreb RN: Short-wavelength color visual fields in glaucoma suspects at risk. AJO 10/1992
10. Sample PA, Martinez GA, Weinreb RN: Color visual fields in suspect eyes and eyes with primary open angle glaucoma: a 5 year prospective study. 1992 (submitted for publication)
11. Sample PA, Esterson FD, Weinreb RN: A practical method for obtaining an index of lens density with an automated perimeter Invest Ophthalmol Vis Sci 30:786-787, 1989

12. Åsman P, Heijl A: Glaucoma hemifield test: automated visual field evaluation. Arch Ophthalmol 110:812-819, 1992
13. Åsman P, Heijl A: Evaluation of methods for automated hemifield analysis in perimetry. Arch Ophthalmol 110:820-826, 1992
14 Sample PA, Cook JN, Weinreb RN: Variability and sensitivity of short-wavelength color visual fields in normal and glaucoma eyes. 1992 (submitted for publication)

The effect of forward light scatter on chromatic sensitivity thresholds

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Abstract

Forward light scatter causes a reduction in image contrast on the retina, the amount of which depends on the quality of the media within the eye. Light scatter is known to attenuate the visual field with the greater effect in the periphery. Recently blue-on-yellow stimuli have been used selectively to isolate the short-wavelength sensitive (SWS) pathways. The effect of forward light scatter on the visual field recorded by blue-on-yellow perimetry is unknown. Eleven young normals were investigated with a modified Humphrey Field Analyzer 630 using a custom program along the 20° meridian. Forward light scatter was induced using 0.08% and 0.16% concentrations of 500 nm suspensions of polystyrene microspheres. The effect of scatter was investigated using white-on-white (stimulus sizes III and V), yellow-on-yellow (stimulus size V, Schott OG530 filters) and blue-on-yellow (stimulus size V, OCLI blue dichroic, Schott OG530) stimuli. Scatter was quantified using the direct compensation technique of van den Berg. Perimetric attenuation increased with increase in forward light scatter. The attenuation was greater for the B-Y stimuli and increased towards the periphery.

Introduction

The quality of the retinal image is affected by a number of factors such as aberrations, refractive imperfections and intraocular light scatter which blurs the retinal image and causes a decrease in image contrast. Light scatter can be separated into forward and backward components. The former produces a veiling luminance which leads to a reduction of image contrast.

Conditions such as cataract produce an increase in the amount of light absorption and of forward light scatter[1,2]. The effect of media changes on an external point source such as a perimetric spot stimulus can be defined in terms of the point spread function (PSF) - the retinal light distribution resulting from the source. The PSF can be represented as a bell-shaped curve made up of two parts: a central region of up to 10 min of arc and a peripheral part (straylight).

The influence of cataract on the visual field has been investigated using simulations including ground glass[3,4], orthoptic occluders[5,6] and neutral density filters[7]. Cataract leads to a general reduction in sensitivity of the visual field and an amplification of existing field loss[8]. Studies have shown a decrease in sensitivity with increased scatter at increasing eccentricities and lower background luminances[9,10].

Recently, there has been renewed interest in chromatic perimetry. SWS stimuli (*i.e.*, blue stimuli on a high luminance yellow background) have been shown to be useful as an early indicator of glaucomatous damage, yielding defects which often precede the presence of visual field defects recorded by conventional white-on-white perimetric stimuli. The SWS response has also been recorded across the visual field in glaucoma[11-13], diabetes[14] and age-related maculopathy[15]. The wavelength dependency of intraocular light scatter remains equivocal[16-19]. Preretinal factors showing a wavelength dependency, *i.e.*, lenticular absorption and macular pigmentation, have been shown to have a significant effect in increment threshold measurements[20]. However, little attention has been given to the relationship between forward light scatter and perimetric attenuation in chromatic perimetry.

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The aim of this study was to investigate the effects of simulated forward light scatter on the SWS sensitivity gradient and to compare the findings with conventional white-on-white (luminance) profiles.

Material and methods

The sample comprised 11 normal young caucasian volunteers (seven males and four females; mean age 24.18 years, SD 3.43) conforming to rigid inclusion criteria. A corrected visual acuity of at least 6/6, emmetropia for the working distance of 33 cm, no history of ocular disease or trauma, no history of amblyopia, no neurological history or history of systemic disease, no systemic medication known to influence visual field sensitivity and normal color vision by the Farnsworth-Munsell 100-hue test. All subjects were experienced in automated perimetry and had all undergone at least four full threshold automated perimetric examinations. One subject had a lightly pigmented iris, eight had medium pigmented irides and two had darkly pigmented irides.

Intraocular light scatter was simulated using 0.08% and 0.16% concentrations of solutions of polystyrene microspheres contained in cells constructed from 75 mm diameter CR39 lens blanks mounted either side of a perspex ring[9]. A bead diameter of 500 nm was chosen since the diameter of protein found in cataractous lenses in humans[21] is between 300 and 500 nm.

Perimetry was performed on the right eye of each subject, using a modified Humphrey Field Analyzer 630. The standard background illumination was extinguished using 5.3 software and a high intensity external illumination system was added using ELE/ELT 80W/30V tungsten halogen bulbs mounted either side of the perimeter housing behind infrared and diffusing filters. Cooling fans were added to dissipate heat produced from the bulbs. The stimulus filter was mounted on the projection arm of the perimeter. Perimetry was performed for each of four stimulus configurations: conventional white-on-white perimetry (31.5 asb, stimulus sizes III and V), blue-yellow perimetry (330 cdm^{-2} background illumination, stimulus size V and OCLI blue dichroic filter transmitting wavelengths below 475 nm and above 650 nm) and yellow-yellow perimetry (330 cdm^{-2} background illumination, Schott OG530 filter transmitting above 500 nm and stimulus size V). The background and filters were calibrated using an LMT L1003 photometer. A custom program along the 20° meridian with 6° inter-stimulus separation out to an eccentricity of 30° was used together with the foveal threshold option. The stimulus duration was 200 msec. The program was repeated four times for each stimulus configuration. Each combination was measured for each of four scatter configurations: the cell-free state, a saline-filled cell and for both scatter cells. The scatter cells were positioned as close to the eye as possible and were mounted on the head rest of the perimeter. Care was taken to ensure that the surface of the cells remained perpendicular to the eye avoiding reflections from the surface of the cells. Group mean pupil size corresponding to each of the cell configurations (*i.e.*, no cell, saline-filled, 0.08% and 0.16% concentrations) for the white background was 5.26 mm (SE 0.22), 5.08 mm (SE 0.17), 5.40 mm (SE 0.23) and 5.94 mm (SE 0.20), respectively, and for the high luminance yellow background 3.70 mm (SE 0.16), 3.76 mm (SE 0.15), 3.34 mm (SE 0.16) and 3.34 mm (SE 0.19).

The degree of intraocular light scatter factor was measured with and without each cell using the direct compensation technique of Van den Berg[22,23]. Observers were required to fixate the center of a 2°-diameter dark spot and to cancel the resulting central 8 Hz flicker emanating from the peripheral glare source by decreasing the luminance of the fixating spot until the counterphase 8 Hz flicker disappeared. Cancellation is achieved when the retinal intensity is equal to the peripheral part of the point spread function. The measurement was repeated six times at 3.5°, 10° and 28° angles of scatter. The scatter factor can be quantified by:

$$\text{Log}\,[\varnothing \times L/E]$$

where $\varnothing$ is the diameter of the glare ring, E is the luminance at the eye of the glare source and L is the luminance required to compensate for straylight.

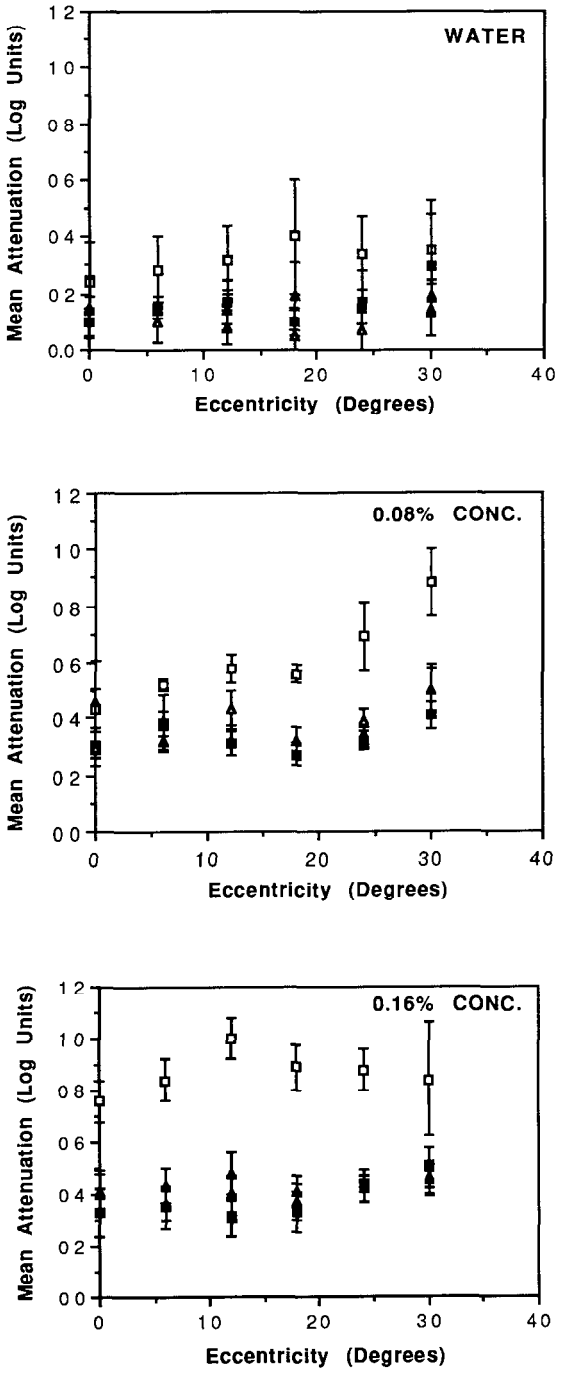

Fig. 1. Group mean of mean attenuation in sensitivity for each cell configuration and stimulus combination as a function of eccentricity. Error bars represent two standard errors of the mean (open symbols represent blue-on-yellow stimuli).

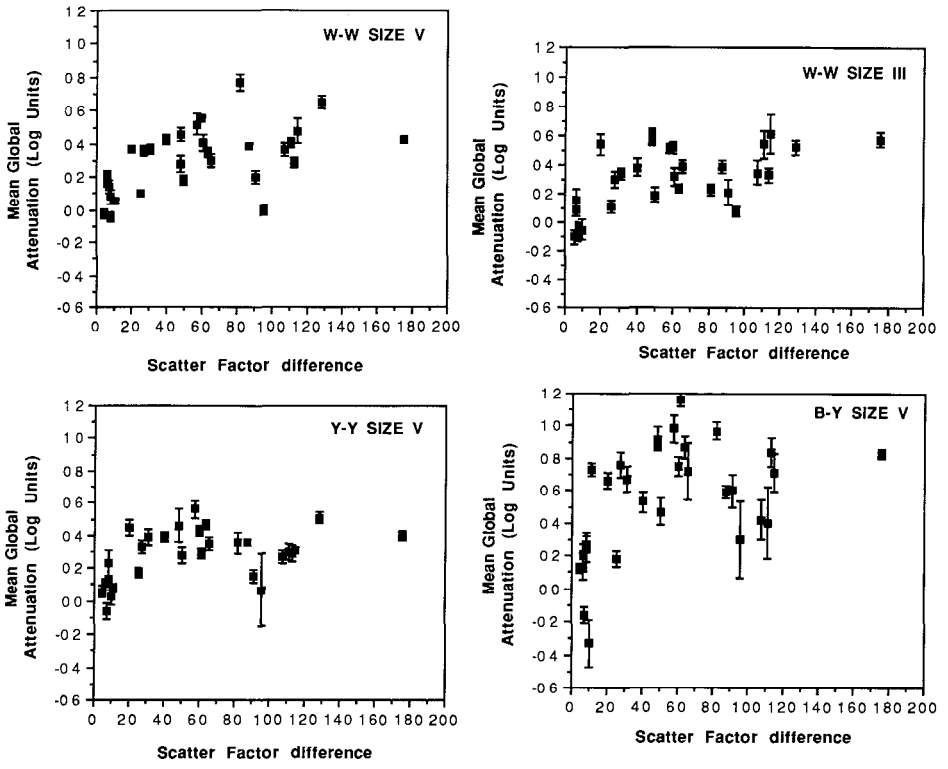

Fig. 2. Mean attenuation in sensitivity for each stimulus combination and cell configuration as a function of the scatter factor difference. Error bars represent two standard errors of the mean.

Results

The group mean of mean attenuation in sensitivity for each cell configuration and stimulus combination was plotted as a function of eccentricity (Fig. 1). The degree of perimetric attenuation increased as a function of cell concentration. The attenuation was greatest for the B-Y stimulus combination. The attenuation increased with increase in eccentricity particularly for the blue stimulus. The degree of attenuation was also greater for the size III white stimulus, than for the size V white stimulus.

The mean attenuation in sensitivity for each stimulus combination and cell configuration was plotted as a function of the difference between the scatter factor for the cell-free condition and each of the cell configurations (Fig 2).

Discussion

Forward light scatter has a detrimental effect on perimetric threshold and confirms earlier studies[4,9]. The model used in the present study has a greater effect on blue stimuli.

The attenuation due to the cell mainly comprises absorption and light scatter as does the human crystalline lens[24]. Both these pre-retinal factors serve to attenuate the proportion of short-wavelength reaching the eye. Scotopic thresholds to stimuli of 410 nm and 560 nm were therefore measured with and without the cells in order to provide an indication of the degree of absorption. The technique, which has been used for measuring human lenticular absorption is described in full elsewhere[24]. Subjects were dark adapted for 30 minutes; stimuli were presented at 15.6° eccentricity using a stimulus duration of 100 msec. Thresholds were determined three times. The absorption data were scaled using the "standard observer" data of Van Norren

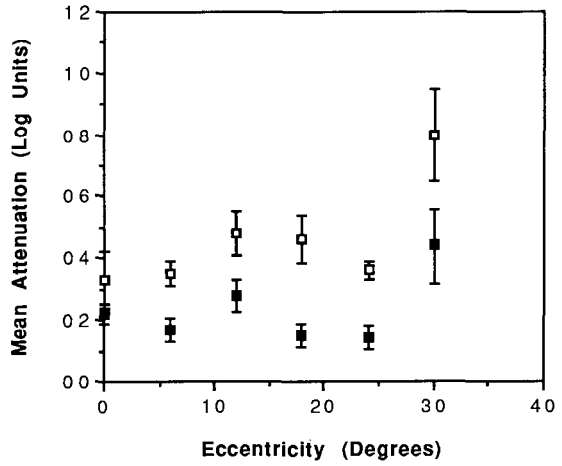

Fig. 3. Group mean of mean attenuation in sensitivity for the 0.08% (filled symbols) and 0.16% (open symbols) scatter cells using blue-on-yellow stimulus configurations after correction for lenticular and scatter cell absorption Error bars represent two standard errors of the mean.

and Vos[24]. A correction factor for lenticular absorbtion of 0.41 log unit (SE 0.02) was then applied to the perimetric data (Fig. 3). The addition of the 0.08% cell produced no increase in absorption whilst that of the 0.16% cell was 0.02 log unit. The resultant perimetric attenuation (mean global attenuation 0.23 log unit (SE 0.05) for the 0.08% cell and 0.46 log unit (SE 0.07) for the 0.16% cell) was therefore primarily considered to be due to forward light scatter. Attenuation increased with eccentricity.

The resultant luminance measured by photometry after passing through the scatter cells was lower than without the cell. An attenuation of retinal luminance in cases of cataract could have a detrimental effect on achieving SWS cone isolation. A background illumination of 200 cd/m^2 is necessary to achieve SWS isolation[25] and the combination of filters and high background illumination achieves 1.2 log units of SWS isolation[20]. However, the magnitude of isolation when retinal luminance is reduced has not been documented. A further study was thus performed on three of the subjects to confirm the existence of blue cone isolation in the presence of the cells. Thresholds for spectral stimuli were measured at the fovea using the modified HFA 630. Thresholds were repeated three times for each of the cell-free, 0.08% and 0.16% conditions. Narrow-band stimulus filters ranging from 410 nm to 605 nm were employed and were

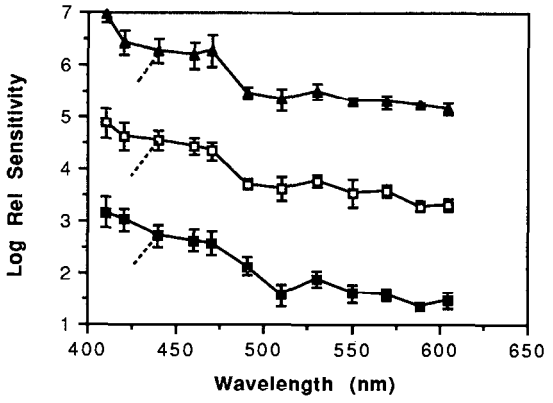

Fig. 4. Foveal increment spectral sensitivity thresholds as a function of wavelength, corrected for preretinal absorption for the cell-free condition (filled squares), 0.08% (open squares) and 0.16% (filled triangles) scatter cell conditions. The 0.08% and 0.16% scatter combinations have been displaced up by 2.0 and 4.0 log units, respectively. Error bars represent two standard errors of the mean. Dashed line represents expected decline in sensitivity.

superimposed on the yellow background (Schott OG530, background illumination 330 cdm^{-2}). The data of Wyszecki and Stiles (1982) was used to scale the measured data for lenticular/cell absorption and a correction was made for macular pigment[26]. The spectral sensitivity measurements revealed an isolation of 1.16 log units in the cell-free state, 0.91 log units with the 0.08% cell and 0.94 log units for the 0.16% cell, with greater variability, after correction for lenticular/cell absorption and macular pigment. This indicates that the relationship between absorption and scattering and SWS isolation should not be ignored.

Pupil size has been shown to be of significance in studies of visual function. In particular, pupil size varies as a function of surrounding luminance. It has been argued, however, that as long as Weber's law is operative pupil size changes do not account for changes in sensitivity[27]. The magnitude of SWS isolation in differing retinal illuminances remains equivocal. Nevertheless, pupil size also will affect the degree of forward light scatter.

It can be speculated from the results that forward intraocular light scatter shows a stimulus dependent effect on retinal sensitivity. This finding is contrary to that of Johnson *et al.*[27] who investigated both yellow and white stimuli and concluded that lens-related scatter was not an important factor in age-related sensitivity loss. The results of the present study show little difference in attenuation between the white and yellow stimuli but pronounced attenuation for blue stimuli.

The study suggests that it may be necessary to correct not only for pre-retinal absorption but also for forward intraocular light scatter before a quantitative assessment can be made of the SWS visual field. Additionally, the reduction in the retinal illumination of patients with media disturbances may be sufficient to reduce the degree of SWS isolation thus negating the use of the technique in the case of media opacity.

References

1. Mellerio J: Light absorption and scatter in the human lens. Vision Res 11:129, 1974
2. De Waard PWT, IJspeert JK, Van den Berg TJTP, De Jong PTVM: Intraocular light scattering in age related cataracts. Invest Ophthalmol Vis Sci 33:618-625 1992
3. Williams RA, Enoch JM, Essock EA: The resistance of selected hyperacuity configurations to retinal image degradation. Invest Ophthalmol Vis Sci 25:389-399, 1984
4. Heur DK, Anderson DR, Knighton RW, Feur WJ, Gressel MG: The influence of simulated light scattering on automated perimetric threshold measurements. Arch Ophthalmol 106:1247-1251, 1988
5. Niesel P, Wiher CI: Modellexperimente zum verhalten glaukomatoser Gesichtsfeldausfalle bei Kataraktentwicklung. Klin Mbl Augenheilk 180:461-463, 1982
6. Urner-Blochl U: Simulation of the influence of lens opacities on the perimetric results, investigated with orthoptic occluders. Doc Ophthalmol Proc Ser 49:23-31, 1987
7. Eichenberger D, Hendrickson P, Gloor B: Influence of ocular media on perimetric results. 2. Effect of simulated cataract. Doc Ophthalmol Proc Ser 49:9-13, 1987
8. Greve EL: Visual fields, glaucoma and cataract. Doc Ophthalmol Proc Ser 19:79-88, 1979
9. Wood JM, Wild JM, Crews SJ: Induced intraocular light scatter and the sensitivity gradient on the normal visual field. Graefe's Arch Clin Exp Ophthalmol 225:369-373, 1987
10. Wood JM, Wild JM, Smerdon DL, Crews SJ: Alterations in the shape of the automated perimetric profile arising from cataract. Graefe's Arch Clin Exp Ophthalmol 227:157-161, 1989
11. Johnson CA, Adams AJ, Lewis RA: Automated perimetry of short-wavelength mechanisms in glaucoma and ocular hypertension In: Heijl A (ed) Perimetry Update 1988/89, pp 31-37. Amsterdam: Kugler Publ 1989
12. Johnson CA: Progression of glaucomatous visual field loss over five years: a comparison of white-on-white and blue-on-yellow perimetry. Invest Ophthalmol Vis Sci (Suppl) 33:1389, 1992
13. Sample PA, Weinreb RN: Color perimetry for assessment of primary open-angle glaucoma. Invest Ophthalmol Vis Sci 31:1869-1875, 1990
14. Adams AJ: Chromatic and luminosity processing in retinal disease. Am J Opt Physiol Opt 59:954-960, 1982
15. Applegate RA, Adams AJ, Cavender JC, Zisman F: Early color vision changes in age-related maculopathy. Appl Opt 26:1459-1462, 1987
16. Le Grand Y: Recherches sur la diffusion de la lumière dans l'oeil humain Rev Opt 16:241-266, 1937
17. Vos JJ: On Mechanisms of Glare. Thesis
18. Wooten BR, Geri GA: Psychophysical determination of intraocular light scatter as a function of wavelength. Vision Res 27:1291-1298, 1987
19. Van den Berg TJTP, IJspeert JK, De Waard PWT: Dependence of intraocular straylight on pigmentation and light transmission through the ocular wall. Vision Res 31:1361-1367, 1991

20. Hudson C, Wild JM: Increment threshold spectral sensitivity functions on coloured backgrounds: implications for color perimetry. 1992 (submitted for publication)
21. Bettleheim FA, Siew EL: Biological and physical basis of lens transparency. In: McDevitt (ed) Cell Biology of the Eye, pp 243-297. New York: Academic Press 1982
22. Van den Berg TJTP, Spekreijse H: Measurement of the straylight function of the eye in cataract and other media disturbances by means of a direct compensation method Invest Ophthalmol Vis Sci (Suppl) 28:397, 1987
23. Van den Berg TJTP: Importance of pathological intraocular light scatter for visual disability. Doc Ophthalmol 61:327-333, 1986
24. Van Norren D, Vos JJ: Spectral transmission of the human ocular media Vision Res 14:1237-1244, 1974
25. Yeh T, Smith VC, Pokorny J: The effect of background luminance on cone sensitivity functions. Invest Ophthalmol Vis Sci 30:2077-2086, 1989
26 Wyszecki G, Stiles WS: Color Science New York: John Wiley 1982
27 Johnson CA, Adams AJ, Lewis RA: Evidence for a neural basis of age-related visual field loss in normal observers. Invest Ophthalmol Vis Sci 30:2056-2064, 1989

MISCELLANEOUS TOPICS

Preliminary implementation of the Functional Vision Score system on the Humphrey Field Analyzer

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Abstract

The Functional Vision Score addresses the relations between impairments, disabilities and handicaps by providing a coordinated system for classification and scoring of visual impairments and visual disabilities. Its disability ranges provide a cross-reference to non-visual disabilities. Its visual acuity ranges are based on the internationally accepted geometric progression of letter sizes and follow the classifications of the WHO (ICD-9, ICD-9-CM) and the International Council of Ophthalmology (ICO) Its functional field score completes the system, it combines the option of calculation with pencil and paper (as in the AMA scales) with the option of using an overlay (as in the Esterman grids) but avoids the inconsistencies of the AMA and Esterman systems. This paper describes a prototype implementation for the Humphrey Field Analyzer which will automate all necessary calculations

Background

For the assignment of disability benefits, it is necessary to evaluate the socio-economic handicap an individual has suffered as a result of certain impairments.

The words impairment, disability and handicap are often used as if they were synonyms. They are not. In this text the words disorder, impairment, disability and handicap are used as defined in the WHO "Classification of Impairments, Disabilities and Handicaps"[1].

- Disorder and impairment refer to conditions of organs. Disorder refers to anatomical changes, impairment refers to the resulting functional changes. Most impairments can be measured on standardized scales.
- Disability and handicap refer to conditions of the individual. Disabilities refer to changes in the skills and abilities of the individual. Few standardized disability scales exist. Handicap refers to the social and economic consequences: need for extra effort, loss of independence, loss of earning power, etc.

A disorder may cause an impairment; an impairment may cause a loss of ability; a disability may result in a socio-economic handicap. Yet, these links are not rigid, at each link there may be aggravating as well as compensating factors. Indeed, the fact that rehabilitation is at all possible depends on this flexibility. Rehabilitation may be seen as the art of influencing these links so that a given disorder results in the least possible handicap. This variability implies that any formula can, at best, turn an impairment measurement into a disability estimate.

Since the assessment of disability and handicap is often fraught with subjective factors, many benefit eligibility rules rely on the more easily measured impairment aspects. Fig. 1 indicates how the "Functional Vision Score" provides a bridge from the measurement of impairment to an estimate of disability. The assessment of the socio-economic handicap is a separate step and must consider additional factors, such as training and prior experience, available job opportunities, retraining potential, etc. These factors are beyond the medical realm.

The Functional Vision Score is built around a general classification of disability ranges (Table 1) which is also applicable for non-visual handicaps. The impairment ranges (visual field and visual acuity, Tables 2 and 3) have been fitted to these disability scales, assuring a

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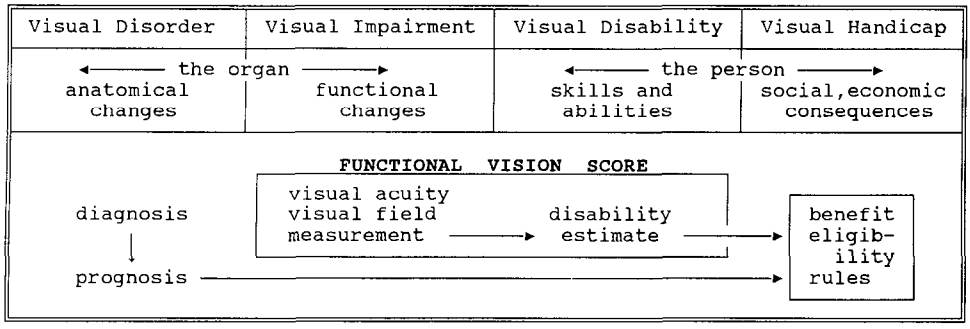

Fig. 1.

level of comparability that is not present in many other systems.

Care has been taken that these ranges match the categories established by the WHO in ICD-9 (1977[2], based on study group proposals from 1972) and ICD-9-CM (1979)[3] and by the International Council of Ophthalmology (ICO) (1978)[4]. The visual acuity levels follow the internationally accepted geometric progression (visual acuity measurement standard, ICO, 1984[5] and ISO, 1986[6]) and translate directly to the logMAR scale for vision loss (5 points FVS loss = 0.1 logMAR). The detailed visual acuity score is a modification of the scoring system used in the clinical studies of the National Eye Institute[7].

Scoring of disability and impairment ranges

The measurement systems for various impairments are quite diverse. How can diverse measurement units, such as those for visual acuity and visual field, be combined to result in a common scale for socio-economic handicap? Conversion to a rating scale or score, expressed in "points" rather than in measurement units provides a solution. A scale from 0 to 100 is often most useful. Assigning 20 points to each range of the general ability classification, places normal performance at 100 and near-total inability at 0 (see Tables 2, 3, 4).

Note that this scale is not a "percentage" scale. A percentage scale, by definition, is truncated at 100 and at 0. The Functional Vision Score is a continuous scale, on which the range from 0 to 100 represents the most commonly used part. This means that 100 is not the absolute maximum but rather a mid value in the normal range. Indeed, healthy adults usually exceed a score of 100 for both visual acuity and visual field. Likewise, 0 does not represent absolute loss of ability, but rather a level at which the skill no longer provides an independent contribution. At best it may serve as an adjunct to other skills.

Transferring this scale to the impairment ranges places "severe visual impairment" (20/200 acuity or 10° field, also known as "legal blindness" in the US) at 50. This seems appropriate from a functional point of view. It differs from the Snell-Sterling "Visual Efficiency" scale (1925)[8] adopted by the AMA[9,10]. The AMA scales place this impairment level at 20. This difference is explained by the fact that the Snell-Sterling scale was based on a study of the economic impact of vision loss in 1925. A person with 20/200 acuity may have lost 80% of earning potential, but is not "80% blind, 20% sighted". The FVS considers 20/200 a half-way point for functional vision and leaves it to other authorities to determine the economic consequences. Another reason for the difference is that the Visual Efficiency scale dates back to the days of "sight saving", when little attention was given to the use of residual vision and to its differentiation. The FVS system reflects today's environment in which rehabilitation has become an important objective.

Inconsistencies in the AMA and Esterman systems

The AMA rules[11], derived from the Snell-Sterling Visual Efficiency rating are widely used. Why is it time to update the system?

One reason is that the FVS system provides a more rational and integrated approach. Yet, by itself, this may not be a sufficient reason to revise the system.

Another reason is that the mathematical basis for the Visual Efficiency scale (a geometric progression of ratings fitted to a linear progression of visual angles) has been shown to be incorrect[12], the FVS system is based on a linear score fitted to a geometric progression of visual angles (Weber-Fechner's law), which is recognized as the best way to accurately scale psychophysical data.

The main reason, however, is that the AMA system through its many revisions, has accumulated many inconsistencies.

Examples for visual acuity include the addition of a scale for near visual acuity (1958). On this scale the criterion level (20) for "legal blindness" is reached at 20/90 rather than at 20/200 (more than twice as good). The scale shows an irregular progression on which the one line change from "newsprint at 50 cm" (20/40) to "newsprint at 40 cm" (20/50) is treated as a 40 (!) point loss, while other one line changes average four points on the near vision scale, eight points on the distance scale. The table to combine distance and near values includes such extremes as 20/20 at distance with 20/200 at near and 20/200 distance with 20/20 near. This suggests the measurement of uncorrected acuities, while the instructions specify "best corrected" acuity.

The visual field rules show similar inconsistencies. While the standard US definition of "legal blindness" is a 10° field (20° diameter), the AMA formula (sum of 8 half-meridians/5) qualifies a 12.5° field. Although Esterman never claimed that his grids were compatible with the AMA rules, since their 1984 revision, the AMA also acknowledges use of the "Esterman grids"[13-15]. This creates additional confusion since the Esterman monocular grid assigns a score of 20 to a 15° field, while the tangent screen grid assigns that score to a 6° field and the binocular grid assigns it to a 20° field (40° diameter, twice the legal criterion).

Furthermore, the distribution of points on the Esterman grids does not fully reflect the claimed functional significance, The fact that the criterion level is placed so low on the scale means that there is little room for differentiation of very narrow fields or paracentral losses. In the peri-central area, the Esterman grids give a 0 value to the two lowest categories on the WHO classification (profound and near-total impairment). In the mid-periphery, the greatest weight (25 points) on the Esterman scale is given to the Bjerrum area (15° to 25°). This is inconsistent with the functional significance of this area: losses in this area are rarely noticed spontaneously by patients. In the far periphery the grids give more weight to the 70° to 80° zone than to the 60° to 70° zone.

Another inconsistency is that the AMA formula gives equal weights to the upper and lower half fields, while the Esterman grids give a double weight to the lower field.

Advantages of the FVS system

The advantages of the FVS system include:

- The FVS score avoids all the above inconsistencies.
- The FVS score combines the best properties of the AMA formula and the Esterman overlays. Because of its regular grid pattern, the FVS field score, like the AMA rating, can be calculated with paper and pencil; like the Esterman grids, it can be used as an overlay.
- Like the Esterman grids, FVS gives more weight (50%) to the lower field, splitting the difference between AMA (no extra weight) and Esterman (100% extra). FVS does this by the simple expedient of counting two half-meridians in each of the upper quadrants and three in each of the lower quadrants.
- Because the measured half-meridians are within each quadrant, rather than on the horizontal and vertical, no special rules for hemianopic defects are needed.
- Unlike the AMA formula and the Esterman grids, FVS gives extra weight to the most central field area. It has been shown that the central 10° provides the input for about half of the primary visual cortex[16]. Assigning 50 points to this area thus reflects the neurophysiology as well as the long established equivalency of the handicap caused by 20/200 acuity and a 10° field.
- If needed for comparison, the FVS score can still be translated to the AMA score by the simple formula: 5 points FVS loss = 8 points AMA loss (average).

- The FVS score also translates directly to the logMAR scale for visual acuity loss: 5 points FVS loss = 0.1 logMAR (exactly).
- The regular grid pattern makes FVS particularly suited for automated perimetry. In the US this is important because to date the Social Security Administration recognizes only Goldmann visual fields for disability certification. With a dwindling number of Goldmann technicians, this has created a serious bottleneck.

Implementation on the Humphrey Field Analyzer

For the first implementation of the FVS system for automated perimetry, the Humphrey Field Analyzer, model 640, was chosen since this equipment is widely used in the US and was available in our department. Implementations on other equipment are equally feasible. The programs were written in C++ on an IBM compatible PC, driving the Field Analyzer through its serial port. A prototype testing, scoring and plotting program is operational; further refinements will still be added.

For manual counting, the ten half-meridians at 20°, 60°, 120°, 160°, 195°, 225°, 255°, 285°, 315° and 345° are used. On each half-meridian 11 dots are placed at 1°, 3°, 5°, 7°, 9°, 15°, 25°, 35°, 45°, 55° and 65°. This places each dot in the center of a 2° or 10° zone. In a normal field, a few superior dots will be missed and a few temporal dots at 65° will be seen, for an average score of about 100. Normal blind spots will go unnoticed between the half-meridians at 345° and 20° or between those at 160° and 195°. Dots are counted if they are inside or just on the III4e isopter. This is equivalent to rounding each value to the nearest multiple of 2° (central field) or 10° (peripheral field) in manual calculation.

For the automated implementation the same array was used, except that alternating dots were moved 7° clockwise or counter-clockwise to achieve a more even coverage. Fig. 2 presents the pattern used for manual calculation and for automated presentation. In the test, all dots are presented in one fixed pseudo-random sequence; central and peripheral points are plotted separately.

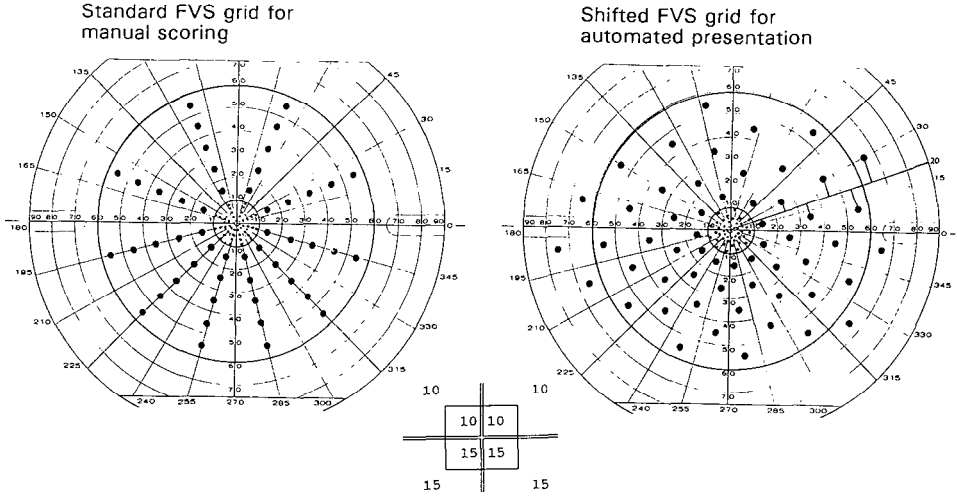

Fig. 2. FVS test points. For manual scoring (left diagram), the basic FVS pattern is arranged along ten half-meridians, two within each upper quadrant, three within each lower quadrant. This gives 50% extra weight to the lower field. The arrangement within each quadrant avoids the need for special rules for hemianopic defects. The central 10° field (which corresponds to half the primary visual cortex) receives 50 points; the peripheral field from 10° to 60° also receives 50 points. A normal field misses some superior points and sees some points temporally beyond 60°, resulting in a score of about 100.
For automated presentation (right diagram), the points are alternately shifted 7° clockwise or 7° counter-clockwise (see the 20° meridian), resulting in a more even coverage. To display the results of the automated test (see Figs. 3 and 4), the central and peripheral FVS points are plotted separately for better separation. This separation applies to the display only; all points are tested together in one random test sequence.

Preliminary results

With this implementation, two groups of subjects were evaluated. The first group had normal eyes which were obscured with masks cut from dark X-ray film, to simulate various severe field deficits. Monocular tests were performed with: *1.* the Goldmann kinetic test (III4e stimulus, the standard for disability assessment), manually scored with the Esterman overlay; 2. the Automated Esterman test (available on the HFA menu after paying licensing fees per Humphrey policy); and *3.* the FVS test, described above. The approximations were encouraging, but further comparisons among normal eyes with simulated defects were abandoned, because of the unavoidable variations in the distance between the opening of the mask and the subject's eyes when moving from one device to the other.

The second group consisted of patients with profound visual field loss, referred from either the Glaucoma or Low Vision Services of our Department of Ophthalmology. We present preliminary data, based on eight eyes of six patients tested on the current configuration of our program. When feasible, binocular tests were performed also.

All subjects performed the FVS test in well under five minutes. The results are printed out in two maps, one for the peripheral and one for the central field. The peripheral map contains an indication, but not an actual representation of the central points.

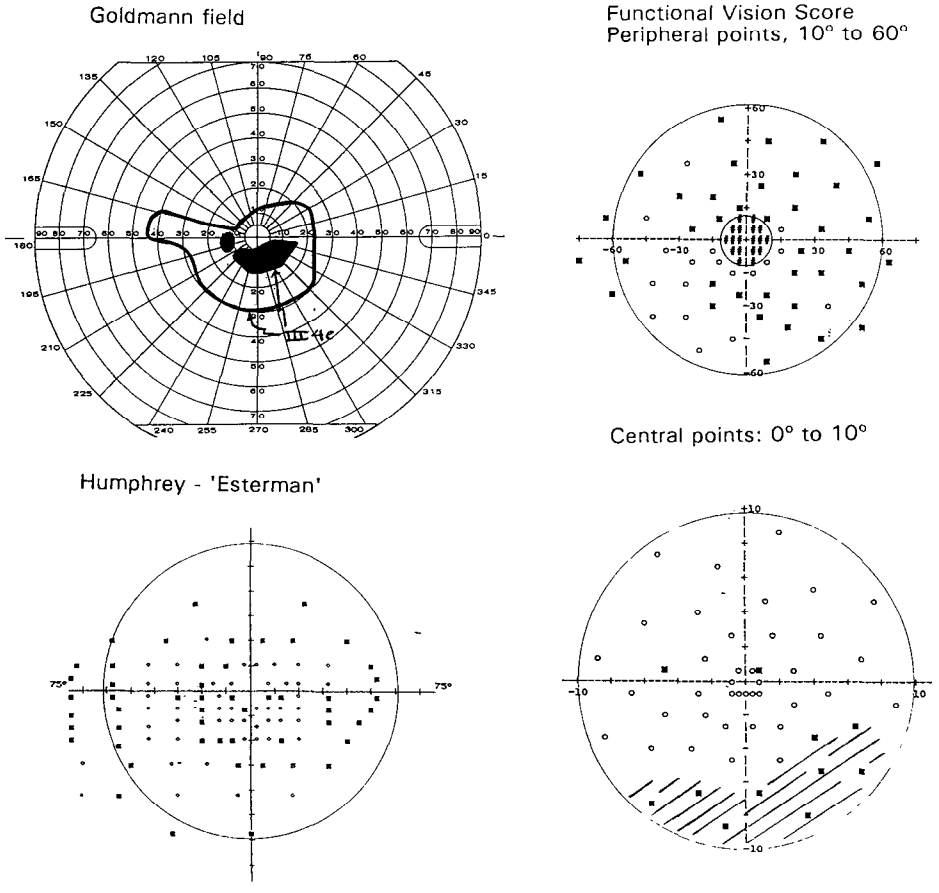

Fig. 3. Patient example. Patient SC. Diagnosis: advanced glaucoma; visual acuity: 20/25. The Goldmann field (top left) shows peripheral loss and a large para-central scotoma. The "Esterman" plot on the Humphrey Field Analyzer (bottom left) and the peripheral FVS plot (top right) show additional peripheral points missed on the Goldmann. The "Esterman" plot misses only four points in the para-central scotoma; the FVS central plot (bottom right) gives a clearer outline of the scotoma.

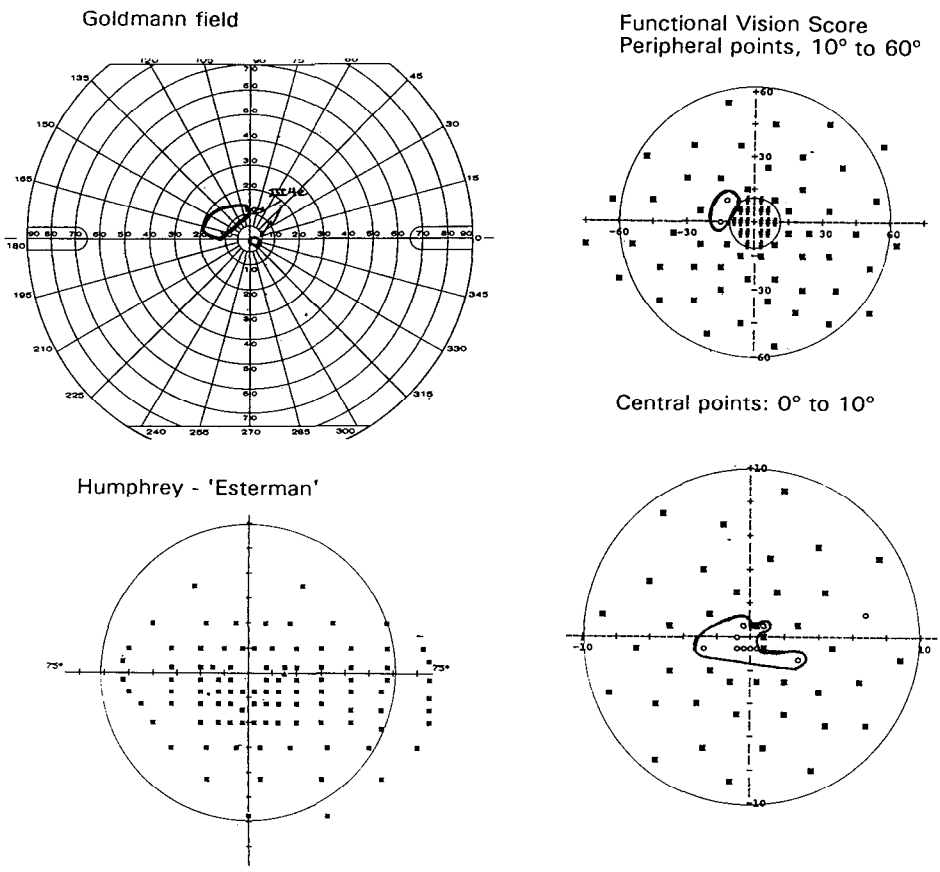

Fig. 4. Patient example Patient AM. Diagnosis: advanced glaucoma; visual acuity: 20/60. The Goldmann field (top left) shows a para-central island and a very small central island in which visual acuity of 20/60 is preserved On the "Esterman" plot on the Humphrey Field Analyzer (bottom left), none of the test points were seen, suggesting total vision loss The FVS test shows both the para-central island (see the peripheral plot, top right) and the central island (see the central plot, lower right).

The automated Esterman test took an average of eight minutes per eye. Of interest was the poor correlation between the manual Esterman score, calculated by overlay on the Goldmann field and the automated Esterman score for the same eye.

Comparing the Esterman Score and the FVS Score for the same eyes, the inherent bias of each test was obvious: the Esterman score emphasizes the peripheral points of preserved vision (Fig. 3), and the Functional Field Score emphasizes eyes with remaining central islands (Fig. 4). Patients with only small preserved islands were particularly appreciative of the relative speed and engagement of the FVS test, since so much of the Esterman test time was spent on the unseen peripheral points.

