Comparison of Conventional and Pattern Discrimination Perimetry in a Prospective Study of Glaucoma Patients

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P U R P O S E. To determine whether pattern discrimination perimetry detects progression of glaucomatous visual fields earlier than conventional static automated perimetry.

M E T H O D S. One hundred nine eyes of 109 patients with open angle glaucoma were enrolled in a longitudinal prospective study. Each patient underwent visual field examinations with conventional and pattern discrimination perimetry using the 30-2 program of the Humphrey Visual Field Analyzer (Humphrey Instruments Inc., San Leandro, CA) and a custom program for the pattern discrimination perimeter, respectively at 6-month intervals. Progression of glaucomatous visual field damage was assessed separately at each visit by predetermined criteria for conventional and pattern discrimination perimetry. The time to progression from baseline was calculated and the hemifield that showed progression first was documented for both conventional and pattern discrimination perimetry.

R E S U L T S. Patients were followed for a mean of 5.1 years and a mean of 11.6 visits. Sixty-eight (62.3%) patients did not show progression with either technique. Of the remaining 41 patients, 15 (36.5%) showed progression with conventional perimetry alone, 9 (21.9%) with pattern discrimination perimetry alone, and 17 (41.4%) showed progression with both techniques. Of these 17 patients, 11 (64.7%) were detected earlier by conventional perimetry, and 6 (35.2%) were detected earlier by pattern discrimination perimetry.

C O N C L U S I O N S. This study suggests that pattern discrimination perimetry is less effective than conventional perimetry in evaluating progressive glaucomatous visual field damage. (Invest Ophthalmol Vis Sci. 2000;41:4150–4157)

M uch research has recently been focused on developing new techniques to detect the earliest visual field damage in glaucoma.1,2 Equally important, however, is the detection of the earliest progression of glaucomatous visual field damage. Because a large proportion of patients attending glaucoma clinics are patients with established visual field loss, the clinical importance of assessing progression is paramount. By knowing whether a patient has progressed or has remained stable, the clinician can then more appropriately decide whether or not to intervene either with additional or different medication or via a laser or surgical procedure.

Currently, progression of established glaucomatous visual field damage is most commonly assessed by conventional static automated perimetry. This task requires the subject to identify a white spot stimulus on a uniform white background.1 Many studies have shown that conventional perimetry may not be able to detect either the earliest visual field loss or its progression before significant structural glaucomatous change has occurred.1,3–6 An increase in the optic disc cup size,7,8 nerve fiber layer abnormalities,5,9,10 a decrease in the number of optic nerve fibers,3 and damage to a significant number of retinal ganglion cells4 have all been reported before any detectable visual field loss by conventional perimetry.

It is not surprising, therefore, that a number of tests have been devised with the purpose of developing one that would detect visual field loss or progressive visual field loss earlier than conventional perimetry. These include short-wavelength automated perimetry,2,11 motion perimetry,2,12 flicker perimetry,13 high-pass resolution perimetry,2,14 and pattern discrimination perimetry.15

Pattern discrimination perimetry is a test that requires the subject to detect a static black and white checkerboard stimulus against a background of black and white dots that are randomly reversing (i.e., black to white and white to black) over time.15–23 The concept underlying this test is that a patterned stimulus would require a response from an integrated unit of ganglion cells rather than a single cell.16,19,20 Because a greater number of ganglion cells would be required to see the patterned checkerboard stimulus, many ganglion cells would need to continue to respond, and hence damage to even a few ganglion cells may theoretically allow for detection of visual field loss earlier than conventional perimetry.

Previous studies have shown that pattern discrimination perimetry can detect significant visual field damage in glaucoma suspects when compared with normal controls.18–20,24 The same studies have found that pattern discrimination pe-
Perimetry can detect an equal number of visual field defects in glaucoma patients when compared with conventional perimetry. To our knowledge, however, no study has been conducted to determine the ability of pattern discrimination perimetry to detect progression of visual field damage in glaucoma patients. Documenting confirmed visual field progression in open angle glaucoma, however, is arduous as it requires a longitudinal follow-up of glaucoma patients over a period of many years. It is, nevertheless, of obvious importance since a sensitive technique for assessing progression in glaucoma patients would prove to be an invaluable tool to the clinician to follow patients. The purpose of this study was to assess the ability of pattern discrimination perimetry to detect progression of glaucoma in patients with established early visual field damage followed prospectively with both conventional and pattern discrimination perimetry.

