# Recent developments in automated perimetry in glaucoma diagnosis and management

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Recently, there have been several new developments in automated perimetry that have contributed to enhanced diagnosis and management of glaucoma. This paper will briefly review four of the latest advances in automated perimetry: (1) efficient test strategies that reduce the testing time and variability of automated perimetric testing, in particular, the Swedish Interactive Threshold Algorithm (SITA) and Tendency Oriented Perimetry (TOP) test strategies will be described; (2) Frequency Doubling Technology (FDT) perimetry, which has been shown to be a rapid, effective method of detecting glaucomatous visual field loss; (3) Short Wavelength Automated Perimetry (SWAP), which has demonstrated the ability to predict the onset and progression of glaucomatous visual field deficits; (4) The Multifocal Electroretinogram (mfERG) and the Multifocal Visual Evoked Potential (mfVEP), which provide an objective measurement of the visual field. Each of these techniques has presented distinct advantages for the diagnosis and management of glaucoma. Curr Opin Ophthalmol 2002, 13:77–84 

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**Abbreviations**

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| **FDT** | Frequency Doubling Technology |
| **mfERG** | Multifocal Electroretinogram |
| **mfVEP** | Multifocal Visual Evoked Potential |
| **SWAP** | Short Wavelength Automated Perimetry |
| **SITA** | Swedish Interactive Threshold Algorithm |
| **TOP** | Tendency Oriented Perimetry |

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For many years, quantitative perimetry consisted of determining detection thresholds for a small white target projected onto a uniform white background (white-on-white), using test procedures that were rather time-consuming. The advent of automated static perimetry offered a number of distinct advantages over manual procedures, but the test procedure still consisted of white-on-white threshold determinations performed with time-consuming test procedures. It has only been in recent years that rapid, efficient threshold procedures have become available, along with new perimetric tests that measure visual functions other than white-on-white thresholds. This paper briefly reviews two new efficient threshold test strategies and three new perimetric test procedures, all of which are commercially available.

## Efficient test strategies

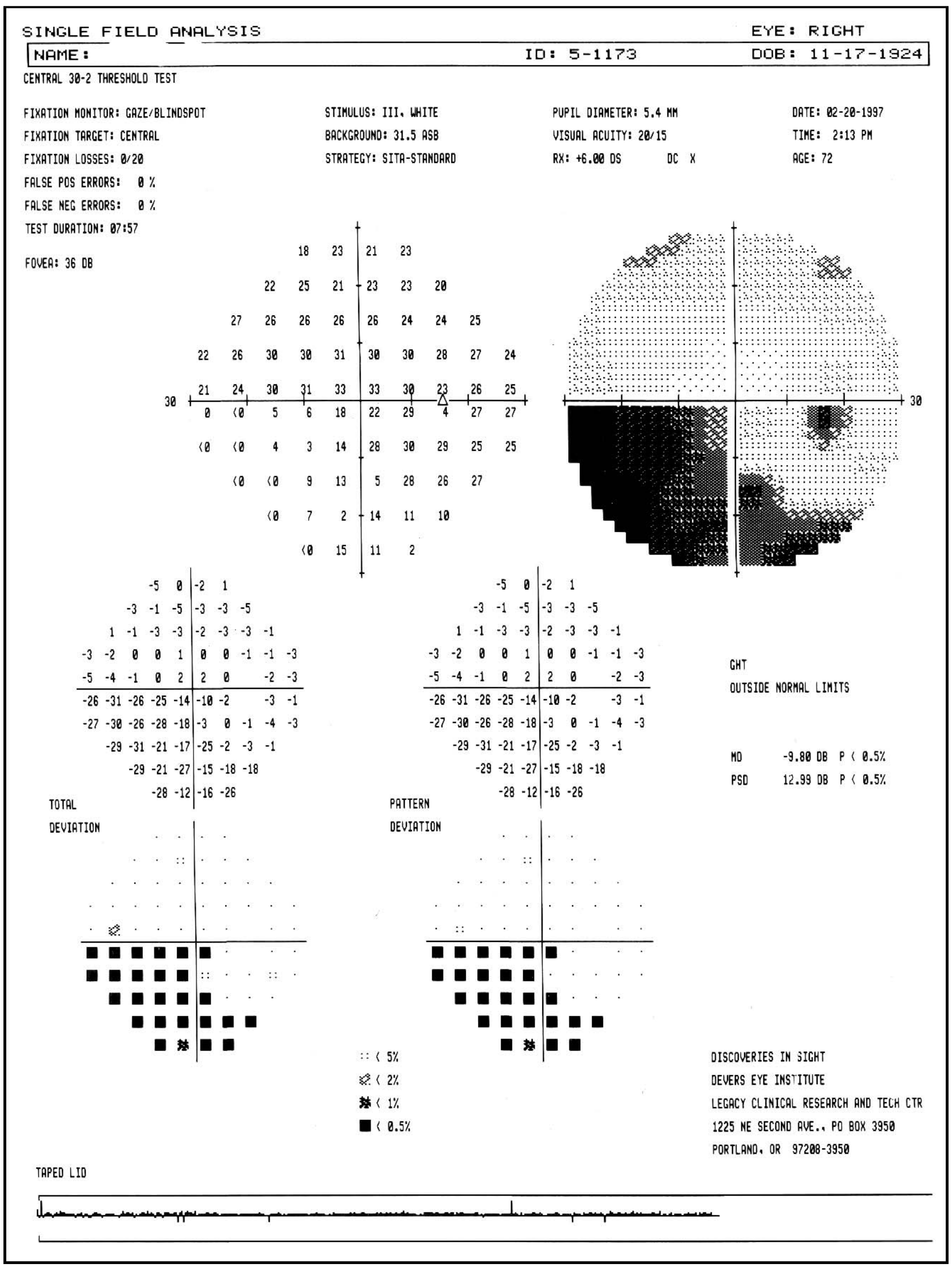
### The Swedish Interactive Threshold Algorithms