Conclusions and plans

To date, too few patients have been tested to draw useful statistical inferences between the two methods. Static-kinetic dissociation is likely a major source of differences. Extensive patient testing will continue to validate and standardize our test and to refine the correlations between computerized disability tests and today's manual kinetic tests and current disability

criteria. We will also enhance the front end of our test program to include all necessary calculations, including calculating the overall Functional Vision Score from the visual acuity values (manually entered at the screen) and the measured Functional Field Score. This will include a provision to prevent double scoring of central scotomata under both visual acuity and visual

Table 1. General classification of disability

GENERAL CLASSIFICATION	SCORE	GENERAL DESCRIPTION of PERFORMANCE RANGES for .... RELATED TASKS		Use of Aids
Range of Normal Ability	100 ±10	(Near-) Normal Performance (may require aids)	Normal Performance of all .... related tasks	none
Near-normal Ability	80 ±10		(Near-)Normal Performance with adjustments and loss of reserves	no need yet
Moderate Disability	60 ±10		(Near-)Normal Performance is possible, but requires aids	Enhancement
Severe Disability	40 ±10	Restricted Performance (even with aids)	Restricted Performance with aids Substitution skills used as adjunct	Substitution skills
Profound Disability	20 ±10		Marginal Performance with aids Often relies on Substitution skills	
Near-total Inability	0 ±10		Relies mainly on Substitution Skills Original Skills used as an adjunct	Original skills
Total Inability		Cannot Perform	Substitution Skills are the only option	

A disability cannot be described without naming the specific task whose performance has been reduced. Yet, certain generalities apply across a variety of tasks. One may consider:
- whether the ability to perform the task is (near) normal, restricted, or impossible;
- whether performance does or does not require certain aids;
- whether the emphasis is on aids that enhance the function, or on aids and techniques that substitute another function for the impaired function.

These considerations lead to the formulation of the following categories:

Range of normal performance: Note that "normal" performance represents a range, rather than a single level. The same is true for each of the subsequent categories. Also note that setting a reference standard should not be confused with specifying "average performance".

Near-normal performance: Since most human functions have a redundant capacity, a range exists in which this redundancy is reduced, while actual performance is not significantly compromised.

Moderate disability: In this range performance begins to be compromised, but the effect of the impairment can still be overcome with appropriate aids that enhance performance. Substitution skills are generally not needed. Availability of such aids is essential for optimal performance. At this level the school system tends to make special educational assistance available.

Severe disability: In this range performance is compromised further. Even with the availability of aids, performance is slower than normal and endurance is less. Performance may be improved or the required effort may be reduced by partial use of substitution skills as an adjunct to the original skills. Economic competitiveness is compromised also. At this level economic assistance (SSI) may become available.

Profound disability: In this range, substitution skills become much more important. The original skills are still useful, but their effectiveness is limited.

Near-total inability: In this range, the original skills have become unreliable. The person mostly relies on substitution skills with the original skills as an adjunct.

Total inability: At this level (total blindness, total hearing loss), substitution skills have become the only option. The original skills are not even an adjunct.

field loss. If visual acuity is reduced, the central scotoma will not be considered, but additional peripheral field loss will, as will para-central scotomata in the presence of good visual acuity. Thus, the seamless integration of the visual field results into an overall picture of a patient's visual impairment will be significantly enhanced by the use of the Functional Vision Score.

Table 2. Visual orientation and visual field loss

GENERAL CLASSIFICATION	SCORE	CLASSIFICATION of VISUAL DISABILITY Based on Performance Ranges for Visual Orientation tasks
Range of Normal	100 ±10	Normal visual Orientation and visual Mobility skills.
Near-normal	80 ±10	Normal 'O & M' performance more scanning, occasionally surprised by events on side
Moderate Loss	60 ±10	(Near-)normal performance requires scanning for obstacles.
Severe Loss	40 ±10	Visual mobility slower than normal requires continuous scanning; long cane useful as adjunct.
Profound Loss	20 ±10	Uses long cane for detection of obstacles, vision for identification.
Near-total Loss	0 ±10	Visual orientation unreliable; Relies on long cane, sound, other 'blind' mobility skills
Total Loss		No Visual Field.

CLASSIFICATION of VISUAL IMPAIRMENT		VISUAL FIELD MEASUREMENT average radius	FUNCTIONAL FIELD SCORE
(NEAR-) NORMAL VISION	Range of Normal Vision	60°	110 -100-
	Near-normal vision	50° loss of one eye 40°	90 80
LOW VISION	Moderate Impairment	30° 20°	70 60
	Severe Impairment	homonymous hemianopia 10° 8°	-50- 40
	Profound Impairment	6° 4°	30 20
(NEAR-) BLIND-NESS	Near-total Impairment	2° 0°	10 - 0-
	Total Impairment	No visual field	

For the sake of simplicity, most examples will assume a concentric vision loss from the periphery inward; it should be noted, however, that the Functional Vision Score deals equally well with irregular losses and localized scotomata

Range of normal vision: Impairment: this range includes persons with loss farther than 50° from fixation. Disability: such losses generally have no perceptible influence on orientation and mobility skills.

Near-normal vision: Impairment: this range includes individuals whose peripheral field loss leaves an average visual field radius of less than 50° but better than 30° Disability: they may occasionally be surprised by an individual showing up at their side, but will generally have little problems getting around with a little more scanning eye movements than usual.

Moderate loss: Impairment: in this range the peripheral field loss encroaches to within 30° of fixation. When looking straight ahead, individuals will not see the ground for several steps ahead. Disability: they may trip over curbs or walk into unexpected obstacles to the side, unless they make constant, conscious scanning eye movements.

Severe loss: Impairment: in this range the visual field is restricted to less than 10° from fixation (20° diameter). Since effective scanning requires a certain overlap between scans, this means that the required number of scans is more than 3× larger than for an individual with a 30° field. Disability: the need for increased scanning slows mobility down. Although visual orientation and mobility is possible, a long white cane to detect obstacles is a worthwhile adjunct. Handicap: in the US, a visual field of "20° (diameter) or less" is the traditional criterion for eligibility for many social and rehabilitative services.

Profound loss: Impairment: in this range the visual field is restricted to less than 5° (10° diameter). Disability: visually detecting all obstacles becomes impractical; reliance on vision substitution (long cane) increases. Once an obstacle is detected using the cane, vision may be used to identify it.

Near-total loss: Impairment: the remaining visual field is restricted to less than 2.5° (5° diameter). Disability: in this range the emphasis is almost entirely on non-visual skills The remaining vision has become an adjunct to the vision substitution skills.

Total loss: Impairment: this group has no vision. Disability: total visual impairment means total loss of visual abilities. Individuals in this group are not useless to society Many totally blind individuals function very well, using vision substitution skills

Table 3. Reading performance and visual acuity loss

GENERAL CLASSIFICATION	SCORE	CLASSIFICATION of VISUAL DISABILITY Based on Performance Ranges for the READING task
Range of Normal	100 ±10	Normal reading performance Normal reading distance
Near-normal	80 ±10	Normal reading performance Shorter reading distance
Moderate Loss	60 ±10	(Near-)normal performance, using magnifiers, other aids
Severe Loss	40 ±10	Slower than normal reading, using magnifiers, other aids
Profound Loss	20 ±10	Limited reading with high power aids, videomagnifier Also relies on Substitution: Talking books, Braille
Near-total Loss	0 ±10	Detail Vision unreliable Relies on readers, talking devices
Total Loss		No Detail Vision

CLASSIFICATION of VISUAL IMPAIRMENT		VISUAL ACUITY MEASUREMENT decimal notation	Snellen fraction (20 ft)	FUNCTIONAL ACUITY SCORE
(NEAR-) NORMAL VISION	Range of Normal Vision	1 6 1 25 1 0 0 8	20/ 12.5 / 16 20/ 20 / 25	110 105 -100- 95
	Near-normal vision	0 63 0 5 0 4 0 32	20/ 32 / 40 / 50 / 60 / 70	90 85 80 75
LOW VISION	Moderate Impairment	25 20 .16 .125	20/ 80 /100 /125 /160	70 65 60 55
	Severe Impairment	.10 .08 .063 05	20/200 20/400	-50- 45 40 35
	Profound Impairment	04 032 025 02	'count fingers' 20/1000	30 25 20 15
(NEAR-) BLIND-NESS	Near-total Impairment	016 .0125 .01 ..	'hand motions' 20/2000	10 5 - 0-
	Total Impairment	No Light Perception (NLP)		0

Range of normal vision: Impairment: this range includes 20/20, but is not truncated at the 20/20 level. Disability: no impairment implies no disability Normal acuity implies a reserve capacity for newsprint.

Near-normal vision: Impairment: this range includes visual acuity levels from 20/30 to 20/60. Disability: comfortable reading distances for this group are from 25 to 40 cm (10" to 15"), with little restriction in reading endurance but with less reserve capacity.

Moderate loss: Impairment: this range includes visual acuity levels from 20/70 to 20/160. In this group shorter reading distances are required: 12.5 to 25 cm (5" to 10") A 4D reading aid or a 25 cm (10") reading distance is the traditional reference point for the magnifying power of aids Disability: the shorter working distance may interfere with writing and with some work habits. Extra magnification in the form of magnifiers or stronger reading glasses (>4 D) is required With appropriate aids individuals in this group can generally maintain near-normal performance levels. Handicap: school systems in the US typically provide special assistance (magnifiers, large print, special education teachers) for students in this range.

Severe loss: Impairment: this range includes visual acuity levels of "20/200 or less". Disability: the required short reading distances (less than 10 cm, 4") preclude binocular viewing. "Inability to read news print" is a common measure of "severe visual disability" in population surveys. In this group vision enhancement (magnifiers, large print, better illumination) is still the predominant way to improve performance. Yet, even with the best of aids, reading speed and reading endurance may be below normal. Individuals may use non-visual skills as an adjunct, finding it easier to listen to the radio than to read a newspaper, while using their magnifier for family news and correspondence. Handicap: "20/200 or less" is the US eligibility criterion for many social and rehabilitative services.

Profound loss: Impairment: this range includes acuity levels of less than 20/400 (3/60). Disability: in this range reliance on vision substitution (use of senses other than vision for traditionally visual tasks) increases. This includes use of hearing (human readers, tape recordings, talking books, radio, TV) or touch (Braille).

Near-total loss: Impairment: this range includes levels often indicated as "hand motions" Disability: in this range the emphasis is almost entirely on non-visual skills. The remaining vision is no longer reliable as an independent source of information and has become an adjunct to the vision substitution skills.

Total loss: Impairment: this group has no vision Disability: total visual impairment means total loss of visual abilities. Individuals in this group are not useless to society Many totally blind individuals function quite well, using vision substitution skills

References

1. International Classification of Impairments, Disabilities and Handicaps, World Health Organization, Geneva, 1980
2. International Classification of Diseases, 9th edn (ICD-9), World Health Organization, Geneva, 1977
3. International Classification of Diseases, 9th Revision-Clinical Modification (ICD-9-CM), 1st edn: Commission on Professional and Hospital Activities, Ann Arbor 1978. Later editions by: US Public Health Service 1980, and by Med-Index 1991
4. Committee on Information, International Council of Ophthalmology: In: 23rd Consilium Ophthalmologicum, Kyoto 1978, Acta: pp 69-74. Amsterdam: Excerpta Medica 1980
5. Visual Acuity Measurement Standard - International Council of Ophthalmology, 1984. Ital J Ophthalmol 2:1-15, 1988
6. ISO Standards 8596 and 8597 on Visual Acuity Testing (draft), International Standards Organization, 1986
7. Early Treatment Diabetic Retinopathy Study Design and Baseline Patient Characteristics: ETDRS Report No. 7. Ophthalmology 98:741-756, 1991
8. Snell AC, Sterling S: The percentage evaluation of macular vision. Arch Ophthalmol 54:443-461, 1925
9. Report of the Committee on Compensation for Eye Injuries. JAMA 85:113-115, 1925
10. Guides to the Evaluation of Permanent Impairment - The Visual System. JAMA 168:475-485, 1958
11. Guides to the Evaluation of Permanent Impairment, 3rd edn, Chicago: American Medical Association, 1988
12. Westheimer G: Scaling of visual acuity measurements. Arch Ophthalmol 97:327-330, 1979
13. Esterman B: Grid for scoring visual fields. I. Tangent screen. Arch Ophthalmol 77:780-786, 1967
14. Esterman B: Grid for scoring visual fields. II. Perimeter. Arch Ophthalmol 79:400-406, 1968
15. Esterman B: Functional scoring of the binocular field. Ophthalmology 89:1226-1234, 1982
16. Wässle H et al: Retinal ganglion cell density and cortical magnification factor in the primate. Vision Res 30:1897-1911, 1990

Visual field and invalidity

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Abstract

The invalidity (disability) percentage attributed to visual field loss varies considerably from country to country and it may also vary within the same country depending on the origin of the visual field damage (*e.g.* war event, work accident, occupational disease, *etc.*)

Such results have been obtained from the analysis of the answers collected by means of a questionnaire sent to all National Ophthalmological Societies and to the members of the IPS Study Groups involved in standards and ergoperimetry.

In order to obtain a standardization in this field, the authors, on the basis of their own experience and thanks to the suggestions of the colleagues consulted through the above mentioned questionnaire, propose new rules for the quantitative assessment of visual field loss, and for the evaluation of the consequent invalidity.

Introduction

The visual acuity assessment is often the only strategy adopted for the medico-legal quantification of the invalidity due to ocular function impairment[1].

Such a method must be frequently integrated with a visual field evaluation since the concomitant perimetric damage may be the determining factor of the visual disability[1,2].

Many authors have proposed personal strategies for visual field impairment quantification as a single parameter or in association with visual acuity by means of particular formulae, but, in this field an international standardization is far from being obtained.[3-14]

Method

In order to collect information concerning the present situation all over the world, a special questionnaire was sent to all the National Ophthalmological Societies and to the members of the IPS Standards and Ergoperimetry study groups (Figs. 1 and 2).

The same questionnaire had the aim of gathering the suggestions of the ophthalmologists interested in this topic.

Results

A total of 105 questionnaires were sent out, but only 23 replies were received from 12 different countries.

The returned questionnaires confirmed that, in this field, a total anarchy exists: every country has its own regulations and frequently the same country has different percentages of invalidity for equivalent impairments according to the origin of the disability (*e.g.* war event, work accident, occupational disease, traffic accident, *etc.*) (Table 1).

Many ophthalmologists stressed the opportunity of establishing standards and sent interesting suggestions regarding the most suitable instruments and strategies to be used for this purpose.

The use of automated perimeters, of programs evaluating the whole visual field and of suprathreshold strategies was generally recommended (Table 2).

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INTERNATIONAL PERIMETRIC SOCIETY

GENOVA: May,21-1992

Dear Collegue,
the need for a standardization of perimetric methods is particularly felt in the field of Ergophthalmology and Legal Medicine

It is the intention of the I P.S study groups interested in Standards and in Ergoperimetry to elaborate common standards for all countries concerning the perimetric damage necessary for obtaining a disability pension or an invalidity percentage

It is therefore necessary to gather certain information, as well as the suggestions of those interested in this subject, and we would thus be grateful if you could answer the enclosed questionnaire

Thank you very much for your cooperation

Sincerely

Prof Enrico Gandolfo
Chairman of the IPS
Ergoperimetry Study Group

Send the completed questionnaire to :
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Fig 1 Letter sent to the experts and to the National Ophthalmological Societies.

*Table 1.*National regulations concerning invalidity due to visual function impairment

Country	*Law yes/no*	*Evaluation criteria for invalidity*	*Different evaluation for different causes*	*Criteria*
Australia	yes	10° or less of arc in the better eye	no	
Belgium	yes	10° longitudinally	yes	accidental damage has particular evaluation
Portugal	no	doctor's criterium	no	
Colombia	no	doctor's criterium	no	
Mexico	no	doctor's criterium	no	
Argentina	no	doctor's criterium	no	
Finland	yes	every defect has its evaluation according to a well detailed formula	no	
France	yes	concentrical damage and emianopiae have precise evaluation	no	
Italy	yes	only concentric damage is considered	yes	accidental damage has particular evaluation
Norway	yes	emianopiae and total constriction are considered by law	no	
Great Britain	no	doctor's criterium	no	
USA	yes	legal blindness for v.f. constriction < 20° plus doctor's criterium	yes	regulations differ with states and circumstances

QUESTIONNAIRE

1) Is there a law in your country which regulates the degree of V.F. damage necessary to obtain a disability pension or an invalidity percentage ?

YES ☐ NO ☐

If "yes", please indicate the adopted V F evaluation criteria:_____

If "no", please indicate how this is handled in practice:_____

2) Are the regulations different with regard to disability originate from accident at work and other disabilities ?

YES ☐ NO ☐

Is "yes", please summarize these differences:_____

3) What type of assessment do you think should be necessary in order to detect the V F impairment ?

a) traditional kinetic perimetry (indicate the most suitable strategy):_____

b) Kinetic perimetry with percent quantification of the damage (indicate the most suitable strategy):_____

c) automatic static perimetry with suprathreshold program (indicate the most suitable instrument, strategy and program):_____

d) automatic static threshold perimetry (indicate the most suitable instrument, strategy and program):_____

E GANDOLFO

Fig. 2. Questionnaire about invalidity regulations.

Table 2. Suggestions of the experts about the most suitable strategies for the visual impairment quantification

Kinetic perimetry	5
Kinetic perimetry and percentual evaluation	3
Static supra-threshold perimetry	9
More than one option	8

In order to obtain a standardization in this field, on the basis of our own experience and that of our colleagues consulted through the above mentioned questionnaire, we propose a new method for the quantitative assessment of visual impairment and for the evaluation of the consequent invalidity.

Procedure (quality of vision test)

The proposed strategy (Fig. 3) is based on a perimetric mixed static and kinetic program easily feasible with modern automated perimeters including custom option.

The test consists of a static suprathreshold phase that explores the central 60 degrees of the visual field by means of 100 target locations with a three-zone strategy (a detailed description of this phase was the topic of a previous paper[11]) and by a kinetic phase that explores the

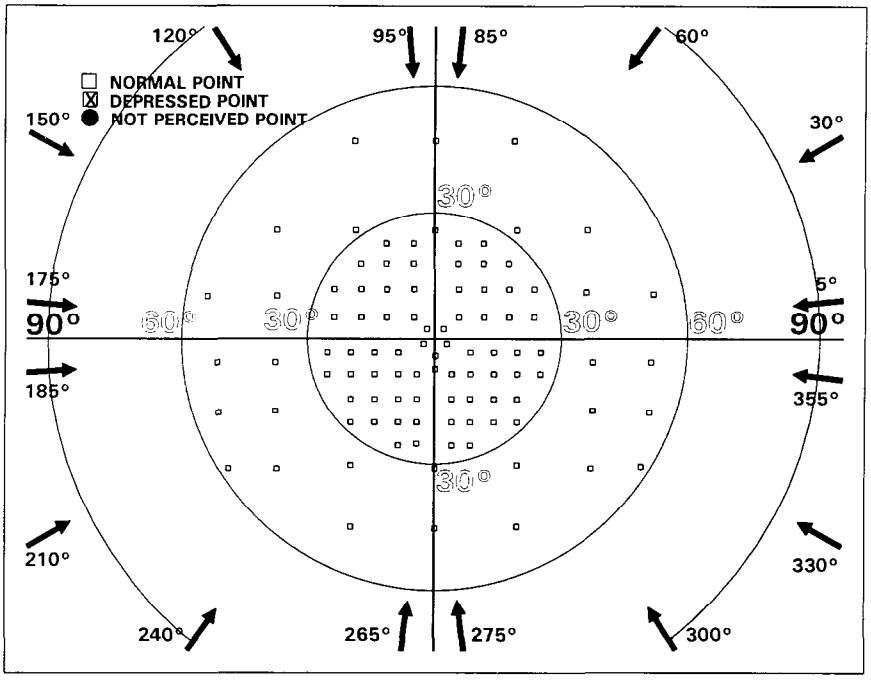

Fig. 3. The test "quality of vision"

extreme periphery of the visual field by means of a large stimulus (size III, luminance 10,000 asb, *i.e.*, 0 dB) presented along 16 centripetal trajectories along the following meridians: 5-30-60-85-95-120-150-175-185-210-240-265-275-300-330-355 degrees.

The kinetic phase was added to the static one in order to better evaluate the visual field periphery which is important for the patient's mobility. We also considered the fact that many cases present a stato-kinetic dissociation which shows a severe visual field impairment if static programs are used despite a good preservation of kinetic capability.

At the beginning of the examination a precise foveal threshold sensitivity assessment is performed in order to quantify the central sensitivity (with standard "up and down" strategy and standard stimulus size, *i.e.*, 4 mm²).

The three phases of the test (foveal threshold, static perimetry and kinetic perimetry) each supply a score which contributes to the total visual impairment score.

Score calculation

Phase 1: (foveal threshold) supplies a value in dB that is well correlated with central sensitivity and visual acuity. For calculating the score, it is necessary to multiply by three the obtained value in dB (the result for a normal eye will be around 100).

Phase 2: (static suprathreshold test) supplies a percentual score by giving the value "1" to the normal points, the value "0.5" to the points with reduced sensitivity and the value "0" to the points with abolished sensitivity, and summing the values.

Phase 3: (kinetic peripheral exploration) must be evaluated by calculating the mean eccentricity of the 16 perceived kinetic stimuli (in a normal visual field this value is around 75 degrees). The score is as follows:

- mean eccentricity > 70 degrees = 25
- mean eccentricity between 70 and 60 degrees = 20
- mean eccentricity between 59 and 50 degrees = 15
- mean eccentricity between 49 and 40 degrees = 10
- mean eccentricity between 39 and 30 degrees = 5

- mean eccentricity < 30 degrees = 0

The sum of the three scores provides a total score which is in normal cases around 200-230. This score, divided by two, represents the percentual residual visual function. The percentual visual impairment is the difference between the score and the value 100. For the invalidity classification we suggest the following criteria:

Percentual visual impairment (average of the two eyes)	*Percentual invalidity*
> 90%	100%
80 - 90%	80%
70 - 79%	60%
60 - 69%	40%
50 - 59%	20%
40 - 49%	10%
30 - 39%	5%
< 30%	0%

From a practical point of view, the procedure we propose is simple and rapid. It requires no more than five (normal cases) to ten minutes (severe field loss cases). The computer itself supplies the final score at the end of the examination (we used the automated perimeter Perikon PCL90[15], but every automated instrument provided with options for kinetic and custom programs may easily be utilized).

In case of necessity, the kinetic phase of the test may be carried out manually using a traditional Goldmann perimeter, adopting the stimulus IV/4/e.

Conclusions

The questions of visual impairment, quantitative invalidity assessment, and above all the problem of international standardization are still far from satisfactory solutions. We hope that our proposal may be useful in stimulating this trial.

References

1. Verriest G: Percentage impairment by visual field defects. Doc Ophthalmol Proc Ser 49:505-525, 1987
2. Engelberg AL (ed): American Medical Association Guides to Evaluation of Permanent Impairment, 3rd edn. Chicago: AMA, 1984
3. Esterman B: Grids for scoring visual fields. I: Tangent screen. Arch Ophthalmol 77:780-786, 1967
4. Esterman B: Grids for scoring visual fields. II: Perimeter. Arch Ophthalmol 79:400-406, 1968
5. Esterman B: Functional scoring of the binocular field. Ophthalmology 89:1226-1234, 1982
6. Mills RP, Drance SM: Esterman disability rating in severe glaucoma. Ophthalmology 93:371-378, 1986
7. Foels A, Jonquères J: L'estimation médico-légale du handicap: l'intérêt du camp visuel binoculaire. Bull Soc Ophthalmol France 89:513-521, 1989
8. Colenbrander MC: Visual acuity, visual field and physical ability. A proposal of a formula. Ophthalmologica 171:100-108, 1985
9. Colenbrander A: Personal Communication, 1992
10. Gandolfo E, Capris P, Facino M, Casagrande P, Ermini D: Accertamento di idoneità perimetrica. Atti 68° Congr Soc Oftalmol Italiana Roma, 1988, 479-484. Roma: Verduci, 1989
11. Gandolfo E, Zingirian M: A new proposal for classification and quantification of visual disability. In: Mills RP, Heijl A (eds), Perimetry Update 1990/91, pp 545-549. Amsterdam/Berkeley/ Milano: Kugler & Ghedini, 1991
12. Gandolfo E, Sboto G, Semino E, Capris P, Romiti S, Zingirian M: Valutazione dell' indice di ipovisione globale in differenti patologie. Boll Ocul (Suppl 4) 71:75-80, 1992
13. Gandolfo E: Functional quantification of the visual field: a new scoring method Doc Ophthalmol Proc Ser 49:537-540, 1987
14. Tucci F: Argomenti di Medicina Legale in Oculistica. Milano: Fogliazza, 1992
15. Zingirian M, Gandolfo E, Capris P, Mattioli R: Perikon PCL 90: a new automatic perimeter In: Mills RP, Heijl A (eds), Petimetry Update 1990/91, pp 403-407. Amsterdam/Berkeley/Milano: Kugler & Ghedini, 1991

The magnitude and locus of perimetric fatigue in normals and ocular hypertensives

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Abstract

The aim of the study was to quantify the magnitude, and identify the locus, of the fatigue effect on the visual field within 30° eccentricity in trained, age-matched normals (n=20) and ocular hypertensives (OHTs) (n=20) Program G1X of the Octopus 1-2-3 perimeter was employed for both eyes of each subject A break of one minute between phases, and of three minutes between eyes, was given. The global visual field indices MD and LV were separately calculated for each of the eight individual stages of Program G1X Furthermore, to identify the locus of any within-test change in perimetric sensitivity, the indices were calculated separately for each of the four hemifields and for annuli inside 17° eccentricity and beyond 17° eccentricity. Group mean global MD deteriorated by 2.57 dB and 2.44 dB for the first and second eyes, respectively, of the normals and by 2.14 dB and 2.33 dB for the OHTs. Group mean global LV deteriorated by 4.29 dB^2 and 7.23 dB^2 for the first and second eyes, respectively, of the normals and by 5.32 dB^2 and 6.02 dB^2 for the OHTs. The local MD showed an overall depression ($p<0.001$) which was exaggerated for the inferior hemifield ($p<0$ 001) and for the peripheral annulus ($p<0.001$). The local LV showed greater localized loss for the superior ($p=0.001$) and nasal ($p=0$ 001) hemifields and for the peripheral annulus ($p<0.001$). In conclusion, fatigue produces an overall sinking and an asymmetrical steepening of the hill of vision.

Introduction

Perimetric fatigue has largely been assessed using the repeated thresholding of a limited number of stimulus locations[1-5] and, therefore, the distribution of the test stimuli has not been representative of a standard perimetric examination. Consequently, the exact locus of the resultant change in sensitivity is unknown. Furthermore, it may be of diagnostic relevance to ascertain whether any difference exists in the locus of the resultant change in sensitivity between normals and ocular hypertensives (OHTs).

The purpose of the study was: to quantify the magnitude of the fatigue effect out to 30° eccentricity for the first and second eyes of trained subjects at a given examination; to identify the locus of any within-test change in perimetric sensitivity; and to determine whether differences exist in the magnitude and locus of such change in perimetric sensitivity between normals and age-matched OHTs.

Methods

The sample comprised 20 normals (mean age 67.2 years, SD 8.2) and 20 age-matched OHTs (mean age 66.5 years, SD 6.5). Stringent inclusion and exclusion criteria were applied. Ocular hypertensives were defined as manifesting an intraocular pressure greater than 21 mmHg on a minimum of two prior occasions. All subjects had previously undertaken a minimum of six Program 30-2 static threshold central visual field examinations with the Humphrey Field Analyzer.

Program G1X of the Octopus 1-2-3 perimeter was employed because: all 59 stimulus loca-

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tions are thresholded in a relatively random order (*i.e.*, not dependent on seed point generation) with respect to eccentricity and hemifield (Table 1); and the examination procedure is divided into two phases and eight stages (Phase 1 comprises stages 1-4 and Phase 2 comprises stages 5-8) which allows the assessment of within-test changes in sensitivity. All stimulus locations in a given stage are thresholded before the start of the ensuing stage. Stimuli in stage 1 share an identical location to those of stage 5, and similarly for stages 2 and 6, 3 and 7 and 4 and 8[6]. The design of the Octopus 1-2-3 is described elsewhere[6].

Table 1 Number of stimulus locations as a function of stage for the superior/inferior hemifields, nasal/temporal hemifields and the central/peripheral annuli

	Stages			
	1 & 5	*2 & 6*	*3 & 7*	*4 & 8*
Superior:inferior	8:8	8:8	6:6	7:7
Temporal:nasal	8:8	8:8	6:6	6:8
Central:peripheral	12:4	6:10	5:8	8:6

Perimetry was undertaken for both eyes of each subject. The first eye was randomly assigned. Subjects were allowed rest periods of 60 seconds at the end of Phase 1 of each eye and of three minutes between the examination of the two eyes. The distance refractive correction was employed due to the projection of the stimulus and fixation target from infinity. The mean pupil sizes for the first and second eyes of the normals were 4.25 mm (SD 0.80) and 4.05 mm (SD 0.60), respectively, and for the OHTs 4.40 (SD 0.9) and 4.60 (SD 1.0).

The Phase 1 results were documented photographically during the 60-second rest period and the stimulus locations corresponding to each stage were identified[6]. The Phase 2 results were calculated from the Phase 1 values and the mean sensitivity of Phase 1 and Phase 2 as displayed in the final printout. Normal values were provided by the manufacturer (personal communication, Interzeag AG, Schlieren, Switzerland) which permitted calculation using the equations of Flammer[7] of the global MD and LV for each of the eight discrete G1X stages. Global SF was also calculated for each of the four stages of Phase 2. A repeated measures ANCOVA was carried out for both global MD and LV with ocular condition as a between-subjects factor; stage, phase, and eye as within-subject factors and age as a covariate. For global SF the within-subject factors were stage and eye.

To identify the locus of any within-test change in perimetric sensitivity, the indices were also separately calculated for each of the four hemifields and for annuli inside 17° eccentricity and beyond 17° eccentricity. The total distribution of stimulus locations between the two annuli was approximately equal (Table 1). However, the annulus analysis was applied cumulatively due to the non-random distribution of the stimulus locations with respect to stage between the two annuli.

Results

The group mean global MD and LV for each eye of the normal and OHT groups as a function of stage are illustrated in Fig. 1. Global MD was poorer in the second eye irrespective of diagnosis ($p<0.001$). It was worse in Phase 2 compared to Phase 1 ($p<0.001$). This difference was accentuated for the second eye ($p=0.022$) and for the OHT group ($p=0.010$) with the difference between groups increasing with increase in age ($p=0.012$). The group mean global MD

Table 2. The deterioration in group mean MD and LV over stage as a function of eye and of group

Eye	*1st*	*2nd*
Global MD (dB)		
normals	2.57	2.44
OHTs	2 14	2.33
Global LV (dB^2)		
normals	4.29	7.23
OHTs	5 32	6.02

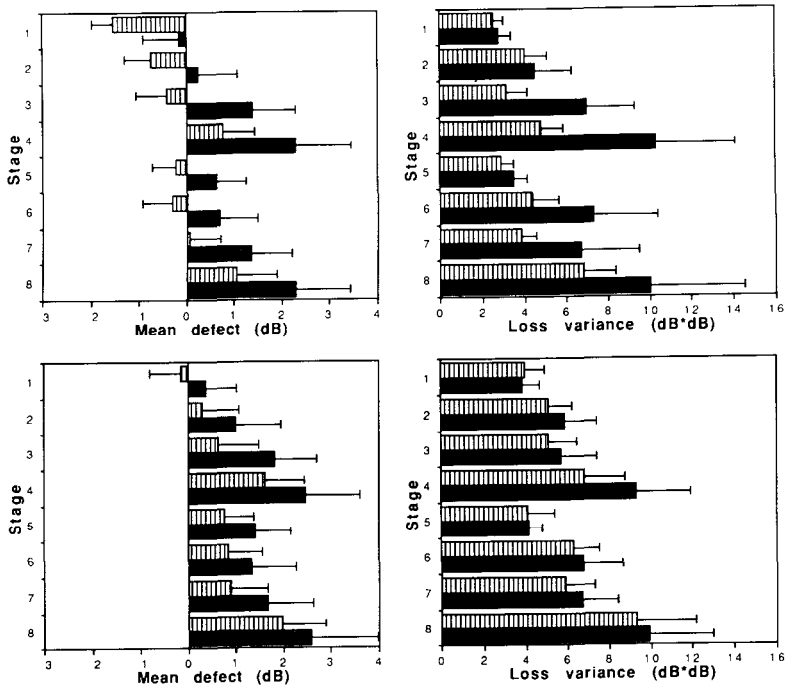

Fig. 1. Bar charts of stage against global mean defect (left) and global loss variance (right) for the normals (top) and OHTs (bottom). Hatched bars first eye; closed bars second eye. The error bars represent two standard errors of the mean.

declined over stage ($p<0.001$) for both groups and deteriorated with increase in age ($p=0.003$). The magnitude of the deterioration in the group mean global MD over stages 1 to 8 for the first and second eyes of both groups is shown in Table 2. The decline in group mean global MD over stage was greater for Phase 1 than for Phase 2 ($p<0.001$).

Global LV was poorer in the second eye irrespective of diagnosis ($p=0.007$). It was worse in Phase 2 compared to Phase 1 ($p<0.001$). This difference was accentuated for the first eye of the OHTs ($p=0.020$). The group mean global LV declined over stage ($p<0.001$) for both groups and deteriorated with increase in age ($p=0.004$). The magnitude of the deterioration in the group mean global LV over stages 1 to 8 for the first and second eyes of both groups is shown in Table 2. The decline in group mean global LV over stage differed for the two phases between the two eyes ($p=0.024$) and was greater in the normals compared to the OHTs ($p=0.012$). This difference in the gradient of decline between the normals and OHTs increased with increase in age ($p=0.021$).

Global SF was similar between the two eyes irrespective of diagnosis ($p=0.061$). The alteration in global SF over stage was not statistically significant ($p=0.066$) and was unaffected by age ($p=0.081$).

The locus of the change in perimetric sensitivity is schematically illustrated in Fig. 2. The inferior hemifield MD was poorer than the superior hemifield MD ($p<0.001$). The deterioration over stage of the inferior hemifield MD compared to the superior hemifield MD was greater for Phase 1 than for Phase 2 ($p<0.001$) and increased with increase in age ($p<0.001$) and was accentuated for the OHT group ($p<0.001$) particularly with increase in age ($p<0.001$). This group-age effect was more pronounced for the second eye ($p=0.009$). The superior hemifield LV deteriorated more over stage than the inferior hemifield LV ($p=0.010$). The superior and inferior hemifield SF were similar regardless of differences in eye, age or group.

The nasal and temporal hemifield MDs exhibited similar deterioration regardless of group. The nasal hemifield LV deteriorated more over stage than the temporal hemifield LV ($p=0.001$). The nasal hemifield SF deteriorated more over stage than the temporal hemifield SF ($p=0.002$).

The peripheral annulus MD deteriorated more over stage than the central annulus MD

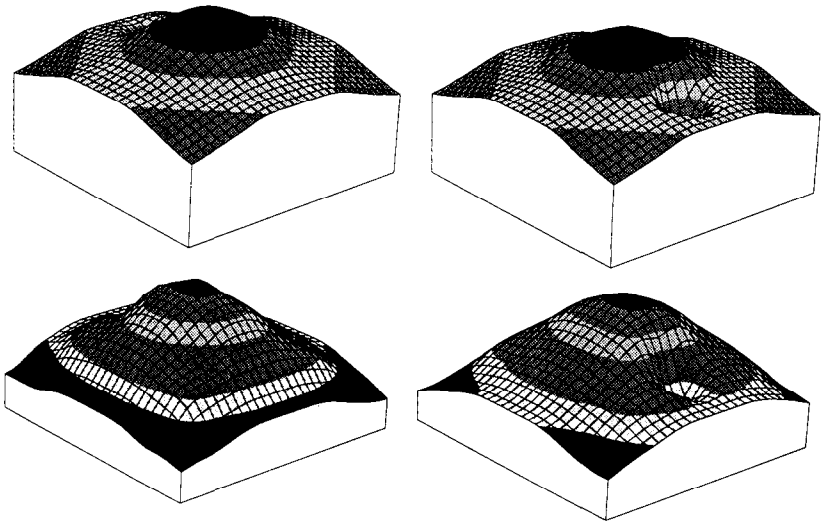

Fig 2. Schematic representation of the fatigue effect Top: prior to the fatigue effect. Bottom: post-fatigue effect. Left: relief of the superior and nasal fields. Right: relief of the inferior and temporal fields.

($p<0.001$) particularly for Phase 1 than for Phase 2 ($p<0.001$). This change was greater in the normals than in the OHTs ($p=0.050$). The difference in the peripheral and central annulus MD was greater for Phase 2 than for Phase 1 ($p<0.001$) and for the normals ($p=0.008$) particularly as age increased ($p=0.009$). The peripheral annulus LV was poorer than the central annulus LV ($p<0.001$). The deterioration of the peripheral annulus LV compared to the central annulus LV was greater over stage ($p<0.001$) and phase ($p<0.001$). The differences over stage were more pronounced for Phase 1 compared to Phase 2 ($p<0.001$). The peripheral annulus SF was greater than the central annulus SF ($p<0.001$) and this difference decreased over stage ($p<0.001$).

Discussion

The within-test fatigue effect can be modelled by a progressive loss in sensitivity, comprising two components: a general sinking of the hill of vision and an asymmetrical steepening of the hill of vision. The MD analysis indicated an overall depression which was more pronounced for the inferior hemifield and beyond 17° eccentricity. Furthermore, the LV analysis indicated greater localized loss in the superior and nasal regions and beyond 17° eccentricity. These changes were accentuated in the second eye.

The difference between the normals and OHTs in the locus of the within test change in perimetric sensitivity was subtle. The normal group exhibited a greater steepening of the hill of vision than the OHTs. The OHT group exhibited a greater sinking and an initial steepening of the hill of vision with an additional depression of the inferior field.

The results are comparable with previous findings[1-4,8]. However, a recent study[5] using the Octopus perimeter found that sensitivity remained stable for the repeated thresholding of three stimulus locations in both normal and glaucomatous eyes over a time period of five to eight minutes. These findings may be explained by the use of only three stimulus locations, as opposed to the 59 used in this study[9]. The spatial uncertainty produced by a greater number of randomly presented stimuli might be anticipated to exaggerate the magnitude of the fatigue effect.

The assessment of the within-test change in sensitivity is contaminated by the variation in the relative proportions of stimuli between the two annuli with progression through the eight stages of the G1X Program (Table 1). As demonstrated in this study and previously[3,8] fatigue effects increase with increase in eccentricity. As a result, an exaggerated deterioration of the

indices between stages 1 and 2 and stages 5 and 6 might have been anticipated.

In addition, the within-test change in perimetric sensitivity was investigated for a constant number of stimulus locations, rather than for a constant time period. The overall examination time was greater for the second eye irrespective of group (p=0.004) and greater for both the first and second eyes of the OHTs (p=0.046). The difference in the group mean examination times between the first and second eyes of the normals was two seconds and of the OHTs was 40 seconds, while the difference between the normals and OHTs for the first eye was nine seconds and for the second eye 46 seconds. However, as this difference in examination time is cumulative over the eight stages of the G1X examination any difference within each individual stage are likely to be minimal.

The progressive within-test decline of the visual field indices indicates that: there is a need for the further development of shorter measurement strategies; and confidence limits for the definition of abnormality using the existing test strategies should reflect the order effect and therefore be different between the two eyes.

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References

1. Searle AET, Wild JM, Shaw DE, O'Neill EC: Time-related variation in normal automated static perimetry. Ophthalmology 98:701-707, 1991
2. Heijl A: Time changes of contrast thresholds during automatic perimetry Acta Ophthalmol 55:696-708, 1977
3. Johnson CA, Adams CW, Lewis RA: Fatigue effects in automated perimetry. Appl Optics 27:1030-1037, 1988
4. Heijl A, Drance SM: Changes in differential threshold in patients with glaucoma during prolonged perimetry. Br J Ophthalmol 67:512-516, 1983
5. Marra G, Flammer J: The learning and fatigue effect in automated perimetry. Graefe's Arch Clin Exp Ophthalmol 229:501-504, 1991
6. In: Octopus 1-2-3 Perimeter Digest. Schlieren, Switzerland: Interzeag AG 1991
7. Flammer J: The concept of visual field indices. Graefe's Arch Clin Exp Ophthalmol 224:389-392, 1986
8. Langerhorst CT, Van Den Berg TJTP, Veldman E, Greve EL: Population study of global and local fatigue with prolonged threshold testing in automated perimetry. In: Greve EL, Heijl A (eds) Seventh International Visual Field Symposium. Doc Ophthalmol Proc Ser 49. Dordrecht: Martinus Nijhoff/Dr W Junk 1987
9. Fujimoto N, Adachi-Usami E: Effect of number of test points in automated perimetry. Am J Ophthalmol 113:317-320, 1992

Reliability indices in automated perimetry

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Abstract

The percentage of errors and fixation losses in automated perimetry shows great variability and difficult predictability. The aim of this study was to detect the characteristics of patients and perimetric tests which may increase the prevalence of positive catch trials. In a retrospective study, the authors analyzed the perimetric results stored by a Humphrey VFA 640, selecting only the first examination for each patient, in order to avoid fatigue and learning effects. They correlated (Spearman's rank test; Mann-Whitney U test) the different kinds of errors to the following parameters: *1.* examination strategy (threshold and suprathreshold); *2.* test duration; *3.* presence and severity of visual field (VF) defects; *4.* diagnosis; *5.* sex; *6.* age; *7.* refractive error and visual acuity The results (520 cases) suggest the following correlations: a. the severity of localized visual field loss is significantly correlated with false negatives; b. global sensitivity depression generates false positives; c test duration and false negatives are correlated; d. in neurological disorders all kinds of errors increase

Introduction

Visual field (VF) examination, like other psycho-physical diagnostic procedures, requires a certain level of attention and cooperation by the patient in order for the result to be considered reliable. In manual perimetry this level of cooperation is assessed directly by the examiner on the basis of his own experience, and the examination may be carried out by being adapted each time to each individual's ability for responding. This cannot be the case in automated perimetry, where the strategy is the same and repetitive for all patients without exception. The only means available to the examiner to obviate this homogeneity, which does not take the patient's individuality into account, is to insert a greater or lesser number of pauses during the examination or to modify some parameters, such as the stimulus presentation duration or the interval between one stimulus and the next. However, this can only be done with some automatic perimeters (*e.g.*, Perikon PCL90, Kowa AP 340) and entails abandoning the standard settings of the instrument, thus making it impossible to use statistical programs. Since the judgment of the examination's reliability in automated perimetry cannot be left to the examiner, automatic cooperation assessment systems ("catch trials") were introduced and are used in nearly all computerized machines, be it with some difference between one model and the next[1-6]. For VF examination purposes, the result of each of these catch trials is expressed numerically: taking these numerical data, or "reliability indices"[7-9], into consideration, both individually and together, it is possible to judge the reliability level of the examination. In several instruments, the statistical significance of the cooperation is given automatically, sometimes by calculating a global cooperation factor (RF with the Octopus), sometimes by analyzing single indices ("catch trials" with the Humphrey)[10,11]. The most common parameters used to obtain these reliability indices are the following:

1. number and percentage of fixation losses
2. number and percentage of false positives
3. number and percentage of false negatives
4. total duration of the examination (and number of presentations and/or repetitions)

Let us briefly see what each of these tests means:

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Fixation losses

The instrument shows the total number of times which the patient's fixation left the target or the reference point; the fixation control system can vary from one instrument to another: in most perimeters fixation is controlled electronically, usually using a telecamera (Octopus, Perikon PCL90) or an infrared device (Kowa AP 340); instead of this, the Humphrey perimeter monitors fixation losses during the examination by periodically presenting a stimulus of maximum intensity in the area corresponding to the blind spot; the patient's perception of this stimulus obviously corresponds to a fixation loss; the relative fixation loss "index" is expressed as a fraction, where the numerator corresponds to the total fixation losses and the denominator to the total number of stimuli presented to the blind spot (from the fractional expression the percentage of false responses can easily be found)[12,13].

False positive responses

The instrument shows how many times the patient has signalled the perception of a stimulus which was not projected onto the screen; such abnormal responses may be induced by the patient's personality (anxious patients, who rush their responses), but especially by the conditioning produced by the repetitiveness of the examination and by the fact that, even if modern projection perimeters are very silent, it often happens that the projection of the luminous stimulus is immediately preceded by a noise, produced by the movement of the mechanical constituents (of course perimeters with LED are an exception to this): this can produce a kind of conditioned reflex in the patient, so that he is induced to signal a perception every time he hears a noise coming from the instrument. In order to monitor these false responses, the instrument produces a mechanical noise several times during the examination without projecting a stimulus; the "index" in this case is also expressed as a fraction, where the numerator is the total number of false responses and the denominator the number of tests or "pitfalls" presented during the examination.