MATERIALS AND METHODS

The present study commenced in 1991 and included glaucoma patients with early visual field damage who were being seen at the glaucoma clinic of the Nova Scotia Eye Centre.

Patients with a diagnosis of open angle glaucoma with characteristic glaucomatous optic discs (comprised of local notching or thinning of the neuroretinal rim and/or evidence of progressive changes) and visual fields (typically comprising of defects compatible with localized nerve fiber layer loss) with a Mean Deviation index of between -2 and -10 dB (program 30-2 of the Humphrey Field Analyzer) were consecutively recruited to the study. Patients had to have a best corrected visual acuity $\geq 20/40$ and be prepared to provide informed consent to participate in the study. Patients who had either concomitant ocular disease, systemic disease or were using systemic medication known to affect the visual field were excluded from the study. Additionally, patients with a refractive error exceeding 5D equivalent sphere or 3D of astigmatism and patients wearing contact lenses were also excluded. Only one eye was selected randomly as the study eye if both eyes were eligible. The study was approved by the Camp Hill Medical Center Research Ethics Committee. Informed consent was obtained, and the tenets of the Declaration of Helsinki were followed.

Perimeters

Conventional perimetry was carried out using the Humphrey Visual Field Analyzer (Model 640; Humphrey Instruments Inc., San Leandro, CA) with the 30-2 program using the standard full threshold strategy. This program tests 76 locations in the central 30° of the visual field using a white spot stimulus on a uniform white background.

The pattern discrimination perimeter (PDP 2000: LKC Technologies Inc., Gaithersburg, MD) consists of a display unit that includes a 5-inch monitor, an infrared camera for monitoring fixation, and a patient response button. It is also equipped with an IBM-compatible computer system that generates the stimuli on the monitor. A fixation target is present in the middle of this display. A separate screen displays a magnified image of the tested subject’s eye that is used by the technician to monitor fixation. In addition, a random number of blank trials are inserted to check for false positive responses. The stimulus and background are displayed at optical infinity with the use of a special optical system. The various parameters of the technique have been explained in detail elsewhere.$^{15-23}$

Briefly, a $20 \times 20$ black and white pixel array forming a static checkerboard is used as a stimulus against a background of random, temporally alternating black and white pixels. We designed and used a custom program$^{14}$ for the pattern discrimination perimeter. This program tests 28 locations in the central 30° of the visual field. The size of the checkerboard varies from 2.5° close to fixation to 12.5° in the midperiphery. The visibility (or coherence) of the checkerboard is varied by changing the percentage of pixels used in forming the stimulus. This is done by randomizing the positions of the remaining pixels so that they blend into the background. Threshold is defined as the least percentage coherence of the checkerboard required to perceive the stimulus. A 100% coherence stimulus represents a complete checkerboard so that all $20 \times 20$ pixels were used in forming the stimulus. In a 0% coherence stimulus, all $20 \times 20$ pixels are randomized so that the stimulus is indistinguishable from the background. A percentage coherence scale can be defined between these two limits (Fig. 1). The test time for this strategy is approximately 14 to 18 minutes per eye.

Testing Protocol

Patients first underwent a complete ophthalmological examination. Visual field examinations were then carried out with conventional perimetry and pattern discrimination perimetry. The patients were retested with each technique after 1 week to establish a baseline. Follow-up examinations were then done with both perimeters every 6 months. Patients with a pupil diameter less than 3 mm were dilated with tropicamide (0.8%) and phenylephrine (5%).

All patients had experience with conventional perimetry, but none had previously been exposed to pattern discrimination perimetry. All visual field examinations were done by the same technician.

Data Analysis

The Glaucoma Change Probability Analysis of the Statpac program was used for analyzing progression of visual field damage by conventional perimetry.$^{25}$ The mean of the first two examinations separated by 1 week was used to establish a baseline. The program then computes the difference in threshold deviation from the baseline at all locations in subsequent visits. This difference in threshold deviation is then compared with test-retest variability percentiles derived from data of stable glaucoma patients with varying severity of glaucomatous visual field defects.$^{26}$ If, at any location, this difference falls outside the 95th or 5th percentiles, a white triangle (indicating probable improvement) or a black triangle (probable deterioration)
is plotted, respectively. To establish criteria for documenting progression, all edge points were removed from the analysis, leaving a total of 50 locations. If 4 or more black triangles were noted in a follow-up visual field, progression was suspected. If in one of the two immediately following visual fields, 4 or more of these black triangles occurred with a complete overlap in location, progression was said to be confirmed. The date of confirmed progression was taken as the progression date, and the time to confirmed progression from baseline was calculated. Additionally, the hemifield in which progression first occurred was documented.