Swedish Interactive Threshold Algorithms (SITA-Standard and SITA-Fast) are two new test procedures that are available on the Humphrey Field Analyzer II, Model 750 (Humphrey Systems, Dublin, CA. The SITA strategies are based on a forecasting procedure employing Bayesian statistics [1–5]. There are four primary features of the SITA strategies: (1) probability density functions (pdfs), which represent the distribution of thresholds in the population at large for each visual field location (separate pdfs are used to represent normal and glaucomatous populations); (2) likelihood functions (frequency-of-seeing curves); (3) dynamic monitoring of patient response times to interactively pace the test; and (4) comparisons of neighboring locations to adjust the final threshold estimate. Initially, the pdf is used to provide a "best guess" as to the value of threshold. The patient's response (or lack of response) and the likelihood function are then used to modify the pdf to produce a revised "best guess" as to the value of threshold. This continues until a specified confidence level (or error level in threshold estimate) for the threshold estimate is reached. The difference between SITA-Standard and SITA-Fast is the amount of error that is allowed for the threshold estimate. Details of this type of test procedure may be found in several excellent references [1,3,4,6]. SITA-Standard reduces testing time by 30–50% as compared with conventional Full Threshold procedures, and SITA-Fast produces an additional 30–50% reduction in test time, with the test results comparing very favorably with the findings obtained with Full Threshold procedures [7].

An example of the test results produced by SITA-Standard is presented in Figure 1. The output is quite similar to that obtained for the Full Threshold test procedure, and includes numeric values, gray scale, total and pattern deviation probability plots, reliability indices and visual field indices.

Within the past year, there have been several new findings with regard to the SITA strategies. Sekhar *et al.* [8] confirmed that SITA-Standard and SITA-Fast produced results that were similar to those obtained with Full Threshold testing, although the average time was approximately 50% less for SITA-Standard and 70% less than SITA-Fast in comparison to Full Threshold testing. Test-retest reliability was excellent for SITA-Standard, but was modestly worse for SITA-Fast. Although the SITA strategies were designed primarily with glaucoma in mind, a recent investigation by Wall *et al.* [9] reports that it is very effective for evaluating other optic neuropathies and hemianopic defects as well. One of the difficulties encountered by clinicians wishing to make the transition from Full Threshold to SITA is how to

**Figure 1. Swedish Interactive Threshold Algorithm-Standard test results**




An example of test results obtained using the SITA-Standard test strategy for the right eye of a glaucoma patient with inferior visual field loss.

compare previous test results obtained using the Full Threshold strategy to new findings obtained using SITA. Although the most desirable alternative is to establish a new baseline with SITA, Heijl *et al.* [10] have derived a method of comparing Full Threshold and SITA results using the Total and Pattern Deviation probability plots when such comparisons are necessary. SITA also recently has been used to perform visual field testing in children [11]. It is clear that SITA has had a significant positive impact on clinical automated perimetric testing.