False negative responses

During the examination the instrument tests several points, of which the threshold value has already been defined, again, projecting a stimulus of suprathreshold intensity; it is obvious that if the patient does not respond to this stimulus he is inattentive or has lost his concentration. In this case, too, the "index" is expressed as a fraction, where the numerator is the total number of false responses and the denominator the number of "pitfalls" presented.

Test duration

This is also a value to be taken into account when assessing the reliability of a perimetric examination: usually an examination which lasts too long is not only due to a severely altered visual field, which thus makes its definition long and elaborate, but it is also often a sign of poor cooperation by the patient, who gives contrasting responses to analogous stimuli. Other parameters, such as the total number of presentations and the number of repeated presentations, may take on the same meaning[14,15].

In the present study we have dedicated ourselves to assessing the behavior of these reliability indices, in relation to a variety of parameters: sex, age, visual acuity, refraction, severity of the perimetric defects, diagnosis, type of examination (screening or threshold); we then assessed whether there were any significant correlations between these parameters.

Material and methods

For our study we used the Humphrey VFA 640 examination archives at our Institute. For each examination we took only the first eye tested: this was in order to have data as homogenous and comparable as possible for statistical analysis, since other factors intervene during examination of the second eye, such as fatigue and the "learning effect"[16-20], which can influence the

quality of the responses. We found each patient's clinical record in our archives and took note of the visual acuity of the tested eye, its refraction, and the diagnosis made or suspected. Both suprathreshold and threshold examinations were taken into account: we chose the programs "120 points" and "24-2", respectively, which are similar in as far as the patient's attention is concerned. The reliability indices available to the Humphrey perimeter are those concerning fixation losses (tested by Heijl-Krakau's method, *i.e.*, by monitoring the blind spot)[21], false positives and false negatives; as was discussed above, we also took the test duration into account. To assess the severity of the defect we considered several perimetric indices (MD, SF and CPSD) for program 24-2 and the number of altered points (absolute defect = 1; relative defect = 0.5) for the program 120 points. The defects were divided into three classes: mild, moderate and severe. The reference ranges for each class were the following:

- Program 24-2
  - mild defect: MD = 3-6 dB; SF = 2.5-3.5 dB; CPSD = 3-6 dB
  - moderate defect: MD = 6.1-10 dB; SF = 3.6-4.5 dB; CPSD = 6.1-10 dB
  - severe defect: MD = >10 dB; SF = >4.5 dB; CPSD >10 dB
- Program 120 p
  - mild defect: 10-20 disturbed points
  - moderate defect: 21-30 disturbed points
  - severe defect: >30 disturbed points

We analyzed 520 perimetric examinations (inexperienced subjects ranging in age from 21 to 78 years), divided into the following groups:

- 228 threshold examinations (program 24-2) carried out in glaucomatous subjects;
- 216 threshold examinations (program 24-2) carried out in normal subjects;
- 36 suprathreshold examinations carried out in subjects with neuro-ophthalmologic disorders (program 120 points, "3 zone" strategy) causing evident perimetric defects;
- 40 suprathreshold examinations (program 120 points, "3 zone" strategy) carried out in normal subjects.

Data analysis and assessment of statistical significance were carried out by Spearman's rank test. We employed the Mann-Whitney method (U test) to compare results between threshold and suprathreshold examinations and between normal and glaucomatous subjects.

Results

Threshold examinations, program 24-2

The following correlations reached statistical significance (Spearman's rank test, $p<0.05$):

Glaucomatous patients

a. percentage of false negatives with test duration;
b. percentage of false negatives with severity of localized perimetric defect (CPSD);
c. percentage of false negatives with short-term fluctuation value (SF);
d. percentage of false positives with percentage of fixation losses;
e. percentage of false positives with severity of perimetric global damage (MD);
f. percentage of fixation losses with SF value.

Normal subjects

a. percentage of false negatives with test duration and with perimetric indices (except for SF);
b. percentage of false positives with MD value and with percentage of fixation losses;
c. percentage of fixation losses with test duration and with percentage of false positives.

No other parameters taken into consideration (age, sex, refraction, visual acuity) significantly influenced error percentages.

Suprathreshold examinations, program 120 points, "3 zone" strategy

For this type of examination, we assessed the presence of significant statistical differences ($p<0.05$), by means of Spearman's rank test, between the two groups considered (normal sub-

jects and neurologic patients with VF defects) as far as percentage of errors was concerned. We observed a significant increase in all three types of catch trials in neurological patients (see Table 1).

Table 1. Results (suprathreshold tests)

	Normal subjects (*n=40*)	*Patients with neurological disturbances* (*n=36*)	*p*
Average percentage of false negatives	1.6%	8.9%	0.03
Average percentage of false positives	0.79%	5 63%	0 0001
Average percentage of fixation losses	1.74%	11.60%	0.004

Comparison between threshold and suprathreshold programs; comparison between normal and glaucomatous subjects

The statistical test employed (Mann-Whitney's U test) did not show any statistically significant difference between normal and glaucomatous subjects as far as percentage of false positives and false negatives and number of fixation losses were concerned[22-25]; neither did the comparison between suprathreshold and threshold examinations show any significant difference in percentage of errors.

Discussion

The results of our study allow us to advance the following considerations:

- not all parameters which should theoretically condition the percentage of errors turn out to have a real influence on these indices;
- the factor which induces a significant increase of false negatives (and also an increase of SF values), is above all the severity of the defect, especially if it is a fascicular glaucomatous one;
- an overall sensitivity reduction somehow seems to increase the number of false positives;
- an examination which lasts too long constantly increases the percentage of false negatives (also due to the onset of possible fatigue phenomena);
- in neurological patients there is a significant increase of all types of catch trials;
- during examinations of comparable duration there are no significant differences as far as the comparison between threshold and suprathreshold strategies are concerned.

References

1. Whalen WR: Routine reliability parameters. In: Whalen WR, Spaeth GL (eds) Computerized Visual Fields: What They Are and How to Use Them, pp 85-86. Thorofare, NJ: Slack 1985
2. Heijl A, Lindgren G, Olsson J: Reliability parameters in computerized perimetry. Doc Ophthalmol Proc Ser 49:593-600, 1987
3 Corallo G, Gandolfo E, Morescalchi F, Semino E, Magnasco A, Novaro C, Danielli Micco M: Indici di affidabilità in perimetria automatica. 12th S.O.N.O Congress, Genova, Italy, June 14 1992 (in press)
4. Bickler-Bluth M, Trick GL, Kolker AE, Cooper DG: Assessing the utility of reliability indices for automated visual fields Ophthalmology 96:616-619, 1989
5. Katz J, Sommer A: Reliability indexes of automated perimetric tests. Arch Ophthalmol 106:1252-1254, 1988
6 Hardage L, Stamper RL: Reliability indices for automated visual fields (letter). Ophthalmology 96:1810-1811, 1989
7 Baraldi A, Altafini R, Toso A, Martini L, Chizzolini M, Cerin O, Dorigo MT: Attendibilità dell'esame perimetrico. Boll Ocul (Suppl 3) 69:141-143, 1990
8. Jenni A: Significance of catch trials Glaucoma 11:6-10, 1989

9. Katz J, Sommer A, Witt K: Reliability of visual field results over repeated testing. Ophthalmology 98:70-75, 1991
10. Heijl A: The Humphrey field analyzer, construction and concepts. Doc Ophthalmol Proc Ser 42:77-84, 1985
11 Humphrey Field Analyzer Operator's Manual. San Leandro CA 1983
12. Henson DB, Bryson H: Is the variability in glaucomatous field loss due to poor fixation control? In: Mills RP, Heijl A (eds) Perimetry Update 1990/91, pp 217-220. Amsterdam: Kugler Publ 1991
13 Sanabria O, Feuer WJ, Anderson DR: Pseudo-loss of fixation in automated perimetry. Ophthalmology 98:76-78, 1991
14. Lee M, Zulauf M, Hoffman D, Caprioli J: A new reliability index for threshold automated perimetry. Invest Ophthalmol Vis Sci (Suppl) 21:1105, 1991
15. Zulauf M, Caprioli J, Boeglin RJ, Lee M: Number of stimuli as a reliability parameter in perimetry. German J Ophthalmol 1:86-90, 1992
16. Marra G, Troiano P, Montanari P, Miglior M: Il learning effect nella perimetria computerizzata. Ist Congress of the Italian Perimetric Society (S.I.Pe.). Minerva Oftalmol 32:103-105, 1990
17. Traverso CE, Gandolfo E, Ermini D, Zingirian M: Parametri di attendibilità in perimetria automatica e livello di scolarità. Ist Congress of the Italian Perimetric Society (S I Pe.). Minerva Oftalmol 32:97-101, 1990
18. Werner EB, Adelson A, Krupin T: Effects of patients experience on the results of automated perimetry in clinically stable glaucoma patients Ophthalmology 95:6, 1988
19 Heijl A, Lindgren G, Olsson J: The effect of perimetric experience in normal subjects. Arch Ophthalmol 107:81-86, 1989
20. Marra G, Flammer J: The learning and fatigue effects in automated perimetry. Graefe's Arch Clin Exp Ophthalmol 229:501-504, 1991
21. Heijl A, Krakau CET: An automatic static perimeter, design and pilot study. Acta Ophthalmol 53:293-310, 1975
22. Reynolds M, Stewart WC, Sutherland S: Factors that influence the prevalence of positive catch trials in glaucoma patients. Graefe's Arch Clin Exp Ophthalmol 228:338-341, 1990
23. Totsuka H, Hatakeyama T: Reliability indices of Humphrey Field Analyzer for glaucoma Jpn J Clin Ophthalmol 44:938-942, 1991
24. Katz J, Sommer A: Screening for glaucomatous visual field loss. The effect of patient reliability. Ophthalmology, 97:1032-1037, 1990
25. Bennett CR, Werner EB, Seraydarian L: Correlation of reliability indices and test-retest reproducibility in normal subjects undergoing automated perimetry on the Humphrey Visual Field Analyzer In: Mills RP, Heijl A (eds) Perimetry Update 1990/91, pp 211-215. Amsterdam: Kugler Publ 1991

Fixational instability during perimetry and the blindspot monitor

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Abstract

The authors considered the nature of normal fixational instability that occurs during automated perimetry and the ability of the blindspot monitor to find such losses. They considered the effect that sampling rate (10-25%) and size of fixation loss (0°, 2°, 5°, 10°) have on the blindspot monitor Twelve young (20-28) normal observers performed 12 consecutive threshold tests (averaging five minutes) Eye movements were recorded using an infrared eye-movement monitoring system to an accuracy of ±0.5° while subjects performed thresholding. The number of fixation losses recorded by the perimeter was very low for all sampling rates. However, analysis of eye movement traces shows considerable fixational instability characterized by slow drifts with an occasional saccadic movement Three degree fixational drifts occur about four times per test (every 78 seconds), 2° drifts occur 14 times per session (every 22 seconds) and 1° drifts happen every eight seconds. Large eye movements (≥3°) were found in all observers. The authors tested the ability of the Heijl-Krakau method to detect repetitive and pseudo-random fixation losses performed by a well-trained perimetric observer in the presence of 2°, 5° and 10° eye movements. Two degree fixation losses were infrequently (5%) detected, whereas all 5° and 10° fixation losses were detected with the 10% sampling rate. The authors conclude that fixational instability is usual during automated perimetry and that the blindspot monitor only detects eye movements ≥5° with any level of reliability. They conclude that increasing sampling rate has little benefit in detecting fixational instability.

Introduction

It is assumed that normal observers maintain steady fixation during perimetry. However, the nature of visual fixation is such that it is never steady[1]. Recent data suggest that most subjects fixate reliably (to within ±3° of the fixation mark) most of the time, although a substantial number have sizable degrees of fixational instability[2]. This observation raises several important questions, namely:

1. what is the nature of fixation during perimetry;
2. why is fixational instability not found by the normal blindspot monitor; and
3. what effect does such instability have on perimetric outcomes?

In this paper, we consider the nature and characteristics of the fixation shown by experienced observers during perimetry. It is possible that the earlier work may have been affected by using naive subjects. However, we confirm that fixational instability is usual in experienced people and find that the blindspot monitoring rate has little effect on its ability to detect fixation loss. In a fellow paper[3], we consider the effect that small eye movements have on perimetric outcomes.

Material and methods

We documented the nature of fixation by continuously recording eye movements from 12 young subjects (20 to 28) with a modified infrared eye monitoring system (Biometrics 200). Head stabilization was achieved with a head clamp to ensure that recordings reflected fixation

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loss and were not contaminated by eye movements associated with changes in head position. The fellow eye to that being tested was continuously recorded using a modified spectacle frame carrying the infrared monitor. The equipment had an accuracy of ±0.5° and calibration was checked at the beginning and end of each test by having the subject make ±10° eye movements between two marks placed inside the cupola.

All subjects had experience with automated perimetry and were informed that their fixational stability was being monitored. They were asked to maintain steady fixation throughout the duration of the threshold test (average time 5.3 minutes). Testing was performed on a modified Medmont M600™, LED perimeter[4]. The Medmont has a 3.2 cdm^{-2} (10 asb) background intensity and a maximum stimulus brightness (*i.e.*, 0 dB) of 318 cdm^{-2} (1000 asb). It has stimuli in concentric rings at various eccentricities and a custom field was developed for this study using 50 points out to and including 30° eccentricity.

A Graeco-Latin square experimental design was used to balance the effects of learning and fatigue among the subject population. Four tests were performed with each subject on three different days and successive tests were separated by a short break (two minutes) giving a total test time of about 30 minutes per session.

The second phase of this study determined the ability of the Heijl-Krakau blindspot monitor to detect repetitive losses of fixation using different monitoring rates. Because of the difficulty and training needed to perform such predetermined fixation losses, we report the data of only one subject who was studied very extensively (20 hours of perimetric testing) over a two-week period. The general trends obtained on this person have been confirmed on two other observers.

Four rates (10%, 15%, 20% or 25%) of blind spot monitoring were used during a single one hour test session. Each session comprised four 15-minute tests with two sessions being completed per day. Intentional eye movements (2°, 5°, or 10°, see Fig. 1) were made to accessory targets inside the cupola during testing using fixation times of pseudo-random duration. Taped instructions were played back via headphones to direct fixation to a new point at the appropriate time. The instructions ensured that:

1. the time spent at each eccentricity was equal; and
2. the time spent looking away from the central point was followed by an epoch of equal duration at the central point.

This produced a 50% fixation loss. All fixation epochs lasted from five to 15 seconds. The results for this section were analyzed using a repeated measure's ANOVA.

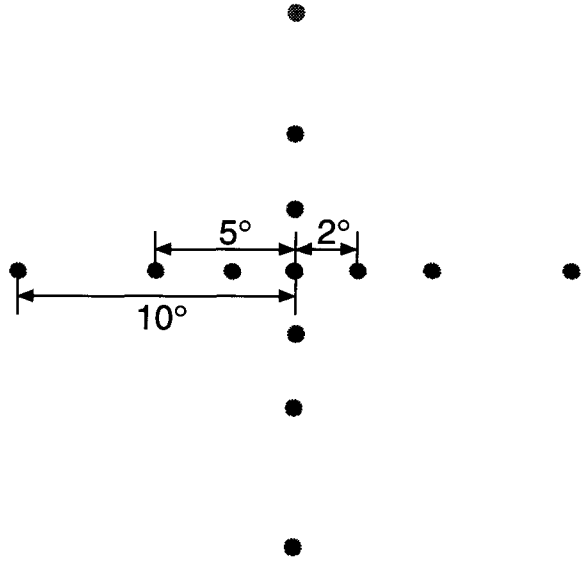

Fig. 1. Organization of the eccentric fixation targets around the central fixation mark. The subject was instructed to look at different locations in a pseudo-random manner during the test (see text for details).

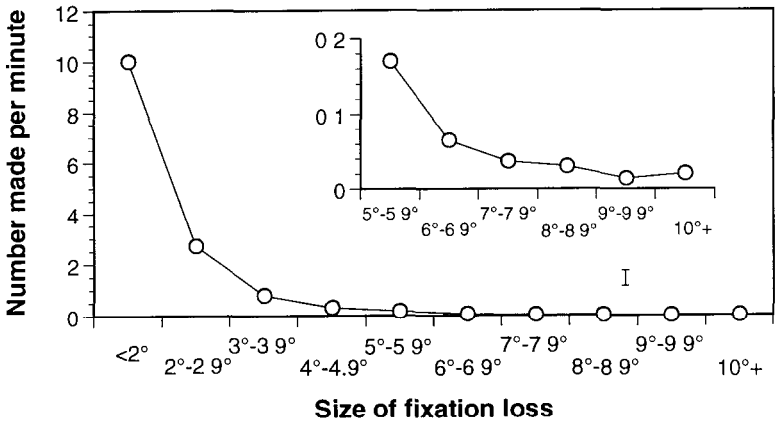

Fig. 2. Average number of fixation losses made per minute by 12 experienced observers during thresholding. The inset is an enlargement of the data from 5° onwards and the error bar shows the average error over all bins.

Results

The 12 observers performed 12 tests each giving a total of 144 results. Excessive blink artefacts made the traces unreadable in ten tests from two individuals. The remaining 134 traces comprised 12 each from ten observers (complete set) and nine and five from the two individuals with artefacts. These 134 have been analyzed and the results are shown in Figs. 2, 3 and 4.

Fig. 2 shows the average size of fixation loss made by our 12 subjects expressed as the number per minute of thresholding. In this figure we grouped eye movements into 1° bins consistent with the resolution limit of our system (±0.5°). Since so many small eye movements (<2°) were found we placed them into a common bin and feel that a more precise classification is unnecessary. The same logic was applied to our largest eye movements which have also been grouped into a common bin (10°+). The inset to Fig. 2 shows the data for the larger eye movements on a different scale. If we consider that a typical threshold test has a duration of 12-15 minutes, then Fig. 2 shows that eye movements ≤3° are often found (120 per test), those from 3°-5. 9° occur seldom (12 per test), those from 6°-8.9° rarely (one per test), and that larger

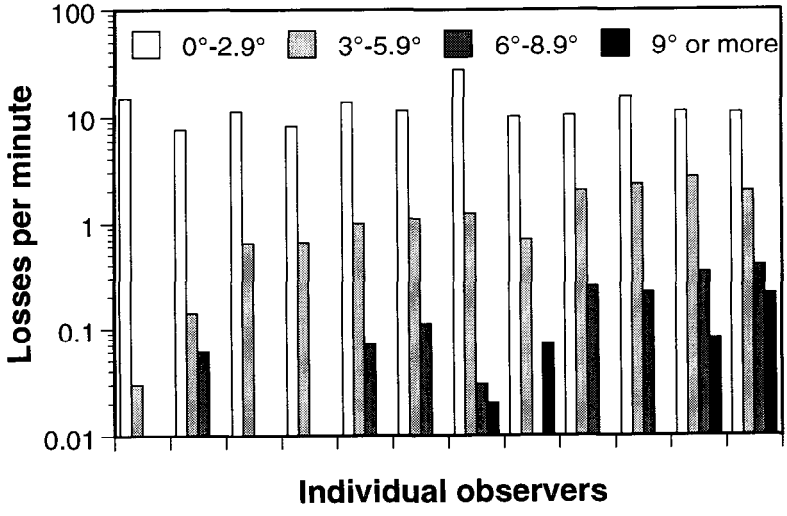

Fig. 3. Average number of fixation losses made per minute by individual observers. The observers have been arbitrarily ranked from best (left) to worst (right). The ordinate is given on a log scale.

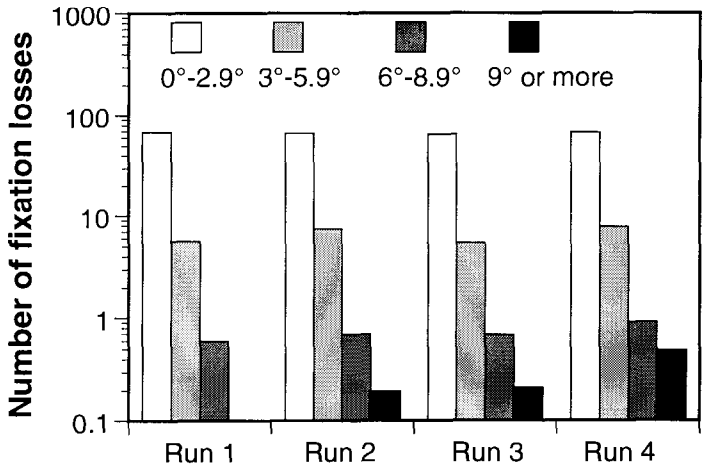

Fig. 4 Average number of fixation losses made per test by our 12 observers The data were obtained over 4 consecutive tests conducted in the same 30-minute session. The ordinate is given on a log scale.

movements (≥9°) are spontaneous and unpredictable events.

Since average trends can mask individual performance, Fig. 3 shows data for each of the 12 observers. Data have been grouped into 3° bins consistent with our previous analysis and a log scale is used along the ordinate (y) to visualize the trends better. Observers have been ranked arbitrarily along the abscissa (x) from the most stable on the left to the least stable on the right. Fig. 3 shows that most people make similar levels of small eye movements (≤3°) and that the greatest variability between observers is found in the number of larger eye movements made. Four observers (33%) could be expected to show large fixational losses (≥6°) at least once during a ten-minute test session.

In Fig. 4 we consider the effect that test time has on fixational stability. When interpreting this figure we need to remember that each run takes about five minutes. Once again data have been grouped into 3° bins and a log scale has been used along the ordinate (y). These data show that small eye movements have similar patterns of occurrence over time. On the other hand,

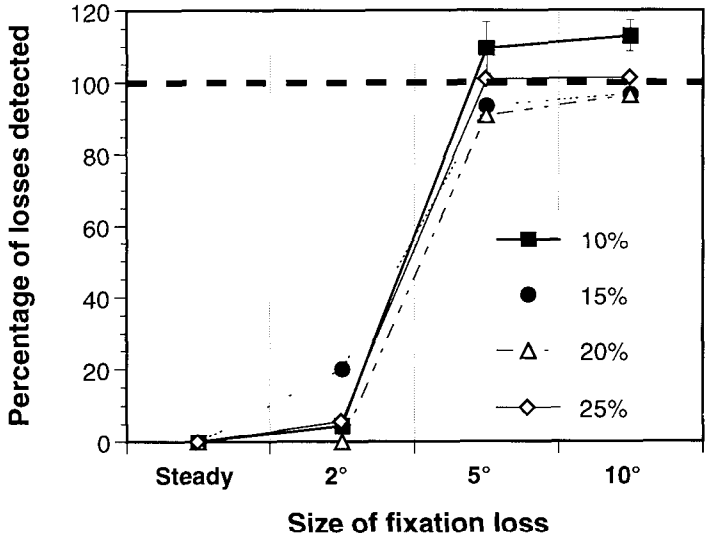

Fig. 5. Percentage of fixation losses detected using four monitoring rates with the Heijl-Krakau blindspot monitor (0.43°) while four sizes of intentional eye movement were performed.

large eye movements (≥6°) increase with test time and very large movements (≥9°) are never found in the first test session (five to six minutes). We believe that this latter finding results from a fatiguing effect.

Fig. 5 shows the effect that the rate of blindspot monitoring has on the ability to detect fixation loss for several sizes of intentional eye movement. It is apparent that altering the rate of the blindspot monitor has little effect on the percentage of fixation losses found with only those ≥5° in extent being reliably detected. A separate study performed on the Humphrey Field Analyzer (size 3 monitor) suggests that 0%, 94% and 100% of 2°, 5° and 10° eye movements respectively will be detected by its fixation monitor (average 8% monitor rate). The marked similarity in these data show that our findings are not equipment specific.

Discussion

Our study shows that fixational instability is normal and that small fixational losses occur regularly during perimetry. We also find that people show two patterns of fixational instability. The majority are generally reliable showing few large eye movements but a substantial number give large fixational losses which appear to occur as a function of test time and possibly reflect a fatiguing effect. If these are fatiguing effects, then they occur some time after five to six minutes of testing. Searle *et al.* have shown that thresholds fatigue over a similar time scale with a reported decrease in mean threshold after about five minutes[5]. If large eye movements were indicators of fatigue, perhaps the level of fixation could be used as a tool by clinicians to flag a fatiguing patient who is in need of a break. Such algorithms could be easily built into commercial perimeters with video-based eye monitors.

We also find that some patients consistently show very poor fixation even after reinstruction, retest or remapping of the blind spot. It should be remembered that, even though all subjects used in this trial were young and experienced, a large proportion were unable to maintain steady fixation. It would be interesting to assess the fixational stability of some elderly, naive observers who so often are in need of an accurate visual field assessment. It is probable that they may give an even worse outcome.

Inability to detect fixation loss is not related to the rate of blindspot monitoring for the range of monitoring rates used in this study. Instead there appears to be a threshold eye movement of about 5° that is reliably detected. Anything smaller than 5° will have a reducing likelihood of detection and anything bigger will most certainly be found. This result is similar to that reported previously by Newman for the Octopus system of video eye monitoring[6] which suggests that the Heijl-Krakau blindspot monitor and the video method may yield similar outcomes. Our data suggest that for young reliable observers a 5-7% blindspot check rate is adequate to detect most large (≥6°) eye movements since they occur at this frequency; older or less reliable people may need a higher frequency of checking.

Fig. 5 suggests that some values of fixation loss were over 100%; an impossible situation. This arises as an artefact of our test method which required the subject to maintain eccentric fixation for a fixed period of time. If during this excursion the blindspot monitor were to test twice for fixation then two losses would be recorded when, in fact, only a single one took place. An extreme example would occur if the subject were to look away for the duration of the test committing only one fixation loss but the recording would imply that many more were found (one for each trial).

This paper reports the fixation of young, experienced individuals during thresholding; it makes no attempt to ascertain the effect that such fixation losses may have on perimetric outcomes. Our other paper quantifies these issues[3].

References

1. Ditchburn RW. Eye Movements and Visual Perception. Oxford: Oxford University Press 1973
2. Murphy P, Fortinski M, Trope JE, Eizenman M, Hunter I: Eye movements and perimetry ARVO Abstracts. Invest Ophthalmol Vis Sci (Suppl) 31:16, 1990
3. Vingrys AJ, Demirel S: The effect of fixational loss on perimetric thresholds and reliability. This Volume, pp 521-526

4. Vingrys AJ, Helfrich KA: The Opticom M600™: a new LED automated perimeter. Clin Exp Optom 73:3-17, 1990
5. Searle AET, Shaw DE, Wild JM, O'Neill EC: Within and between test learning and fatigue effects in normal perimetric sensitivity. In: Mills RP, Heijl A (eds) Perimetry Update 1990/1991, pp 533-537. Amsterdam: Kugler Publ 1991
6 Newman SA: Insensitivity of the automated monitoring system of the Octopus 2000R to small eye movements. ARVO Abstracts. Invest Ophthalmol Vis Sci (Suppl) 28:270, 1987

The effect of fixational loss on perimetric thresholds and reliability

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Abstract

Automated perimeters calculate several reliability indices for each threshold test including: fixation loss, false positives, false negatives and short-term fluctuation. This study was designed to assess the effect that poor fixation has on threshold and these reliability indices. A well-trained observer performed thresholds on the Humphrey Field Analyzer using a modified 12°×16° grid pattern and a size 3 (0.43° diameter) target. The grid had a 2° inter-stimulus spacing and was centered on the blind spot or mirrored into the equivalent nasal field of the same eye. The subject performed a repetitive pseudo-random set of intentional fixation losses during testing. The effect that different sized fixation losses (0°, 2°, 5°, and 10°) and the presence or absence of a scotoma (physiological blind spot) had on thresholds and on reliability indices was evaluated. Mean threshold was increased in the presence of a moving scotoma. False positives occurred infrequently and were unrelated to fixational stability False negatives only occurred in the presence of a scotoma and only if fixation was unstable. Short-term fluctuation was significantly higher in the presence of a scotoma and higher still if fixation was unstable. These findings led the authors to the following conclusions: *1.* false negatives may not only indicate poor reliability but also the presence of a moving scotoma; *2.* short-term fluctuation may be increased by the movement of a small, steep-sided scotoma within the field; and *3.* eye movements decrease perimetric reliability and flatten the hill of vision. There may be a role for intentional eye movements in clinical perimetry

Introduction

In a fellow paper we confirm that fixational instability is common in experienced observers performing perimetric thresholds[1]. We also show that the size of this fixation loss is not trivial with a considerable number being at least 3° in extent. More importantly, we find that the blindspot monitor is limited in its ability to detect fixation losses <5° in size[1]. This means that patients may be making eye movements that go undetected by the clinician.

The purpose of this study was to determine the effect that eye movements have on perimetric outcomes and specially our capacity to detect small or early scotomata. As such we considered the effect that eye movements have on normal retinal as well as scotomatous regions. For this latter study we assumed that the normal physiological blindspot provides an adequate model of a pathological scotoma.

Material and methods

This paper reports the results of one subject studied extensively for 20 hours of perimetric testing over a two-week period. The general trends have been confirmed on two other observers using more limited testing. In short, four 15-minute tests were performed in one session with two sessions completed per day. While undergoing field testing, a pseudo-random set of intentional eye movements were performed to accessory fixation targets attached to the inside of the perimeter bowl. Four levels of eye movement were used, namely; 0°, 2°, 5°, or 10° from the central fixation point (see Fig. 1 of ref 1). Only one level of eye movement was tested at any single test session. Headphones were used to playback instructions that directed the subject

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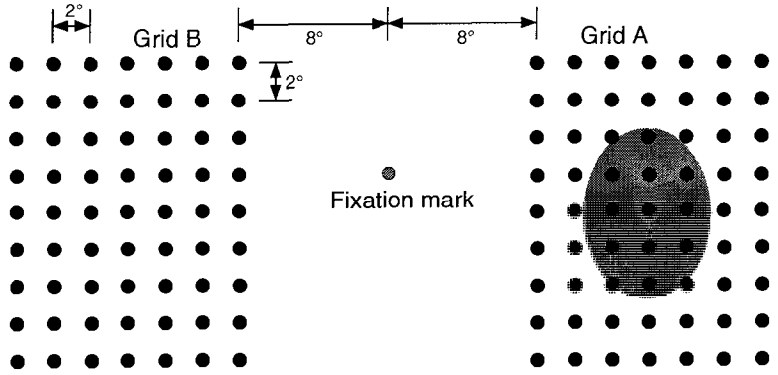

Fig. 1. Schematic representation of the two 12°×16° user defined grids used in this study. Both were located 8° from fixation with one centered on the blindspot and the other being a mirror image in the fellow hemifield.

to look towards different locations. Eccentric fixation periods lasted from five to 15 seconds and instructions were such that:

1. the time spent viewing the central and all eccentric points was equal (50% fixation loss);
2. equal times were spent at each eccentricity; and
3. times were shared equally among the four directions (left, right, up, down) of a given eccentricity.

For this study we developed a 12°×16°, 63-point, grid pattern using an inter-stimulus spacing of 2° (Fig. 1) on the Humphrey Field Analyzer (HFA). This grid was either centered on the blindspot (grid A, in Fig. 1) or in the mirror image location of the fellow hemifield (grid B, in Fig. 1). The closest grid point was 8° away from the central fixation point. Each grid and eye movement level was tested on four different occasions so our data are averages of four repeats obtained over 32 trials (2 grids × 4 levels × 4 repeats). The experimental design used a Graeco-Latin square over all tests.

We intentionally included the large eye movement (10°) as an internal check of the effect that a moving scotoma has on false negatives. The false negative rate can be modeled given the geometry of the test grid (Fig. 1), the size of the blindspot, the size of an eye movement and by assuming that our observer provides reliable responses. Following an eye movement the false negative rate will reflect the ratio between the new number of spots now falling in the blindspot compared with the total number of spots outside of it or the original blindspot. In our case, if we assume that the blindspot involves nine locations (see Fig. 1), we could then expect a maximum false negative rate of 10-15% with 5° eye movements. The 2° eye movement will only move the blindspot by one line of grid elements and we predict a false negative rate of 2-5% for this case depending upon the number of points effected. We expect no or very few (0.2%) false negatives with the 10° eye movement because the blindspot will be removed from the test grid.

All results were analyzed with either the Student's *t* test (mean comparison) or F ratio (fluctuation comparison) using steady fixation and grid B (0°, normal retina) as the control condition.

Results

Fig. 2 shows the effect that fixational stability has on normal and scotomatous thresholds. It gives mean thresholds averaged over the four trials for both grids; the error bars show the average level of local fluctuation. As expected grid A (filled circles) shows a lower average threshold than does grid B (open circles, normal retina), reflecting the presence of the blindspot. This difference only reaches statistical significance for the 0° fixation loss condition ($t=5.33$, $df=248$, $p<0.001$). Increasing eye movements have little effect on normal retinal sensitivity (31.9 dB), however, a significant increase in threshold is found for the scotomatous region (22.2 dB *versus* 28.7 dB, $t=2.66$, $df=248$, $p<0.01$). This increase is most marked with even a

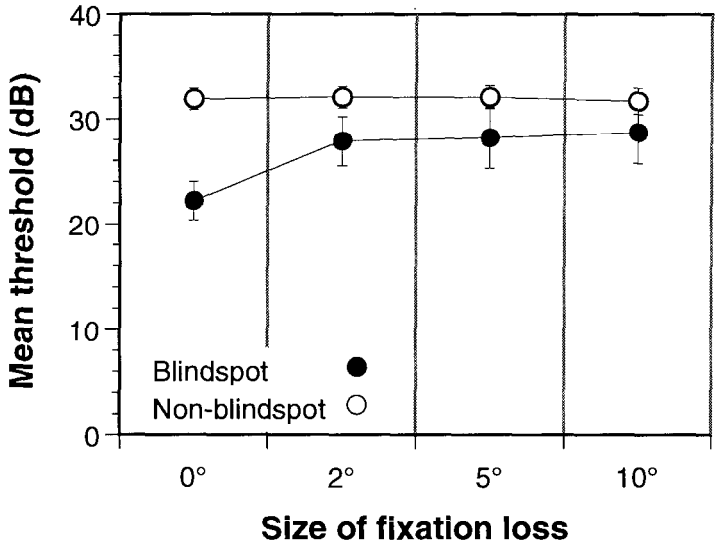

Fig 2. The effect that fixation loss and the presence of scotoma has on mean threshold Error bars show local fluctuation.

small eye movement (2°) ($p<0.01$) and no significant difference is observed between the three levels of fixational loss (2°-10°).

Fig. 3 shows the effect that scotoma and fixation loss have on fluctuation. In this figure local fluctuation was determined by taking the average standard deviation of the four repeats in a point-wise manner (square root of average variance). Note that the presence of a scotoma significantly increases local fluctuation ($F_{248,248}=1.87$, $p<0.01$) and that fixational instability further increases fluctuation beyond the stable condition ($F_{248,248}=1.29$, $p<0.05$) only in the presence of a scotoma. Although some ceiling may be expected in these data the levelling off found in our study (Fig. 3, 5° to 10°) is most likely due to the limited size of our sampling grid.

Fig. 4 shows the effect that fixation loss and the presence of scotoma has on two reliability indices, false positives and false negatives. Our observer was reliable making few false posi-

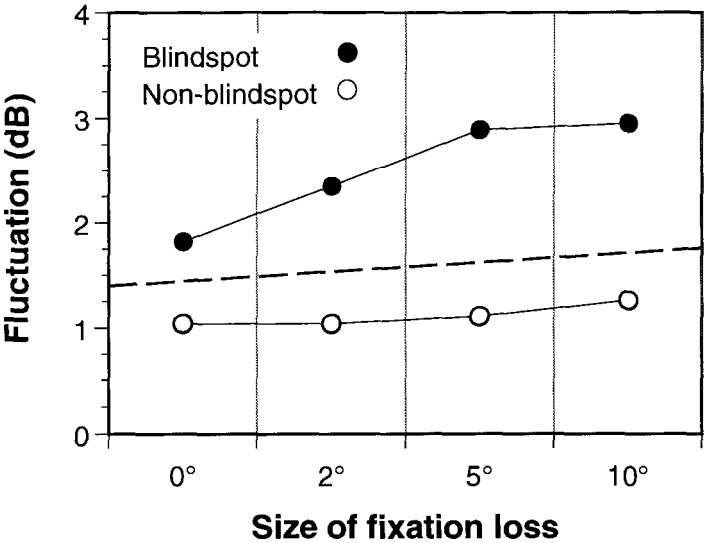

Fig. 3. The effect that fixation loss and the presence of scotoma has on local fluctuation. The dashed horizontal line shows statistically significant values at $p<0.01$.

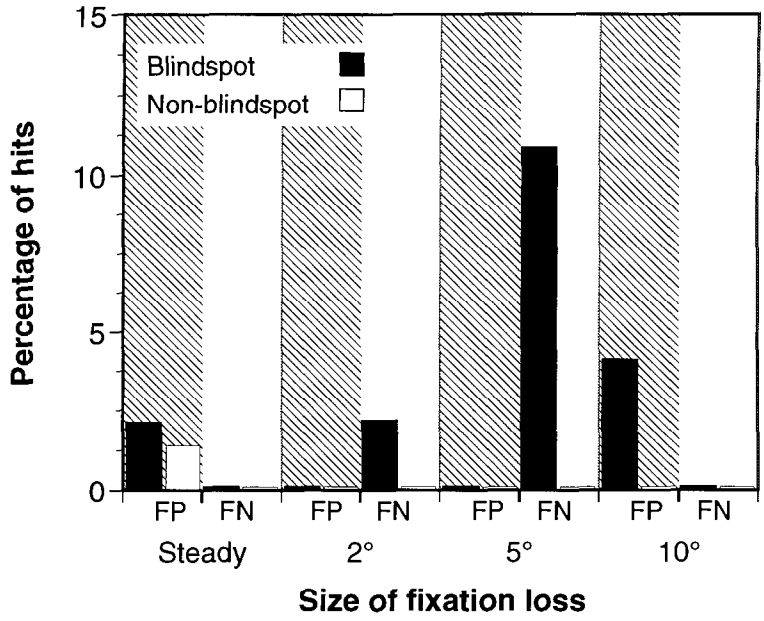

Fig 4 The effect that fixation loss and the presence of scotoma has on false positives (FP) and false negatives (FN). The cross-hatched region identifies FP values. The FN drop-off at 10° is consistent with a model based on a moving scotoma.

tives (0%-4.3%). Those that do occur show no obvious association with the presence or absence of the blindspot or fixational loss. On the other hand, false negatives were only found in association with the scotoma and increase from 2-11% as the size of the eye movement increases from 2-5°. There are no false negatives found with 10° movements. These results are consistent with our modeling (see methods) and indicate that they arise from the presence of a moving scotoma across the test grid.

Fig. 5 is a 3-D representation of the average blindspot obtained with steady fixation and following 5° eye movements. The depth of the scotoma is significantly shallower ($t=6.47$, $df=6$, $p<0.001$) and the edges are not as steep in the presence of the eye movement. The size of the scotoma is also larger in the presence of the eye movement.

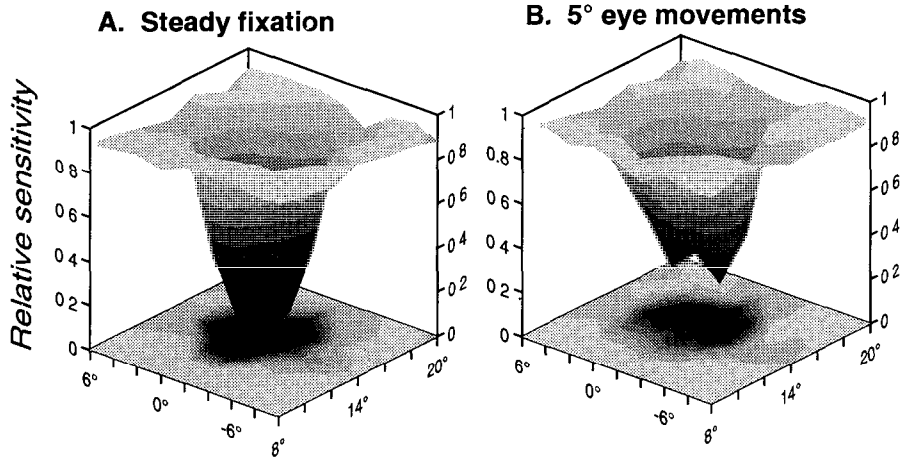

Fig. 5. A 3-D plot to show the effect that fixation loss has on scotoma depth and size. Fixation instability blurs out such a deep scotoma. A. blindspot obtained with steady fixation. B. blindspot obtained with 5° eye movements.

Discussion

Several important conclusions are evident from this study regarding the relationship between perimetric indices, thresholds and eye movements; they are summarized in Table 1 and the following discussion.

Table 1. The effect that eye movement and scotomatous presence have on perimetric thresholds and reliability

Parameter	*Scotoma present*	
	Yes	*No*
False positives	none	none
False negatives	increased*	none
Threshold	increased*	none
Fluctuation	increased*	none

*values are statistically significant at $p<0.01$

False positives

We found that the presence of a scotoma or fixational instability has no effect on false positives and conclude that these are spontaneous and unrelated events indicating the patient's internal level of reliability or "trigger happiness".

Thresholds

Fig. 2 shows how a significant loss (9.8 dB) can evaporate to become an insignificant depression (3-4 dB) following eye movement. Moreover, our data indicate that even small eye movements (2°) produce significant elevations (6 dB) of abnormal thresholds and that no effect is found in the absence of a scotoma. This means that eye movements make shallow scotomata harder to find based on normative comparisons (STATPAC) in the presence of small eye movements and practitioners should bear this in mind when looking for early losses.

Fluctuation

Fig. 3 shows how local fluctuation is increased in the presence of a moving or stationary scotoma but remains unaffected in normal regions regardless of the fixational pattern. If this finding is coupled with the previous observation on thresholds it means that definition of an early scotomatous region will be much more difficult given fixational losses. This fact is evident in Fig. 5 where eye movements have blurred out a deep and sizable scotoma making the slopes shallower and depth less pronounced.

False negatives

Fig. 4 shows that false negatives increase in the presence of a moving scotoma. These trends are consistent with our model based on a moving scotoma (see method) assuming a reliable patient. Hence our data suggest that this index may be a sensitive gauge of small scotomatous losses in the visual field.

Clinical application

Our conclusion is that small eye movements will blur out scotomata and make them less visible. However, at the same time they will increase the fluctuation and false negative rate. These data provide a scientific basis for the clinical observation that the earliest defect with disease can be an abnormal fluctuation or increased false negative rate[2-4]. In fact it supports a hypothesis, made elsewhere[2], that an increased local fluctuation can arise from the movement of a small scotoma across the test grid. Others have also shown that fluctuation is increased near or in scotomatous regions[5,6].

One interesting aspect of this research is that there may be some merit in using intentional

5° eye movements for the detection of early and shallow scotomata that may otherwise go undetected due to undersampling by the test grid. In these cases eye movements may prove an ally to the clinician; they will spread the test grid over a larger area and provide a larger net for the detection of an otherwise small and local scotoma. The clinician should monitor the fluctuation and false negative rate in such cases because thresholds will be elevated. Although our data suggest that this should be possible we have not confirmed it by a clinical trial.

It should be mentioned that the present global index of fluctuation, calculated by most perimeters using a root mean square (RMS), is inadequate for this purpose and a local index should be used[2,7]. We believe that clinicians confronted with a person with near normal thresholds but who has an increased false negative rate and elevated local fluctuation should consider this as evidence of the presence of a small scotoma in some region of the visual field. Hence, we recommend that perimeters adopt local measures of fluctuation in order to enhance the detection of early and shallow scotomata. In the absence of such indices the practitioner should visually inspect the level of variability on a point-wise manner. Our results suggest that a repeatable change of more than ±5 dB on four retests would most likely indicate an abnormal level of local fluctuation associated with a scotomatous region.

References

1. Vingrys AJ, Demirel S: Fixational instability during perimetry and the blindspot monitor. This Volume, pp 515-520
2. Vingrys AJ, Verbaken JH: Perimetric fluctuation in normal and diseased eyes. ARVO Abstracts. Invest Ophthalmol Vis Sci (Suppl) 31:191, 1990 (also Invest Ophthalmol Vis Sci 1993 in press)
3. Flammer J, Drance SM, Zulauf M: Differential light threshold: short- and long-term fluctuation in patients with glaucoma, normal controls, and patients with suspected glaucoma. Arch Ophthalmol 102:704-706, 1984
4 Anderson DR: Automated Static Perimetry. St Louis: CV Mosby Co 1992
5. Haefliger IO, Flammer J: Increase of the short-term fluctuation of the differential light threshold around a physiological scotoma Am J Ophthalmol 107:417-420, 1989
6 Henson DB: Is the variability in glaucomatous field loss due to poor fixation control? In: Mills RP, Heijl A (eds) Perimetry Update 1990/1991. Amsterdam: Kugler Publ 1991
7. Casson EJ, Shapiro LR, Johnson CA: Short-term fluctuation as an estimate of variability in visual field data. Invest Ophthalmol Vis Sci 31:2459-2463, 1990

Performance of unreliable patients on repeat perimetry

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Abstract

Twenty-nine patients who were unreliable on initial Humphrey 30-2 testing were tested further using the Humphrey 24-2 and the high-pass resolution (HRP) standard threshold programs. Criteria for unreliability were as follows: fixation losses ≥15% (despite active technician involvement), false positives ≥15%, or false negatives ≥30%. While reliability rates did show some improvement in 66% of patients, 23/29 remained unreliable on one or both of the repeat tests, most often because of high fixation loss rates The HRP device utilizes several software features not employed by the Humphrey perimeter that are designed to improve performance on reliability catch trials. In this group of patients, the overall reliability on retest was the same on both Humphrey and HRP, the Humphrey recording somewhat fewer false negatives and the HRP fewer fixation losses Thus, in patients who are inherently unreliable, software features to improve attentiveness do not usually convert the patient into a reliable perimetry subject.