Because previous data were not available for pattern discrimination perimetry, we created our own test–retest variability characteristics and stratified these for sensitivity level (Fig. 2). We removed the effect of any linear change, such as possibly may occur due to aging or linear progression during the follow-up, by adjusting the sensitivity values at each point by taking the sum of the residuals from linear regression and the mean sensitivity across the follow-up. These adjusted sensitivities from visit two to visit six were then used to compute the test–retest variability. The first visit results were removed to counter the small improvement in group mean sensitivity in the second test, likely due to learning. The mean sensitivity changes after the second test were negligible. All possible combinations of baselines (mean of two visits) and follow-ups were used to analyze variability as a function of sensitivity level. Finally, 5% and 95% confidence intervals were established and are shown in Figure 2. Ideally, these confidence intervals should be determined in an independent sample, however, to minimize this weakness, we used a jackknifing technique whereby a given patient’s data, when analyzed, did not contribute to the computation of the test–retest variability data.

A similar set of analyses was then performed for documenting glaucoma progression as was done for conventional perimetry. However, to reduce the influence of learning, we excluded the first visit from our analysis. A baseline was then established by calculating the mean visual field from the second and third visit (i.e., the 7-day and 6-month examination). The difference in threshold from the baseline at all tested locations in subsequent visits was then calculated. We devised a computer program for pattern discrimination perimetry similar to the Glaucoma Change Probability Analysis for conventional perimetry that identified locations where the difference between the respective test and baseline fell outside the 95% confidence limits (analogous to the black triangles in conventional perimetry printout).

As there is a difference in the number of test locations between the two perimeters, we developed different criteria for confirming progression with pattern discrimination perimetry. We analyzed a subset of patients that had either shown confirmed progression with both conventional and high-pass resolution perimetry, an independent test, or had remained stable by both techniques.27 Hence, two groups were established; one group had patients that were highly likely to have visual field progression and the other group were highly likely to have remained stable. There were 79 patients in this subgroup of whom 26 were classified as progressors (progression with both conventional and high-pass resolution perimetry), while 53 were classified as having remained stable (stable with both conventional and high-pass resolution perimetry). We used Receiver Operating Characteristic (ROC) analysis to derive the optimum number of stimuli (locations where the difference in threshold deviation was outside the 95% confidence limits) with pattern discrimination perimetry that would yield the highest sensitivity and specificity in documenting progression (Fig. 3). We computed sensitivity, specificity and a performance score ([Sensitivity × True positives/Total number of patients] + [Specificity × True negatives/Total number of patients]) for different progression criteria based on 1 through 14 test locations (Table 1).

The highest performance score was obtained when we used three locations in the criteria for documenting progression. Therefore, suspected progression was said to have occurred if 3 or more locations outside the 95% confidence limits were present in a follow-up visual field. Confirmed progression

![Figure 2](https://iovs.arvojournals.org/pdfaccess.ashx?url=/data/journals/iovs/933215/)

**Figure 2.** Test–retest variability distributions (5th, 50th, and 95th percentiles) of pattern discrimination perimetry coherence thresholds as a function of baseline coherence threshold (mean of the first two tests).

![Figure 3](https://iovs.arvojournals.org/pdfaccess.ashx?url=/data/journals/iovs/933215/)

**Figure 3.** Receiver Operating Characteristics (ROC) curve for number of stimuli (locations where the difference in threshold deviation was outside the 95% confidence limits) used in the criteria for documenting progression with pattern discrimination perimetry.
occurred when if 3 or more locations outside the 95% confidence limits recurred with a complete overlap in location in one of the two, immediately following visual fields. The time to confirmed progression was calculated and the hemifield in which progression first occurred was documented.

RESULTS

One hundred nine patients were included in the study. The mean age at enrollment was 61.6 years (SD, 13.1; range, 15–87 years). Fifty-two (47.7%) of the patients were male and 57(52.3%) were female. The mean number of visits was 11.6 (SD, 2.2; range, 5–15) and the mean follow-up period was 61.6 months (SD, 13.4; range, 22–80).