## Tendency Oriented Perimetry

Tendency Oriented Perimetry (TOP) is an efficient test strategy that has been developed for the Octopus 101 and 300 Series perimeters (Interzeag AC, Schlieren, Switzerland) [12]. Tendency Oriented Perimetry uses a staircase procedure, but does so by sequentially evaluating neighboring locations so that each location is tested only once. The visual field is divided into squares of four neighboring test locations and the first location in each square is tested with the initial stimulus intensity. The stimulus intensity for the second presentation is adjusted according to whether or not the patient responded to the first stimulus. The second location in the square is tested with the new stimulus intensity. A similar procedure is employed for the third and fourth members of the square, and a threshold estimate is thus obtained after 4 stimulus presentations. Each threshold estimate is thus based on one direct and three indirect responses from neighbors.

Tendency Oriented Perimetry is approximately four times faster than conventional staircase threshold procedures, needing about three minutes per eye to complete the test [12]. At the present time, there is limited information available concerning the clinical performance of TOP [12]. However, a recent investigation indicates that the short duration of TOP makes it a viable method of performing visual field testing in children down to the age of 6 years [13].

## Frequency Doubling Technology perimetry

The frequency doubling effect is created by a low spatial frequency sinusoidal grating (<1 cycle/degree) undergoing high temporal frequency counterphase flicker (>15 Hertz), thereby producing the appearance of twice as many light and dark bars than are physically present (*ie*, the spatial frequency of the bars appears to be doubled). This effect is thought to be mediated by magnocellular (M-cell) retinal ganglion cells with nonlinear response properties. Frequency Doubling Technology (FDT) testing for detection of glaucomatous visual field loss consists of determining contrast sensitivity measures for detecting the frequency doubled stimulus. The commercial version of FDT perimetry (Humphrey Systems, Dublin CA and Welch Allyn, Skaneateles NY, USA) evaluates contrast sensitivity for stimulus detection at 17 or 19 locations throughout the central visual field.