Introduction

It has long been known that patient attentiveness and reliability during perimetry are essential to obtaining valid results. The high-pass resolution perimeter (HRP) has many features that are designed to maintain patient attention and fixation and thereby improve the reliability of the results[1-3]. These features are made possible by the use of a high-definition video monitor as the test surface rather than a projection bowl as in conventional perimeters.

The HRP fixation target, consisting of a high-contrast cross that contracts just before stimulus presentation, is dynamic to attract attention, cues the patient to the impending stimulus, and prevents its fading from view. The target is occasionally replaced by the text "look here" as a patient reminder. If the patient responds to a high contrast stimulus presented in the physiologic blind spot, a text message "error" appears in place of the fixation target and the computer sounds loud beeps. A similar error message appears when the patient responds to a "false positive" catch trial in which no stimulus is shown.

In comparison, the Humphrey Field Analyzer (HFA) has a steady fixation target[4]. The only feature designed to improve fixation is the routine which is activated after a fixation loss. When a patient responds to a bright stimulus in the physiologic blind spot more than twice, the perimeter sounds a beep to remind the examiner to try to re-instruct the patient about fixating centrally. False positive responses are recorded without an audible alarm, so the perimetrist must be alert to the need for patient reminders.

Many patients tend to look away from the fixation target towards the stimulus to confirm its location. Stimulus durations for both the HRP (165 msec) and the HFA (200 msec) are less than the latency time for voluntary movement, so refixations are discouraged. In addition, after each correct patient response to a stimulus, the HRP displays a large dark square at the location of the stimulus so the patient can verify the stimulus location without having to look towards it. The HRP automatically adjusts the speed of the test to the patient's reaction time, while the HFA runs the entire test at a preselected rate.

While the added features of the HRP seem to enhance the attentiveness and reliability of the average patient, it is not known whether patients previously documented as unreliable show a similar improvement in behavior. This study focused on such a study population, comparing reliability parameters on repeat testing with HFA and HRP devices.

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Material and methods

Twenty-nine patients who were unreliable on initial Humphrey 30-2 clinical testing agreed to return for participation in the study. Criteria for unreliability included one or more of the following present in both eyes: false positives ≥15%, false negatives ≥30% or fixation losses ≥15%. Patients were excluded if severe visual field loss was found which could have contributed to a high false negative error rate[5-7] or if their physical condition precluded completion of testing with either perimeter used in the study. Both on the initial and on subsequent testing, the perimetrist adjusted patient position when fixation losses occurred in spite of subjectively adequate patient fixation behavior.

Visual fields were performed with both the HFA using the 24-2 central threshold strategy (Fig. 1) and the HRP using the standard ring test (Fig. 2). Corrective lenses as required for the respective perimeters were supplied. Only one eye of each patient was tested: the eye with the better visual acuity, or if equal, right eyes on even dates and left eyes on odd dates. The two study tests were administered on the same day in pseudo-random order, and patients were given

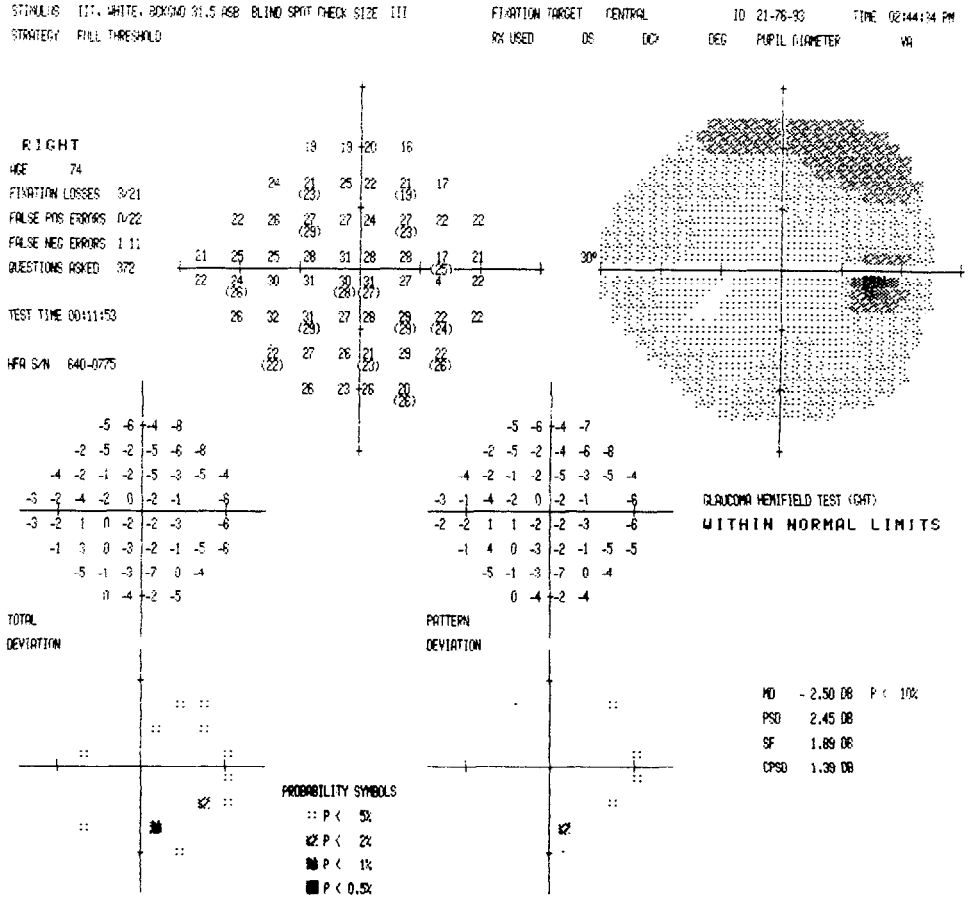

Fig. 1. Central 24-2 threshold test

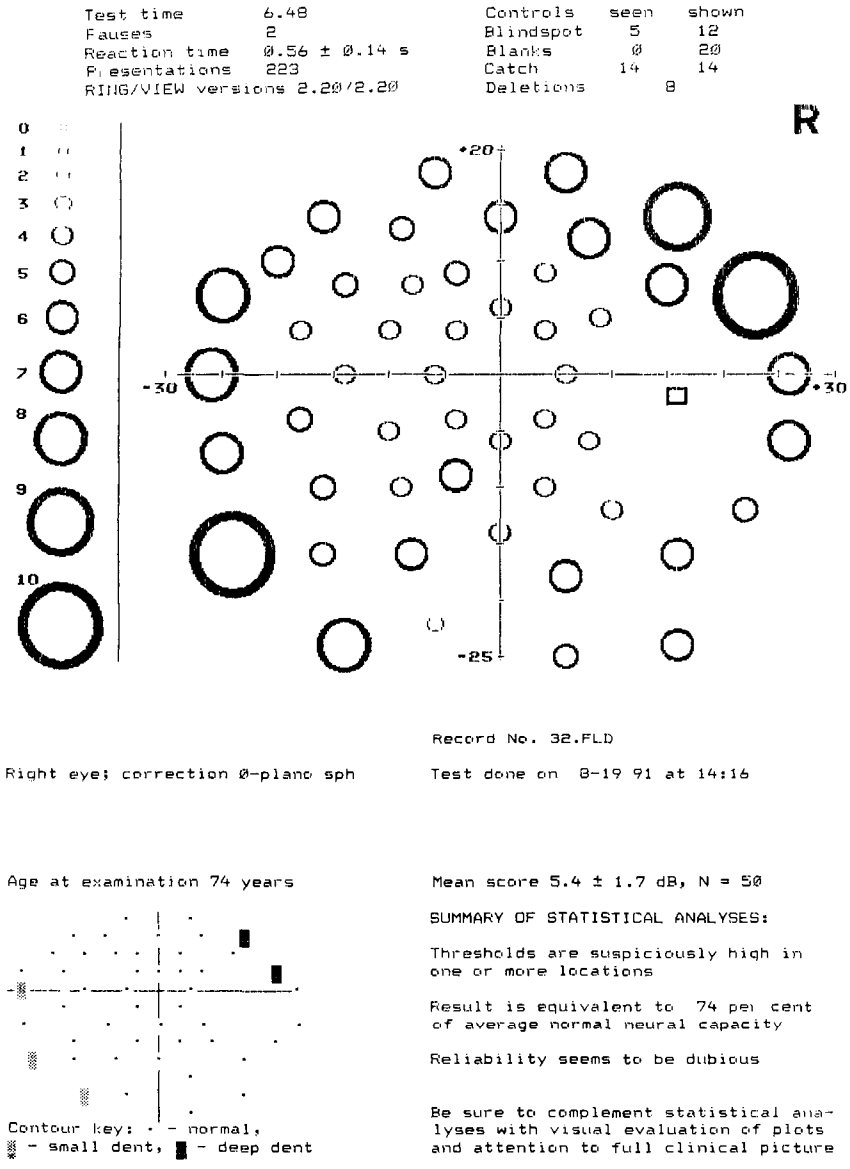

Fig. 2. Standard ring test.

ample opportunity to rest during and between tests as necessary.

For each test, the reliability parameters (false positive, false negative, and fixation losses) were recorded as a percentage derived from the ratio of catch trials missed divided by catch trials attempted. In addition, a "reliability index" was calculated for each test using an unweighted average of the percentages of the three reliability parameters[8].

Results

Thirty-three patients meeting the eligibility criteria were enrolled in the study. One patient repeatedly failed the study appointments, and three could not complete study testing because of fatigue or illness. The 29 remaining study patients ranged in age from 37 to 85 years (mean 57.3). Sixty-six percent of the patients demonstrated an improved reliability index on the study

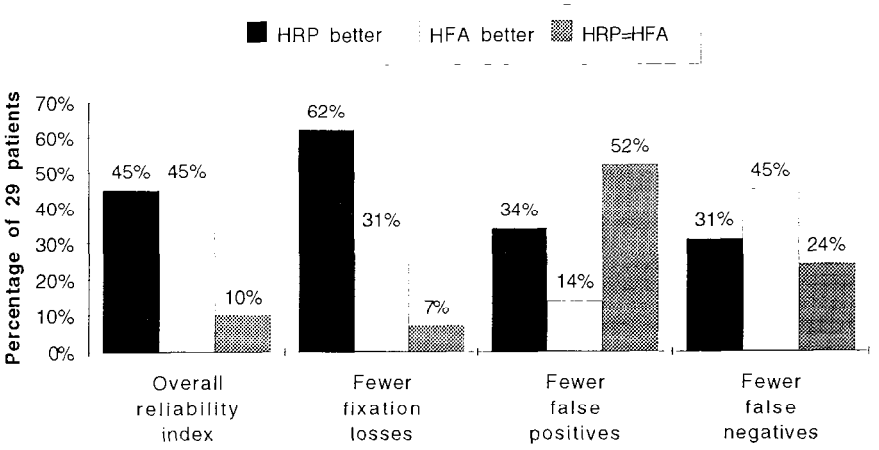

Fig. 3. Performance of unreliable patients on repeat perimetry

tests when compared to the initial, qualifying field, although 23/29 continued to meet the criteria for unreliability on one or both of the study tests. In most cases, this resulted from a persistently high fixation loss rate with or without high false negative or positive rates.

Fig. 3 shows that the overall "reliability index" was equal on the two perimeters. Forty-five percent of our patients had better reliability on the HRP, 45% performed more reliably on the HFA, and 10% performed equally. However, the HRP perimeter showed fewer fixation losses than the HFA in 62% of patients, while in 31% there were fewer fixation losses on the HFA (7% tied). False positive rates were low in most patients. They were (zero) in over half the patients, but in the remainder the HRP tended to show lower rates. False negative rates were lower on the HFA in 45% of patients as compared with 31% on the HRP (24% tied).

Patients were divided into two groups depending on whether they were consistently unreliable on more than one previous HFA 30-2 test session, or whether the initial qualifying field was the first 30-2 test they had ever performed (Fig. 4). Of the 12 patients consistently unreliable on HFA testing, the HRP demonstrated a better overall reliability index in 58%, while the HFA had better reliability in only 33% of patients. Among the 17 patients with only one prior unreliable HFA field, the reverse was true. The HFA showed better reliability in 53%, while the HRP was better in only 35% (Fig. 5).

There was no apparent effect of progressive fatigue over the duration of testing. The second of the two study tests, whether HFA or HRP, had a lower reliability index than the first test only 48% of the time, the opposite being the case in the remainder.

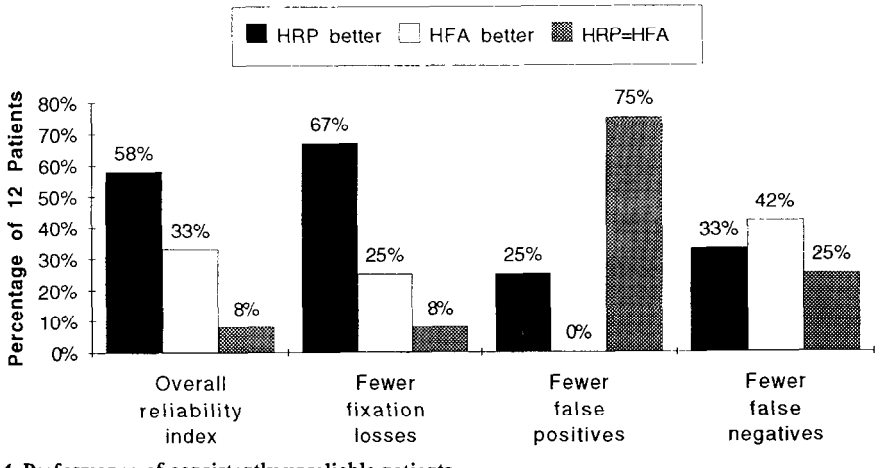

Fig. 4. Performance of consistently unreliable patients.

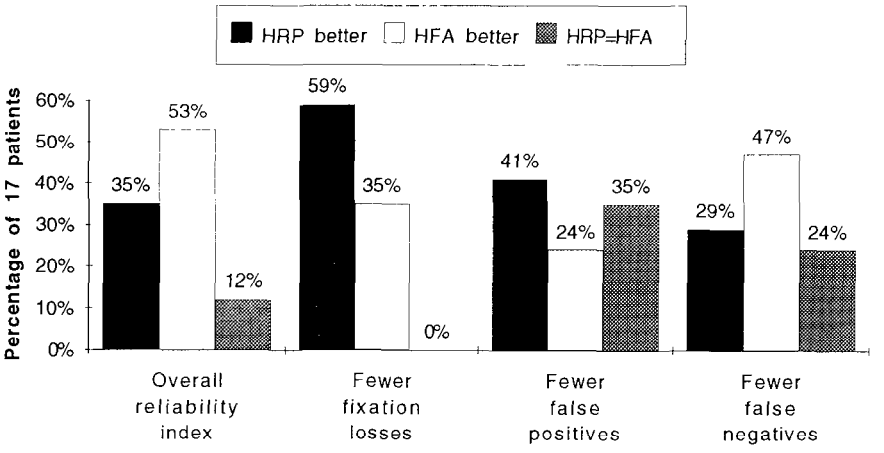

Fig 5. Performance of unreliable patients new to automated perimetry.

Discussion

As expected, unreliable patients tended to remain unreliable on repeat testing. Reliability did improve in the majority, but not enough to meet accepted criteria for a reliable examination. When consistently unreliable patients are encountered in routine clinical practice, one must either accept the likelihood that performance will remain substandard on future testing, or select an alternate method of visual field testing, such as a manual technique using the Goldmann perimeter.

Most of our patients failed the fixation loss criterion of reliability. It is well known that fixation behavior is enhanced by active technician intervention[9], so we were careful to ensure that this was provided during both the qualifying and the repeat test phase of the study.

Despite great differences in perimeter hardware and software design of the HFA and HRP instruments, unreliable patients performed equally poorly in terms of overall reliability on the two perimeters. There was a distinct tendency to a lower rate of fixation losses on the HRP, probably because of the dynamic fixation target, periodic fixation reminders, and correct response verification features, all of which tend to favor central fixation behavior. Interestingly, there was a tendency to a higher false negative rate on the HRP, despite the presence of patient feedback, which is employed to improve alertness and *decrease* false negatives,

In the majority of patients having had only one previous 30-2 test, their performance on the HFA was more reliable than the HRP. This may indicate that, having learned about the Humphrey test, patients performed better on a repeat HFA test than they did on the less familiar HRP device.

Conversely, in those patients showing consistently unreliable HFA fields, performance on the HRP tended to be better. Having proven themselves unreliable on the HFA, patients improved reliability somewhat during testing with a very different device.

It should not be construed that software features designed to improve attentiveness and reliability are valueless. This study did not consider the vast majority of patients who pass the reliability criteria, and whose performance may well be improved by such software features. In a population of unreliable patients, however, such software features on the HRP do not tend to convert unreliable patients into reliable ones, nor do they improve reliability above the levels achieved by the HFA.

References

1. Frisén L: A computer-graphics visual field screener using high-pass spatial frequency resolution targets and multiple feedback devices. Doc Ophthalmol Proc Ser 49:441-446, 1987
2. Ophthimus System Manual, Version 2.0: High Tech Vision, Malmö, Sweden, 1991
3. Frisén L: Computerized perimetry: possibilities for individual adaptation and feedback. Doc Ophthalmol 69:3-9, 1988

4 Haley MJ (ed): The Field Analyzer Primer, 2nd Edn. San Leandro: Allergan Humphrey 1987
5. Heijl A, Lindgren G, Olsson J: Reliability parameters in computerized perimetry. Doc Ophthalmol Proc Ser 49:593-600, 1987
6. Katz J, Sommer A: Reliability indexes of automated perimetric tests. Arch Ophthalmol 106:1252-1254, 1988
7 Jenni F, Flammer J: Experience with the reliability parameters of the Octopus automated perimeter. Doc Ophthalmol Proc Ser 49:601-603, 1987
8. Mills RP, Lau W, Schulzer M: Clinical comparisons of two estimates of short-term fluctuation. In: Mills RP, Heijl A (eds) Perimetry Update, 1990-91, pp 203-208. Amsterdam: Kugler Publ 1991
9. Bickler-Bluth M, Trick GL, Kolker AE, Cooper DG: Assessing the utility of reliability indices for automated visual fields: testing ocular hypertensives. Ophthalmology 96:616-619, 1989

Estimation of receptive field area and density of human retina using computer simulation

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Abstract

The relationship between the detection threshold and the area of light stimulus (which is called the area-threshold relationship) can be explained by the TAMIT model (total activity model for increment threshold) TAMIT is essentially composed of two processing stages The first stage corresponds to information processing by the retinal ganglion cell (RGC). The second stage is for summation of all outputs from the RGC. RGCs are threshold elements with a receptive field in the retina It is assumed that if the total output (total activity level) exceeds the psychological threshold, light is detected. In this paper, the authors vary all the eight changeable parameters of TAMIT and simulated an area-threshold curve By fitting a curve to the psychophysical area-threshold curve, they estimated the radius of complete spatial summation area and density of the receptive field.

Introduction

TAMIT (total activity model for increment threshold), developed by Inui *et al.*[1] is a computer simulation model of the human retina. TAMIT can simulate not only the response of single retinal ganglion cells, but also the total response of plural retinal ganglion cells. By this method TAMIT is a psychophysically accurate model. The purpose of this model is to explain partial summation area accurately. But Inui *et al.* presume receptive field density using the size of receptive field by the Glezer method. In this paper, we tried to re-examine the appropriateness of Inui's model, changing all the changeable parameters and fitting the simulated area-threshold curve to the physiological area-threshold curve.

Method

The computer simulation model TAMIT is a threshold detection system. TAMIT is constructed by two processes. One process corresponds to the information processing stage of a single retinal ganglion cell (RGC), the other to summation of all outputs from the RGC. When the total output exceeds the psychological threshold, light is detected. The structure of TAMIT is shown in Fig 1.

TAMIT has eight parameters. We tried to change all these parameters on this simulation.

A	maximum center sensitivity
AQ	maximum surround sensitivity
σe	radius of receptive field center
σi	radius of receptive field surround
θn	threshold of one neuron
θp	psychological threshold
Dr	receptive field density
E	retinal eccentricity

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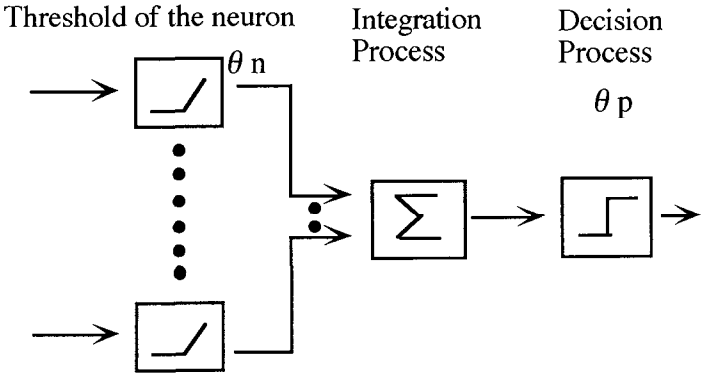

Fig. 1.

On TAMIT, the receptive field of each RGC is described as a function of DOG (difference of Gaussian). The distribution of receptive field sensitivity is formulated below. Standard deviation of each DOG is shown as σe and σi. The peak of each DOG is shown as A and AQ. r is the distance from the receptive field center (Fig. 2).

$$G(r) = A(\exp(-r^2/\sigma_e^2)-Q\cdot\exp(-r^2/\sigma_i^2))$$

The diameter of the surrounding area is three times the diameter of the central area of the receptive field. It is not dependent on eccentricity of the retina.

$$\sigma i = 3\sigma e$$

And from the physiological data of Linsenmeier *et al.*[2]:

$$A = 2.13/\sigma\ e^{1\ 23}$$

From these formulas, A and σi are fixed by σe.

And from Drasdo's approximation, while E<30°, Dr is a formula of E. On this simulation E=0, which means the central area of the retina was chosen. d is given a definition by the formula below, in which Dy is the density of receptive field of retinal ganglion cells.

$$Dy = Dr\cdot d$$

From the above, independent parameters of TAMIT for this simulation are Q,θn,d, and σe.

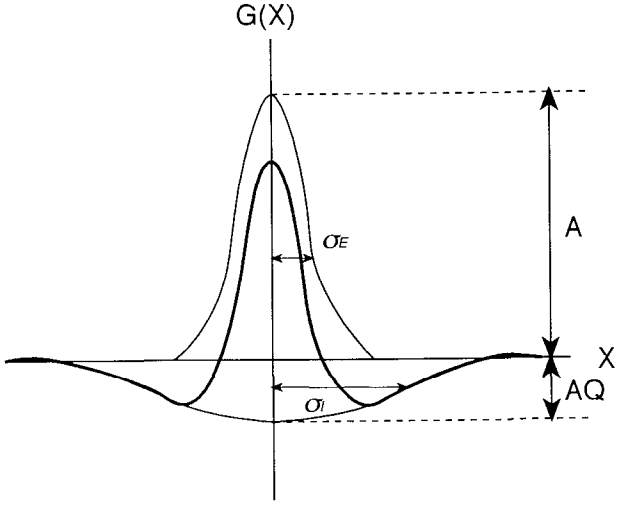

Fig 2. Distribution of RGC receptive field sensitivity

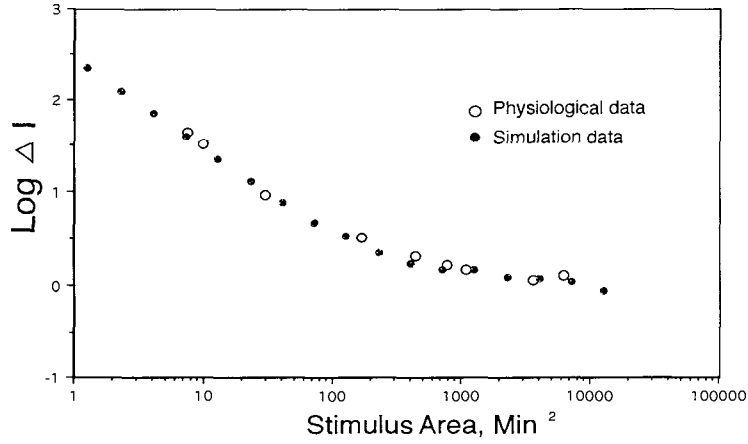

Fig. 3. Area-threshold curve.

We have changed Q,θn,d and 2σe of TAMIT, and simulated the area-threshold curve. We then compared the result of TAMIT simulation data to physiological data[3], to determine the most suitable parameters. The variation of parameters are:

Q	0.2, 0.12, 0.10, 0.05
θn	4, 2, 1, 0
d	4%, 2%, 1%, 0.01%, 0.005%
2σe	4.15×4, 10.0, 4.15×2, 4.15, 3.1, 4.15/2, 4.15/4

Results

We changed TAMIT parameters and determined the most suitable parameters by comparing physiological data with simulation data (Fig. 3). The most suitable parameters were:

2σe = 3.1 d = 0.02 Q = 0.12 θn = 2.0

Discussion

These results are very similar to the simulation data of Inui *et al.* They showed that the Glezer method is good to approximate the size of the human receptive field. According to these results, TAMIT is a reliable method for simulating data processing of the human receptive field.

We are planning to increase the simulation speed of TAMIT, and to simulate off central areas of the human retina and also to simulate damaged retinas according to various eye diseases.

References

1. Inui T, Kani K et al: Estimation of the receptive field density of Y cells in the human retina. Neuro-Ophthalmol Jpn 6:383-389, 1989
2 Linsenmeier RA et al: Receptive field properties of X and Y cells in the cat retina derived from contrast sensitivity measurement. Vision Res 22:1173-1183, 1982
3. Inui T, Mimura O et al: Retinal sensitivity and spatial summation in the foveal and parafoveal region J Opt Soc Am 71:151-154, 1981

Examination of receptive fields using an automatic perimeter

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Introduction

A retinal ganglion cell connects with receptor cells and forms a receptive field. The characteristics of the receptive field have been determined by electrophysiological experiments in animals. The psychophysical properties of spatial summation are presumed to relate to the receptive field organization of the ganglion cells[1].

We investigated the characteristics of human retinal receptive fields psychophysically using a fundus haploscope[2-6]. This instrument is useful because we could easily arrange the Maxwellian view system and could monitor the retinal location, as well as eye movement. This method, however, is too complicated to apply to clinical patients.

We have developed a clinically useful method to investigate the retinal receptive fields using an automatic perimeter.

Method

Minor modifications were made to a Topcon computerized perimeter SBP2020. Two small stimuli, 0.8′ and 1.6′ in diameter were added. Eight stimulus sizes, 0.8′, 1.6′, 3.2′, 6.5′, 13′, 26′, 52′ and 103′ in diameter were used. The background luminance was 31.5 asb.

Nine retinal points were tested; the fovea, 5°, 10°, 15° and 20° from the fovea at 45° above and below the nasal horizontal line in the visual field. The full examination consisted of eight sections. In each section, nine retinal points were randomly stimulated using one stimulus size per section. Each section of the examination took from one and a half to three minutes. Between sections, there was a one minute break. The increment threshold was determined to 1 dB using a standard threshold program bracketing strategy. The stimulus duration was 200 msec.

Results

Seventeen eyes of normal subjects were examined. The subjects consisted of 12 males and five females whose ages ranged from 24 to 38 years and whose mean age was 30.3 years. Fig. 1 shows the log light energy of the increment threshold plotted against the log diameter of the stimulus (diameter-threshold curve). The diameter-threshold curves are parallel to the abscissa where the stimuli are smaller than 2′ in diameter. This shows complete summation. Where the stimuli are larger than 30′ in diameter, the slope of the curves approaches 45°, showing non-summation. These curves are similar to those obtained by precise psychophysical examinations[2,4].

Forty-nine eyes of 27 patients were tested. Irregular patterns in the complete and incomplete summation area of the diameter-threshold curves were seen in 16 eyes of 18 eyes tested with glaucoma, in all 14 eyes with normal tension glaucoma and in all four eyes with optic neuropathy. Normal patterns were observed in cases of optic disc anomaly and recovered pituitary adenoma. In eye with central retinal vein occlusion, the diameter-threshold curves were elevated in the area where the stimulus sizes were smaller, but the shape was smooth. In eyes with central serous retinochoriopathy, the curves were normal.

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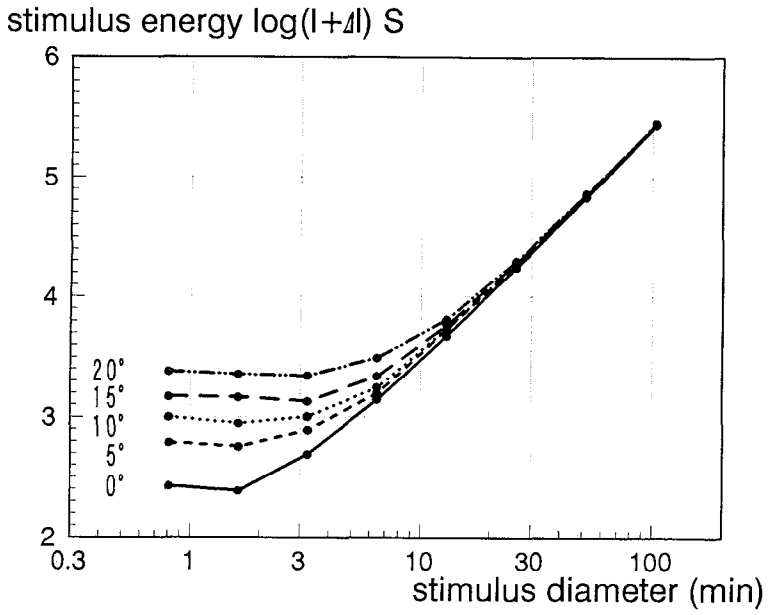

Fig. 1 Normal diameter-threshold curve. Total threshold energy of the stimulus at each retinal eccentricity is plotted against the stimulus diameter.

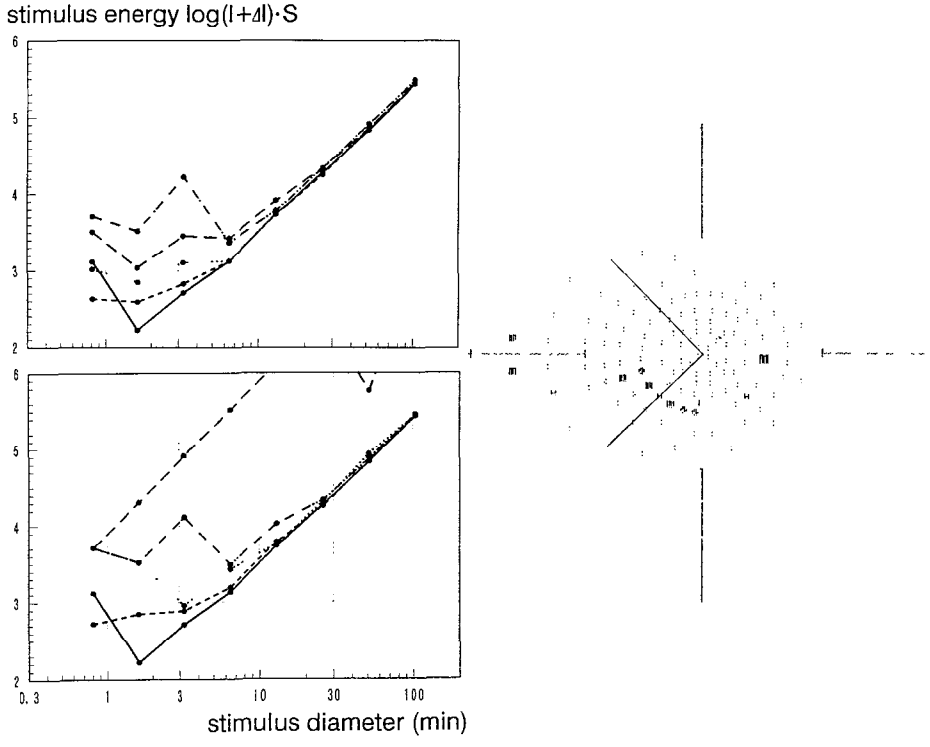

Fig. 2. Visual field and diameter-threshold curve of the right eye of case 1, primary open angle glaucoma.

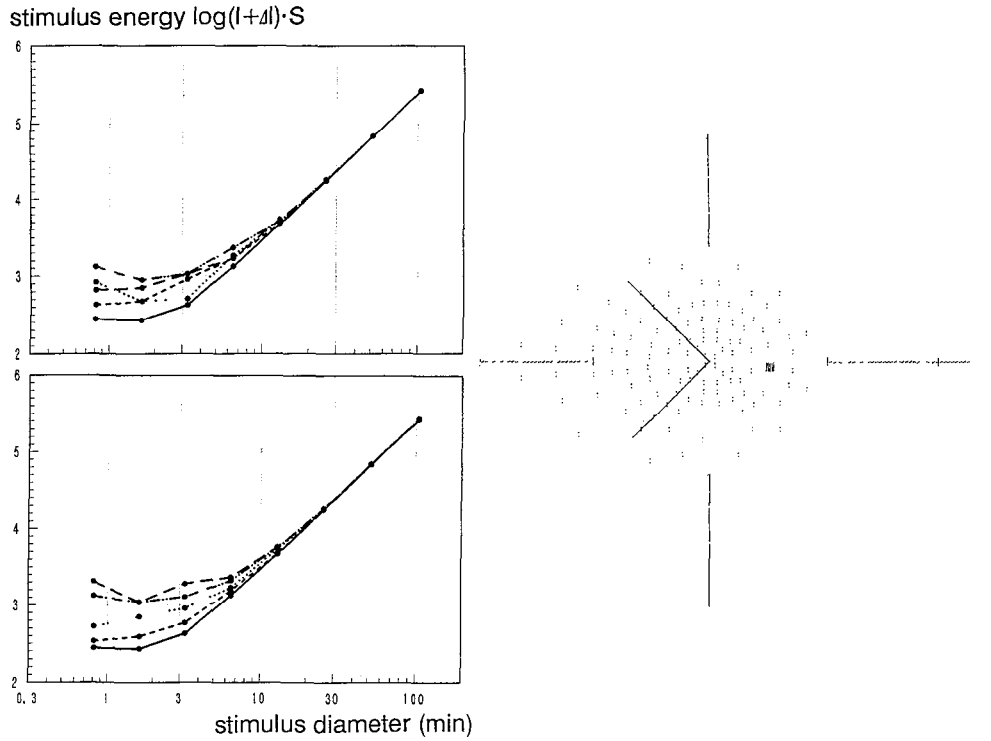

Fig. 3. Visual field and diameter-threshold curve of the right eye of case 2, ocular hypertension.

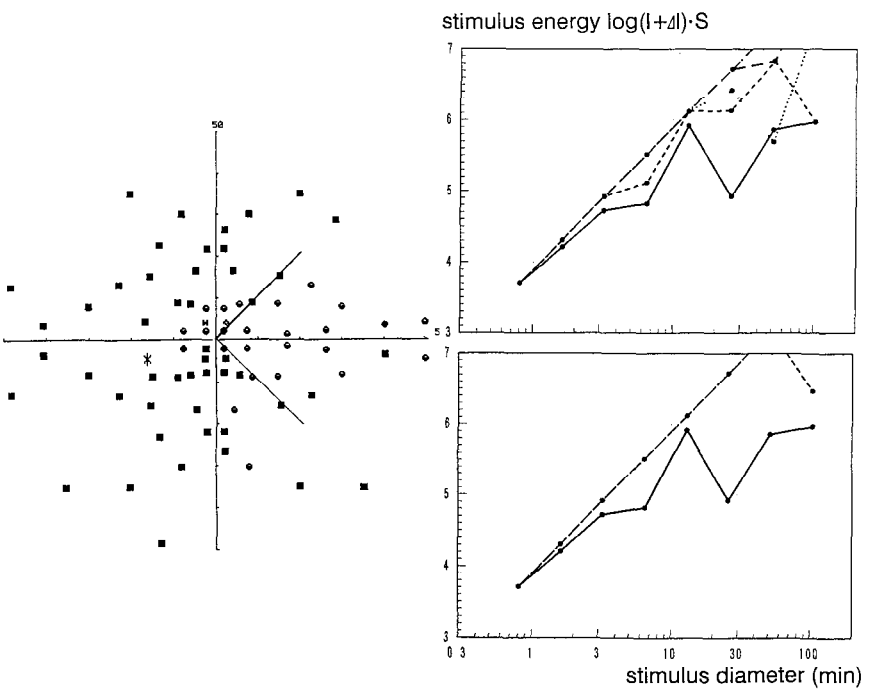

Fig. 4. Visual field and diameter-threshold curve of the left eye of case 3, rhinogenous optic neuropathy. Two days after the visual acuity had recovered to 1.2.

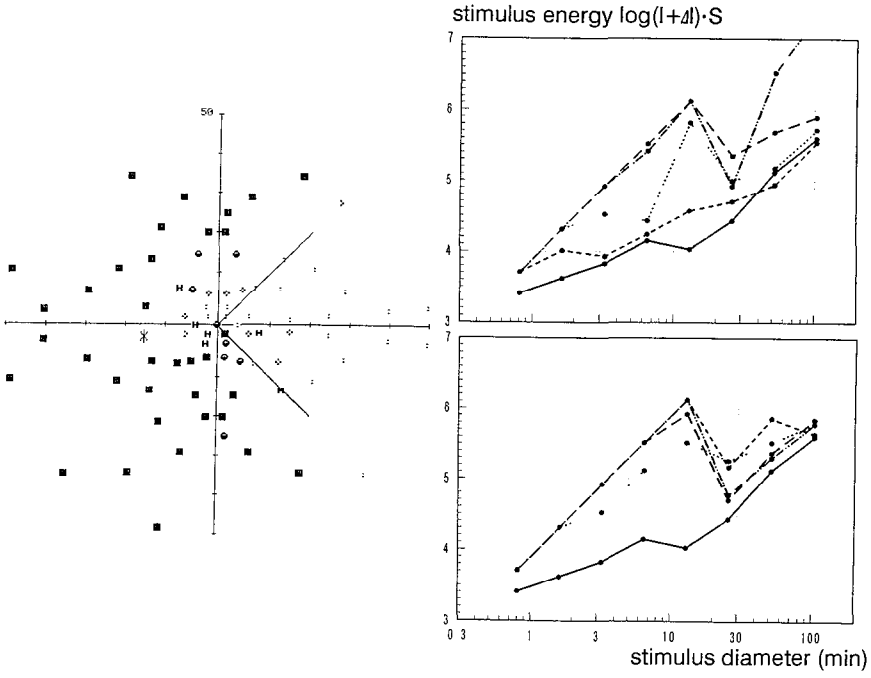

Fig. 5. Case 3: 20 days after the visual acuity had recovered.

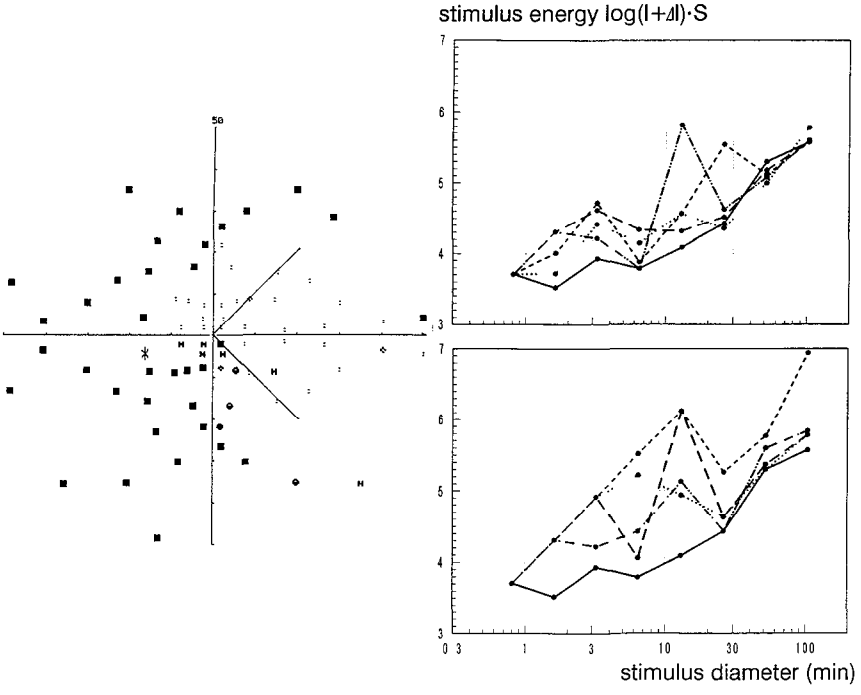

Fig. 6. Case 3: 27 days after the visual acuity had recovered.

Case 1

KK, a 57-year-old female had a history of elevated intraocular pressure in both eyes. Her best corrected visual acuity was RE: 1.5 and LE: 1.2. Large and deep disc cupping with nerve fiber bundle defects were observed in both eyes. Bjerrum area scotoma was seen in the right eye and nasal step in the left eye. In her right eye, 15° on the nasal lower meridian showed high threshold elevation and the diameter-threshold curve was over-ranged. On the upper nasal meridian, where no scotoma was found, the threshold was elevated in the complete summation area (Fig. 2).

Case 2

HA, a 36-year-old male was referred to us because of elevated intraocular pressure. His visual acuity was 1.2 in both eyes. The intraocular pressure was RE: 28 mmHg and LE: 24 mmHg. The disc cupping was physiological. The visual field, as well as the diameter-threshold curves were normal (Fig. 3).

Case 3

KT, this 39-year-old man had a sudden visual loss in his left eye on November 3, 1991 and five days later he had no light perception. His right eye was normal. After administration of 1000 mg methylprednisolone, the visual acuity rapidly recovered to 1.2. Pyocele in the left posterior ethmoid sinus and the left sphenoid sinus was found and removed. Visual fields and diameter-threshold curves in the recovery stage are shown in Figs. 4, 5 and 6. Abnormality in the complete and incomplete summation areas is seen.

Discussion

We sometimes observe early glaucoma cases where no visual field abnormality is detected using ordinary static perimetry, even when nerve fiber bundle defects are seen. This does not mean that there is no functional disorder. Mimura found receptive field abnormality in one optic neuritis case[3,5]. He mentioned that the receptive field was larger than normal three days after visual acuity had recovered and became normal two weeks later. In the course of optic nerve disease, some changes would occur in the network among retinal cells and they would be revealed in the receptive field.

Very few psychophysical studies on the receptive field have been performed on patients with optic nerve diseases because of the difficulty in applying precise psychophysical procedures to clinical patients. Our method is simple enough to apply in clinical cases. The results for normal subjects were satisfactory, even though these examinations were the subjects' first experience of this procedure. In clinical cases, the abnormalities were found in the disturbed area of the retina. In cases of optic nerve diseases, especially in glaucoma, irregular diameter-threshold curves were observed. This irregularity may correspond to optic nerve fiber defects, which resulted in receptive field defects.

We think that this method could be useful in detecting early visual disturbances.

