Comparison of Standard Automated Perimetry, Frequency-Doubling Technology Perimetry, and Short-Wavelength Automated Perimetry for Detection of Glaucoma

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PURPOSE. To compare the performance of standard automated perimetry (SAP), frequency-doubling technology (FDT) perimetry, and short-wavelength automated perimetry (SWAP) in detecting glaucoma.

METHODS. One hundred thirty-two eyes of 95 glaucoma patients and 37 normal subjects had retinal nerve fiber layer (RNFL) imaging and visual field testing by SAP, Matrix FDT perimetry, and Swedish interactive thresholding algorithm (SITA) SWAP at the same visit (all perimeters by Carl Zeiss Meditec, Inc., Dublin, CA). Visual field defects were confirmed with two or more consecutive examinations by the same types of perimetry. Glaucoma was defined with the reference to the RNFL thickness deviation map score (≥4, glaucomatous; ≤2, normal). The sensitivity, specificity, and area under the receiver operating characteristic curve (AUC) of MD (mean deviation) and PSD (pattern standard deviation) of the perimtries were compared.

RESULTS. Taking all glaucoma patients into consideration, the sensitivity was highest for Matrix FDT perimetry (69%), followed by SAP (68%), and then SITA SWAP (59%). When the analysis included only patients with early glaucoma, the sensitivity decreased to 52%, 46%, and 34%, respectively, with a significant difference detected between Matrix FDT perimetry and SITA SWAP (P = 0.034). The specificity was ≥97% for all perimtries. The AUCs of MD and PSD followed a similar order, with Matrix FDT perimetry having the greatest AUC (0.89–0.94), followed by SAP (0.87–0.94), and then SITA SWAP (0.69–0.90). There were significant differences in sensitivities at 90% specificity between Matrix FDT perimetry and SITA SWAP (P ≤ 0.005 for MD; P ≤ 0.039 for PSD).

CONCLUSIONS. The performance for glaucoma detection was comparable between FDT perimetry and SAP. FDT perimetry had a higher sensitivity for detecting glaucoma than did SWAP at a comparable level of specificity. (Invest Ophthalmol Vis Sci. 2011;52:7325–7331) DOI:10.1167/iovs.11-7795

Standard automated white-on-white perimetry (SAP), frequency-doubling technology (FDT) perimetry, and short-wavelength automated perimetry (SWAP) are three of the prevailing visual field testing technologies in use in clinical practice. Although SAP is considered the reference standard for detecting visual field loss in glaucoma, there is evidence suggesting that FDT perimetry1–3 and SWAP4–7 detect visual field changes earlier than SAP does. FDT perimetry and SWAP have been proposed to be selective for specific populations of retinal ganglion cells.8,9 By presenting a low spatial and high temporal frequency stimulus, FDT perimetry may preferentially stimulate a subset of retinal ganglion cells (RGCs) in the magnocellular pathway (My cells), although recent studies have indicated that the frequency-doubling effect may not be generated by the My cells, but by many RGC types.10–12 By contrast, SWAP generates a blue-violet (440-nm wavelength) stimulus over a bright yellow background and may preferentially stimulate the RGCs in the koniocellular pathway.

Current knowledge of the relative diagnostic performance of SAP, FDT perimetry, and SWAP is largely derived from the first generation of the instruments. Published data comparing the latest technologies is sparse. In contrast to the first generation of FDT, the Matrix FDT perimeter (Carl Zeiss Meditec, Inc., Dublin, CA) increases the spatial resolution by adopting a 24-2 testing pattern similar to SAP. The Swedish Interactive Thresholding Algorithm (SITA) has been incorporated into SWAP to shorten test duration and improve test–retest variability. These advancements may further improve the diagnostic performance of FDT perimetry and SWAP. Understanding their roles and performance in clinical practice is pertinent to the management of glaucoma. The objective of this study was to compare the diagnostic sensitivity and specificity of SAP (SITA standard), Matrix FDT perimetry, and SITA SWAP, using a reference standard based on the assessment of the retinal nerve fiber layer (RNFL) thickness deviation map derived from spectral-domain optical coherence tomography (Cirrus HD-OCT; Carl Zeiss Meditec, Inc.).