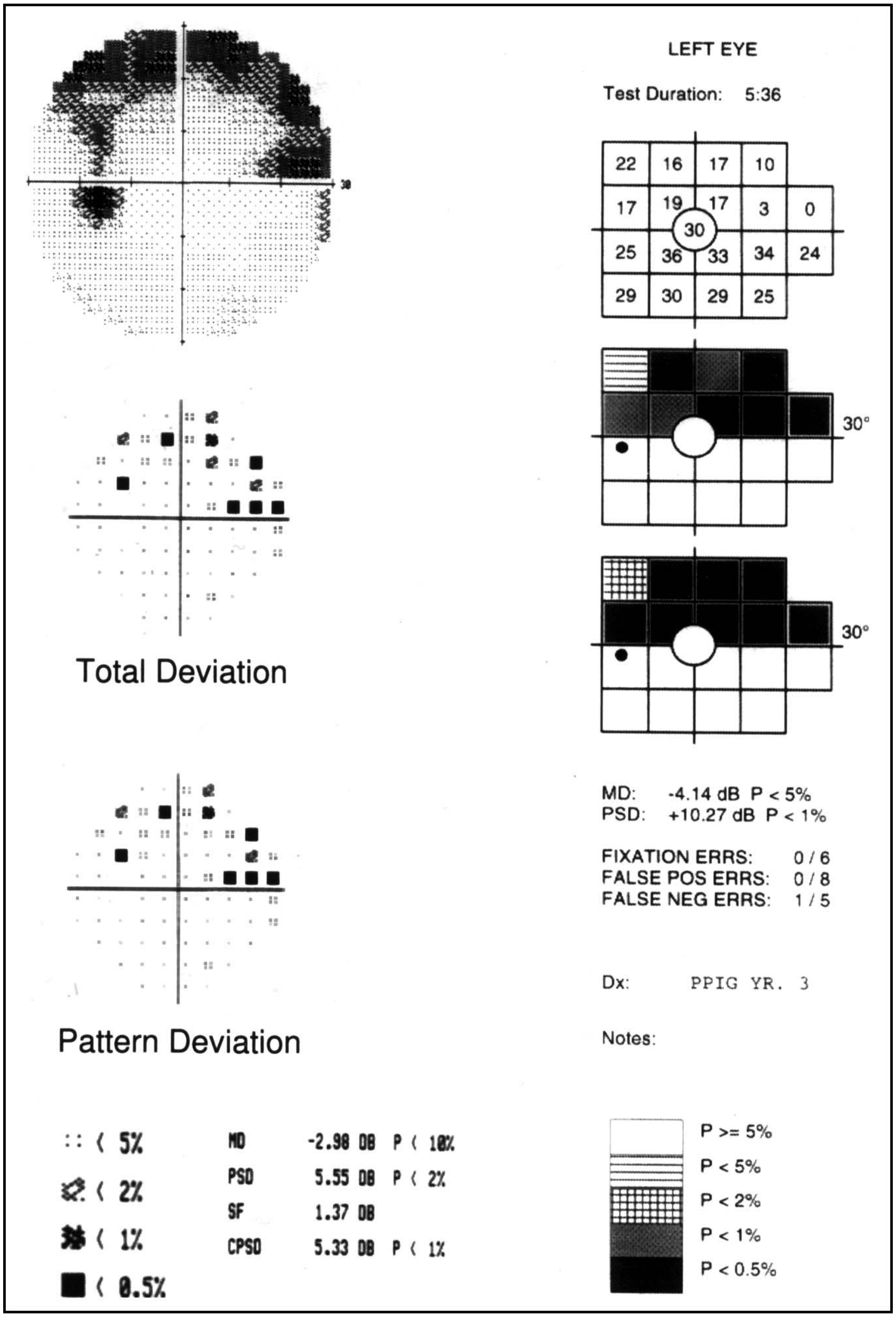
Previous investigations of FDT perimetry indicate that it has high sensitivity and specificity for detection of glaucomatous visual field loss, [14,15] and recent studies have confirmed these findings [16,17,18–20]. In addition, the specificity of the rapid screening test for FDT can be modestly improved by confirming abnormal results [19]. The results of Wu *et al.* [20] suggest that FDT may detect glaucomatous visual field loss earlier than standard automated perimetry. Similarly, Paczka *et al.* [21] found that FDT perimetry had better overall sensitivity and specificity for detection of glaucomatous damage than either scanning laser polarimetry or assessment of retinal nerve fiber layer photographs. Thus, FDT may be sensitive to the earliest changes produced by glaucoma. In addition to its capabilities for detecting glaucomatous visual field loss, FDT perimetry also has been reported to be useful for the detection of certain retinal diseases [22], optic neuritis [23], and other neuro-opththalmologic deficits [24]. In its present form, however, FDT perimetry has more limited utility for detection of macular disorders [22] and hemianopic defects [24]. Unlike standard automated perimetry, FDT is not affected by the presence of myopia, even in cases of high myopia [25]. Figure 2 presents an example of FDT results obtained in a patient with glaucomatous visual field loss in comparison to findings obtained for standard automated perimetry using the Humphrey Field Analyzer.

## Short Wavelength Automated Perimetry

Short Wavelength Automated Perimetry (SWAP) is conducted by projecting a large blue stimulus onto a bright yellow background, which permits the sensitivity of the short wavelength (blue) pathways to be isolated and measured. Short Wavelength Automated Perimetry testing is available on two commercial automated perimeters, the Humphrey Field Analyzer II Model 750 (Humphrey Systems, Dublin CA, USA) and the Octopus 1-2-3 perimeter (Interzeag AC, Schlieren, Switzerland). Previous investigations have established that SWAP is more sensitive than standard automated perimetry for detecting early glaucomatous defects, shows greater progression of existing glaucomatous defects and several other desirable clinical features. An excellent review of the principles underlying SWAP and the results of previous investigations may be found in Sample's recent article [26].