References

1. Glezer VD: The receptive fields of the retina. Vision Res 5:497-525, 1965
2. Inui T, Mimura O, Kani K: Retinal sensitivity and spatial summation in the foveal and parafoveal regions. J Opt Soc Am 71:151-154, 1981
3. Mimura O, Kani K, Inui T: Spatial summation in the foveal and parafoveal region. Doc Ophthalmol Proc Ser 26:139-146, 1981
4. Kani K, Inui T, Haruta R, Mimura O: Lateral inhibition in the fovea and parafoveal regions. Doc Ophthalmol Proc Ser 35:391-396, 1983
5. Mimura O, Inui T, Kani K, Ohmi E: Retinal sensitivity and spatial summation in amblyopia. Jpn J Ophthalmol 28:389-400, 1984
6. Koh T, Iwasaki H, Takashima M, Kani K: Spatial summation measured with visual evoked potentials. Neuro-Ophthalmology 12:53-57, 1992

Characteristics of frequency-of-seeing curves in glaucoma

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Abstract

The authors undertook this study to determine factors that affect the characteristics of frequency-of-seeing curves in glaucoma patients and suspects. Our sample consisted of 60 subjects (22 normals, 12 glaucoma suspects, and 36 glaucoma patients) whose mean ages were 54.27, 54.83 and 66.78 years, respectively. A program was written to interface with the Humphrey Field Analyzer to enable them to measure frequency-of-seeing curves. The authors presented stimuli 8 dB either side of the estimated threshold in 1 dB intervals with five repetitions at each stimulus intensity They tested between four and six locations in each subject with the stimulus intensity and location randomized. Fixation was monitored using the Heijl-Krakau method They obtained 124 curves from the normals, 71 from the suspects and 183 from the glaucoma patients Using a probit program they calculated the threshold, interquartile range (an estimate of the slope) and the mean confidence interval (an estimate of goodness-of-fit) of each curve In all three groups of subjects the slope of the frequency-of-seeing curve was highly correlated to threshold or threshold deviation. The mean confidence interval was also correlated to the threshold and deviation, although some glaucoma patients produced remarkably "clean" curves with significantly elevated thresholds while others produced "noisy" curves with near normal thresholds.

Introduction

Frequency-of-seeing curves describe the relationship between the probability of seeing a stimulus and stimulus intensity. They can be thought of as cumulative gaussian functions which depict local threshold variability[1]. Frequency-of-seeing curves with conventional perimetric stimuli have been described previously in both normals and glaucoma patients[2-4], although the samples have generally been small. The characteristics of frequency-of-seeing curves have implications not only for perimetric thresholds and their variability, but also for modelling responses in simulation experiments. Perimetric responses in normals can be modelled adequately, since the slope of the frequency-of-seeing curve can be described by the local threshold, visual field location and age[2]. It is not clear whether the same applies to responses in patients with glaucoma.

We wanted to undertake a comprehensive study of the characteristics of frequency-of-seeing curves in glaucoma patients, glaucoma suspects and normals. We were particularly keen to compare frequency-of-seeing curves obtained at locations in glaucoma patients and normal subjects with similar thresholds and similar threshold deviations.

Subjects and methods

Subjects

The study sample contained 22 normals (mean age 54.27 years; range 34 to 76), 12 glaucoma suspects (mean age 54.83 years; range 36 to 77) and 36 open-angle glaucoma patients (mean

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age 66.78 years; range 36 to 86). All subjects had a visual acuity of >6/9, a pupil diameter of >3 mm when tested and a spectacle correction of <4.00 D (equivalent sphere). The glaucoma patients had early to advanced field damage.

Testing methods

We wrote a program on a personal computer to interface with the Humphrey Field Analyzer (Humphrey Instruments, San Leandro, CA). One module of the program allows measurement of frequency-of-seeing curves.

In normals and glaucoma suspects, we tested locations along either the 45°, 135°, 225° or 315° meridian, chosen randomly. In glaucoma patients, we tested locations in scotomas, near scotomas and in areas with normal threshold. Only one eye of each subject was tested. In most subjects we tested six locations, although in a small number glaucoma patients we tested four or five locations. The position of the center of the blind spot was first determined carefully to monitor fixation during testing[5]. The thresholds at the chosen locations were then estimated using a standard 4-2 staircase procedure. We presented stimuli ranging 8 dB either side of the estimated threshold in 1 dB steps with five trials at each stimulus intensity. There were, therefore, 85 trials per location. Both the location and stimulus intensity were randomized during testing.

Data analysis

The frequency-of-seeing at each stimulus intensity was computed. These data were subjected to a probit analysis which calculated the frequency-of-seeing curve. In addition we determined the following parameters from the fitted curve: *1.* the threshold (stimulus intensity corresponding to the 50% frequency-of-seeing); *2.* the interquartile range (stimulus intensity interval corresponding to between 25% and 75% frequency-of-seeing); and *3.* the mean confidence interval (mean 95% confidence interval corresponding to the 25%, 50% and 75% frequency-of-seeing). The interquartile range is a function of the slope of the curve and the mean confidence interval an indicator of the goodness-of-fit or the "noisiness" of the data. All calculated parameters are shown in Fig. 1.

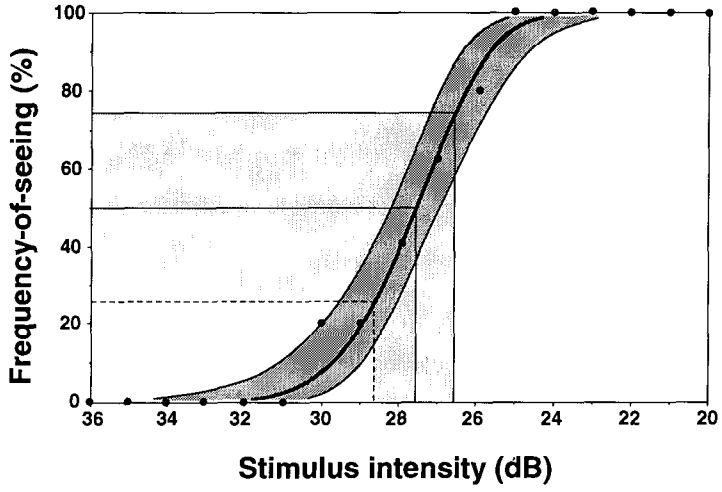

Fig. 1 Example of a frequency-of-seeing curve. The data points represent the raw data, the solid line the fitted function and the shaded area around the curve the 95% confidence interval. The interquartile range is the stimulus intensity interval corresponding to the 25% and 75% frequency-of-seeing.

Results

Distribution of frequency-of-seeing curve parameters

We were able to fit frequency-of-seeing curves to 124 of the 132 (94%) locations in normals, to 71 of the 72 (98%) locations in glaucoma suspects and to 183 of the 203 (90%) of the locations in glaucoma patients. Table 1 shows the distribution characteristics of the curves in the three groups.

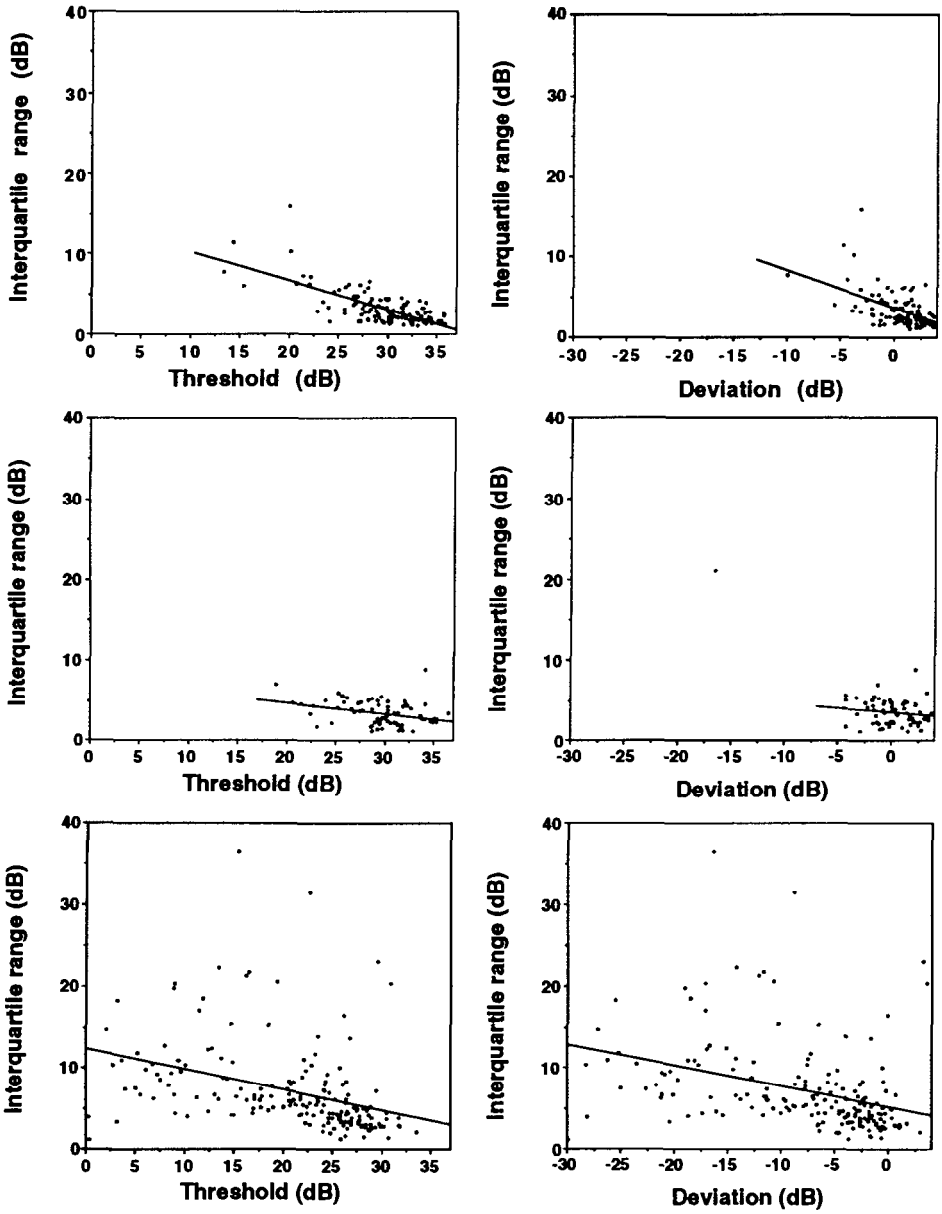

Fig. 2. Relationship between interquartile range, and threshold (left) and threshold deviation (right) of the frequency-of-seeing curves obtained in normals (top), glaucoma suspects (center) and glaucoma patients (bottom). The solid line represents the least-squares linear fit through the data.

Relationship between interquartile range, and threshold and deviation

There was a significant correlation between interquartile range and threshold in all three subject groups (Fig. 2). The degree of correlation in the three groups was, however, different with highest correlation found in normals (r=-0.71), followed by the glaucoma (r=-0.37) and glaucoma suspect (r=-0.32) groups. The same pattern was evident in the relationship between interquartile range and threshold deviation. In order to compare the groups across similar thresholds and deviations, we next included only those locations with thresholds lower (or sensi-

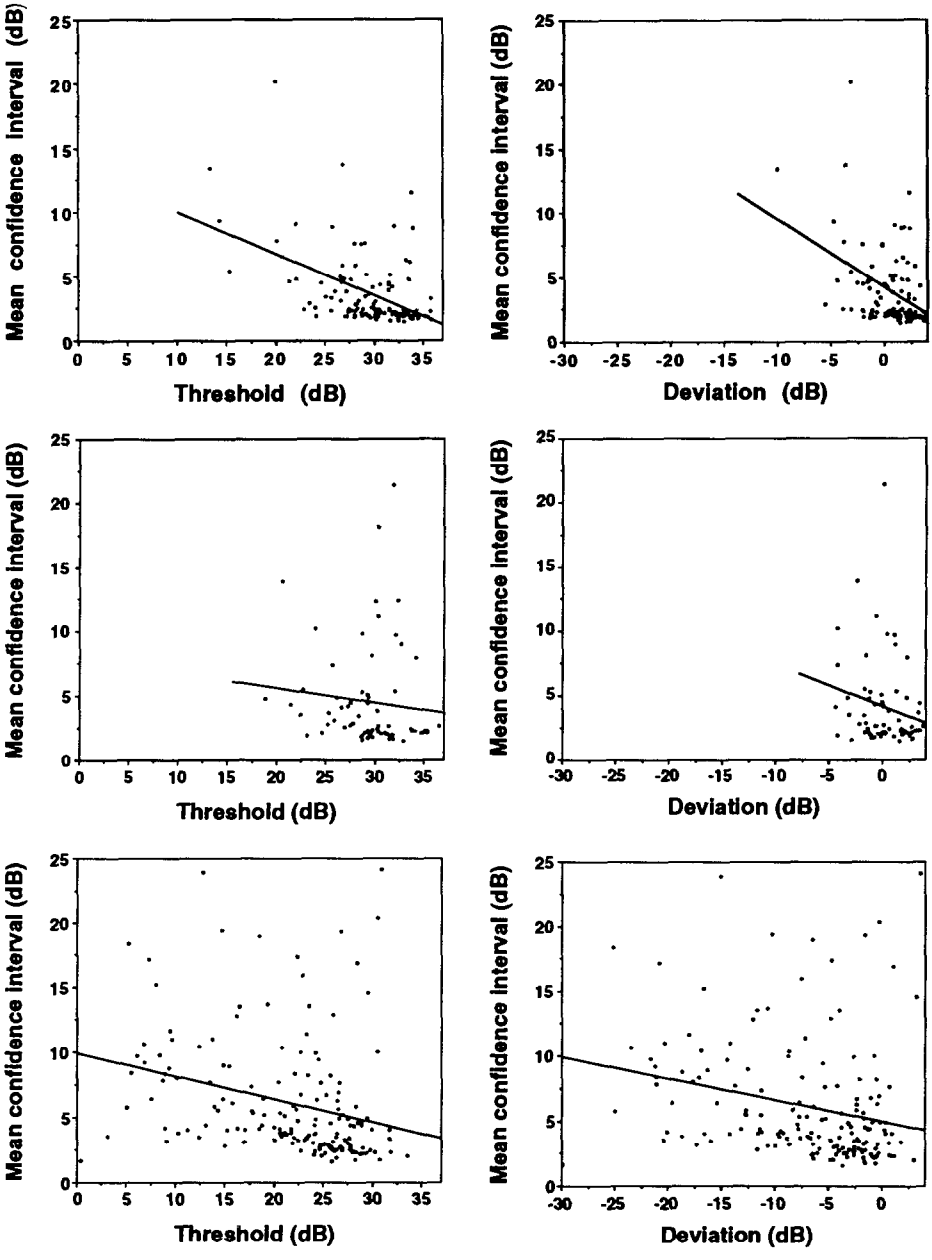

Fig. 3. Relationship between mean confidence interval, and threshold (left) and threshold deviation (right) of the frequency-of-seeing curves obtained in normals (top), glaucoma suspects (center) and glaucoma patients (bottom). The solid line represents the least-squares linear fit through the data.

Table 1. Summary statistics of the parameters of the frequency-of-seeing curves*

	Normals	*Glaucoma suspects*	*Glaucoma patients*
Eccentricity of tested location (°)	21.2 (2.8, 42.4)	17 2 (2 8, 35.4)	15 8 (2.8, 31 1)
Threshold (dB)	30.2 (13.3, 35.9)	29 9 (18.9, 36.5)	23 1 (0.3, 37 0)
Deviation (dB)	1.3 (-10 0, 5.0)	0.1 (-4.4, 4.5)	-5 3 (-29 9, 3.6)
Interquartiler ange (dB)	2.9 (1 0, 16.1)	3.4 (1.2, 8 9)	5.4 (1.1, 36.6)
Mean confidence interval (dB)	2 4 (1 5, 21.0)	2.7 (1 5, 21.4)	4.3 (1.6, 24.1)

*values shown are median (minimum, maximum)

tivities higher) than 24 dB and deviations not exceeding 5 dB (deviations >-5 dB). The same trends found in the whole data persisted, indicating that in areas with normal or mildly elevated thresholds, the relationship between interquartile range and threshold (or deviation) was different in the normal, and the suspect and glaucoma groups.

Relationship between mean confidence interval, and threshold and deviation

Although there was a correlation between the mean confidence interval and threshold (or deviation), some data points departed significantly from the least-squares fit (Fig. 3). The

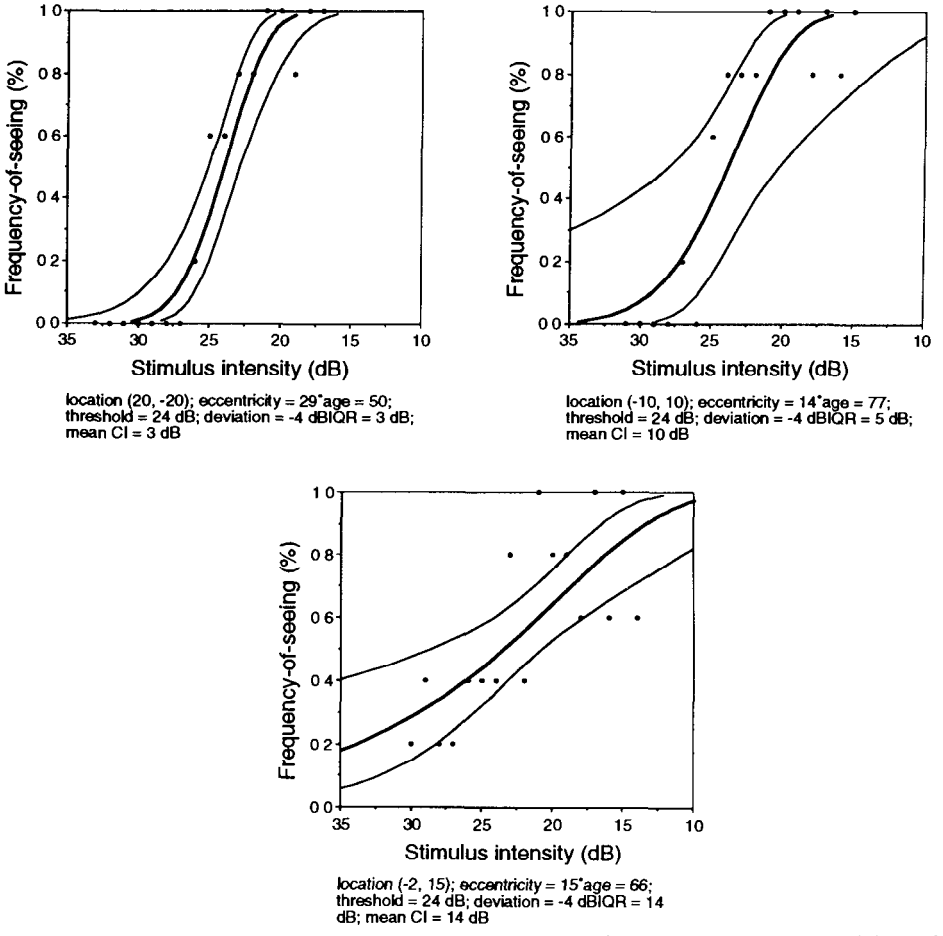

Fig. 4. Frequency-of-seeing curves obtained from a normal (top left), glaucoma suspect (top right) and glaucoma patient (bottom). The thresholds and deviations in all three cases are identical, yet the curves are remarkably different.

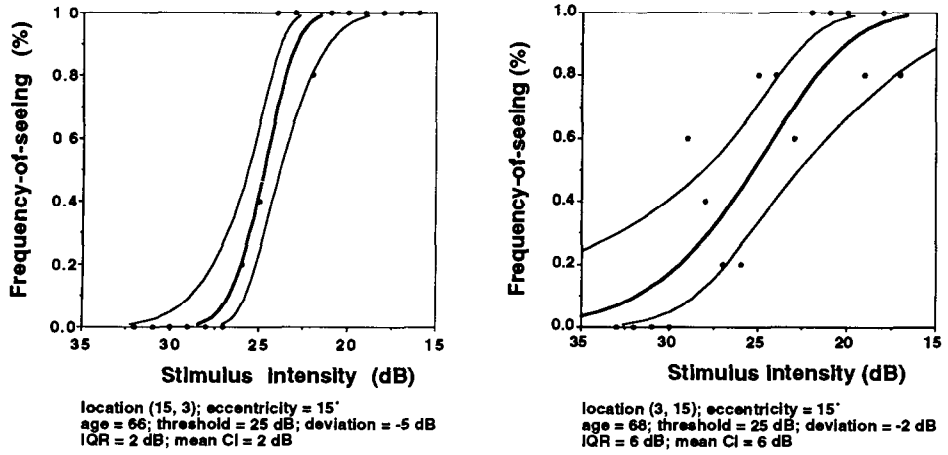

Fig. 5. Frequency-of-seeing curves obtained from two glaucoma patients of similar age at locations with identical thresholds and eccentricities The curves show large differences.

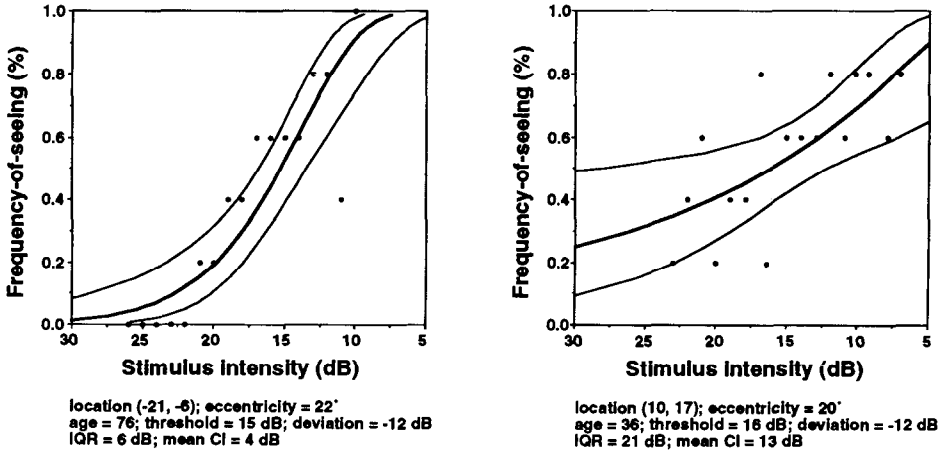

Fig. 6. Frequency-of-seeing curves obtained from two glaucoma patients of dissimilar age at locations with identical threshold deviations and similar eccentricities. These curves also show large differences.

glaucoma data in particular showed a considerable number of individuals who produced very "noisy" curves with normal or near normal thresholds, and equally commonly, individuals with markedly elevated thresholds who produced "clean" curves.

Case examples

Fig. 4 shows frequency-of-seeing curves obtained from a normal, a suspect and a glaucoma patient. The thresholds and deviations of the tested locations were similar, yet the three curves were dissimilar. Fig. 5 shows curves obtained from two glaucoma patients at locations with the same threshold value. The left curve is fairly clean with a low confidence interval while the lower curve is considerably shallower and noisier. The final example (Fig. 6) shows curves from locations in glaucoma patients with the same threshold deviations. These curves again are very dissimilar.

Discussion

Our study showed a relationship between the interquartile range (or slope) of the frequency-of-seeing curve and threshold. This relationship is analogous to that reported previously be-

tween short-term fluctuation and threshold using staircase procedures[6,7]. While the relationship is statistically strong, our results suggest that threshold or threshold deviation cannot reliably predict the interquartile range or confidence interval of the curves, particularly in glaucoma suspects and patients. For this reason, we believe that there may be fundamental differences in visual field areas of normals and glaucoma patients with similar thresholds (or deviations).

The results of this study have implications for studies which employ theoretical models in perimetric simulations. While the errors incurred in assuming a monotonic relationship between fluctuation level and threshold may be small in normal subjects, in glaucoma patients they may be significant. Simulation experiments based on real data may be more accurate.

The reasons for obtaining results such as those shown in Fig. 4 are not obvious. It is possible that small fixation errors, undetected by the Heijl-Krakau method, when testing locations close to steep sensitivity gradients, could lead to shallow and noisy curves. It is unlikely, however, that all "spurious" curves could be a result of fixation error. Further psychophysical studies in both normal and abnormal areas of glaucoma patients are currently underway to explain the results of this study.

References

1. Woodworth RS, Schossberg H: Experimental Psychology New York: Holt, Rinehart and Winston 1954
2. Chauhan BC, House PH: Intratest variability in conventional and high-pass resolution perimetry. Ophthalmology 98:79-83, 1991
3. Weber J, Rau S: The properties of perimetric thresholds in normal and glaucomatous eyes. German J Ophthalmol 1:79-85, 1992
4. Lynn JR, Batson EP, Fellman RL: Internal consistencies vs root mean square as measures of threshold variability. Doc Ophthalmol Proc Ser 36:7-15, 1985
5. Heijl A, Krakau CET: An automatic perimeter for the glaucoma visual field screening and control: construction and clinical cases. Graefe's Arch Clin Exp Ophthalmol 197:13-23, 1975
6. Holmin C, Krakau CET: Variability of glaucomatous visual field defects in computerized perimetry. Graefe's Arch Clin Exp Ophthalmol 1976:235-250, 1976
9. Flammer J, Drance SM, Fankhauser F, Augustiny L: Arch Ophthalmol 102:876-879, 1984

Frequency-of-seeing in computerized perimetry

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Abstract

Knowledge about the perimetric frequency-of-seeing curve is of value when designing algorithms for visual field testing, and for analyses of visual field data. The authors measured frequency-of-seeing curves during computerized field testing with the Humphrey Field Analyzer. To each conventional 24-2 test they added 80 stimulus exposures at a preselected test point and at four levels of intensity. Threshold estimates and slope characteristics, σ, were calculated at each selected point, assuming gaussian frequency-of-seeing curves and using false positive and false negative rates estimated from the catch trials. In a first group of 32 subjects (nine normal subjects, 19 patients with glaucoma and four with cataract), they found that σ depended strongly on the deviation of the threshold from the age-corrected normal value A regression equation on this deviation was clearly significant ($p<0$ 0001) A second group of eight subjects (four normals and four with glaucoma) were tested three times at each of two test locations The σ values in the second group were well predicted by the regression equation in the first group. Interestingly, the residual variation due to subject was non-significant while the location-dependent variation within subjects was significant ($p = 0.015$; analysis of variance in a nested model). The authors conclude that slopes of frequency-of-seeing curves show large variation Since the major part of this variation is related to deviations from the age-corrected normal thresholds, the width of a subject's frequency-of-seeing curve may nevertheless be fairly accurately predicted

Introduction

Frequency-of-seeing (FOS) curves of simple visual stimuli have often been measured, but mostly with manual techniques using many consecutive stimulus presentations at the same test point location. Such experiments in normals have indicated relatively sharply defined differential light thresholds. In contrast, automated perimetry has often shown large threshold variations within and between tests.

Our aim was to measure FOS curves under conditions as similar as possible to standard automated perimetry, and to see whether response characteristics depended on, *e.g.*, deviations from age-corrected normal threshold values, age, test point eccentricity and diagnosis. The obvious response characteristic is the threshold value. An increased short-term fluctuation has been observed in glaucoma subjects, suggesting that other response characteristics can be of interest. Our aim was to investigate the slope of the FOS curve at the threshold value and to separate individual slope variations into general, point-specific and residual components.

Table 1. Intensity levels of 80 FOS stimuli, relative to the preliminary threshold estimate. The majority of stimuli were at sub-threshold levels

No. of stimuli	*Relative stimulus level (dB)*
10	-15
10	-1
26	1
34	3

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Material and methods

Test procedure

We measured FOS curves during computerized visual field testing, using a modified Humphrey Field Analyzer (HFA) full threshold, 24-2 test. One test point in each field was selected for FOS measurements. The measurements consisted of 80 additional exposures at four levels of intensity, mostly at sub-threshold levels (Table 1). The levels were defined during the test, after determination of a preliminary threshold.

Subjects

Two groups of subjects were tested. The first (Group 1) included 32 subjects; nine normal subjects, 19 patients with glaucoma and four with cataract. One eye of each subject was measured once. Data from this group were used to determine the dependence on threshold deviation from age-corrected normal threshold values, age, test point eccentricity and diagnosis. In normal and cataract subjects, test point locations were randomly selected. We required a previous threshold estimate between 5 and 15 dB in half the tested points in the glaucoma eyes.

A second group (Group 2) of four normal and four glaucoma subjects was measured at two different test points of the same eye and three times for each point (Table 2). Data from Group 2 made it possible to differentiate between general, point-specific and residual variation.

Table 2. Selected points in Group 2. Four normal (N) subjects and four glaucoma (G) subjects The averages of threshold and σ estimates are shown

	Point I			*Point II*		
Diagnosis and subject	*x,y*	*average threshold*	*average σ*	*x,y*	*average threshold*	*average σ*
N1	3,-3	35	1.0	-3,-9	33	1.1
N2	-3,21	30	1.2	21,-9	31	1.4
N3	3,-3	35	1.3	-3,-9	33	0.6
N4	-3,21	-	-	21,-9	29	2.0
G5	9,3	18	2.5	-15,-15	16	4.3
G6	-27,3	-2	7.5	-3,-9	24	5.5
G7	-9,-21	20	3.4	-9,-3	30	1 0
G8	-9,-21	25	1.3	-15,3	24	2.2

Statistical methods

The FOS measurements made for each tested eye were used to calculate estimates of the threshold t and the slope characteristic σ of the FOS curve. We used the maximum likelihood estimation method, assuming a gaussian FOS curve. Thus, the probability of response to a stimulus of intensity d was assumed to be $fp + (1 - fn - fp) \times \Phi[(t-d)/\sigma]$, where Φ is the standard normal distribution function. Prior to the maximization the false positive and false negative rates, fp and fn, were estimated for each field, using catch trials.

Since fp and fn are estimated separately, only two parameters (t and σ) remain to be estimated. Hence, if gaussian FOS curves are used, only two different intensity levels are needed for the estimations. On the other hand, if the purpose is to investigate the fit of the gaussian model, a larger number of intensity levels should be used. Our main purpose was to estimate the slope characteristic and we decided to use four intensity levels.

We added 16 extra fp catch trials to the standard number as determined by the perimeter. The resulting numbers were between 19 and 37 for fp and between 3 and 16 for fn. Despite the additional catch trials, the error of the standard catch trial estimates were too large to permit a good estimation. We therefore preferred bayesian estimates, assuming beta priors[1]. Beta prior parameter values taken from Olsson[2] give the estimators:

$$fp = \frac{1+\text{fp catch trial errors}}{29+\text{fp catch trials}} \quad \text{and} \quad fn = \frac{1+\text{fn catch trial errors}}{22+\text{ fn catch trials}} .$$

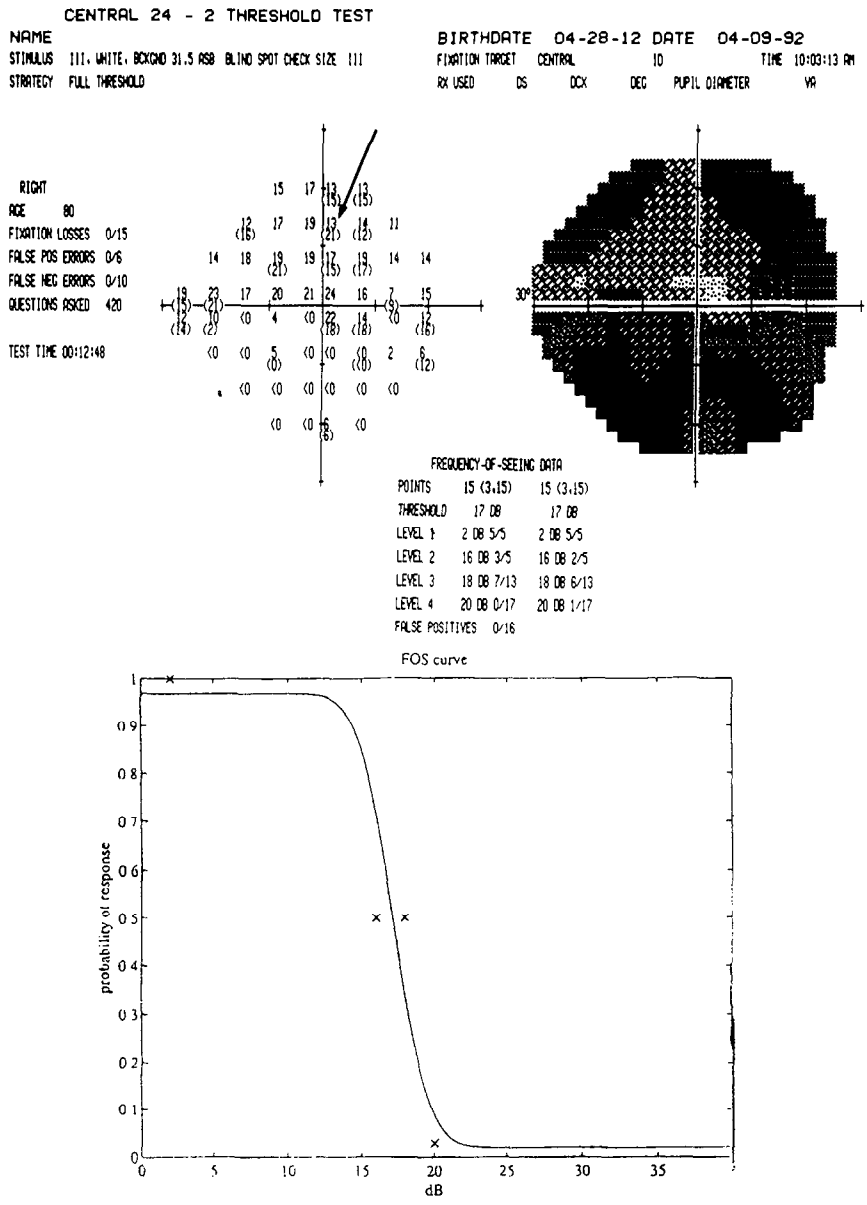

Fig. 1. a. FOS measurement and b. fitted FOS curve. Parameters of curve are *fp* = 2%, *fn* = 3%, σ = 1.93 dB (measurement error = 0.13 dB) and threshold = 17.2 dB (measurement error = 0.5 dB).

We also calculated standard deviations of the estimates of threshold and σ, or transformed estimate of σ, using the Fisher information[1] and assuming that *fp* and *fn* were known. Thus, an estimated measurement error - this standard deviation - was available for each estimate. An example of FOS measurements and the estimated FOS curve is shown in Fig. 1.

For Group 1, we performed a weighted linear regression of ln(σ) on the threshold deviation from the age-corrected normal values, *tdev*, and on threshold values themselves, using the inverse of the squared measurement error of the ln(σ)-estimate as weights.

In a subsequent analysis of Group 2, the difference between ln(σ) of a specific test and the regression line $\ln(\hat{\sigma})$ from Group 1, was computed. Analysis of variance was performed on

these values assuming the nested model:

$$\ln(\sigma)_{ijk}\text{-}\ln(\hat{\sigma}) = \mu + \tau_i + \beta_{j(i)} + \varepsilon_{(ij)k} \qquad i = 1,\ldots,8, j = 1,2, k = 1,2,3.$$

In this model i is subject, j point and k measurement. Thus. τ_i is the main effect of the individual, $\beta_{j(i)}$ is the effect of point j within subject i and $\varepsilon_{(ij)k}$ is the residual effect. The residual effect has two components; (i) measurement error caused by randomness and the finite number of stimulus presentations, and (ii) a test-retest slope variation. All effects were assumed to be gaussian random variables. The average estimated squared measurement error of the $\ln(\sigma)$ estimate was calculated for Groups 1 and 2.

The deviance[3] was calculated for each FOS measurement and the values were compared to the χ^2_2 distribution. The sum of all n deviances was compared to the χ^2_{2n} distribution.

Results

We found $\ln(\sigma)$ to depend strongly on the threshold deviation from the age-corrected normal value ($p<0.0001$) (Fig. 2), or alternatively on the threshold ($p<0.0001$). Adding age, test point eccentricity or diagnosis in a multiple regression analysis did not significantly improve the fit.

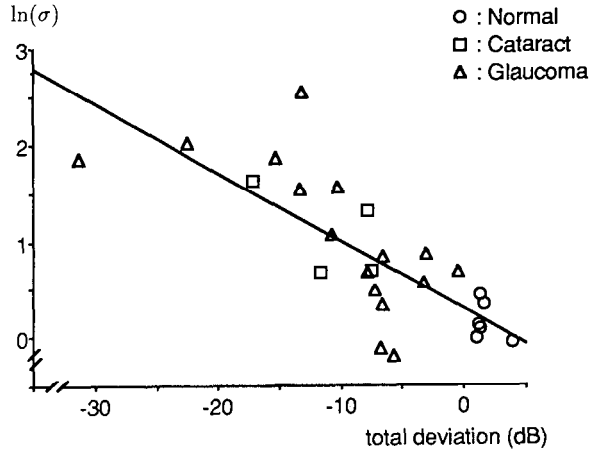

Fig. 2. $\ln(\sigma)$ estimates *versus* age-corrected normal value, *tdev*. Regression equation $\ln(\hat{\sigma}) = a + b \times tdev$ had estimates $a = 0.25$ (standard error 0 11) and $b = -0.075$ (standard error 0.012).

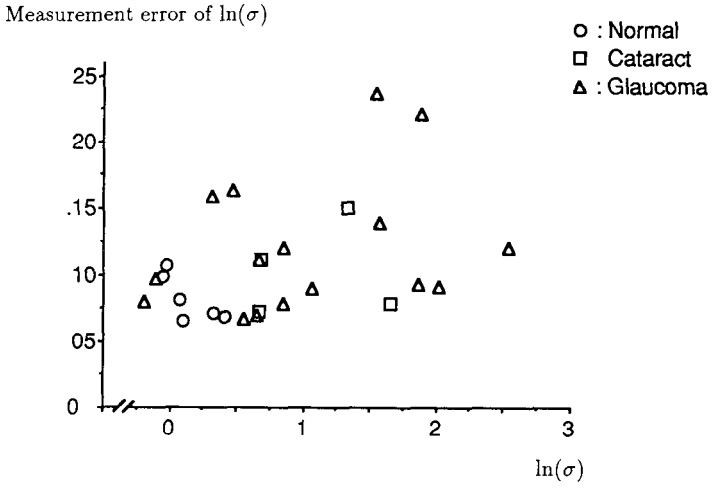

Fig. 3. Measurement error of $\ln(\sigma)$ *versus* $\ln(\sigma)$ estimates. Average squared measurement error is 0.014.

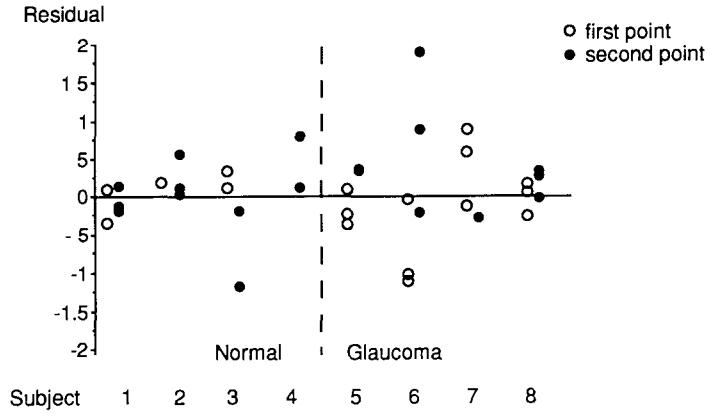

Fig. 4. The differences, $\ln(\sigma)$ - $\ln(\hat{\sigma})$, for each of the eight subjects in Group 2.

Using $\ln(\sigma)$ made the measurement errors reasonably independent of σ (Fig. 3). Note that the size of the measurement errors seems small in comparison to the distance from the regression line of Fig. 2.

The differences $\ln(\sigma)$ - $\ln(\hat{\sigma})$ are shown in Fig. 4. The variation due to subject, τ_i, was found to be non-significant while the variation due to test point location within a subject, $\beta_{j(i)}$, was significant (p = 0.015). The nested model was applied again to determine the variance of the random effects. The main effect of subject, τ_i, was then set to zero and the expected sums of squares were equated to the actual sums of squares. The variance of $\beta_{j(i)}$, the effect of point within subject, was estimated at 0.119. The residual variance was estimated at 0.205. We found an average estimated squared measurement error of 0.014 in Group 1 and 0.049 in Group 2.

All these variances are in the $\ln(\sigma)$ scale. As an example it can be mentioned that the variance of 0.119 for the $\beta_{j(i)}$ effect is equivalent to a standard deviation of 0.38σ dB, disregarding the other effects.

After removal of fields where σ was badly estimated, six normal subjects, 16 subjects with glaucoma and four with cataract remained in Group 1, and 15 tests from normal subjects and 21 from glaucoma subjects remained in Group 2. The hypothesis that the FOS model fitted was rejected at the 5% level in only four of 62 tests. The sum of all 62 deviances was 139 which is clearly non-significant.

Discussion

We conclude that variation of σ of FOS curves is very large. Most of the variation can be predicted from the deviation of the threshold from the age-corrected normal value. Thus, σ is fairly predictable when threshold estimates are available, but a part of the variation of σ depends on other factors.

The fit of our FOS model was very good despite the fact that frequencies of false positive and false negative values were estimated.

Our qualitative conclusions agree with those of Weber and Rau[4], who fitted the central part of the FOS curve only. However σ values measured by us were only half as large as theirs. A possible explanation may be that the long test durations of Weber and Rau may have increased disturbing influences of visual fatigue. A few figures of 10 FOS measurements by Lynn *et al.*[5] seem to agree with our σ values. It would be interesting to separate the influence of deviations from age-corrected normal threshold values and that of the threshold values themselves. This is very difficult, however, due to the strong correlation between these two variables.

It is interesting that, in this material, the main effect of subject was not significant while the point within-subject effect was significant. This means that we found no subject with consistently large/small slopes in all test points, but the particular test points deviated somewhat from the equation $\sigma = \exp(a + b \times tdev)$. The small measurement error, as compared to the residual variation, suggests a change in the slope value between tests.

The results of the current study can be used, *e.g.*, for designing efficient staircase algorithms and in threshold estimation, and they provide a possible explanation for the increased short-term fluctuation in defective parts of the field[6].

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References

1. Rao GR: Linear Statistical Inference and Its Applications, 2nd edn, pp 329, 335. New York: John Wiley & Sons 1973
2. Olsson J: Statistics in Perimetry, TFMS-1007. Doctoral dissertation, p 20. University of Lund, Sweden 1991
3. McCullagh P, Nelder JA: Generalized Linear Models, 2nd edn, p 118. London: Chapman and Hall 1989
4. Weber J, Rau S: The properties of perimetric thresholds in normal and glaucomatous eyes. German J Ophthalmol 1:79-85 1992
5. Lynn JR, Batson EP, Fellman RL: Internal inconsistencies vs root mean square as measures of threshold variability Doc Ophthalmol Proc Ser 42:7-15, 1985
6. Langerhorst CT: Automated Perimetry in Glaucoma. Amsterdam: Kugler Publ 1988

An analysis of spatial summation using a Humphrey Field Analyzer

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Abstract

The characteristics of spatial summation in the visual field were examined using a Humphrey Field Analyzer (HFA) on five normal subjects. The threshold static perimetry was performed with programs 30-2 and 60-2 of the HFA using test target sizes I, II, III, IV and V. The results were transferred to a personal computer and the results were compiled and analyzed. The coefficient of summation for each examined point was calculated assuming that the summation curve was a straight line. The mean coefficient of summation at the center of the field (0′) was 0.36, at 10 degrees from the center was 0.54, at up to 20 degrees was 0.59, at 30 degrees was 0.71, at 40 degrees was 0.79, at 50 degrees was 0 87 and at 60 degrees was 0.79. As a result, it was confirmed that the coefficient of summation increased with eccentricity This method could be useful for studying the characteristics of spatial summation in various diseases

Introduction

As the test target size increases, a large number of photoreceptor cells are stimulated and the threshold will decrease. This phenomenon is called spatial summation. But this summation ability is lost when the test target size exceeds certain limited areas. For a normal observer, it is confirmed that spatial summation increases as the test target moves to the periphery[1-5]. Furthermore, it is pointed out that the characteristics of spatial summation are important for investigating the pathogenesis of both retinal or neural disorders[2,4,6].

In this paper, the characteristics of spatial summation from the center of the visual field up to 60 degrees were examined using an automated perimeter.

Subjects and methods

Threshold static perimetry was performed on five normal subjects using a Humphrey Visual Field Analyzer (HFA) type 620 with programs 30-2 and 60-2 using test target sizes I, II, III, IV and V. The results were transferred to a personal computer with an RS232C communication port.

First of all, a program was developed to calculate the curved surface in accordance with the raw data, and then the contour line (equal sensitivity line) was obtained for each given step. The intervals between the contours were filled with consecutive colors from blue, representing the low sensitivity area, to red, representing the high sensitivity area. Then the result could be displayed more distinctly and exactly than with the gray scale of the HFA, because the step of the contours could be set at 1 dB or less.