METHODS

Subjects

Normal subjects and patients with glaucoma were consecutively enrolled during the period from August 2008 through October 2009 at the University Eye Center and Hong Kong Eye Hospital (general and glaucoma clinics), Chinese University of Hong Kong. These subjects were observed for the research study, RNFL imaging with spectral-
domain OCT, designed to investigate the roles of RNFL imaging for detecting and observing the progress of glaucoma. All participants underwent a full opthalmic examination, including measurement of visual acuity, refraction, and intraocular pressure, gonioscopy, and fundus examination. Subjects were included if they had a visual acuity of at least 20/40 and spherical refractive error within the range of $\pm$8.0 D. Subjects were excluded if they had clinical evidence of macular disease, refractive or retinal surgery, neurologic disease, or diabetes. All participants had prior experience of performing standard automated perimetry (SAP) before they were enrolled in the present study. During the same visit, each participant had Cirrus HD-OCT RNFL imaging, SAP (Humphrey Field Analyzer II; Carl Zeiss Meditec, Inc.), FDT perimetry (Matrix Frequency Doubling Perimeter; Carl Zeiss Meditec, Inc.), and Swedish interactive thresholding algorithm short-wave-length automated perimetry (SITA SWAP; Humphrey Field Analyzer II; Carl Zeiss Meditec, Inc.) in random order, with at least a 10- to 15-minute break between tests (described below) by a team of four experienced technicians. All visual field defects were confirmed by at least two consecutive examinations by the same types of perimetry.

The reader (LS) of the index tests and reference standard (described below) was masked to the results of other clinical information. Repeated visual field testing was performed at a separate visit within 4 months. One eye of each subject was randomly selected if both eyes were eligible. The study was conducted in accordance with the ethical standards stated in the 1964 Declaration of Helsinki and approved by the local research ethics committee, with informed consent obtained. The reporting of diagnostic performance complied with the Standards for the Reporting of Diagnostic Accuracy Studies (STARD).

**Cirrus HD-OCT RNFL Imaging**

Spectral-domain OCT imaging was performed with the Cirrus HD-OCT (software ver. 5.0; Carl Zeiss Meditec, Inc.). The details of the principles of spectral-domain OCT have been described.18 An optic disc cube scan protocol was used to measure RNFL thickness in a $6 \times 6$ mm$^2$ area consisting of 200 $\times$ 200 axial scans (pixels) of the optic disc region. The RNFL thickness at each pixel was measured, and an RNFL thickness map was generated. Abnormal RNFL measurement at the $6 \times 6$ mm$^2$ parapapillary area was analyzed and displayed in the RNFL thickness deviation map, composed of $50 \times 50$ pixels. Each pixel was colored yellow or red if the RNFL measurement fell outside the lower 95% and 99% of the centile ranges, respectively. All the OCT scans had a signal strength of at least 7. Saccadic eye movement was detected in the line-scanning ophthalmoscope overlaid with OCT en face during OCT imaging. Images with motion artifact were rescanned at the same visit.

**Visual Field Testing**

Static automated white-on-white threshold perimetry (SAP) was performed with the 24-2 SITA standard program (ver. 4.1) of the Humphrey Field Analyzer II (Carl Zeiss Meditec, Inc.). Each of the achromatic Goldmann size III targets was presented for 200 ms on a background illumination of 10 cd/m$^2$. FDT perimetry was performed with the Matrix FDT Perimeter (Carl Zeiss Meditec, Inc.). The 0.5-cyc/deg sinusoidal gratings undergoing counterphase flickering at 18 Hz were sequentially displayed over $54 \times 54$ squares, using the 24-2 zippy estimation by sequential testing (ZEST) thresholding algorithm. SWAP was performed with the 24-2 SITA program (ver. 4.1) of the Humphrey Field Analyzer II (Carl Zeiss Meditec, Inc.). Each of the narrow-band blue (440-nm wavelength) Goldmann size V targets was presented for 200 ms on a 100 cd/m$^2$ yellow background. Lens correction was accomplished according to the manufacturer’s recommendation. For SAP and SWAP, the patients’ appropriate near correction was corrected with a trial lens inserted in the lens holder. For Matrix FDT perimetry, the patients wore their own prescription glasses. A visual field was defined as reliable when fixation losses and false-negative errors were $\leq$3% and false-positive errors were $\leq$15%. Four subjects were excluded because of an increase in fixation losses in one or more visual field tests. A field defect was defined as having three or more significant ($P < 0.05$) non-edge-contiguous points, with at least one at the $P < 0.01$ level on the same side of the horizontal meridian in the pattern deviation plot (PDP) and confirmed with at least two consecutive examinations by the same types of perimetry. The same criteria were used to define visual field defects for SAP, Matrix FDT perimetry, and SITA SWAP. The severity of glaucomatous damage was classified as mild (MD $\geq$ –6 dB) and moderate to advanced (MD $< -6$ dB), according to the values of MD calculated in SAP.14 There were no adverse effects of the OCT imaging or visual field testing.