Recent investigations of SWAP have characterized the long term variability of SWAP in comparison to standard automated perimetry, and have established that it exhib-

**Figure 2. Frequency Doubling Technology test results**

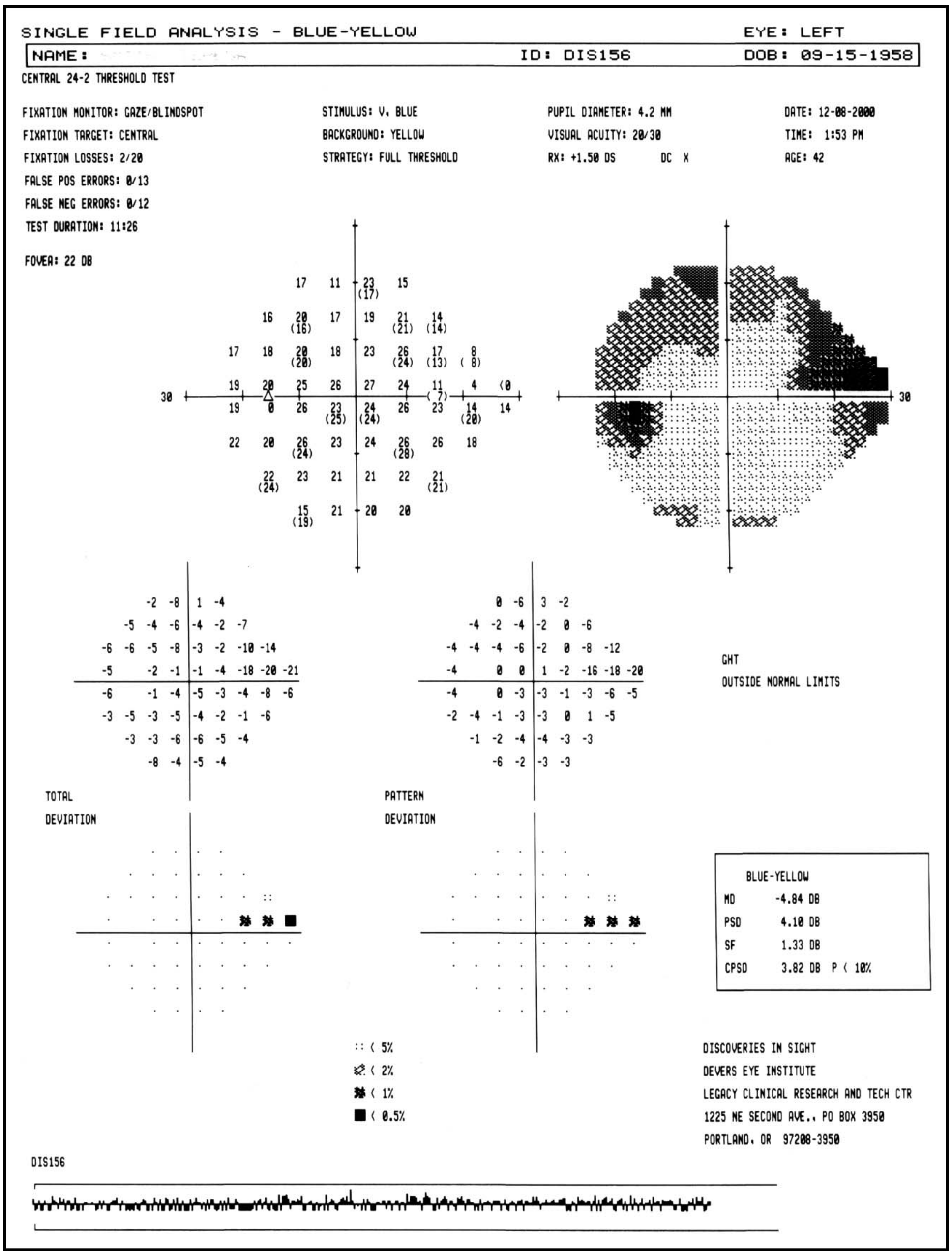



An example of a superior arcuate deficit for Frequency Doubling Technology (FDT) perimetry in comparison to the results obtained for standard automated perimetry with the Humphrey Field Analyzer. Note that the FDT deficit is more extensive than those obtained with standard automated perimetry.

its greater variability [27]. Optimum criteria for detection of glaucomatous visual field loss with SWAP have been developed, and consist of a cluster of four or more points worse than the $p < .05$ level or a cluster of three or more points worse than the 1% level [28]. An investigation of methods to detect SWAP progression indicates that using a ranked threshold distribution analysis is closely related to results obtained using pointwise analysis, and is more useful for identifying a diffuse component of change in the visual field [29]. An investigation of a large group of ocular hypertensive patients revealed that there was a higher prevalence of SWAP deficits than for standard automated perimetry, but that the incidence of new SWAP and standard automated perimetry deficits was equivalent [30]. This indicates that both test procedures are monitoring the same underlying glaucomatous disease process, but that SWAP deficits are detecting the damage at an earlier stage. It is interesting to note that a recent study of SWAP and FDT testing in ocular hypertensives showed that both techniques found deficits that were not picked up with standard automated perimetry, and that SWAP and FDT abnormalities were highly correlated [31].