Next, the coefficients of spatial summation for each examined point were calculated. In general, the threshold-area curve (summation curve) as seen in Fig. 1 was used to explain the spatial summation. In this figure, the abscissa indicates the target area in log units and the ordinate indicates the product of the target area and threshold in log units. Where the target size is small, the product of the target area and threshold is constant (shown by A), *i.e.*, spatial summation is complete. If the target size becomes large enough, spatial summation is lost and the summation curve becomes a straight line with a slope of 1 (shown by C). In the part shown by B, the spatial summation is partial. These characteristics are usually expressed in perimetric

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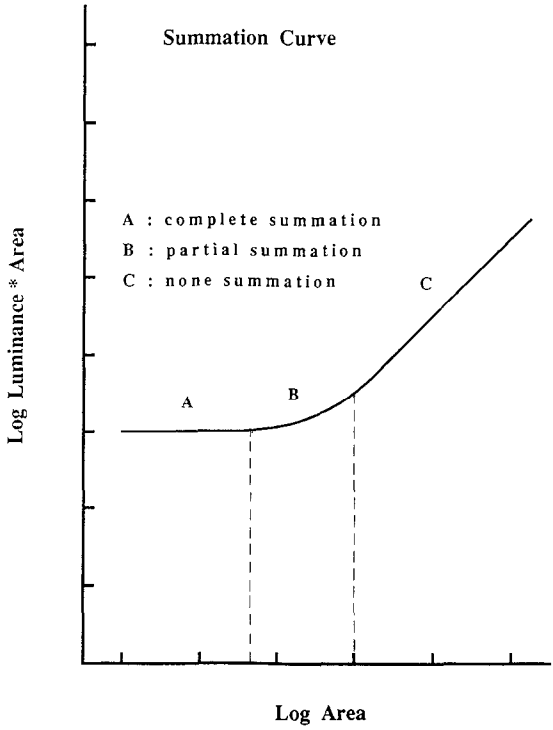

Fig 1. Threshold area curve The abscissa indicates the area of the target in log units, and the ordinate indicates the product of luminance and the area of the stimulus in log units.

literature by the formula $\Delta L \times S^x = \text{constant}$, where ΔL is the threshold luminance of the target and S is the target size. In this formula, the index x is the coefficient of summation. In Fig. 1, the index x is equal to 1 in area A, x is equal to 0 in area C, and x varies from 0 to 1 in area B. Therefore, the spatial summation can be expressed by index x.

Results

In Fig. 2, the results of subject AK are displayed. In this figure, the results of programs 30-2 and 60-2 were synthesized and analyzed by using the curve surface method. And then the contour was calculated every 1.5 dB step. From this figure, the sensitivity was highest in the center of the field and gradually descended towards the periphery.

Furthermore, the sensitivity difference between each of the target sizes was calculated. The sensitivity difference between the target size I and III for subject AK is displayed in Fig. 3. The sensitivity difference between target size III and V for the same observer is displayed in Fig. 4. In each figure, the blue area represents the lowest sensitivity difference and the red area represents the highest. From these figures, it is confirmed that the sensitivity difference between targets I and III is larger than between targets III and V

The average sensitivity for every 10 degrees from the center of the field to periphery was calculated for five subjects and displayed in Fig. 5. In this figure, the abscissa indicates the eccentricity and the ordinate indicates the mean sensitivities for the five subjects with 1 SD. The sensitivity difference decreases more rapidly for the larger targets than the smaller targets with an increase in eccentricity.

The summation curve of five normal subjects for the center of the field is displayed in Fig. 6, and peripheral 40 degrees is displayed in Fig. 7. From these figures, the data can be expressed by a straight line and least-square method is applied at this time. The slope of the straight line in the center of the field (Fig. 6) was 0.64, and the coefficient of summation was 0.36. The

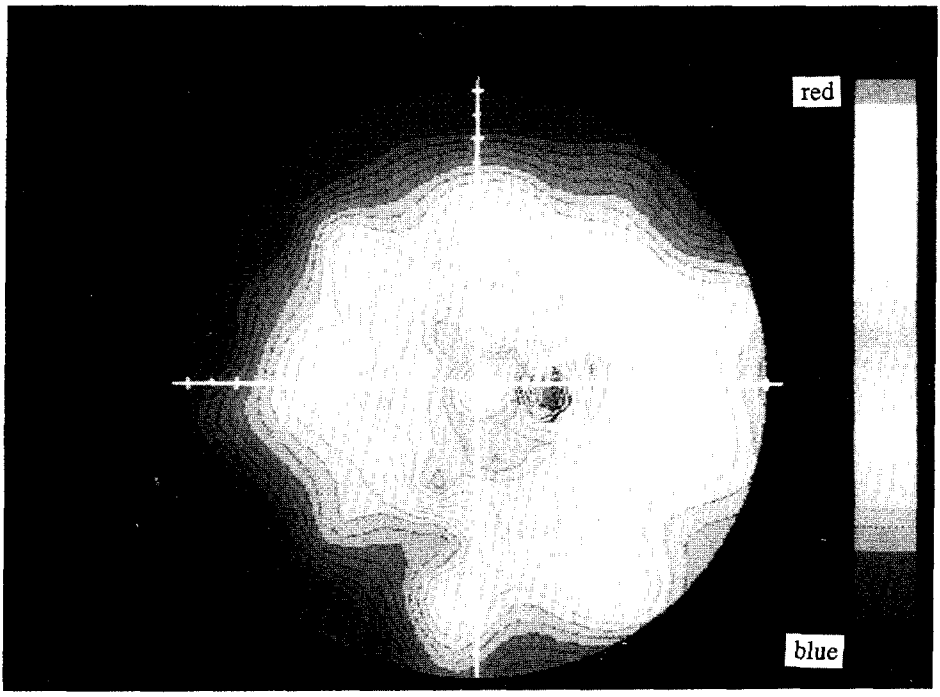

Fig. 2. The computer display represents the colored contour map. The contour represents every 1.5 dB. The area filled with blue represents the low sensitivity area and red represents the high sensitivity

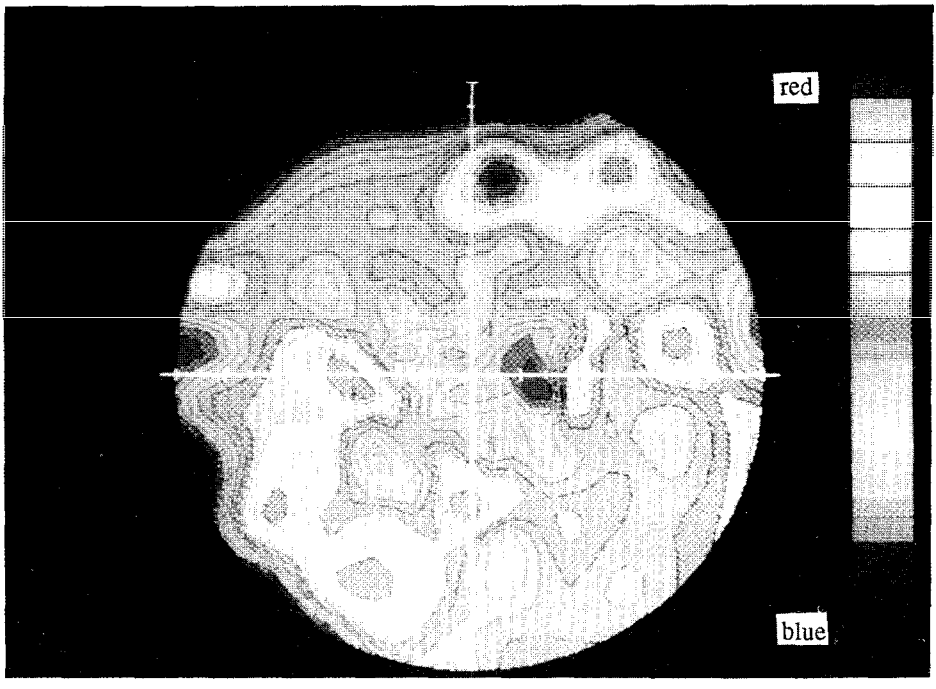

Fig. 3. The sensitivity difference is calculated between targets I and III. The area filled with blue represents the small sensitivity difference and red represents the large sensitivity difference. The sensitivity difference at the periphery is greater than at the center.

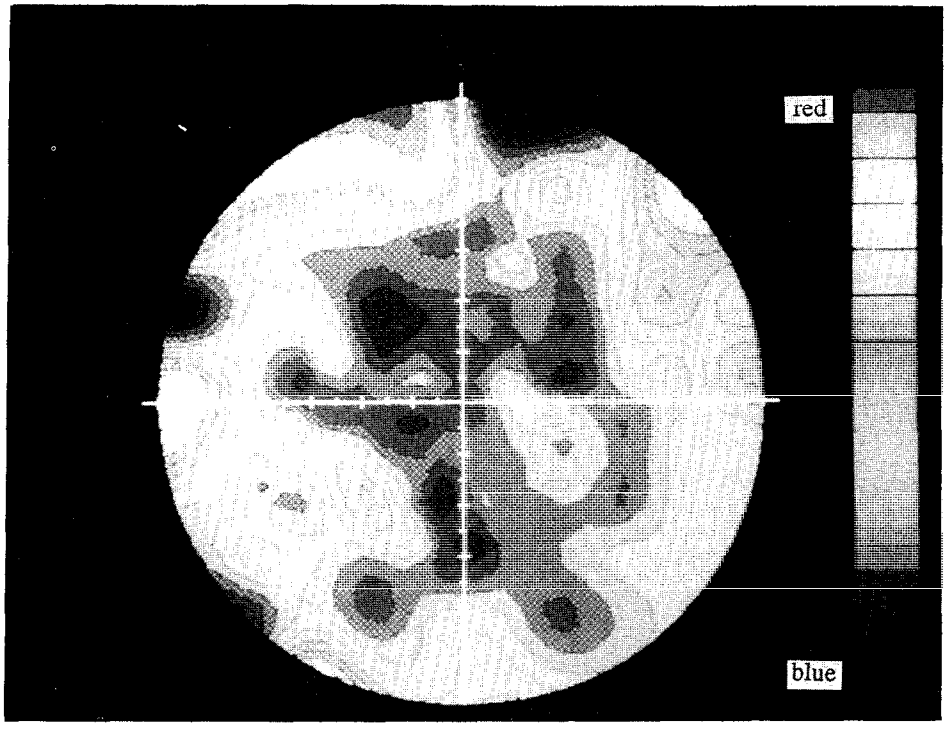

Fig. 4. The sensitivity difference calculated between targets III and V.

slope of the peripheral 40 degrees (Fig. 7) was 0.24 and the coefficient of summation was 0.76.

By the same method, the coefficient of summation for each examined point of five normal subjects was obtained. It was confirmed that the coefficient of summation increased as a concentric circle moving toward the periphery. Then the mean coefficient of summation from the center to the periphery was calculated every 10 degrees. The results are displayed in Table 1 and Fig. 8. It was confirmed that the spatial summation increased towards the periphery for normal subjects.

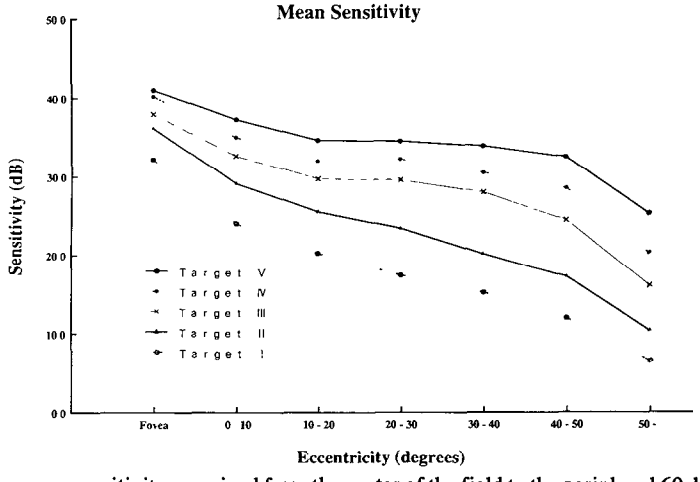

Fig. 5. The average sensitivity examined from the center of the field to the peripheral 60 degrees for every 10 degrees on five normal subjects. The sensitivity difference decreases more rapidly in the larger targets than the smaller targets with an increase in eccentricity.

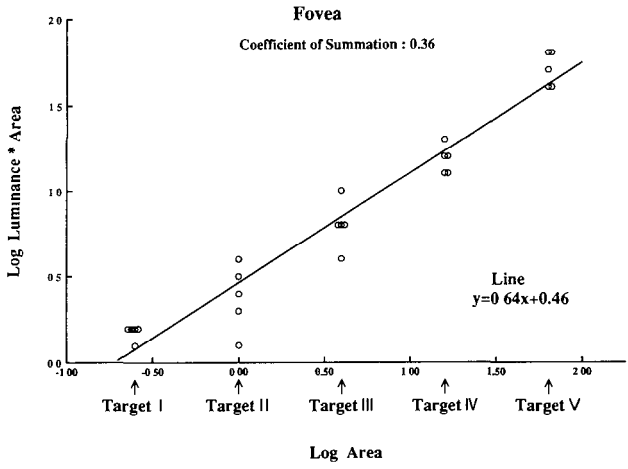

Fig. 6. The summation curve for the center of field on five normal subjects. In this figure data are expressed by a straight line. The slope of the straight line is 0.64, while the coefficient of summation is 0.36.

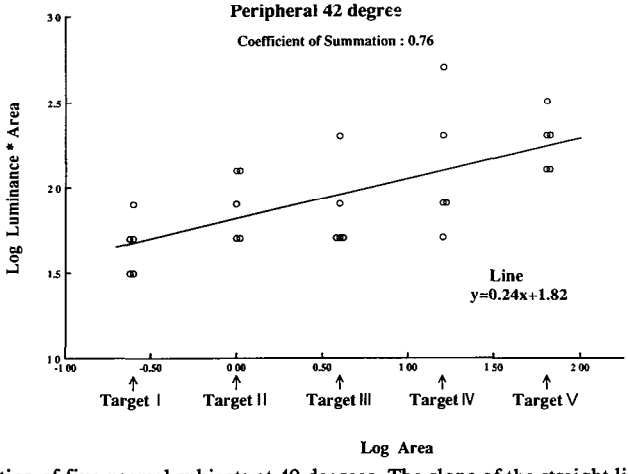

Fig. 7. The summation of five normal subjects at 40 degrees. The slope of the straight line is 0.24, while the coefficient of summation is 0.76 calculated in the same way as in Fig 6.

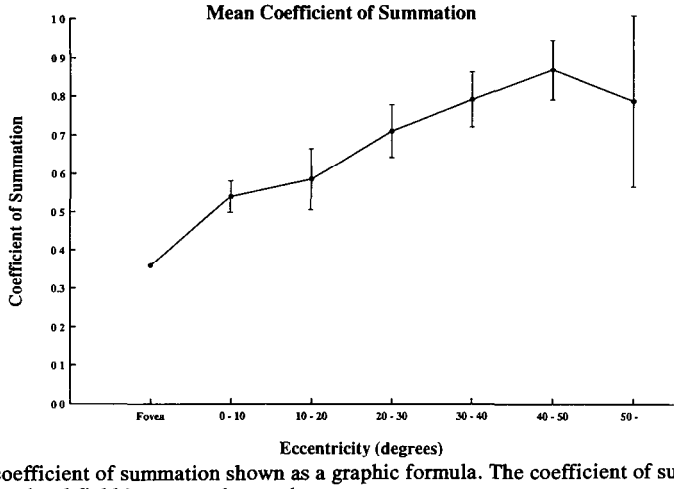

Fig. 8. The mean coefficient of summation shown as a graphic formula. The coefficient of summation at the periphery of the visual field is greater than at the center.

Table 1. Coefficient of summation

Eccentricity	*Mean*	*No.*
Center	0.36	1
0-10	0.54±0.04	12
10-20	0 59±0.08	20
20-30	0 71±0 07	44
30-40	0.79±0.07	16
40-50	0.87±0.08	20
50-	0.79±0 22	32

Comments

The spatial summation is thought to be caused by the consolidating function of nerve transmission. The reaction from each photoreceptor cell is consolidated in the cells of the high levels. The mean coefficient of summation in the center of the field is 0.36, from 0 to 10 degrees is 0.54, from 11 to 20 degrees is 0.59, from 21 to 30 degrees is 0.71, from 31 to 40 degrees is 0.79, from 41 to 50 degrees is 0.87 and for more than 51 degrees is 0.79. In this experiment, we used the automated perimeter to study the summation characteristics. As a result, it was confirmed that the coefficient of summation increased with eccentricity. Therefore, we feel that the automated perimeter could be very useful in investigating the spatial summation clinically.

References

1. Dubois-Poulsen A: New technique for the peripheral vision Acta Soc Ophthalmol Jpn 65:1369-1376, 1961
2. Matsuo H: Studies on the visual field. Acta Soc Ophthalmol Jpn 83:1815-1854, 1979
3 Inui T, Mimura O et al: Retinal sensitivity and spatial summation in the fovea and parafoveal region. J Opt Soc Am 71:151-154, 1981
4 Kani K: Visual field. 3. Neural system and visual field. Neuro-Ophthalmol Jpn 5:156-160, 1988
5. Baba K et al: Photometric harmony in the static perimetry. Jpn Orthoptics 18:56-61, 1990
6. Osako M et al: Comparison of spatial summation between glaucoma and optic neuritis with statokinetic dissociation Jpn J Clin Ophthalmol 46:837-841, 1992

Retinal toxicity of silicone oil studied by means of computerized perimetry

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Abstract

Variations of retinal function were studied by means of computerized perimetry on patients operated on by vitrectomy with silicone oil tamponade. The aim of the study was to verify retinotoxic effects of silicone. Perimetric examination was performed on a group of 18 patients treated for vitreoretinal pathologies and selected from a large number of cases The selection criteria were: good postoperative condition and sufficient visual acuity. Silicone oil remained in the 18 eyes for a period of 120 ± 15 days. Five examinations (macular threshold test of Humphrey Field Analyzer = 16 points + foveal threshold) were performed, two during the period of persistence of silicone oil in the vitreous cavity, and three after its removal. The authors considered the SLD for every point tested by the program (total points 17) and calculated the mean value of these points for each test, making statistical comparisons. The *t* test and ANOVA test applied to the results did not show significant variations of SLD.

These data suggest an absence of retinotoxic effect of silicone oil when it is removed within four months.

Introduction

Nowadays, silicone oil (PDMS) is a very often used tamponade substance in vitreoretinal surgery. Silicone oil causes some early and late postoperative complications[6] such as: corneal damage, uveitis, intraocular hypertension (resulting from pupillary block in the aphakic eye, or a block of the trabecular meshwork), intraocular hypotension (caused by damage to the ciliary body), emulsification in the anterior chamber or in the vitreal cavity, perisilicone proliferation (especially with fluorosilicone oil), and subretinal infiltration.

Some authors have reported the retinal toxicity of silicone oil[1,20,24,25]. Histopathological findings on enucleated eyes showed alterations of the retinal layers and of the optic nerve[2,26,28,29,31,33] while electrophysiological studies did not agree with these results. In fact, no damage is documented[9,11,23,30].

It is necessary to balance the advantages of using PDMS as a tamponade substance and the problems linked to a long persistence in the vitreal cavity causing a poorly defined retinal toxicity, besides the well known complications[6,27].

The optimal time to remove PDMS has still to be established.

The aim of our study was to verify the eventual retinotoxic effects, by examining the variations of macular sensitivity light differential (SLD) threshold by means of computerized perimetry in patients operated on by vitrectomy and silicone oil injection in the vitreal cavity, during the period of persistence of PDMS in the eye, and after its removal.

Materials and methods

Intravitreal surgery utilizing silicone oil was performed on 320 eyes of 316 patients between November 1988 and June 1992. From this group we selected 18 eyes of 18 patients (10 males, 8 females). Age range 19-57 (average 42.2).

Inclusion criteria were:

- exclusion of pathologies involving macula and posterior pole (macular hole and retinal breaks);

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- good visual acuity (constant for all the periods of the study) to perform the perimetric examination;
- optimal postoperative course with no complications like cataract, intraocular hypertension, emulsification or perisilicone membranes.

Case report

- Retinal detachment with giant tear in the superior section (four cases);
- retinal detachment with PVR stage C2 (three cases) and C3 (two cases);
- diabetic retinopathy with vitreal hemorrhage (five cases);
- vitreoretinal foreign bodies (four cases)

All patients underwent vitrectomy with or without membrane peeling, with silicone 1000 cs injection.

When it was necessary the foreign bodies were removed and laser endophotocoagulation was performed. The 18 patients were operated on by the same surgeon. In the 18 eyes, postoperative visual acuity range was 20/200-20/20 and constant during the follow-up period.

The persistence of PDMS in the vitreous cavity was 120 ± 15 days.

All examinations were performed by means of a Humphrey Field Analyzer (HFA model 630). The program used was "macular threshold" test 16 points, 2 degrees resolution, plus foveal threshold (standard parameters: background luminance 31.5 asb, stimulus size III, stimulus intensity ranging from 50 dB to 2 dB).

All tests were performed with the pupil in mydriasis.

Each patient performed five perimetric examinations:

1. the first, 30 days after PDMS injection;
2. the second, about 10 days before PDMS removal (110 ± 20 days);
3. the third, 30 days after PDMS removal;
4. the fourth, 90 days after PDMS removal;
5. the fifth, 180 days after PDMS removal.

During the follow-up period we examined visual acuity, intraocular pressure, anterior segment, especially the lens, and the posterior pole. We calculated the averages of SLD for the 17 points tested in every examination. Statistical analysis by means of Student's *t* test was applied to study the variations of macular SLD.

We compared:

a. the mean values in dB of I and II examinations (during silicone oil persistence in the vitreous cavity);
b. the mean values in dB of III and IV examinations (after silicone oil removal);
c. the mean values in dB of I and II examinations (after silicone oil injection) and the mean values in dB of III and IV examinations (after silicone oil removal).

An ANOVA test was employed to study the variations among the five perimetric examinations performed.

Results

In Table 1 it can be seen that the difference between mean values of SLD in dB of I and II examinations is not statistically significant.

Table 1. Paired *t* test applied to the averages of SLD values in dB of I and II examinations (after PDMS injection)

Examination	*Cases*	*Average*	*Standard deviation*
I	18	24.36	±3 70
II	18	24.38	±4 04
Difference		-0.02	±0.89

Confidence limits of 95% from: -0 68 to +0 64 $p>0.05$

In Table 2 the difference between mean values of SLD in dB and III and IV examinations is not statistically significant

Table 2. Paired *t* test applied to the averages of SLD values in dB in III and IV examinations (after PDMS removal)

Examination	*Cases*	*Average*	*Standard deviation*
III	18	24.89	±4.06
IV	18	24.91	±4.04
Difference		-0.02	±0 21

Confidence limits of 95% from: -0.21 to +0 18. $p>0.05$

Comparing the mean values of SLD in dB of I + II examinations (after PDMS injection) with the mean values of SLD in dB of III + IV examinations (after PDMS removal) a slight improvement of SLD can be noticed (Table 3) but it is not statistically significant.

Table 3 Paired *t* test applied to the difference of SLD mean values in dB during the persistence of PDMS in the vitreous cavity (I and II) and after its removal (III and IV)

Examination	*Cases*	*Average*	*Standard deviation*
I-II	18	24 37	±3 85
III-IV	18	24 90	±4 05
Difference		-0.53	±0.82

Confidence limits of 95% from: -1.16 to +0.08. $p>0.05$

Variance analysis by means of an ANOVA test showed a certain variation among patients with different pathologies. The variation within patients (due to the treatment) was not as high (Table 4).

Table 4. ANOVA test applied to the mean values of SLD in dB of the five macular tests

$$F = \frac{\text{variance among patients}}{\text{variance in patients}} = 2\,42$$

$p>0.05$

Discussion

Since its introduction in vitreoretinal surgery, silicone oil effects and complications as a tamponade substance have been studied. Our information arises from histopathological findings and electrophysiological studies.

Lee and Mukay[20,24,25], studying enucleated eyes of animals in which the tamponade substance remained in the vitreous cavity for a period ranging from two days to 12 months, noticed retinal changes in the superficial layers (nerve fibers and ganglion cells) and in the inner layers with a partial photoreceptor loss. They proposed a migration of phospholipids of cell membranes towards the vitreous cavity. These phospholipids enlarged the junctions between Müller cells, making silicone bubbles penetrate into the retinal layers. Their histopathological findings were supported by some authors[4,24,25,32] and discussed by others. In fact, it is difficult to exclude histopathological artifacts even on enucleated human eyes.

The toxicity of PDMS shown by histopathological findings was supported by the reduction of A and B ERG amplitudes, recorded when PDMS was in the vitreous cavity[1,20].

More recent studies have provided evidence that the electrophysiological variance was due to the pre-existing retinal changes and the electric insulating effect of the liquid silicone oil[9,11,16,22,23,30].

Prompt recovery of A and B waves was noted after the removal of silicone[27,30].

The period of persistence of PDMS in the vitreous cavity does not seem to influence the

electrophysiological examinations. Thus, up to now, there is no absolute proof of retinal toxicity due to PDMS, even with fluorescein angiography[5].

It is difficult to study retinal toxicity by means of computerized perimetry because patients must cooperate during the examination; their optical media must be transparent, retinal conditions must be good, and the pathology must not disturb the examination, generating poorly reliable results.

We analyzed SLD variations by means of a macular threshold test that is fast, sensitive, well accepted by patients, and reveals early changes in SLD due to damages to photoreceptors and ganglion cells[7].

Statistical analysis applied to the results did not show a significant difference between the I and II examinations performed during the persistence of PDMS in the vitreous cavity, between the II and IV examinations performed after its removal, and between the examinations performed after PDMS injection (I + II) and the examinations performed after PDMS removal (III + IV).

These data are supported by ophthalmoscopy and electrophysiological studies, so we can assert that they did not find retinotoxic effects on the patients they studied. The ANOVA test allowed us to consider the fifth examination performed 180 days after PDMS removal.

In conclusion no signs of functional damage caused by PDMS were detected when it remained in the vitreous cavity for about four months. For this period we can assert absence of retinotoxicity, detected by means of computerized perimetry, considering the limits of this examination.

The purpose is to continue the study, with more patients, to be able to find the optimal time to remove silicone oil.

References

1. Alexandridis E, Daniel H: Results of silicone oil injection into the vitreous. Dev Ophthalmol 2:24, 1981
2. Blodi FC: Injection and impregnation of liquid silicone into ocular tissues. Am J Ophthalmol 71:1044-1051, 1971
3. Cibis PA, Becker B, Okun E, Canaan S: The use of liquid silicone in retinal detachment surgery. Arch Ophthalmol 68:590-599, 1962
4. Cockerham WD, Schepens CL, Freeman HM: Silicone injection in retinal detachment. Arch Ophthalmol 83:704, 1970
5. De Molfetta V, Carlevaro G, Bottoni F, Ortolina S: Fluorescein findings in eyes with short term intravitreal silicone oil. Int Symp on Fluorescein Angiography (ISFA), Venezia, 8-12 Sept, 1990
6. De Molfetta V, Arpa P, Carlevaro G, De Casa N: La chirurgia vitreoretinica nel distacco di retina regmatogeno. Relazione officiale al LXX congresso SOI, 1990. Milano: Ghedini Publ, 1990
7. Douglas R, Anderson H: Perimetry with and without Automation. CV Mosby Co, 1987
8. Durlu YK, Ishiguro SI, Yoshida A: Response of Müller cells following experimental lensectomy-vitrectomy. Graefe's Arch Clin Exp Ophthalmol 228:44, 1990
9. Esser J, Foerster MH, Laqua H: ERG-befunde bei Patienten mit intraocularer Silikonolfüllung. Fortschr Ophthalmol 80:128-129, 1983
10. Federman JL, Lloyd J: Automated static perimetry to evaluate diabetic retinopathy. 120th Ann Mtg of The American Ophthalmological Soc, 1984
11. Foerster MH, Esser J, Laque H: Silicone oil and its influence on electrophysiologic findings. Am J Ophthalmol 99:201-206, 1985
12. Gonvers M: Temporary use of intraocular silicone oil in the treatment of detachment with massive periretinal proliferation. Ophthalmologica 184:210-218, 1982
13. Gonvers M: Temporary silicone oil tamponade in the management of retinal detachment with proliferative vitreoretinopathy. Am J Ophthalmol 100:239-245, 1985
14. Gonvers M, Hornung JP, De Courten C: The effect of liquid silicone on the rabbit retina. Histologic and ultrastructural study. Arch Ophthalmol 104:1057, 1986
15. Isashiki M, Ohba N: Recovery of differential light sensitivity following surgery for rhegmatogeneous retinal detachment. Graefe's Arch Clin Exp Ophthalmol 224:184-190, 1986
16. Kellner U, Foerster MH: Der Einfluss von flüssigen Silikon auf die Funktion des Nervus opticus. Fortschr Ophthalmol 85:562-564, 1988
17. Kirchhof B, Tavakolian H, Helmann K: Histopathological findings in eyes after silicone oil injection. Graefe's Arch Clin Exp Ophthalmol 224:34-37, 1986
18. Labelle P, Okun E: Ocular tolerance to liquid silicone: an experimental study. Can J Ophthalmol 7:199-204, 1972

19. Laroche L, Pavlakis C, Saraux H, Orcel L: Ocular findings following intravitreal silicone injection Arch Ophthalmol 101:1422-1425, 1983
20. Lee PF, Donovan RH, Mukai N et al: Intravitreous injection of silicone: an experimental study I Clinical picture and histology of the eye. Ann Ophthalmol 1(2):15-25, 1969
21. McCuen BW, Landers MB, Machemer R: The use of silicone oil following failed vitrectomy for retinal detachment with advanced proliferative vitreoretinopathy. Ophthalmology 92:1029-1034, 1985
22. Meredith TA, Lindsey DT, Edelhauser HF, Goldman AI: Electroretinographic studies following vitrectomy and intraocular silicone oil injection. Br J Ophthalmol 69:254-260, 1985
23. Momirov D, Van Lith GHM, Zivojnovic R: Electroretinogram and electrooculogram of eyes with intravitreously injected silicone oil Ophthalmologica 186:183-188, 1983
24. Mukai N, Lee PF, Schepens CL: Intravitreous injection of silicone: an experimental study. II Histochemistry and electron microscopy. Ann Ophthalmol 4:273-287, 1972
25. Mukai N, Lee PF, Oguri M, Schepens CL: A long-term evaluation of silicone retinopathy in monkeys Can J Ophthalmol 10:391-402, 1975
26. Ni C, Wang WJ, Albert DM, Schepens CL: Histopathological findings in a human eye after 12 years. Arch Ophthalmol 101:1399-1401, 1983
27. Reibaldi A, Avitabile T, Scalia G, Panta G: Instrumental investigation and silicone oil. Poster presentato alla Fondazione G.B. Bietti per l'Oftalmologia. Atti 3rd Int Congress on Vitreo-retinal surgery, 12-14 Sept 1991
28. Rentsch FJ, Ayler P, Liesenhoff M: Histologische und elektronenmikroskopische Untersuchungen an einem menschlichen Auge nach mehrjahriger intravitrealer Silikon Implantation. Ber Zusammenkunft Dtsch Ophthalmol Ges 75:70-74, 1977
29. Rentsch FJ: Electromicroscopical aspects of acid compartments of the ground substance and of collagen in different cases of intravitreal tissue proliferation Dev Ophthalmol 2:385-395, 1981
30. Scalia G, Pucinotti B, Lo Monaco S, Valvo F, Di Pietro M: Comportamento dei reperti elettrofunzionali in soggetti sottoposti a tamponamento con olio di silicone Atti XVI Congr SOSI Taormina 22-24 Feb 1991
31. Sugar HS, Okamura ID: Ocular findings six years after intravitreal silicone injection Arch Ophthalmol 94:612-615, 1976
32. Suzuki M, Okada T, Takeuchi S, Ishii Y, Yamashita H, Hori S: Effect of silicone oil on ocular tissues. Jpn J Ophthalmol 35:282-291, 1991
33. Watzke RC: silicone retinopexis for retinal detachment. Surv Ophthalmol 12:333-337, 1967

Using the high-pass resolution perimeter in determining the usefulness of CPF lenses in retinal dystrophies

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Abstract

In order to determine the usefulness of CPF and Retinex lenses for patients with retinal dystrophy, we measured the visual fields of ten normal observers and 14 patients with retinal dystrophy (seven cone-rod dystrophy and seven rod-cone dystrophy) using the high-pass resolution perimeter. These measurements were taken both with and without the CPF 511, 527, 550, and the Retinex OB and YB. In two patients with cone-rod dystrophy, the visual field showed a significant increase when wearing CPF lenses. In patients with rod-cone dystrophy, the visual field did not improve when wearing CPF lenses. It is felt that the high-pass resolution perimeter could be a means to determine the usefulness of CPF lenses for retinal dystrophy.

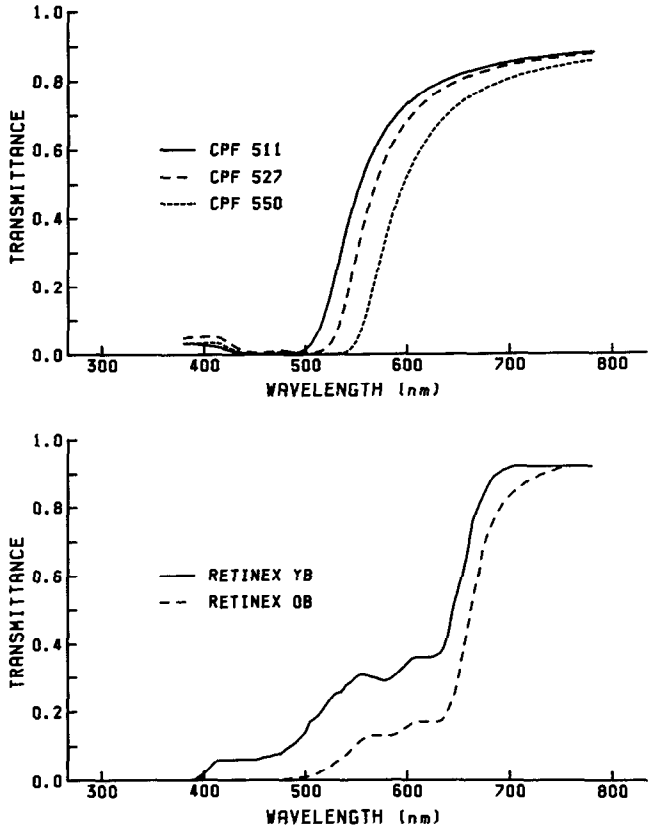

Fig. 1. The transmittance of CPF and Retinex lenses.

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Methods

We measured the visual field of ten normal observers and 14 patients with retinal dystrophy using the high-pass resolution perimeter[1]. These measurements were taken both with and without the CPF 511, 527, 550, and the Retinex YB and OB (Fig. 1)[2-4]. In some cases the measurements were taken with all the lenses, and in some cases with only some of them. The visual field was measured under ordinary conditions. The core, border and background luminances of the test target were set at 25, 15 and 20 cdm^{-2}, respectively.

Results

In normal subjects, there was a slight decrease in sensitivity when wearing CPF or Retinex lenses as shown in Fig. 2. This tendency was observed both with CPF lenses and with Retinex lenses, and it was more obvious with the CPF 550 and Retinex OB than with the other lenses.

A case of rod-cone dystrophy is shown in Fig. 3. In this case, the sensitivity was decreased when using Retinex YB. Also, it was impossible to measure the sensitivity by using the high-pass resolution perimeter when wearing Retinex OB lenses. In four cases of rod-cone dystrophy, every target was missed in all four quadrants of the first phase of the high-pass resolution

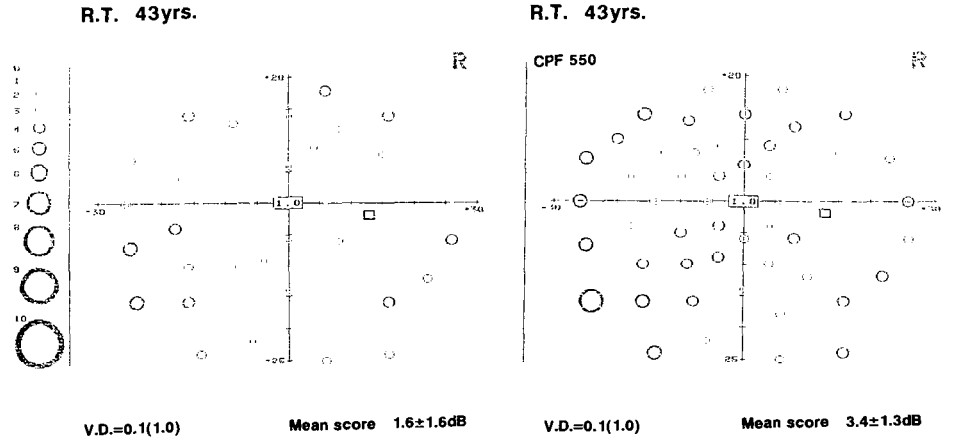

Fig. 2. The result of normal subject RT. The ring size indicates the threshold of high-pass perimetry. The left side is without and the right side with CPF lenses. There is a slight decrease in sensitivity when wearing them.

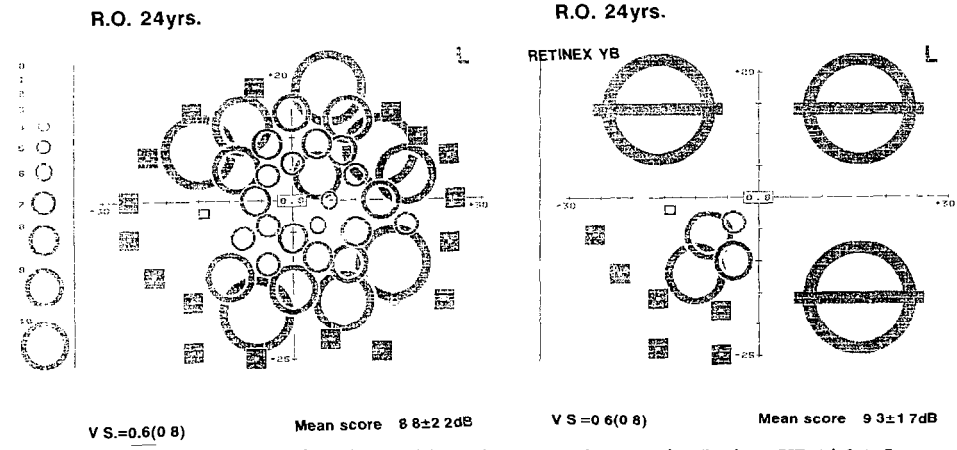

Fig. 3 A case of rod-cone dystrophy. The sensitivity decreases when wearing Retinex YB (right). It was impossible to measure the sensitivity by high-pass resolution perimeter with Retinex OB.

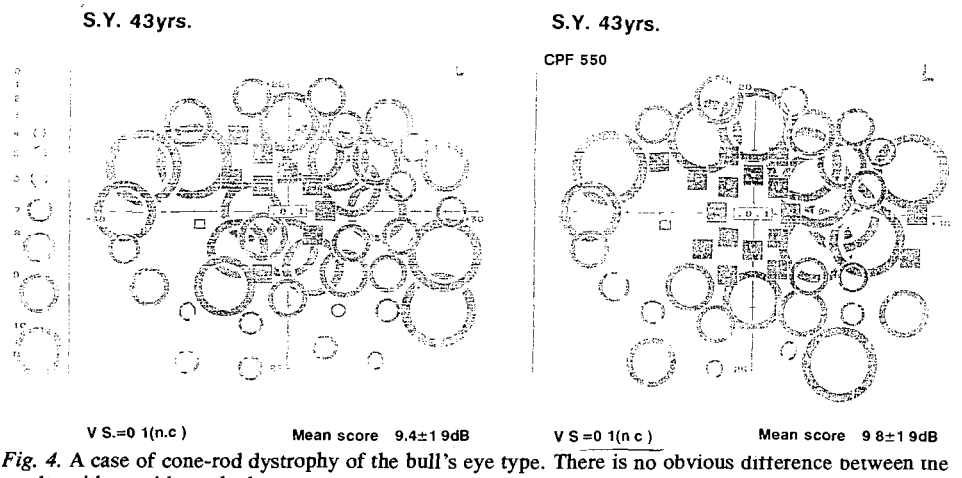

Fig. 4. A case of cone-rod dystrophy of the bull's eye type. There is no obvious difference between the results with or without the lenses

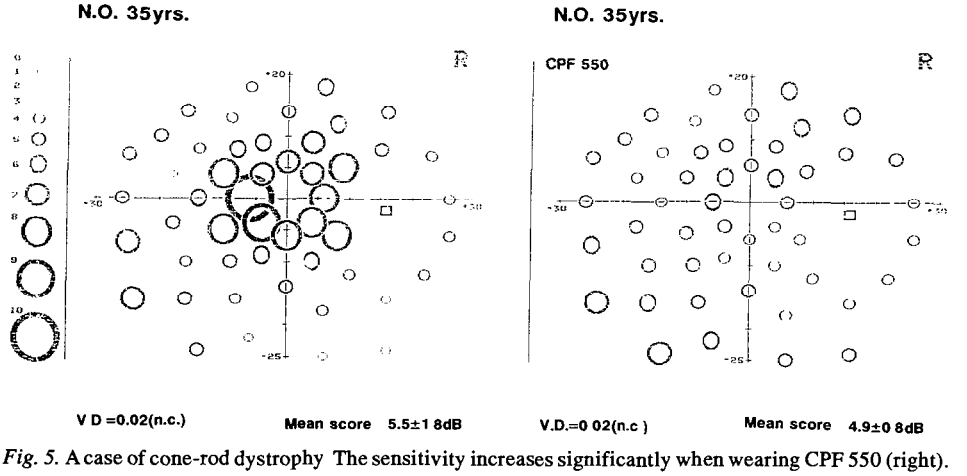

Fig. 5. A case of cone-rod dystrophy The sensitivity increases significantly when wearing CPF 550 (right).

perimetry, both with and without the lenses, and so it was impossible to compare the sensitivity. There were no cases of rod-cone dystrophy which showed an increase in sensitivity with those lenses.

Fig. 4 shows the results of a patient with cone-rod dystrophy of the bull's eye type. There is no obvious difference between the results with or without the lenses.

Two cases of cone-rod dystrophy showed a significant increase in sensitivity with the lenses, as shown in Fig. 5. They were quite similar to blue cone monochromat in spectral sensitivity measurements. We noted that the sensitivity increased especially at points near 5 degrees from the center. In those cases, the patients were very satisfied when using CPF lenses in their daily lives.

The total results are summarized in Table 1.

Table 1. Summary of the results

Effect on high-pass resolution perimetry by using CPF and Retinex lenses	*Worse*	*No change*	*Better*	*Total*
Rod-cone dystrophy	2	1		3
Cone-rod dystrophy	2	3	2	7
Total	4	4	2	10

Four cases of rod-cone dystrophy which failed every target in the first phase of the high-pass resolution perimetry were omitted. In this table, "worse" means that the threshold increased by more than 5%, and "better" means that the threshold decreased by more than 5%

Discussion

This time there were no cases of rod-cone dystrophy which showed an increase in sensitivity with the lenses. Taking into account that CPF lenses are popular with patients especially on very bright days, we might have to consider other ways or conditions to determine the usefulness of these lenses in those cases. Otherwise, some patents with cone-rod dystrophy showed a significant increase in sensitivity with the lenses when using the high-pass resolution perimetry.

As a result, it is felt that the high-pass resolution perimeter could be a means of determining the usefulness of the CPF lenses for cone-rod dystrophy.

References

1. Frisén L: A computer-graphics visual field screener using high-pass spatial frequency resolution targets and multiple feedback devices. Doc Ophthalmol Proc Ser 49:441-446, 1987
2. Leat SJ et al: Do long wavelength pass filters improve low vision performance? Ophthalmic Physiol Opt 10:219-224, 1990
3. Barron C et al: An evaluation of visual acuity with the Corning CPF 527 lens. J Am Optom Assoc 58:50-54, 1987
4 Megala GK: Selectively absorbing glasses for the potential prevention of ocular disorders. Appl Opt 22:1216-1220, 1983

A dissociation of thresholds between Goldmann kinetic perimetry and high-pass resolution perimetry in retinitis pigmentosa

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Abstract

The authors previously reported the differences between the automated static perimetry with the high-pass resolution perimeter and kinetic perimetry with the Goldmann perimeter in 12 patients with retinitis pigmentosa[1]. In this study, we included five new patients for a total of 17. In a total of 16 eyes of 10 patients, the patients were not able to recognize a large screening target even though the target was within the isopter of Goldmann perimetry in 31 quadrants. In these cases there were 12 quadrants in which only one side of a large screening target was not recognized in a total of eight eyes of six patients even though their visual field showed a symmetrical isopter in upper and lower or right and left quadrants in Goldmann perimetry. As a result it was felt that the possible causes of the dissociation could be a greater decrease in sensitivity for the low spatial frequency target than the high spatial frequency target or a greater decrease in resolution sensitivity than differential light sensitivity or a combination of both in retinitis pigmentosa.

Introduction

The high-pass resolution perimeter is a computer-graphic visual field screener, designed by Frisén in 1987[2]. Some clinical trials demonstrated that it was useful in glaucoma and in the area of neuro-ophthalmology because of its short testing time compared with a conventional perimeter[3-5]. But it was pointed out that in some cases high-pass resolution perimetry (HRP) had an absolute defect, whereas the conventional perimeter still showed some remnants of sensitivity, due to an early conclusion of the test program in the initial phase[4].