**Definitions of Normal and Glaucomatous Eyes**

Subjects were classified as normal or glaucomatous with reference to the Cirrus HD-OCT RNFL thickness deviation map, regardless of perimetry findings. Each RNFL thickness deviation map was graded between 0 and 5, taking the defect size, shape, depth, location, and distance from the optic disc into consideration. The details of this scoring scheme have been reported.19 In brief, an RNFL defect was defined as a pixel at the $\pm$5% level (in yellow or red) in the RNFL thickness deviation map. A score was applied to a map for RNFL defects that met each of the following requirements: (1) size ($\geq 20$ pixels at the $\pm$5% level; in yellow or red); (2) shape (wedge-shaped, with the width of defect increasing from the disc margin toward the edge of the map, either localized to a specific clock hour or diffusely affecting the superior and/or inferior sectors of the optic disc); (3) depth ($\geq 10$ pixels at the $\pm$1% level, in red); (4) location (defect located at the supertemporal and/or inferotemporal clock hours—i.e., 6–8 o’clock and/or 10–12 o’clock, righthand orientation); or (5) distance from the optic disc (at least 1 pixel was within 1.73 mm from the disc edge). Each aspect was scored independently by a masked observer. When there was more than one isolated defect in the map, each defect was scored separately and the one with the highest score was recorded. In this study, glaucoma was defined with a score $\geq 4$, and a score $\leq 2$ was considered normal.

**Statistics**

Demographics (age, refraction), OCT average RNFL thickness and visual field MD (mean deviation), and PSD (pattern SD) measurements between the normal and glaucoma groups were compared with independent t-tests. Diagnostic sensitivity for detection of visual field abnormality between perimetries was compared on the basis of the asymptotic normality of the natural logarithm on the proportion of the true-positive rate. The 95% confidence interval was calculated with the Wilson score method using asymptotic variance.16 The area under the receiver operating characteristic (AUC) curve was used to assess the diagnostic performance of global visual field indexes (MD and PSD) among the perimetries.17 With estimated rank correlations of 0.9 and 0.2 between MD/PSD values derived from SAP, Matrix FDT perimetry, and SITA SWAP in the normal and glaucoma groups (calculated from a pilot dataset), respectively, the current sample size had a statistical power of 80% and a type I error of 5% to detect at least a difference of 0.14 in AUC at any value above 0.80. The method described by Huang and Pepe18 was used to compare the area and the sensitivity at a $P < 0.05$ level.

**RESULTS**

With reference to the Cirrus HD-OCT RNFL thickness deviation map for classification of 132 eyes of 132 subjects, 95 were glaucomatous and 37 were normal. The average RNFL thickness was 69.69 $\pm$ 11.52 and 97.84 $\pm$ 7.53 $\mu$m, respectively ($P < 0.001$). The average MDs of SAP, Matrix FDT perimetry, and SITA SWAP in the glaucoma group were $-8.13 \pm 7.65$, $-9.10 \pm 6.65$, and $-11.15 \pm 7.65$ dB, respectively. Considering all visual field tests analyzed in the study, 99.8% of the
reliability indices (fixation losses and false-positive and -negative errors) were ≤20%. Of the field tests, 58.9% (n = 56) had early glaucomatous visual field defects by the Hodapp-Parrish-Anderson criteria on SAP.14 There were significant differences in MD and PSD in all visual field tests between the normal and glaucoma groups (all with P < 0.001; Table 1). For the 95 glaucoma patients, 30 (31.6%), 29 (30.5%), and 39 (41.1%) had normal results by SAP, Matrix FDT, and SITA SWAP, respectively. For the 37 normal subjects, 1 (2.7%) had visual field defect in Matrix FDT perimetry, 1 (2.7%) in SITA SWAP, and none in SAP. Figure 1 shows the proportional agreement of visual field defects detected by the three perimetries.