Thirty-two patients (29.3%) showed progression with conventional perimetry, and 26 (23.8%) showed progression with pattern discrimination perimetry. Among the patients that progressed, 17 (41.4%) showed progression with both, 15 (36.5%) showed progression with conventional perimetry only, and 9 (21.9%) showed progression with pattern discrimination perimetry only.

Of the 32 patients who showed confirmed progression with conventional perimetry, 13 (40.6%) showed confirmed progression in all (1–7) subsequent field tests, 13 (40.6%) had either confirmed and/or new suspicious progression. In 5 (15.6%) patients, confirmed progression occurred in the last examination analyzed. Only 1 (3.1%) patient failed to confirm progression in his three subsequent field tests.

Of the 26 patients who showed confirmed progression with pattern discrimination perimetry, 7 (26.9%) showed confirmed progression in all (2–7) subsequent field tests, and 9 (34.6%) had either confirmed and/or new suspicious progression. In 5 (11.5%) patients, confirmed progression occurred in the last examination analyzed. Seven (26.9%) patients failed to confirm progression in subsequent field tests.

Among the patients who showed progression with both techniques, 11 (64.7%) progressed earlier with conventional perimetry (mean, 15.6 months earlier), while only 6 (35.2%) patients were detected earlier (mean, 20.4 months earlier) by pattern discrimination perimetry (Fig. 4). In 9 (52.9%) of 17 patients, there was concordance as to the hemifield that showed progression first.

Case Report

A 55-year-old male with open angle glaucoma was followed for a period of 6 years. He underwent testing with conventional and pattern discrimination perimetry at 6-month intervals. Conventional perimetry showed an asymmetry between the two hemifields in his right eye (study eye) with an inferior nerve fiber bundle visual field defect and confirmed progression inferiorly 3.5 years after his initial visit (Fig. 5). Corresponding optic disc photographs also showed progression superiorly and inferiorly (Fig. 6). However, when tested with pattern discrimination perimetry, there was no asymmetry between the hemifields and no progression was detected, despite 6 years of follow-up (Fig. 5).

DISCUSSION

Our results showed that pattern discrimination perimetry detected progression of glaucomatous visual field damage in fewer patients (26 as opposed to 32) than conventional perimetry. Additionally, among patients that progressed with both techniques, only 6 of 17 were detected earlier by pattern discrimination perimetry. Analysis of those patients who progressed with conventional perimetry showed that the large majority continued to show progression, suggesting that our criteria were specific enough and that progression was not occurring by chance. This degree of repeatable confirmed progression was not observed in pattern discrimination perimetry. Our study suggests that pattern discrimination perimetry may not be a good indicator of progressive visual field damage in glaucoma.

In another study, we demonstrated that high-pass resolution perimetry is significantly more sensitive than conventional perimetry at identifying progressive visual field damage.27 We therefore felt justified that by combining the data from conventional and high-pass resolution perimetry, we would produce an adequate standard against which data from pattern discrimination perimetry can be compared.

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FIGURE 4. Histogram showing the difference in time to progression between conventional perimetry and pattern discrimination perimetry in the 17 patients who showed progression with both tests.
discrimination perimetry could be reviewed. As illustrated in Table 1, we evaluated 14 different sets of criteria (number of locations where the difference in threshold deviation was outside the 95% confidence limits) for progression with pattern discrimination perimetry and chose the optimum number of stimuli that yielded the highest sensitivity and specificity for progression. Despite this, we obtained poor results with pattern discrimination perimetry. Also as evident from Table 1, when confirmed progression required only one location to be outside the variability limits (a criterion that would favor high sensitivity but low specificity), the sensitivity of pattern discrimination perimetry to detect progressive damage still remained low, that is, only 85% while the specificity was 57%.