We thought some diseases might have the possibility of differential damage between light sensitivity and resolution sensitivity, so we made an attempt to compare HRP and Goldmann perimetry in patients with retinitis pigmentosa.

Subjects and method

Thirty-two eyes of 17 patients with retinitis pigmentosa were examined, nine males and eight females, aged 10 to 55 with an average age of 38. The subjects were examined with the Goldmann perimeter and high-pass resolution perimeter. The results of Goldmann perimetry and HRP were transferred to a personal computer, and simultaneously printed out on a graph.

In the first phase of the test on HRP, a large screening target (diameter 20 degrees) is presented in each of the four quadrants. If the subject fails to see one or more of these, he is given a second chance. If this also fails, the corresponding quadrant is deleted from further testing. Because of the number of absolute quadranopsias (being unable to recognize a large screening target) found in retinitis pigmentosa and the difficulty in comparing the two perimeters directly and quantitatively, only the quadrants with absolute quadranopsias using HRP are discussed in this report.

Due to the early conclusion of the program in the initial phase, we felt that the use of only a large screening target did not give completely accurate results. In order to prove this, we had the examiner push the button for the examinee when he/she did not see the large screening target and we continued with the testing in 35 quadrants of 14 eyes of eight patients.

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Results

In HRP testing, 55 quadrants showed an absolute quadranopsia, and in all of these quadrants Goldmann perimetry showed some remnants of sensitivity. A case of a 44-year-old male without conflicting results between these two methods is shown in Fig. 1a. The crossed-out ring means that the large screening target was not able to be recognized and the corresponding quadrant was deleted from further testing. In this case, large screening targets were not recognized in all of the quadrants, and the targets were not within the isopters of Goldmann perimetry. Similarly in 11 eyes of six patients, there were 24 quadrants in which large screening targets,

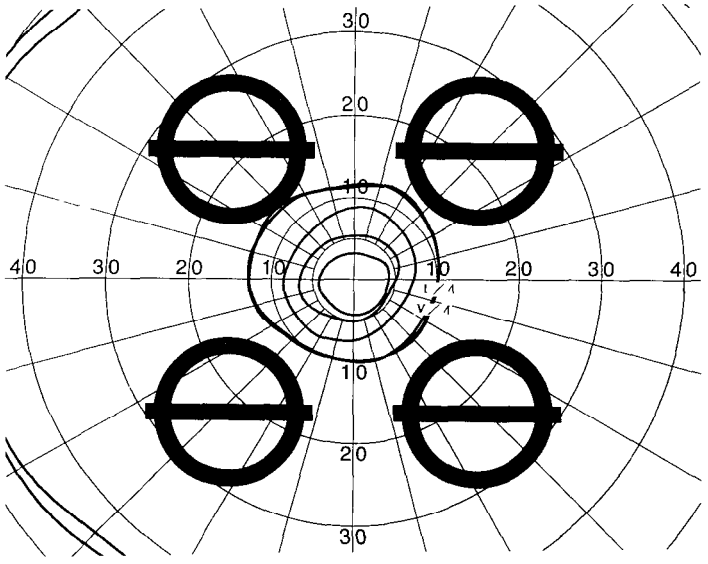

Fig. 1a. Case 1: The result of HRP on a 44-year-old male, showing absolute quadranopsia despite remnants of sensitivity of kinetic perimetry. Large screening targets were outside the isopter of kinetic perimetry.

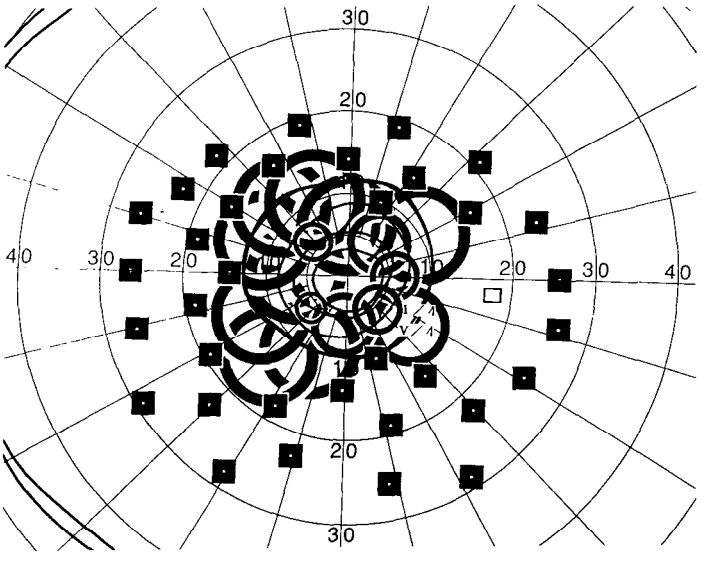

Fig. 1b. The result of the continued testing in case 1. Smaller ring targets were recognized in the remnants of kinetic perimetry.

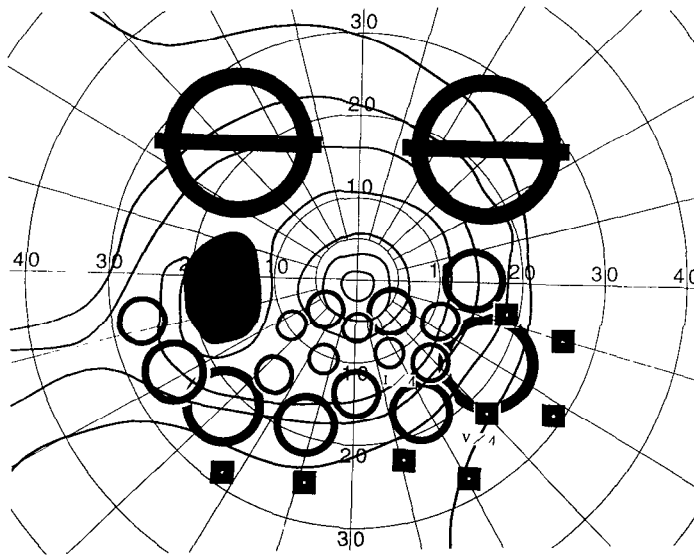

Fig. 2a. Case 2: A 22-year-old female, showing absolute quadranopsia of HRP in upper nasal and upper temporal quadrant. Large screening targets were within the isopter of kinetic perimetry Upper and lower isopters of kinetic perimetry were almost symmetrical.

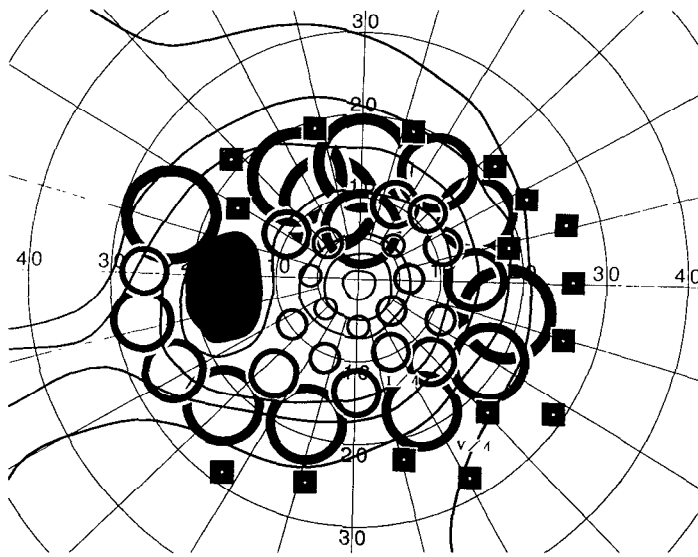

Fig. 2b. The result of the continued testing in case 2. Smaller ring targets were recognized.

which were outside the isopter of Goldmann perimetry, were not recognized. The result of the continued testing in this case is shown in Fig. 1b. Smaller ring targets were recognized in the area where large screening targets were not seen, and the targets were located along the remnant field of light sensitivity. Therefore, it was suggested that HRP gave a precipitate conclusion of the program in the initial phase, and that a large screening target did not check the remnant field of light sensitivity. From this viewpoint there were no conflicting results between tests done with the two perimeters.

A case of a 22-year-old female is shown in Fig. 2a. Large screening targets were not recognized in the upper quadrants in spite of the fact that they were within the isopters of V /4, III /4 and II /4. Moreover, because upper and lower isopters are almost symmetrical, a dissociation between HRP and Goldmann perimetry was suggested. Also, in 16 eyes of 10 patients, we found 31 quadrants in which the patients were not able to recognize a large screening target even when the target was within the isopter of Goldmann perimetry. Furthermore, in a total of eight eyes of six patients, there were 12 quadrants in which only one side of a large screening target was not recognized even though their visual field showed symmetrical isopters in upper and lower or right and left quadrants in Goldmann perimetry. The continued testing was also performed in this case, and smaller targets were recognized in the two upper quadrants where HRP had shown absolute quadranopsia (Fig. 2b).

Smaller targets were recognized in all of the 35 quadrants where we continued with the testing.

Comment

The target does not check the field range from five degrees above to seven degrees below the horizontal meridian, and the range from five degrees left to five degrees right to the longitudinal meridian judging from the size and the testing location of a large screening target, so there were no conflicting results between the two tests in the quadrants which large screening target outside the isopter of kinetic perimetry was not recognized. It has been pointed out that the high-pass resolution perimeter has an inadequate program in the initial test phase. This was demonstrated by the continued testing; which showed that resolution sensitivity, at least in some cases, would remain in the quadrant even if a large screening target was not recognized. Other possible causes of absolute quadranopsia of HRP suggested were differential damage between differential light sensitivity and resolution sensitivity or a greater decrease in sensitivity for the low spatial frequency than the high spatial frequency in retinitis pigmentosa.

In this paper we compared the static perimetry (HRP) and kinetic perimetry (Goldmann). We feel that it is important to conduct further research using HRP and conventional static perimetry in retinitis pigmentosa.

References

1 Tokuhisa T, Oyama K, Tamaki R: A dissociation of threshold between Goldmann kinetic perimetry and high-pass resolution perimetry in retinitis pigmentosa. Acta Soc Ophthalmol Jpn 96:1429-1432, 1992

2 Frisén L: A computer-graphics visual field screener using high-pass spatial frequency resolution targets and multiple feedback devices Doc Ophthalmol Proc Ser 49:441-446, 1987

3. Oyama K, Tamaki R, Kitahara K: The use of high-pass resolution perimeter in normal subjects, glaucoma, optic nerve diseases and other clinical cases. Folia Ophthalmol Jpn 43:338-343, 1992

4 Dannheim F, Roggenbuck C: Comparison of automated conventional and spatial resolution perimeter in chiasmal lesions In: Petimetry Update 1988/89, Heijl A (ed). Amsterdam: Kugler & Ghedini Publ, 1988

5. Dannheim F, Abramo F, Verlohr D: Comparison of automated conventional and spatial resolution perimeter in glaucoma. In: Perimetry Update 1988/89, Heijl A (ed) Amsterdam: Kugler & Ghedini Publ, 1988

Visual field and vitamin A deficiency

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Abstract

The authors describe the perimetric findings (Perikon PCL 90, program DSK) in 15 patients suffering from severe vitamin A deficiency following biliopancreatic by-pass surgery for pathological obesity (seven subjects) or synthetic retinoid fenretinide treatment (eight subjects).

In all patients dark-adaptation time, ERG results and ocular surface were found abnormal Visual field examination showed a diffuse decrease of sensitivity with an increase in MD and isopter contraction as well as localized relative defects in the paracentral area with significant alteration of LV

All functional deficits improved after vitamin A administration

Introduction

Vitamin A is a liposoluble alcohol that is present in nature as retinol or dehydro-3-retinol synthesized from precursors (provitamins) originating in the vegetable kingdom and in some invertebrates. Among the provitamins, the alpha, gamma and, particularly, the beta-carotene represent the biologically most important compounds[1]. The general function of vitamin A is the maintenance of the epithelial tissues in the respiratory, digestive, renal and sexual tracts[2]; being liposoluble it can penetrate the phospholipidic membranes so that an excess or lack of it can disorganize them and cause them to rupture.

Retinol-phosphate mannose has been isolated in the membrane of different types of cells and the vitamin has a primary function in the synthesis of the glycoproteins[3].

Vitamin A has a fundamental role in growth; it is indispensable to the trophism of the goblet cells of the conjunctiva and it controls two very important functions of the retina: adaptability to different forms of light and chromatic perception[5]. A lack of it can cause hemeralopia and xerophthalmia in the eyes[6]. Recently two cases of severe hypovitaminosis A have been noted in which the subjects also clearly manifested alteration of the visual field[7,8]. In order to verify and amplify these cases we examined a group of patients affected by an abnormal concentration of retinol in the plasma before and after substitutive therapy.

Materials and methods

Our study included 15 patients affected by hypovitaminosis A, divided into two groups (Group A and Group B).

Group A consisted of seven patients (one women and six men) between 42 and 67 years of age (average age 45) whose plasma concentration of retinol was between 50 and 70 ng/dl. All the subjects in this group had undergone biliopancreatic by-pass surgery for pathological obesity, according to Scopinaro *et al.*[9], in the previous three to eight years.

Group B consisted of eight patients (four women and four men) between 46 and 81 years of age (average age 56) whose plasma concentration of retinol was between 70 and 150 ng/dl. In Group B the women were affected by the consequences of total mastectomy and the men by the consequences of bladder carcinoma surgery. All the patients in Group B had undergone chemotherapy with fenretinide (4 HPR) in daily doses of 200 mg in the last 12 to 36 months.

The control group of 10 patients (five women and five men) between 45 and 71 years of age,

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had levels of vitamin A between 500 and 700 ng/dl. All the women in this group had undergone surgery for removal of breast cancer and the men for removal of bladder neoplasia.

All the patients included in the study had the ocular surface evaluated and the retinal function analyzed. The ocular surface was studied by examination with a biomicroscope Topcon SL 50 camera. Each patient then underwent impression conjunctival cytology[10].

The study of the retina function included:

1. global adaptometry using the Goldman-Weekers adaptometer for 25 minutes after preadaptation at 2100 apostilb for 5 minutes[11].
2. ERG, by cutaneous electrodes Ag/AgCl, positioned at the inferior orbital margin level, widelens flash stimulation (cupula AMPLAID) of 2J intensity (one stimulation every two seconds) for a total of 50 stimulations; done first by adaptation to 1500 lux for 10 minutes and then by adaptation to the dark for another 10 minutes[12].
3. perimetry using an automatic Perikon PCL 90 perimeter with DSK program[13] that provided a mixed static-kinetic threshold strategy that provides exploration of the central 30 degrees by means of a grid of 80 static points, and the exploration of the periphery with two isopters, integrated in a program for the calculation of the perimetric indexes for the statistical evaluation of the significance of the perimetric defects.

All the tests were performed before and after one month Vitamin A supplementation with 300,000 IV i.m. daily for Group A and 50,000 IV orally twice a week for Group B.

Results

Biomicroscopy showed that in three cases (all in Group A) Bitot's spot was monolaterally present and remained unvaried, after the 30 days of substitutive therapy.

The conjunctival cytology impression showed alterations in both Group A and B; with this method it was possible to evaluate two stages of seriousness in the alteration of the eye surface, the first, less serious, in which, because of an absence of the goblet cells, the conjunctival epithelium had lost the characteristics of normal epithelium, the second, more serious, in which the epithelial cells manifested the characteristics of keratinization with progressive reduction of the nuclear cytoplasmic relationship.

The frequency of the alterations before and after the substitutive therapy with vitamin A is shown in Table 1.

Table 1 Impression cytology: number of eyes divided pathologically during follow-up

	Before therapy			*After therapy*		
	Group A	*Group B*	*Control*	*Group A*	*Group B*	*Control*
Absence of goblet cells	6	7	2	4	2	2
Epithelial metaplasia	8	7	0	0	0	0
Normal	0	2	18	10	10	18

The dark adaptometry fundamentally showed two types of alteration: the first consisted of the elongation of the photopic segment after eight minutes with persistence of the scotopic segment; the second did not show the scotopic segment and the terminal threshold had a value of 5 UL picostilb. The exact results are reported in Table 2.

Table 2. Adaptometry: number of cases divided into types of alteration during the follow-up

	Before therapy			*After therapy*		
	Group A	*Group B*	*Control*	*Group A*	*Group B*	*Control*
Delay in adaptation	3	4	0	1	1	0
Absence of adaptation	4	4	0	0	0	0
Normal	0	0	10	6	7	10

The photopic electroretinogram showed normal results in all cases, the scotopic one showed two types of alterations: a median defect in which the increase of the latency was between 2 and 4 msec and the amplitude to between 3 and 5 microvolts and a serious defect that consisted of an increase of the latency above 2 msec, and also a decrease of the amplitude, inferior to 3 microvolts. The results are reported in Table 3.

Table 3. Scotopic ERG: number of the eyes on the basis of the observed defect during the follow-up

	Before therapy			*After therapy*		
	Group A	*Group B*	*Control*	*Group A*	*Group B*	*Control*
Median defect	4	10	0	4	4	0
Serious defect	10	6	0	0	0	0
Normal	0	0	20	10	12	20

The examination of the visual field demonstrated four types of alterations:
- decrease of the central threshold between 6 and 15 decibels;
- fascicular defects in the superior sectors with a loss variance between 8 and 40;
- isopter contraction more evident in the superior and nasal sectors at eccentricities between 15 degrees and 30 degrees;
- decrease of the global sensitivity between 4 and 12 decibels.

In particular in Group A we observed an alteration of the visual field with global reduction of sensitivity in 35.7% of the cases that was not noticeably reduced at the end of the follow-up. The fascicular defects were the earliest, most frequent and most persistent of the alterations (42% at the end of the follow-up). Isopter contraction at 20 degrees was always associated with fascicular defects and was particularly serious in 28.5% of cases. The reduction of the central threshold was found in a few cases and was always associated with other perimetric defects.

In the patients affected by hypovitaminosis A the visual field between the eyes of the same patient were always asymmetrical in relation to the depth and type of alteration. The results for Group B were very similar to those for Group A, but with a lower level and percentage.

The visual fields of the patients in the control group did not show statistically significant alterations of the perimetric indexes. The results are reported in Table 4.

After 30 days of substitutive therapy the tests performed showed an improvement, except that the Bitot spots did not show a reduction even following prolonged therapy with vitamin A[15] (Table 5).

The percentage of improvement in the different tests are reported in Table 5.

Table 4. Visual field: number of eyes affected by various alterations on the basis of group during follow-up

	Before therapy			*After therapy*		
	Group A	*Group B*	*Control*	*Group A*	*Group B*	*Control*
Foveal depression	6	5	0	0	0	0
Isopteric contraction	8	7	0	4	2	0
Fascicular defects	11	9	0	6	4	0
Global depression	5	2	0	0	0	0
Normal	0	3	20	8	12	20

Table 5. Percentage of improvement

	Group A	*Group B*
Biomicroscopy	*	*
Cytology	71.42%	85.7%
Adaptometry	85.71%	87.5%
ERG	71 42%	75.0%
Visual field	57.14%	62.5%

Discussion

In our study we confirmed that a low level of vitamin A, caused by malabsorption or competitive inhibition with 4 HPR[16] produced morphological and functional alterations in the eye, which are related to the plasma levels of retinol, in accordance with other findings[17,18]. In fact the most evident alterations are confirmed in the patients in Group A in which the plasma levels of vitamin A were clearly lower than normal.

The eye surface was affected by a progressive deficit of goblet cells in the conjunctiva that can lead to xerosis[2] which is however reversible after the implementation of substitutive therapy.

The most evident manifestations were, overall, the functional ones.

In fact with ERG a lack of increase of the amplitude of the scotopic a and b wave was observed in Group A and B; furthermore an insufficient increase of the latency of the scotopic waves can result in damage of the rods and Müller cells. Adaptometry has shown a lack of the lowering of the curve, more evident in Group A, and confirmed the functional deficit of the rods.

Other authors[19] have observed that the dark adaptometry defect disappeared only after at least five months of substitutive therapy; in our study this alteration generally disappeared at the end of the follow-up, so that only 13.3% of all cases continued to show a delay in adaptation.

In contrast to the other tests, the examination of the visual field showed the most frequent alterations at the end of the follow-up (66.6% of all cases).

The examination of the visual field revealed both the concentric contraction of the isopters (already described)[8] and the presence of the fascicular defects. While the contraction of the isopters and the sensitivity depression are the symptoms of the functional alteration of the photoreceptors, the fascicular defects are connected to an alteration of the ganglion cells[20].

Conclusion

In conclusion we can presume that damage from hypovitaminosis A, however caused, does not affect only the functions of the photoreceptors but also the Müller cells, very important in the metabolic role in the retina[21] and ganglion cells, and the whole system that carries the nervous pulse to the superior centers.

We can therefore hypothesize that vitamin A plays a fundamental role in the biochemistry of cells because a strict relationship exists between vitamin A and the biological membranes[3] and in particular mitochondria[1] in which ATP, important for axonic transport, is produced.

Other studies are necessary to establish the exact limits of these alterations and to integrate the functional, biochemical and physiological data that overall exists between vitamin A and the visual apparatus.

References

1. Dianzani MU: L'alimentazione come causa di malattie. In: Patologia Generale, pp 476-481. Torino: UTET, 1991
2. Robbins SL, Cotran RS, Kumar V: Pathologic Basis of Disease, p 427. Philadelphia: Saunders, 1991
3. De Luca LM: The direct involvement of vitamin A in glycosyl transfer reactions of mammalian membranes. In: Munson PL, Glover J, Diczfalusy E, Olsom RE (eds) Vitamins and Hormones, Vol 35, pp 1-57. New York: Academic Press, 1977
4. Wolf G: Multiple functions of vitamin A. Physiol Rev 64:873-937, 1984
5. Wald G: The molecular basis of visual excitation. Nature 219:800-806, 1968
6. Mindell JS: Vitamins. In: Duane TD, Jaeger EA (eds) Biomedical Foundation of Ophthalmology. Philadelphia: Harper & Row, 1987
7. Kemp CM, Jacobson SG, Faulkner DJ, Walt RW: Visual function and rhodopsin levels in humans with vitamin A deficiency. Exp Eye Res 46:185-197, 1988
8. Grey RHB: Visual field changes following hepatic translation in a patient with primary biliary cirrhosis. J Ophthalmol 75:377-380, 1991
9. Scopinaro N, Gianetta E, Civalleri D, Bonalumi V, Friedmann D, Bachi V: Partial and total biliopancreatic by-pass in the surgical treatment of obesity. Intern J Obesity 22:421-429, 1981

10 Wittpen JR, Tseng SCG, Sommer A: Detection of early xerophthalmia by impression cytology. Arch Ophthalmol 104:237-239, 1986
11. Marmor MF: Fisiologia clinica della retina. In: Pejman GA (ed) Oftalmologia Principi e Pratica, Vol 2, pp 811-843. Roma: Verduci, 1991
12. Fioretto M, Fava GP, Rossi P, Sannita WG: Elettroretinografia da stimolo non strutturato: stimolazione full-field con monitoraggio in tempo reale della fissazione Boll Ocul 64 (Suppl 11-12):101, 1985
13. Zingirian M, Gandolfo E, Capris P, Mattioli R: Perikon PCL 90: a new automatic perimeter In: Mills RP, Heijl A (eds) Perimetry Update 1990-91, pp 403-407 Amsterdam: Kugler, 1991
14. Catignani GL, Bieri JG: Simultaneous determination of retinol and tocopherol in serum or plasma by liquid chromatography. Clin Chem 29:708-712, 1983
15. Paton D, McLaren DS: Bitot's spot Am J Ophthalmol 50:568-574, 1960
16. Kaiser-Kupper MI, Peck GL, Caruso RC, Jaffen J, Di Giovanna JJ, Gross EG: Abnormal retinal function associated with fenretinide, a synthetic retinoid. Arch Ophthalmol 104:69-70, 1986
17. Rogers E, Douglass W, Russel R, Bushmann L, Hubbard T, Iber F: Deficiency of fat soluble vitamins after jejunoileal by-pass surgery for morbid obesity. Am J Clin Nutr 33:1208-1214, 1980
18 Russel RM, Smith VC, Multack R, Krill AE: Dark adaptation testing for diagnosis of subretinal vitamin A deficiency and evaluation of therapy. Lancet 21:1161-1164, 1973
19. Wachtmeister L, Bjorklem I, Diczfalusy U, Emani A: Attempts to define the minimal serum level of vitamin A required for normal visual function in a patient with severe fat malabsorption. Acta Ophthalmol 66:341-348, 1988
20. Waber J, Ulrich H: A perimetric nerve fiber bundle map Int Ophthalmol 15:193-200, 1991
21. Miller NR: Walsh and Moyt's Clinical Neuro-Ophthalmology, Vol 1 Chp 3 Baltimore: Williams & Wilkins, 1985
22. De Luca LM: Epithelial membranes and vitamin A In: Jamison, Robertson DM (eds) Vol 3, pp 231-249. London: Butterworths, 1977

Do laser scars grow in spite of successful laser coagulation of subretinal neovascularizations

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Introduction

Laser scars grow in spite of the successful coagulation of a subretinal neovascularization[1-3]. In a prospective study, we attempted to correlate the anatomical growth of the laser scars to changes in the corresponding visual fields.

Patients and methods

Nine laser coagulations in eight patients who had successfully been treated for subretinal neovascularization (SRNV) (successful means disappearance of SRNV on the angiogram) were studied. There were seven females and one male with a mean age of 40.8 years. Seven SRNVs were characterized as idiopathic (one with presumed fractures in the choroid, no Groenblad-Strandberg syndrome), one POHS, one more than six diopters myopic.

Laser therapy was carried out with an argon-laser in the argon-green mode using a spot size of 50-500 µm, energy of 0.15-0.5 W and a duration of 0.1-0.5 seconds. One patient was treated in another hospital, and therefore no data on laser parameters were available in her case.

Each patient was examined at least twice. Each time, a fluorescein angiogram and a special visual field was obtained in addition to a full clinical examination. The baseline examination was performed 30 days after laser therapy (range 10-93 days), further follow-ups took place after 107 (range 68-180) and 409 (range 167-1035) days. All changes in the patients' laser scars and visual fields were related to the baseline examination 30 days after laser therapy. We chose 30 days because we expected edema caused by SRNV to have disappeared after that period, so that changes in the visual field could not be explained by the reduction of edema but only by changes in the laser scars themselves.

Using Sargon utilities, we created a visual field program for the Octopus perimeter[4] testing 48 test locations in the central 12° of the visual field (Fig. 1). Eight test points were checked twice in order to calculate a reliability parameter. As such, we chose the standard deviation of the difference of the twice tested locations.

We counted the number of test points having a differential light sensitivity of ≥5 and ≥10 dB below the age-corrected normal values. These two parameters were selected for describing the extent of the scotoma caused by the laser scar. Furthermore, the mean sensitivity was used as a global parameter.

The fluorescein angiograms of our patients were photographically enlarged. Black-and-white copies were presented to two experienced independent examiners in a random sequence. These examiners determined the borders of the laser scars, which were finally measured by a third person using a mechanical planimeter. The mean of the two values per laser scar was corrected for variations in the photographic enlargement. Furthermore, the mean difference of the two values per laser scar was calculated to make a guess at the reproducibility of their measurement.

The area of the laser scar, the mean sensitivity and the number of test points with ≥5 and ≥10 dB defects were plotted against the time and a linear regression analysis was performed ($p \leq 0.05$).

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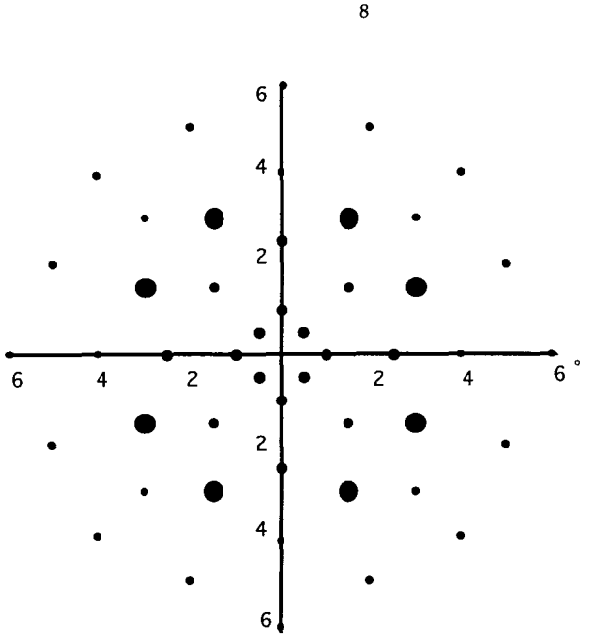

Fig 1

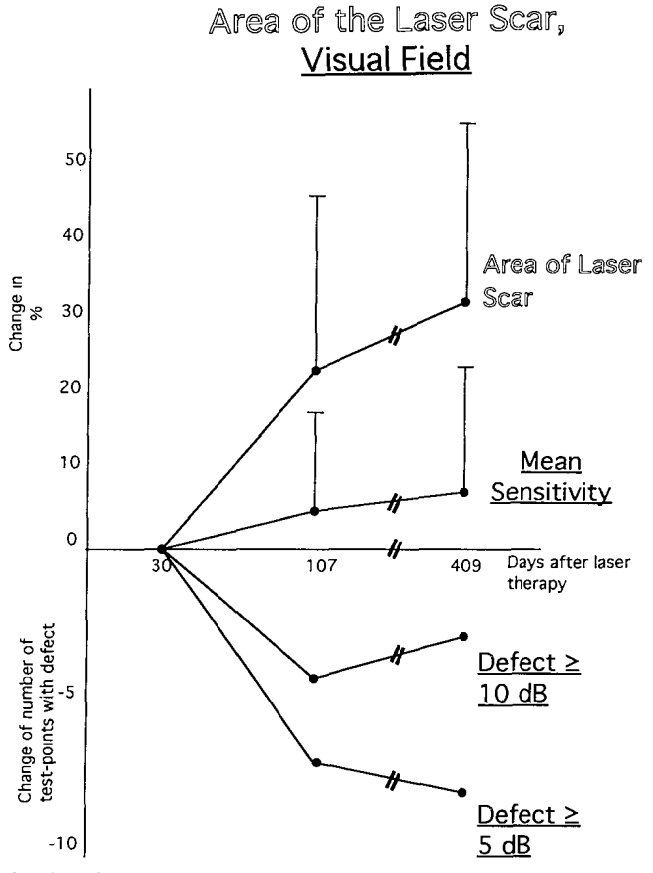

Fig 2. Summary of patient data.

Table 1. Overview of patient data

Age (years)	*Sex*	*baseline examination: days after laser*	*First control Δ compared to baseline examination*				*Final control Δ compared to baseline examination*			
			days after laser	*Δ area (%)*	*Δ mean sensitivity (%)*	*Δ test points with defect ≥5/≥10 dB*	*days after laser*	*Δ area (%)*	*Δ mean sensitivity (%)*	*Δ test points with defect ≥5/≥10 dB*
1. 45	F	10	78	-9	5	-9/-2	167	0	1.6	-7/-2
2. 25	F	21	68	-1	20.9	-12/-9				
3. 30	F	13	92	41	8.7*	-11/-6*	201	57	10.6	-15/-5
4. 50	F	16	100	45	-21.3**	8/8**				
5. 40	F	14	73	4	6	-10/-1	283	30	-16.7	22/16
6. 61	M	14	90	21	15.7	-4/-13				
7. 61	M***	14	101	59	-7	-1/2				
8. 29	F****	75	180	16	16	-22/-13	1035	52	28.4	-31/-15
9. 47	F	93	177	27	0	-1/-4	360	23	13.6	-8/-8
Mean		30	107	23	4.9	-6.9/-4.2	409	32	7.5	-7.8/-2.8
Range		10-93	68-180	-9-59	-21.3-20.9		167-1035	0-57	-16.7-28.4	
SD				22.7	13.1			23.1	16.6	

*visual field after 43 days; **visual field after 37 days; ***second laser therapy in the same eye; ****after two laser coagulations in the same eye

Results

Reliability tests

The mean SD of all twice checked test points (Fig. 1) was 2.3 dB. The mean difference of the area of the laser scar as measured by the two independent observers was 10.3%.

Changes of the laser scars and visual fields

The laser scars (Fig. 2) grew on average by 23% between 30 and 107 days (range -9% to 59%, SD 22.7%). After 409 days, the respective values were 32% (range 0% to 57%, SD 23.1%). The changes were significant only in one case (regression analysis).

The mean sensitivity increased by 4.9% (range -21.3% to 20.9%, SD 13.1%) after 107 days and by 7.5% (range -16.7% to 28.4%, SD 16.6%) after 409 days. The central visual field improved not only according to the global parameter mean sensitivity but also to the number of disturbed test points. The number of test points with a defect of ≥5 dB decreased on the average by 6.9 and 7.8 after 107 and 409 days, respectively. The corresponding values for test points with a defect of ≥10 dB were 4.2 and 2.8.

Anatomical laser scar growth was not accompanied by a deterioration of the visual field. In five of seven cases in whom the laser scar increased, the mean sensitivity increased (Table 1). Because of the small sample size, no χ^2 was calculated.

Discussion

We measured anatomical laser scar growth and changes of the visual field after successful coagulation of an SRNV. In our patients, the laser scars grew by 23% and 32% at 107 and 409 days after laser therapy. Visual field parameters did not deteriorate even in those patients in whom the laser scar area increased.

Laser scar growth in our patients was at the lower margin of the range in the literature (16-50% per year[1-3,5,6]. Even if we take into account that our follow-ups were not as long as those in the literature, we should expect a more pronounced increase in the area of the laser scar. The reason being that laser scar growth is most intense in the first three months after therapy[1]. Another drawback in our data was that in two patients the baseline examination was done six months after laser therapy, so that their phase of most intense growth was not encountered. We think, however, that in spite of these methodological differences compared to the literature, laser scar growth was not as intense as previously described. There are three plausible explanations for this:

1. In our study, patients with idiopathic SRNV were most prominent, whereas Brancato *et al.*[1], who encountered the greatest laser scar growth, devoted their study to myopic patients alone. In those patients Bruch's membrane may be more fragile and therefore more prone to laser scar growth. It is interesting that in our group the most pronounced scar growth was found in one patient with high myopia and in another with presumed fractures in the choroid.
2. We measured laser scar growth on angiograms. The mean difference of the laser scar area between the two independent observers was 10.3% in our study. Using color photographs in a subset of our patients, the same two observers differed by 27.2%. Therefore, using color photos (for example, ref[3]) for measuring the laser scar growth seems to be less accurate. Perhaps, the increasing pigmentation at the border of the laser scar can be mistaken for real scar growth.
3. According to other studies[7,8], the range of subclinical damage occurring in the retina and choroid at the time of laser coagulation is larger than can be seen by whitening of the retina by the laser burns. It is conceivable that laser scar growth is nothing more than an increasing visualization of damage occurring to the eye at the time of laser coagulation. Therefore, different laser parameters may explain different laser scar growth.

Even if laser scars grow anatomically (and this also happened in our patients), their growth was - according to our data up to now - not accompanied by a deterioration of the visual field. On the contrary, all visual field parameters improved. This was no training artefact because all

our patients had experience with computerized perimetry as they had also been examined before laser therapy.

The reliability of our visual field program has already been described in detail[4]. Specificity and sensitivity were 85%. Another problem may have arisen from the fact that only the central 12° of the visual field was tested. Most of our laser scars extended beyond that. If, however, laser scars do grow, they do so particularly in the direction of the fovea[2]. This would have been detected by our visual field program.

References

1. Brancato R, Pece A, Avanza P, Radrizzani E: Photocoagulation scar expansion after laser therapy for choroidal neovascularization in degenerative myopia. Retina 10:239-243, 1990
2. Othenin-Girard P, Zografos L: Néovaisseaux sous-rétiennes: évolution des cicatrices de photocoagulation en l'abscence de récidives. Klin Mbl Augenheilk 196:364-368, 1990
3. Shah S, Schachat AP, Murphy RP, Fine SL: The evolution of argon laser photocoagulation scars in patients with the ocular histoplasmosis syndrome. Arch Ophthalmol 106:1533-1536, 1988
4. Janknecht P, Soriano JM, Funk J, Hansen LL: Automatische Perimetrie des zentralen Gesichtsfeldes bei Erkrankungen der Makula. Klin Mbl Augenheilk 199:259-26, 1991
5. Fine SL: Observations following laser treatment for choroidal neovascularization. Arch Ophthalmol 106:1524-1525, 1988
6. Morgan C, Schatz H: Atrophic creep of the retinal pigment epithelium after focal macular photocoagulation. Ophthalmology 96:96-103, 1989
7. Birngruber R, Weinberg W, Gabel VP: Der Einfluss der Expositionsparameter auf die Schadensausdehnung bei der Netzhautkoagulation, dargestellt anhand eines thermischen Modells. Sitzungsberichte der DOG 78:599-602, 1981
8. Weinberg W, Gabel VP, Birngruber R, Lorenz B, Müller W: Die zeitliche Entwicklung der Weissfärbung in Korrelation zur Schadensausdehnung bei der Photokoagulation der Netzhaut. Sitzungsberichte der DOG 78:603-606, 1981

A touch-screen multi-stimulus video campimeter

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Abstract

A novel computerized test has been developed for the examination of the central 30 degree visual field with simultaneous exposures of static multiple stimuli. The test operates on an IBM compatible personal computer fitted with a touch-screen high resolution monitor and a printer. The test parameters can be changed by the operator. The patient indicates the stimulus detection by touching on the screen at the approximate locations where the stimuli appeared. The test makes the threshold peripheral contrast sensitivity determination possible using an ascending staircase method with 2 dB steps. This method may be useful as a low cost alternative to the existing automated perimetric techniques and may provide additional diagnostic information in glaucomatous and neuro-ophthalmic visual system involvement using dark-on-bright stimuli.

Introduction

The efficiency of automated perimetry is restricted by cost, availability and, sometimes, the requirement of patient cooperation.

Computer assisted touch screen (CATS) campimetry has been developed as a user-friendly, low cost alternative for situations where conventional automated perimetry is inaccessible or impossible.

Hardware

The test system operates on a standard IBM compatible personal computer with VGA graphics, a high resolution IBM Touch-Screen monitor fitted with a head-rest to maintain the test distance, and a printer. The current "Touch-Screen" model is a robust video display unit which uses strain gauges mounted at the corners of the cathode-ray tube (CRT) to detect a touch on the screen. The amount of touch pressure required for a computer response can be adjusted under software control. The device requires once only calibration.

Software

The CATS software package is capable of presenting static multi-stimuli with a novel fixation monitoring system. Achromatic and colored stimuli and background combinations can be arranged to create either bright-on-dark or dark-on-bright stimuli using a palette of 64 achromatic or 262 144 color shades. Stimuli color, contrast, duration, size (pixels), grouping format, coordinates and the test grid can be altered using a spreadsheet (Microsoft Works). The size and contrast of the dark stimuli can also be compensated for age and the eccentricity in the visual field automatically.

This project was supported by the International Glaucoma Association, the International Perimetric Society, W.H. Ross Foundation, and The Royal National Institute for the Blind

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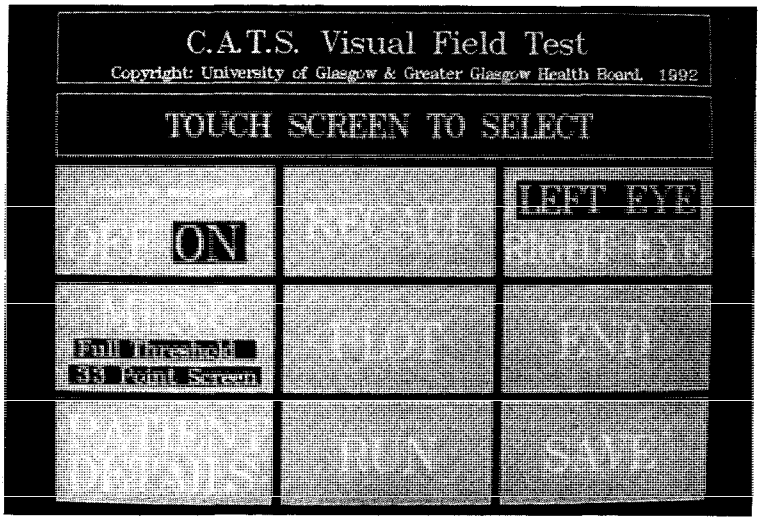

Fig. 1 The opening menu for CATS campimetry. Selection is activated by touching on the required function boxes.

CATS campimetry

An opening menu is presented on the video-display unit (VDU) screen, with instructions to press on a section to select a function (Fig. 1).

When the "run" command is given, a fixation cross is displayed on the uniform test background. At the touch of a button by the operator a set of square stimuli (either 1, 2, 3 or 4) appear and disappear at preselected coordinates on the screen. The patient is asked to touch on the approximate locations where the stimuli were presented. The response locations are recorded, and the test proceeds to the next set of stimuli automatically.

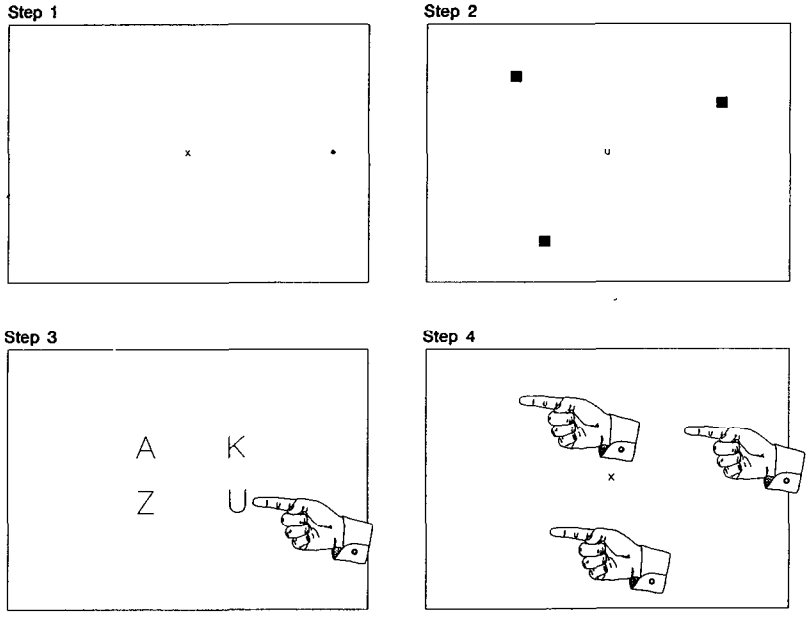

Fig. 2. CATS campimetry test sequence with fixation monitoring. These steps are repeated until the whole grid is completed. The missed locations are retested with the same and higher stimulus contrasts to document the accuracy and to quantify the depth of detected abnormality.

CATS fixation monitoring

If "fixation monitoring" was activated prior to the test, the fixation cross changes to a random letter at the same time as the test stimuli appear. Following stimuli exposure, a selection of four random letters are presented on the screen. The patient then selects the letter the fixation target changed to during the stimuli exposure (Fig. 2). If the patient's answer is incorrect, the

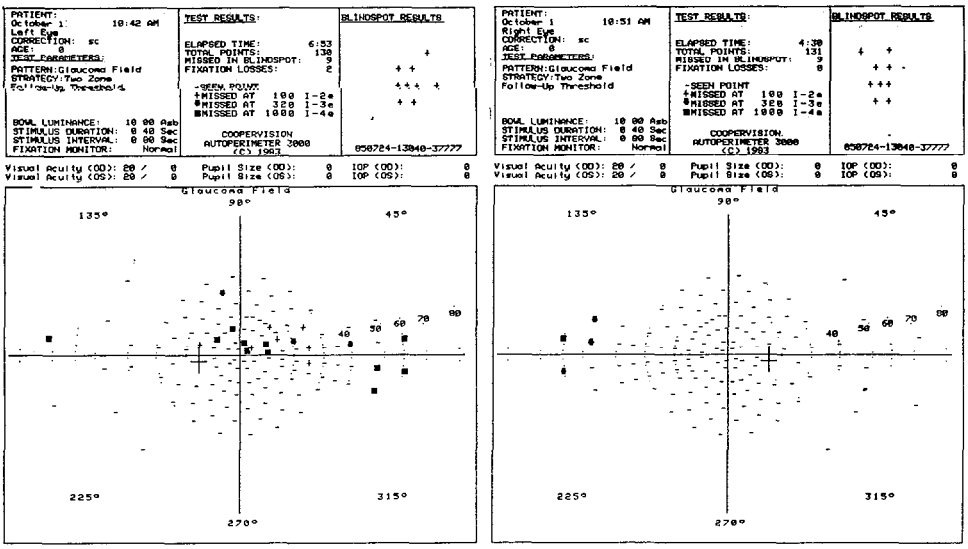

Fig. 3a.