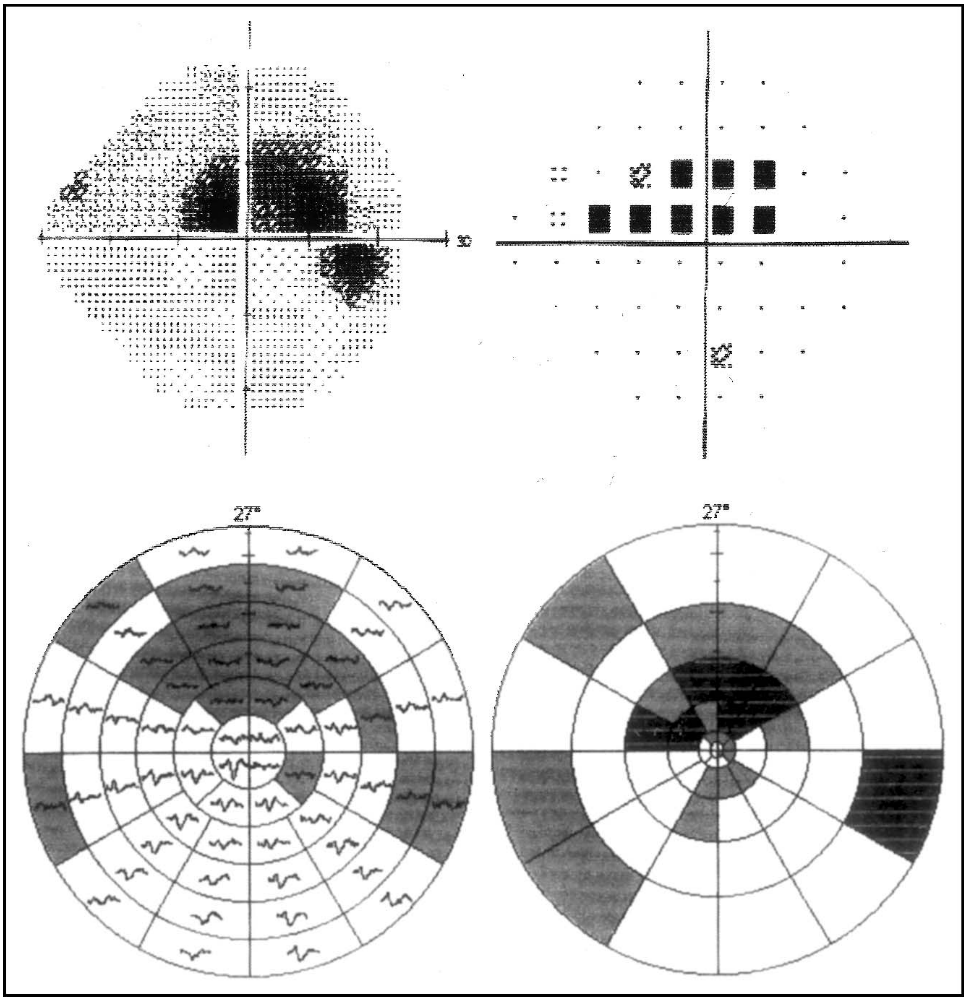
Short Wavelength Automated Perimetry deficits have been found to correlate well with glaucomatous neuroretinal rim abnormalities [32], retinal nerve fiber layer defects [33] and optic disc damage [34]. In addition, SWAP has been reported to be superior to standard automated perimetry for identifying patients with progressive optic disc cupping, and may therefore be quite useful for determining progressive changes in glaucoma [35].

**Figure 3. Short Wavelength Automated Perimetry test results**




An example of a superior nasal step that is present for Short Wavelength Automated Perimetry (SWAP) in a patient with evidence of glaucomatous damage to the inferior portion of the optic nerve, but has normal visual fields for standard automated perimetry.