There are several potential factors that could explain our results. First, it should be understood that our purpose was to identify progressive damage in patients with established visual field damage. Johnson et al.28,29 in their work with short-wavelength automated perimetry noted that once a significant amount of glaucomatous damage had occurred, little or no short-wavelength sensitivity remained at those locations. Like-

Figure 5. Follow-up visual fields of the right eye of a 55-year-old man from April 1993 to September 1998 (dates of examination given in column 5). Discrete areas of visual field damage particularly in the inferior hemifield are detected by conventional perimetry (column 1 and 2). The Glaucoma Change Probability Analysis (column 4) with conventional perimetry confirmed progression inferiorly on March 18, 1996. A similar analysis (test locations with difference in coherence thresholds from baseline outside the 95% confidence limits for test-retest variability shown as filled squares) for change with pattern discrimination perimetry (column 7) did not show any visual field progression.
wise, it is possible then that by the time glaucoma is detected (using conventional clinical criteria), substantial damage has already taken place such that not enough ganglion cell reserves remain for evaluating progressive damage by pattern discrimination perimetry. Therefore, it is likely that pattern discrimination perimetry may be sensitive in detecting damage, but once damage has occurred, it is not sensitive in detecting the difference as damage progresses.

Second, the coherence threshold scale used in pattern discrimination perimetry reaches its maximum value of 100% when the defect in conventional perimetry is moderate or even relatively mild (1–2 log units). This coherence limit could underestimate the degree of advanced defects in glaucoma patients and consequently restrict the ability to detect progression.

Third, our study showed that a high degree of variability exists in glaucoma patients tested with pattern discrimination perimetry. As a result of this high variability, the changes in coherence thresholds were quite large to confirm progression. For baseline coherence threshold of 70%, the 95% confidence interval was exceeded only if the subsequent coherence threshold was ≥ 90%. For baseline coherence threshold of 80%, the corresponding value was ≥ 97%. For higher initial baseline coherence thresholds, the upper end of the confidence bounds was truncated due to a limitation in dynamic range. This effect has also been reported in conventional pe-
The increase in variability may be attributed to factors such as fatigue and difficulty of the task.

Finally, we observed that no correlation between pattern discrimination and conventional techniques existed in 8 of 17 patients with regard to the hemifield that showed progression first. This lack of correlation has been reported previously. Another reason for the difference in sensitivity to detect progression could be attributed to the fact that the two techniques were detecting different aspects of glaucomatous damage. If this were the case, different techniques may be appropriate for different mechanisms of glaucomatous damage, which to date have not been identified.

Although the units for conventional and pattern discrimination perimetry are different, we used test–retest variability characteristics for each technique to derive confidence limits based on probability levels. Progression was documented to occur at any location if the measurements exceeded the variability limits, hence we feel the comparison between the two perimeters was justified.

In assessing whether a new technique can detect glaucomatous progression earlier than conventional perimetry, it is important to know the rate of false progression by that technique in a parallel group of normal controls. However, since our study indicated that pattern discrimination perimetry did not identify progressive damage in a greater number of patients than conventional perimetry, the issue of false cases of progression was not applicable. For this reason, we feel that, although having a control group would have been useful to study the characteristics of pattern discrimination perimetry in normals, it would not have made a meaningful difference to our conclusions.

A sharp distinction lies between detecting early visual field damage and detecting early progressive visual field damage. The former requires testing a group of subjects in whom no previous damage has been noted and who presumably have a higher ganglion cell reserve. The latter involves evaluating further damage in patients with established visual field damage, who presumably have a relatively lower ganglion cell reserve. It is therefore likely that a test may be very sensitive at detecting early visual field damage but poor in detecting progressive damage and vice versa. Visual field testing strategies in the future may need modification such that different strategies are used to detect these two equally important aspects of clinical glaucoma management.

Previous studies have shown that pattern discrimination may detect significant visual field damage in glaucoma suspects. Although we have shown that pattern discrimination perimetry is not sensitive for detecting progressive damage, our study is not necessarily incompatible with reports showing its efficacy in demonstrating preclinical damage in glaucoma suspects. However, pattern discrimination perimetry is as time-consuming as conventional perimetry (using the conventional bracketing thresholding algorithm) in addition to being a difficult test for most patients. In contrast several new techniques such as high-pass resolution and frequency doubling perimetry are much faster (test time 5 to 6 minutes), primarily because they test fewer locations and have a higher patient acceptance. Additionally, high-pass resolution perimetry has been shown to detect progressive glaucomatous visual field damage earlier than conventional perimetry. Furthermore, faster testing strategies with conventional perimetry such as the Swedish Interactive Thresholding Algorithm (SITA) may prove to be more efficacious for detecting progression than conventional techniques. Given these facts and that pattern discrimination perimetry is not effective in evaluating progressive glaucomatous visual field damage, its role in clinical glaucoma management currently appears limited.

References
Pattern Discrimination Perimetry in Progressive Glaucoma