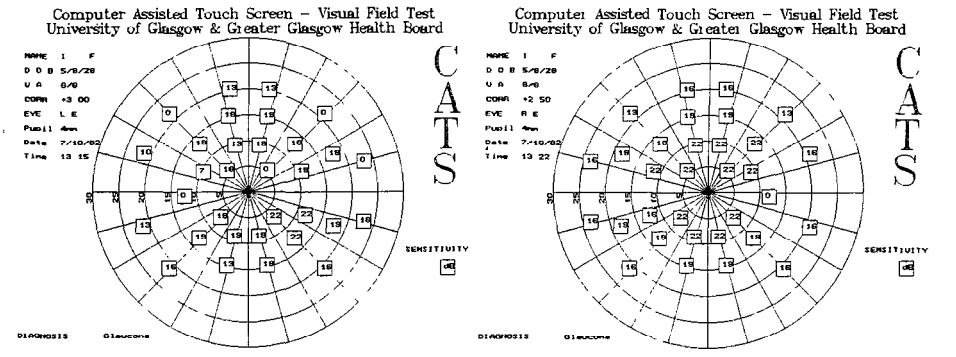

Fig. 3b.

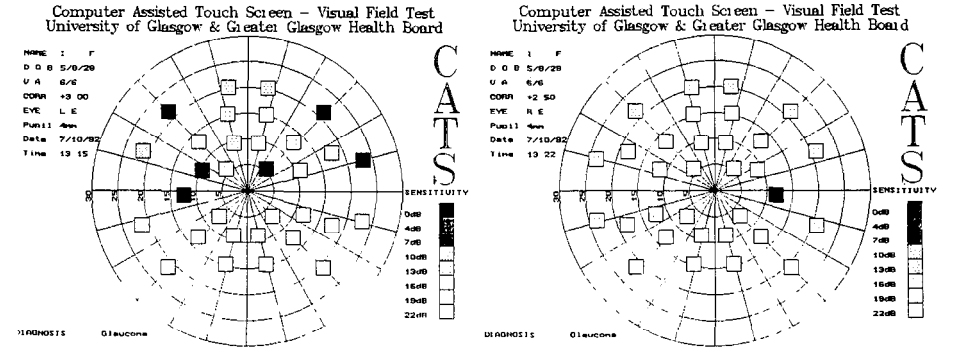

Fig. 3c.

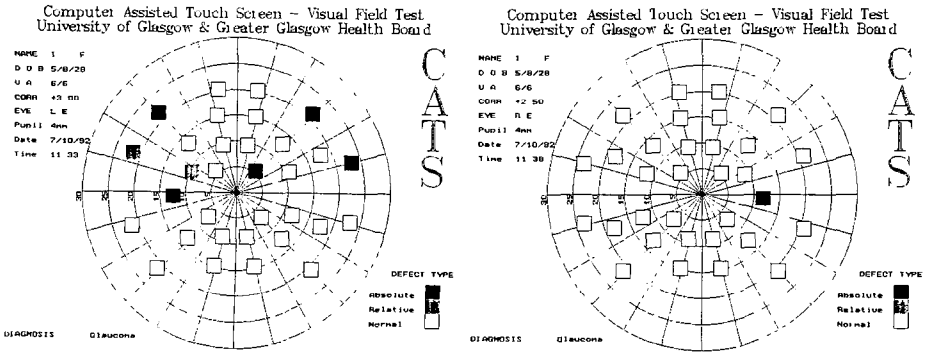

Fig. 3d.

Fig. 3. Glaucomatous visual field loss in the left eye appears on results from: *a.* Dicon autoperimeter; *b.* CATS campimeter's 33-point thresholding test numeric; and *c.* symbols print-out formats; as well as the *d.* three-zone screening test using dark-on-bright stimuli.

same set of stimuli is re-presented.

The results from each eye can be saved, retrieved and printed in symbolic or numeric format together with the patient details (Fig. 3).

Algorithm

Threshold examination with an ascending staircase and single-crossing technique is possible with 2 dB steps in stimulus contrast. The current version employs grey stimuli on a bright background (negative contrast) and 3 dB steps. For quick screening, options for single intensity testing or three-zone examination with low, intermediate and high intensity stimuli are available (Figs. 3 and 4). The dark-on-bright stimulus parameters can be eccentricity and age compensated to follow the normal slope of the hill of vision[1,2].

Future aid for interpretation

Statistical evaluation and interpretation software packages are being prepared for incorporation into the CATS campimeter to enable total dB sensitivity and percentage visual field survival calculations as well as "neural network" pattern recognition of the defects[3].

Discussion

CATS campimeter, as a low cost, user-friendly and flexible technique, may prove to be a useful addition to the existing conventional techniques in:

1. community screening;
2. ophthalmic and non-ophthalmic (*e.g.*, neurology, neurological surgery, general medicine) clinical practice; and
3. perimetric research into parallel visual processing[1,4].

Acknowledgement

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References

1. Mutlukan E, Damato BE: Visibility threshold for dark perimetric stimulus. This Volume 1992
2. Mutlukan E, Damato BE: Static dark-on-bright perimetric stimulus: the effect of stimulus size, eccentricity, background and patient's age on the visibility. (in preparation)
3. Keating D, Mutlukan E, Damato BE, Evans AL: The performance of a back propagation network in the classification of visual field results. Phys Med Biol 1992
4. Mutlukan E, Damato BE: The dark perimetric stimulus. Br J Ophthalmol 76:264-267, 1992

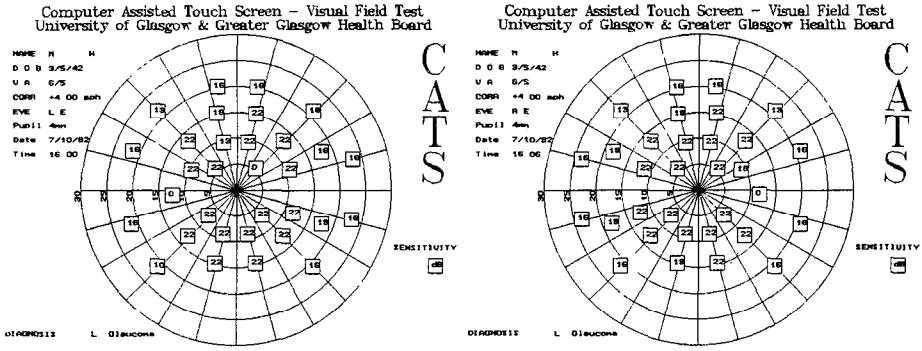

Fig. 4a.

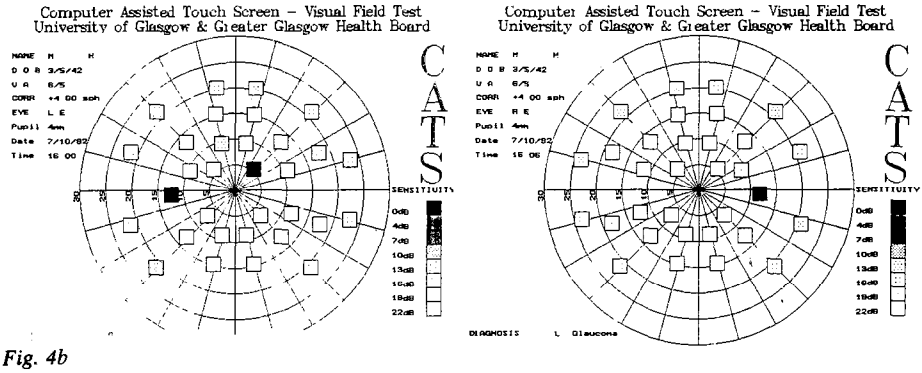

Fig. 4b

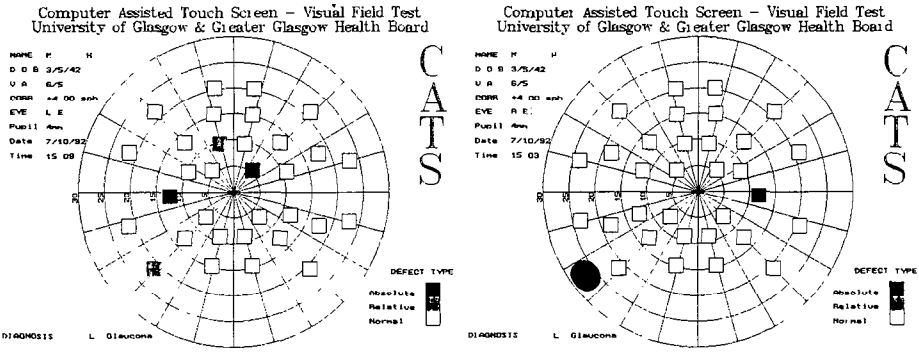

Fig. 4c.

Fig. 4. a. The numeric (Weber's Contrast dB) and *b.* symbols print-out formats of CATS 33-point thresholding and *c.* three-zone (normal, relative or absolute defect) screening programs display the field defect in the left eye which was also documented by *d.* (next pages) the Humphrey Field Analyzer thresholding program 30-2.

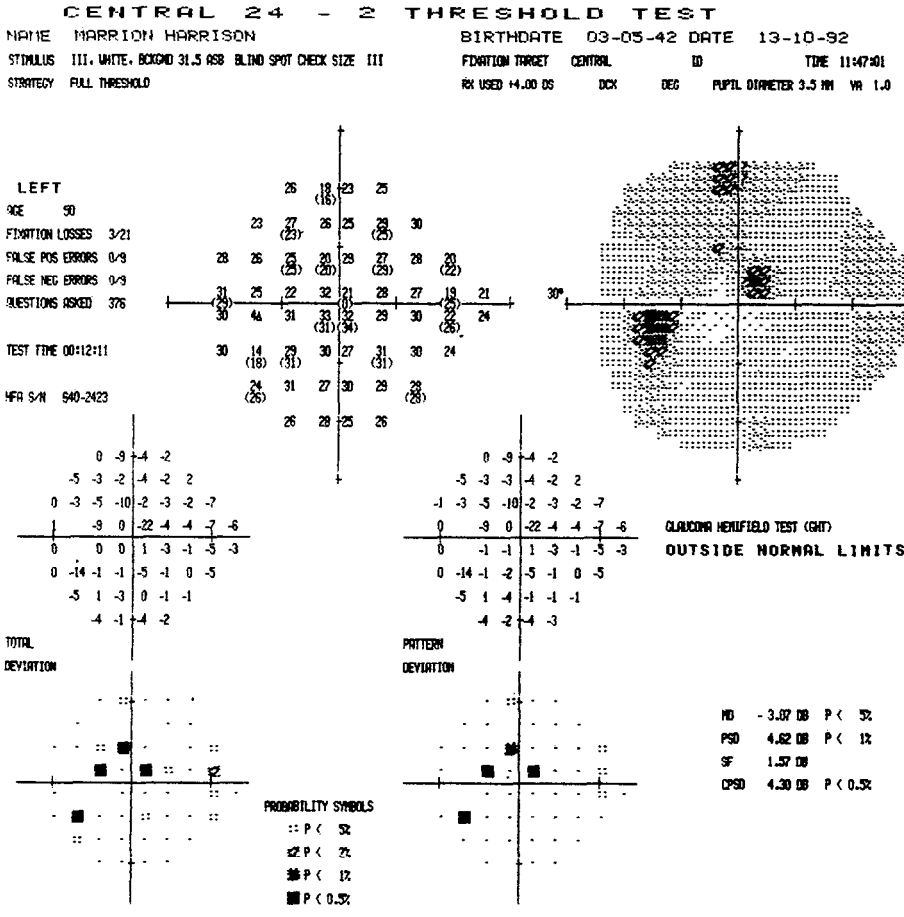

Fig. 4d. Left eye.

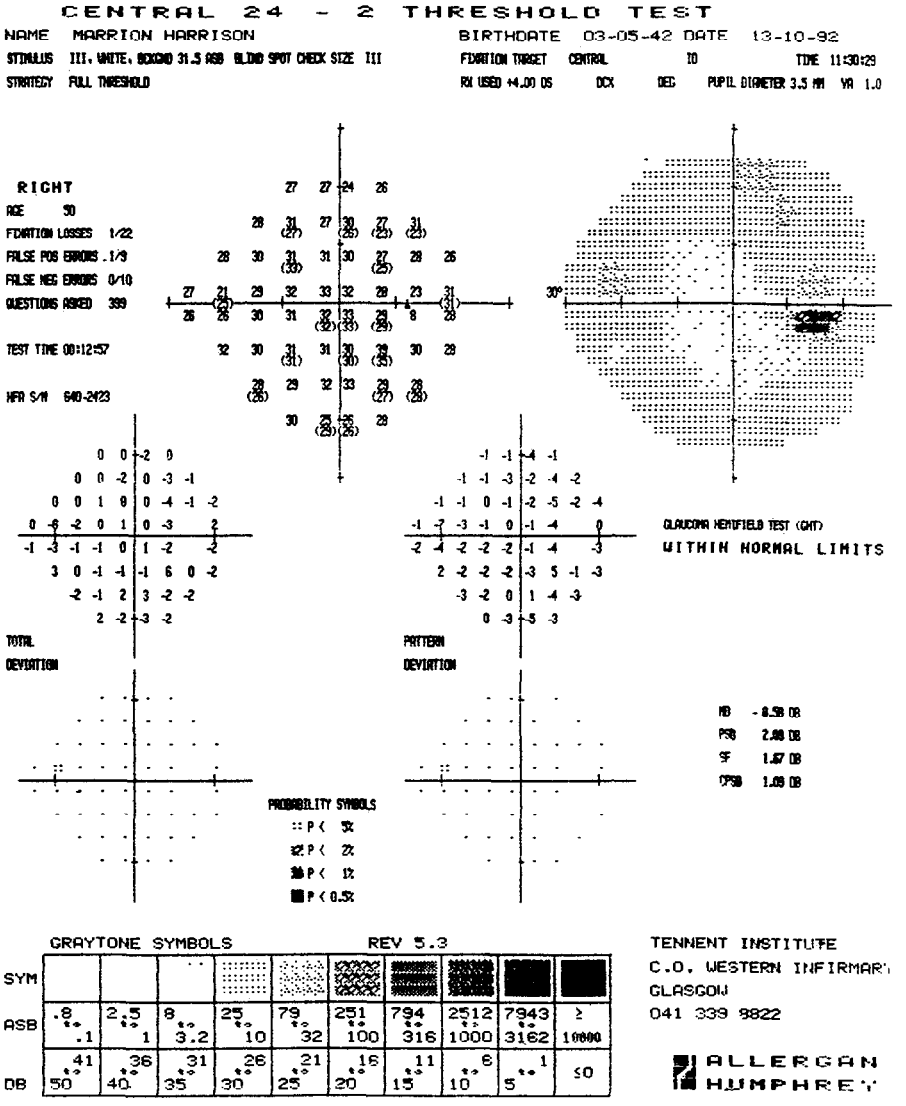

Fig. 4d. Right eye.

Preliminary report on objective perimetry by visual evoked potentials

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Abstract

The authors report a preliminary study on the objective assessment of target perception up to 25° eccentricity by visual evoked potentials (VEP).

A flash full field stimulator was appropriately modified to allow the stimulation of a predetermined grid of points.

Twelve healthy volunteers were subjected to stimulation of 20 points by means of decreasing light intensity stimuli, and VEP were registered until the traces were no longer recordable.

Our data showed the possibility of objectively quantifying perimetric thresholds.

Introduction

Modern methods for examining the visual field (VF) make it possible to distinguish a relative scotoma of fairly modest width and depth. The perception of these scotomas depends on the patient's cooperation, which is an essential condition for a correct examination and assessment of VF.

In order to obviate this condition, which is not always attainable, many authors have set up different methods using the pupil reflex[1-4], or visual evoked potentials (VEP). As far as VEP are concerned, pattern reversal stimulations have mainly been used[5-9]. This method makes it possible to distinguish a hemianopia[10-15] and a quadrantanopia[16], while macular function is assessed by means of special electroretinographic methods[17-21].

In order to objectively search for the presence of defects of small size and relative depth, we have set up a special electrophysiologic method based on visual potentials evoked by a flash stimulus of small dimensions.

Materials and methods

We examined 12 healthy volunteers (seven males and five females) aged 25 to 34 years (mean 29.6 ± 2.4) with refractive error less than ± 1.5 D and pupil diameter measured with a Goldmann perimeter under standard conditions between 3 and 4 mm. These subjects underwent a complete ophthalmic examination and computerized VF examination with Octopus 2000 program G1, in order to carry out research on subjects without any defects. The subjects then underwent an objective perimetric examination in the following way: a black screen, with a slightly phosphorescent round fixation point 1.5 mm in diameter at the center, was placed on an Amplaid bowl for full-field stimulation. The screen also contained a hole of predetermined diameter and eccentricity such as to let the light of the flash pass through it. The luminance of the background was reduced to zero.

The holes were made so as to stimulate a grid of 20 points (Fig. 1) with the following characteristics:

2 points at 5° eccentricity (meridians 0°, 180°)
4 points at 10° eccentricity (meridians 45°, 135°, 225°, 315°)
6 points at 15° eccentricity (meridians 0°, 60°, 120°, 180°, 240°, 300°)

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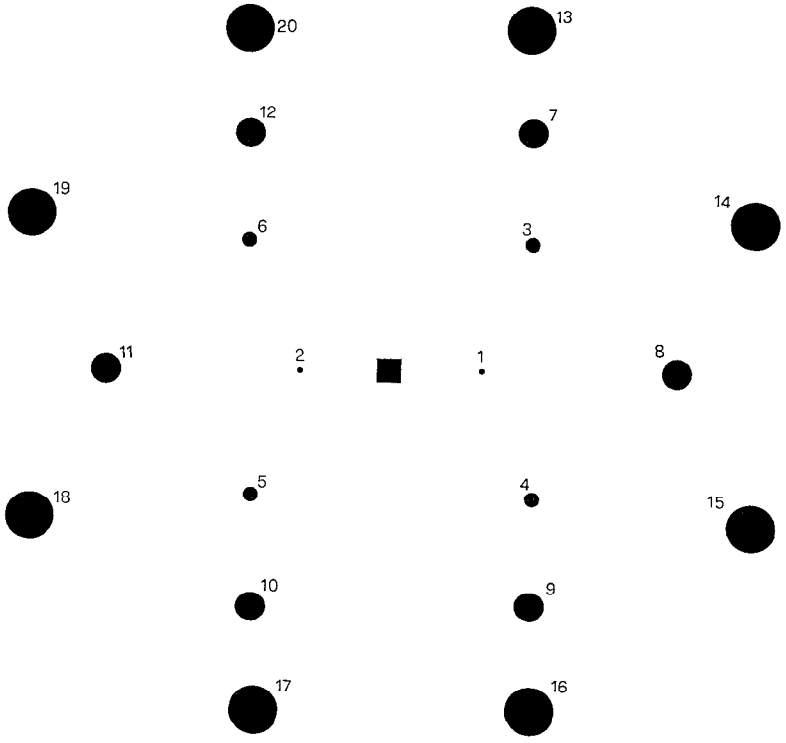

Fig 1.

8 points at 20° eccentricity (meridians 22.5°, 67.5°, 112.5°, 157.5°, 202.5°, 247.5°, 292.5°, 337.5°)

Angular dimensions equal to those of Goldmann's target III (0.431° for stimuli localized at 5° eccentricity).

For the other stimuli their angular dimension was calculated to give them a stimulation power

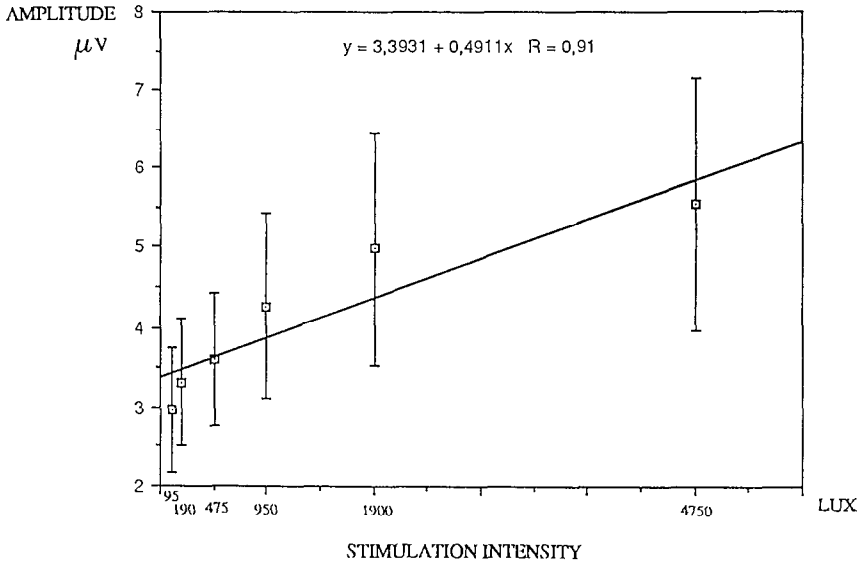

Fig. 2. Regression line of amplitude.

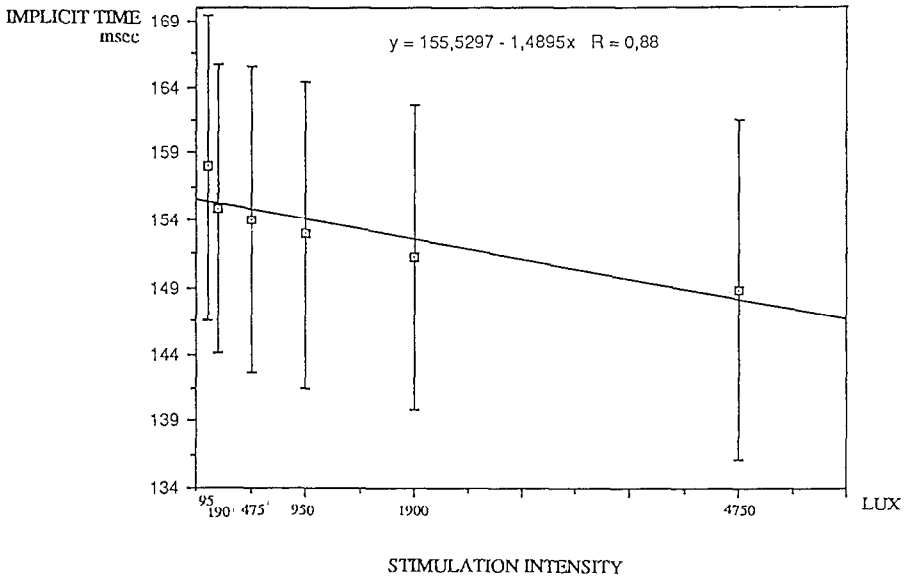

Fig. 3. Regression line of implicit time.

equivalent to those localized at 5°, using the same light intensity on the basis of a normal sensitivity gradient and a spatial coefficient of 0.83°[22] (Fig. 1).The subjects, acoustically isolated and after 10 minutes of dark adaptation, were placed with the corneal apex of the examined eye at 20 cm from the tangent screen.

For every subject examined the stimulus was set at decreasing intensities: 5, 2, 1, 0.5, 0.2, 0.1 J, which correspond to 4750, 1900, 950, 475, 190 and 95 LUX respectively at the level of the hole in the tangent screen.

The number of stimuli was 500 for each intensity examined.

Calibration of the machine for VEP examination and electrode mounting were those of a normal flash VEP examination:

- skin electrodes placed at O2 and O1 (exploring electrodes) (10-20 International System), Fpz (reference) and Fz (ground)
- band pass: 1-100 Hz
- sampling time: 300 msec
- stimulation frequency: 2 Hz

Implicit time of wave P2 and its amplitude measured from peak to peak (N2-P2) were assessed.

Results

For all points examined it was possible to record a visual evoked potential definitely defined from background noise. The amplitudes of wave N2-P2 were directly proportional to the increase of stimulus intensity for every point examined. The points having greatest eccentricity, albeit of greater surface area, recorded significantly smaller amplitudes with respect to those nearest to the center, for equal stimulation intensities (Table 1, Fig. 2).

We did not find statistically significant variations between the four quadrants.

As far as implicit times of wave P2 are concerned, they increased with the decreasing of stimulus intensity and above all by stimulating points with greater eccentricity (Table 2, Fig. 3). In several cases these points, stimulated at low light intensity, did not make it possible to record traces that could be clearly distinguished from background noise (Tables 1-2).

Table 1. Twelve patients: Intensity stimulation - amplitude

N	*1 J = 95 LUX*	*0.2 J = 190 LUX*	*0.5 J = 475 LUX*	*1 J = 950 LUX*	*2 J = 1900 LUX*	*5 J = 4750 LUX*
1	4.1±0.8	4.3±1.1	4.2±1.5	5 5±0.9	7.2±1.3	7.8±1.4
2	3.9±1.0	4 5±1.3	4.8±1.1	6.2±1.6	7.1±1.5	8 1±1.5
3	3.8±0 7	4.1±1.3	5.0±1.8	5.6±1.2	6.9±1.6	7.6±1.9
4	4.0±1.4	4.2±1.1	4 3±1.0	5.8±1 5	7.0±1.7	7.9±1.6
5	4.2±0.8	4.1±1 1	4.7±0.9	5.9±1.8	7.3±2.1	7 5±1.9
6	3.9±1.1	4.6±1.8	4.5±1.2	6.1±1 4	7 0±1.3	8.2±2.0
9	2.8±0.6	3 4±1.2	3.9±1.5	3.9±1.3	4.8±1.1	5 1±1.9
8	3.2±1.8	3.8±1.1	4.0±1.6	4.1±1.0	4.6±2.1	4.9±2.2
9	2.4±1.3	3 6±1.8	4.1±1.0	4.5±1.3	4.5±1.2	4.8±1.7
10	3 4±0.9	3.2±1.3	3.5±1.1	4.1±1.6	4.3±1.3	5.0±1.1
11	2.9±1.3	3.4±1 6	3.8±1.2	4.2±1.3	4.5±0.9	5.2±2.3
12	3 1±1.2	3.0±1.2	3.3±1.6	3.9±1.9	4.2±1.1	4.8±2.0
13	2.1±0.6(9 pz)	2.4±1.0(10 pz)	2.5±0.9	3.2±1.1	3.8±1.2	4.2±1.4
14	2.3±0.8(7 pz)	2.3±0.7(9 pz)	2.6±1.2	3.1±0.9	3.5±1.3	4.3±1.0
15	2.0±1.0(11 pz)	2.7±0.9(11 pz)	2.6±1.2	3.4±1.2	3.9±1.6	4.5±0.8
16	2.6±1.3(11 pz)	2 9±1.4	3.0±1.0	3.7±1.1	4.1±1.2	4.6±1.4
17	2.2±0.7(9 pz)	2.6±0.6(9 pz)	3.1±0.9	3.3±1.0	4 0±0.9	4.2±1 1
18	2.4±1 1(11 pz)	2.3±0.8	2.8±1.1	2 9±1.2	3.7±1.1	4.0±0.6
19	2.1±1.0(10 pz)	2.3±0.9(10 pz)	2.5±1.0	2.8±1.1	3.5±1.6	4 1±0.9
20	2 0±0.5(11 pz)	2.4±1.1(11 pz)	2.7±0.9	3 1±0.8	3.6±1.5	4.2±1.4

N: tested points (see Fig.1)

Table 2. Twelve patients: Intensity stimulation - Implicit time

N	*1 J = 95 LUX*	*0.2 J = 190 LUX*	*0.5 J = 475 LUX*	*1 J = 950 LUX*	*2 J = 1900 LUX*	*5 J = 4750 LUX*
1	139.2± 9.8	138.6±11.3	134.2± 9.4	133.3±10.6	132 8± 9.2	127.5± 8.8
2	140.6± 7.2	139.3± 8.4	137.5± 7.1	138.2± 8.2	134.6±11.8	130.6±10.3
3	144.1± 8.6	144.2±13.1	139.3± 9.6	138.7± 9.7	135.3± 6.4	128.6± 9.2
4	146.2± 8.8	141.3± 8.1	140.8± 8.2	139.2± 5.6	137.3± 8.3	131.2± 8.4
5	142.3± 6.1	140.9± 5.2	140.3± 8.3	138.2± 7.3	138.5± 4.1	135.2± 8.2
6	144.8± 5.9	141.9± 9 5	141.6± 8.4	140.7± 7.7	137.2±11.4	133.7±12.1
9	157.3± 9.1	154.6±11.2	154.2± 9.1	151.7± 9.8	152.3±10.3	150.8± 9.9
8	159.2± 6.7	156.3± 8.4	156.9± 7.7	153.4± 7.2	154.2± 8.1	153.2± 6.6
9	156.5± 8.3	152.4± 9.3	152.8±10.6	151.3± 6.9	150.3± 6.6	150.7± 7.1
10	160.0± 9.2	157.3± 7 3	155.4± 6.1	155.6± 5.8	154.3± 9.2	151.2± 6.8
11	158.3± 8 1	153.8± 6.1	153.6± 9.3	155.2± 7.5	151.4± 9.1	152.6± 7.3
12	155.6± 9.1	150 3± 4.2	151.6± 5.3	150.9± 9.2	150.4± 7.2	148.6± 9.1
13	169.3±11.2(9 pz)	163.4± 8.5(10 pz)	164.6±11.3	158.9± 9.4	157.5± 8.1	158.1± 7.3
14	170.0± 9 1(7 pz)	168.6± 9.2(9 pz)	168.3± 5.7	167.6± 6.2	165.8± 7.3	161.4± 8.1
15	168.3± 9.3(11 pz)	167.6± 5.4(11 pz)	166.8± 8.3	164.2± 5.8	164.9± 8.2	163.4± 6.6
16	167.5±10.3(11 pz)	164.3± 7.0	163.8± 8.1	160.5± 8.4	158.6± 5.3	157.2± 8.1
17	171.3± 7.5(9 pz)	170.2± 6.3(9 pz)	166.8± 7.8	168.3± 8.1	162.4± 6.1	161.8± 6.7
18	170.3± 8.7(11 pz)	165.3± 8.4	165.1± 7.1	168.3± 6.4	165.3± 6.3	162.5± 6.9
19	168.3±12.2(10 pz)	160.7± 9.2(10 pz)	162.1± 6.0	161.3± 5.8	160.3± 5.1	157.6± 5.8
20	171.2± 9 9(11 pz)	166.6± 8.3(11 pz)	165.8± 8.3	164.3± 5.7	161.8± 7 1	160.8± 8.1

N: tested points (see Fig.1)

Conclusions

The method, although it has not yet been sufficiently investigated, has been shown to have good sensitivity and reliability.

The recording of a visual evoked response at the cortical level by stimuli of variable surface area and intensity needs a very good standardization of the recording method and a large number of stimuli in order to extrapolate the signal from the background noise. The necessary increase in examination time is tiring for the patient, who has to pay attention to keep fixation.

Steady-state stimulation could be much more rapid; we have not assessed its practicality.

At the present state of the research the method presents three restrictions:
1. exploration of only the central 20°;
2. small number of points examined;
3. excessive duration of the examination.

By increasing the number of points tested one could explore larger areas of the VF with greater precision.

This requires a more complete normative study as well as a further increase in the duration of the examination.

The present method has to be considered a preliminary one since by interfacing a computerized perimeter it will be possible to obtain more precise responses in relatively shorter times, as well as providing electronic control of fixation with automatic rejection of response acquisition when fixation is lost.

In this way it will be possible to obtain a correct objective quantification of the visual field, whereas the method can at the present time only have clinical importance in detecting large defects or in unmasking patients who simulate visual loss.

References

1. Aoyama T: Pupillographic perimetry. Acta Soc Ophthalmol Jpn 79:1247-1256, 1975
2. Aoyama T, Kani K: Pupillographic perimetry. Jpn J Clin Ophthalmol 69:960-963, 1975
3. Aoyama T, Kani K: Pupillographic perimetry; a case of temporal hemianopsia caused by meningioma of the tuberculum sellae. Folia Ophthalmol Jpn 26:190-193, 1975
4. Alexandridis E, Krastel H: Pupillographische Perimetrie mit dem "Octopus". Fortschr Ophthalmol 86:692-694, 1989
5. Onofrj M, Bodis-Wollner I, Mylin L: Visual evoked potential diagnosis of field defects in patients with chiasmatic and retrochiasmatic lesions. J Neurol Neurosurg Psychiat 45:294-302, 1982
6. Aminoff MJ, Maitland CG, Kennard C, Hoyt C, Hoyt W: Visual evoked potential and field defects. In: Nodar RH, Barber C (eds) Visual Evoked Potentials, Clinical Application, pp 329-334. Oxford: Butterworth, 1984
7. Drasdo N, Peatson WC: Sampling system for visual field assessment and computerised perimetry. Br J Ophthalmol 64:705-712, 1980
8. Flanagan JG: Objective and subjective assessment of the visual field in compressive lesions of the chiasm. In: Heijl A (ed) Perimetry Update 1988/89, pp 129-134. Amsterdam/Milan: Kugler & Ghedini Publ, 1989
9. Vaughan HG, Katzwan R, Taylor J: Alterations of visual evoked response in the presence of homonymous visual defects. Electroencephalogr Clin Neurophysiol 15:737-746, 1963
10. Cobb WA, Morton HB: Evoked potentials from the human scalp to visual half field stimulation. J Physiol 208:39-40, 1970
11. Shagass C, Amadeo M, Roemer RA: Spatial distribution of potentials evoked by half-field pattern-reversal and pattern onset stimuli. Electroencephalogr Clin Neurophysiol 41:609-622, 1976
12. Blumhardt LD, Barrett G, Halliday AM: The asymmetrical visual evoked potential to pattern reversal in one half field and its significance for the analysis of visual field defects. Br J Ophthalmol 61:545-461, 1977
13. Lehmann D, Skrandies W: Visually evoked scalp potential fields in hemiretinal stimulation Doc Ophthalmol Proc Ser 23:237-243, 1980
14. Kuroiwa Y, Celesia GG: Visual evoked potential with hemifield pattern stimulation. Their use in the diagnosis of retrochiasmal lesions. Arch Neurol 38:86-90, 1981
15. Wildberger HGH, Van Lith GHM, Wijngaarde R, Mak GTM: Visually evoked cortical potentials in the evaluation of homonymous and bitemporal visual field defects. Br J Ophthalmol 60:273-278, 1976
16. Michael WF, Halliday AM: Differences between the occipital distribution of upper and lower field pattern-evoked responses in man. Brain Res 32:311-324, 1971
17. Arden GB, Bankes JLK: Foveal electroretinogram as a clinical test. Br J Ophthalmol 50:740, 1966
18. Arden GB, Carter RM, Macfarlan A: Pattern and Ganzfeld electroretinograms in macular disease. Br J Ophthalmol 68:878-884, 1984
19. Bagolini B, Porciatti V, Falsini B, Neroni M, Moretti G: Simultaneous macular and paramacular ERGs recorded by standard techniques. Doc Ophthalmol 65:343-348, 1987
20. Bagolini B, Porciatti V, Falsini B, Scalia G, Neroni M, Moretti G: Macular electroretinogram as a function of age of subjects. Doc Ophthalmol 70:37-43, 1988
21. Vaegan, Billson FA: Macular electroretinograms and contrast sensitivity as sensitive detectors of early maculopathy. Doc Ophthalmol 63:399-406, 1986

A prototype automated flicker perimeter

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Abstract

A prototype automated flicker perimeter is described An enclosed hemispherical bowl forms the housing for 80 ultrabright light emitting diodes which are viewed through a flush fitting opalescent white perspex screen. Test conditions are operator specified and flexible but reproducible. Test strategies include differential light sensitivity, modulation threshold and critical flicker fusion frequency.

Introduction

Recent research has shown that a subpopulation of larger retinal ganglion cells is preferentially lost early in glaucoma[1,2]. These cells have characteristic psychophysical properties, in particular they respond to flickering stimuli[3]. A growing body of evidence suggests that eyes with glaucoma have abnormalities of sensitivity to flicker[4-7]. It is hoped that psychophysical tests utilizing flickering stimuli will identify the earliest of defects in glaucoma, which are beyond the current capability of automated static perimeters. Although various commercially available perimeters have a flicker capability, there is none which is able to provide the range and flexibility of test conditions and stimulus parameters required for research into the role of temporal contrast sensitivity in visual field analysis. We have therefore designed and built our own prototype automated flicker perimeter as part of a program of research into the role of flicker perimetry in the assessment of ocular hypertensives, glaucoma patients and normal controls. The main features of the perimeter are outlined in this report.

The perimeter and computer system

The perimeter is built around a hemispherical fiberglass bowl into which are mounted 80 flush fitting "ultrabright" light emitting diodes (LEDs, Kingbright Electronics, Chung Ho City, Taiwan). This bowl is lined by a further bowl of opalescent white perspex (Imperial Chemical Industries grade 40, air bubble molding by Cox Thermoforming, Tring, UK) to form the perimeter screen of radius 30 cm. The perimeter components, together with a standard head rest and trial lens holder are mounted on an extruded aluminum chassis and encased in foamex panels (Fig. 1). Integral perimeter hardware consists of an Intel 286 16 mHz microprocessor (Isis Technology, Manchester, UK) and custom-built interface electronics. The stimulus presentation control software is written in Hi-Tech "C" (Grey Matter, Ashburton, UK). The perimeter is linked via a RS 232 port to an IBM compatible personal computer (1 Mb RAM, 40 Mb hard disc). PC control software has been written in Microsoft Professional Basic version 7.1. The menus and test routine specifications and results are displayed on a color video display unit and hard copy is provided by a color ink jet printer.

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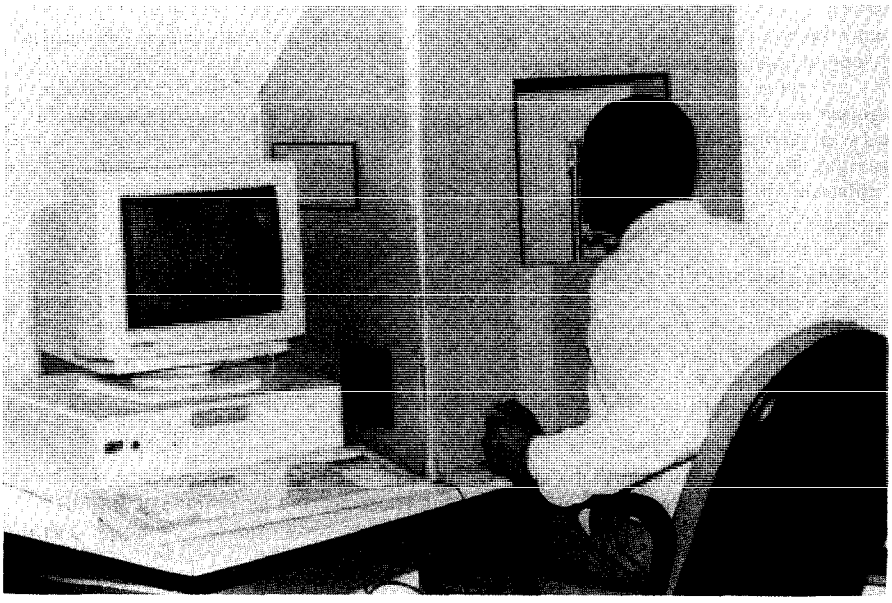

Fig. 1. The prototype automated flicker perimeter.

Test strategies

The following test strategies are available:
- differential light sensitivity (luminance threshold), where the perception of the presence of the stimulus is tested;
- modulation threshold and critical flicker fusion frequency, where the perception of flicker is tested using a stimulus whose luminance is suprathreshold.

The perception of a stimulus is signalled by pressing a hand-held switch, which also sounds an audible alarm.

For differential light sensitivity tests the threshold value is measured at specified flicker frequency and modulation at each test location by a standard double threshold crossing method using a 4-2 dB staircase. For modulation threshold and critical flicker fusion frequency tests, the mean luminance is specified together with either the stimulus modulation or flicker frequency. LEDs are illuminated in groups of three or four (specified by the operator - see below re-fixation monitoring) of which only one LED flickers according to a test algorithm similar to that for light sensitivity testing. The modulation or the rate of flicker is varied until a threshold value for the perception of flicker is reached. For purposes of research, each location is thresholded three times and the mean threshold value calculated. Full threshold tests have been performed in studies to date, modifications of the test strategies and algorithms are planned to allow for suprathreshold screening tests.

Stimuli and test conditions

Stimuli are provided by an array of 80 ultrabright LEDs of 5 mm diameter subtending at an angle of approximately 1° at the eye. LED luminance is variable between 0.025 and 3183 cdm^{-2} (0.08-10000 asb) calibration being by a spot photometer (model 5370 optometer, United Detector Technology, Hawthorne CA) and the luminance threshold values obtained in clinical testing expressed in decibel (dB) equivalents to allow for comparison with existing automated static perimeters. Stimulus duration is specified by the operator and is variable between 0 and 9999 msec, with a standard of 200 msec for luminance threshold tests. For modulation threshold and critical flicker fusion frequency tests, the stimulus consists of three continuous phases:

onset of stimulus, steady state sinusoidal flicker, offset of stimulus. The duration of each of these phases is specified by the operator, default values for the onset and offset phases being 200 msec and that for the steady state flicker phases 500 msec. The purpose of these elements of the stimulus is to ensure a smooth transition to and from steady state test conditions such that there is no stimulation of any parts of the visual system sensitive to onset or offset. A waiting time between stimuli is also specified, the default value being one second.

Background illumination is provided by two 21 W automobile headlight bulbs and is variable between 0 and 40 cdm^{-2}. The standard background illumination is 10 cdm^{-2} (31.5 asb) to allow for comparison with Goldmann and Humphrey perimeters.

Indicators of subject reliability

Fixation monitoring

This is achieved by a modification of the technique of Heijl and Krakau[8]. Each test commences with a blindspot determination using a separate array of blindspot plotting LEDs. The test location nearest to the center of the blindspot is identified and presented at specified intervals during the remainder of the test as a monitor of fixation. These presentations are of the same configuration as the stimuli of the test being performed. That is, for modulation threshold and critical flicker fusion frequency tests the flickering blindspot monitoring LED is added to a group of three non-flickering LEDs. As the threshold determinations are carried out with groups of either three or four LEDs illuminated (only one of which flickers during each stimulus group presentation), the subject is unable to recognize the fixation monitoring grouping by virtue of the number of illuminated LEDs. Perception of the fixation monitoring stimulus is recorded as a fixation loss.

False positive and false negative errors

At specified intervals a stimulus is presented such that a response from the subject would be inappropriate. For CFF and modulation tests, this is a non-flickering stimulus, for a differential light sensitivity test this takes the form of a pause in the test of the same duration as a test stimulus presentation. A response is recorded as false negative error.

At specified intervals a suprathreshold stimulus is presented such that a response from the subject would be expected. The parameters for this stimulus are derived from the mean of the first four threshold values obtained during the test. Failure to respond to the suprathreshold stimulus is recorded as false positive error.

Discussion

We report the design and construction of a prototype automated flicker perimeter. A pilot study has confirmed the ability of the perimeter to identify defects in the field of vision of known glaucoma patients[9]. Clinical trials have commenced, and an initial study has investigated the effect of stimulus flicker frequency on light sensitivity in glaucoma patients, ocular hypertensives and controls[10]. Current studies are evaluating the effects of stimulus modulation, eccentricity and the value of critical flicker fusion frequency perimetry.

References

1. Quigley H: Chronic glaucoma selectively damages large optic nerve fibers. Invest Ophthalmol Vis Sci 28:913, 1987
2. Glovinsky Y, Quigley H: Retinal ganglion cell loss is size dependent in experimental glaucoma. Invest Ophthalmol Vis Sci 31:484, 1991
3. Livingstone M: Psychophysical evidence for separate channels for the perception of form, movement and depth. J Neurosci 7:3416, 1987
4. Tyler CW: Specific deficits of flicker sensitivity in glaucoma and ocular hypertension. Invest Ophthalmol Vis Sci 20:204, 1981

5 Lachenmayr BJ: Automated flicker perimetry versus quantitative static perimetry in early glaucoma. In: Heijl A (ed) Perimetry Update 1988/89, p 361. Amsterdam: Kugler Publ 1989
6. Lachenmayr BJ: Correlation of retinal nerve fibre loss, changes at the optic nerve head and various psychophysical criteria in glaucoma. In: Mills RP, Heijl H (eds) Perimetry Update 1990/91, p 27. Amsterdam: Kugler Publ 1991
7 Lachenmayr BJ, Airaksinen PJ, Drance SM, Wijsman K: Correlation of retinal nerve fiber layer loss, changes at the optic nerve head and various psychophysical criteria in glaucoma. Graefe's Arch Clin Exp Ophthalmol 229:133, 1991
8. Heijl A, Krakau CET: An automatic static perimeter, design and pilot study. Acta Ophthalmol (Copenh) 53:293-310, 1975
9. O'Brien C, Austin MW, Wishart PK: Flicker perimetry in the early detection of glaucoma. Eye (submitted for publication)
10. Austin MW, O'Brien C, Wishart PK: Luminance threshold flicker perimetry: the effect of flicker frequency. This Volume, p 441

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