**Figure 4. Multifocal Visual Evoked Potential test results**




Example of correspondence of visually evoked potential perimetry with standard automated perimetry in a glaucoma patient with a superior paracentral arcuate defect. (Reprinted with permission from Klistorner and Graham, Ophthalmology 2000, 107:2283–2299).

Figure 3 presents an example of a superior nasal step that was detected by SWAP but is not detected by standard automated perimetry. The patient had evidence of glaucomatous optic disc changes that were consistent with the presence and location of the SWAP deficit, but standard automated perimetry results were within normal limits.

Finally, it has previously been reported that SWAP is also useful in evaluation of ocular diseases other than glaucoma [26]. Recent studies have indicated that SWAP is useful in evaluating diabetic retinopathy[36] and macular function [37].

## Multifocal Visual Evoked Potential

Perimetric assessment of the visual field has traditionally been performed using techniques that require a subjective response on the part of the patient. However, with the development of multifocal electrophysiologic techniques by Sutter *et al.* [38,39], it is now possible to obtain objective measures of visual function from a number of localized regions of the visual field. A detailed description of the principles underlying multifocal techniques is beyond the scope of this review, although there are several excellent references available for readers interested in this information [38–40].

There are two multifocal techniques that are presently being used, the multifocal electroretinogram (mfERG), which measures the local electrical responses of the retina throughout the central (26 degrees radius) visual field and the multifocal visual evoked potential (mfVEP), which measures the localized electrical responses from the primary visual portion of the brain (occipital cortex) for the central (26 degree radius) visual field [40]. Recent investigations of mfERG in patients with glaucomatous visual field loss indicate that they show abnormalities in the mfERG [41–43]. In some instances, glaucoma patients will exhibit reductions in the amplitude of the mfERG, particularly in the most central portion of the visual field [42]. In addition, reductions in a portion of the mfERG waveform, known as the Optic Nerve Head Component, will be reduced or absent in patients with glaucomatous visual field loss [44]. However, these abnormalities in the mfERG can be rather subtle, even in the presence of significant visual field loss for standard automated perimetry. Moreover, the mfERG findings in most glaucoma patients do not correlate well topographically with visual field losses that are present on standard automated perimetry [42]. The usefulness of the mfERG in glaucoma is therefore somewhat limited.

On the other hand, recent investigations of the mfVEP have indicated that it can provide an objective determination of glaucomatous visual field loss that shows very good correspondence with standard automated perimetry results [40,45,46]. Recent investigations within the past year have reported several improvements to the mfVEP technique. Comparisons of mfVEP results with Humphrey Field Analyzer is complicated by the fact that the two tests have different spatial arrangements for their stimulus presentations. In this view, Hood and Zhang [40] developed an interpolation procedure to permit more direct comparisons of mfVEP and Humphrey Field Analyzer test results, and found very good correspondence between the two techniques in terms of characterizing glaucomatous visual field loss. Klistorner and Graham [46] found that by summing responses according to visual field sectors was useful for reducing variability and enhancing waveforms, provided that the sector grouping was conducted appropriately. Klistorner and Graham also found that more robust signals could be obtained by obtaining recordings from four electrode channels rather than one, particularly along the horizontal meridian, and that reproducibility was very good [45].

Figure 4 presents an example of the left eye of a patient with a superior arcuate nerve fiber bundle deficit as measured with standard automated perimetry (top) and the mfVEP (bottom). Note that the mfVEP procedure not only detects the glaucomatous damage, but the topographic location of the mfVEP abnormalities correlate very well with the region of visual field damage for standard automated perimetry. Multifocal visual evoked potential seems to be a promising new technique for objectively assessing the central visual field and will probably be most useful for patients who are difficult to test with conventional perimetric procedures.

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- •• Of outstanding interest


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In this study, the authors compared the ability of three diagnostic tests to adequately screen for glaucoma: frequency doubling technology (FDT) perimetry, scanning laser polarimetry (GDx) and nerve fiber layer (NFL) photographs. The findings indicated that FDT had the best diagnostic performance of the three methods evaluated.

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Short Wavelength Automated Perimetry (SWAP) was performed in 95 glaucomatous eyes and 128 normal eyes. The authors then applied various analysis criteria to determine which criteria provided the best sensitivity and specificity for SWAP defects. The findings indicated that a cluster of 4 or more points beyond the 5% probability level or 3 or more points beyond the 1% probability level provided the best performance.

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