**Comparison of Sensitivity and Specificity for Detection of Visual Field Defects**

Taking all glaucoma patients into consideration (n = 95), the sensitivity for detection of visual field defects was highest for Matrix FDT perimetry (69.5%; 95% confidence interval: 59.6%–77.8%), followed by SAP (68.4%; 58.5%–76.9%) and then SITA SWAP (58.9%; 48.8%–68.3%; Table 2). There were no significant differences in sensitivities among the perimetries (P ≥ 0.050). Including only patients with early glaucoma (n = 56), the respective sensitivities decreased to 51.8% (39.0%–64.3%), 46.4% (34.0%–59.3%), and 33.9% (22.9%–47.0%), respectively, and a significant difference was detected between Matrix FDT perimetry and SITA SWAP (P = 0.034). The specificities were 97.3% (86.2%–99.5%), 100.0% (90.6%–100.0%), and 97.3% (86.2%–99.5%), respectively.

**Comparison of Area under the ROC Curves of Visual Field MD and PSD**

The ROC curves of MD for Matrix FDT perimetry, SAP and SITA SWAP are shown in Figures 2A (including all glaucoma patients) and 2B (including early glaucoma patients). The AUCs of Matrix FDT perimetry and SAP were significantly greater than that of SITA SWAP (P < 0.001). Taking all glaucoma patients into consideration, the sensitivities at 90% specificity were 84.2% (65.3%–93.7%) for Matrix FDT perimetry, 82.1% (70.5%–92.6%) for SAP, and 56.8% (42.1%–69.5%) for SITA SWAP, with significant differences detected between SAP and SITA SWAP (P = 0.003), and between FDT perimetry and SITA SWAP (P = 0.005), but not between SAP and Matrix FDT (P = 0.800; Table 3). When patients with moderate and advanced glaucoma were excluded, the respective sensitivity decreased to 73.2% (42.9%–89.3%), 69.6% (51.8%–87.5%), and 32.1% (12.5%–50.0%). Likewise, there were significant differences between SAP and SITA SWAP (P = 0.006), and between Matrix FDT perimetry and SITA SWAP (P = 0.010), but not between SAP and Matrix FDT perimetry (P = 0.790). Although there were no significant differences in the area under the ROC curves of PSD between the perimetries (P ≥ 0.076; Figs. 2C, 2D), significant differences in sensitivities at 90% specificity were observed in the comparison between FDT perimetry and SITA SWAP (P ≤ 0.039), but not between SAP and SITA SWAP (P ≥ 0.096), in the analyses including all patients and early glaucoma patients (Table 3). Figure 3 illustrates a patient with a glaucomatous optic disc and RNFL changes. Repeatable inferonasal visual field defects were noticed on Matrix FDT perimetry and SAP, but not on SITA SWAP.

**DISCUSSION**

Using the RNFL thickness deviation map generated from the Cirrus HD-OCT as a reference standard for glaucoma diagnosis, we showed that Matrix FDT perimetry outperformed SITA SWAP, using different defining criteria for visual field abnormality including the number and severity of visual field defects in the pattern-derivation plot, and the values of MD and PSD. Although Matrix FDT perimetry demonstrated the highest diagnostic sensitivity among the three perimetries, there were no significant differences in diagnostic performance between SAP and Matrix FDT perimetry. With a higher diagnostic performance and potential logistic advantages including portability and more tolerance to refractive errors, Matrix FDT perimetry could be a preferable option over SITA SWAP in identifying glaucomatous visual field defects.

Previous studies have yielded divergent views regarding the diagnostic performance of FDT perimetry and SITA SWAP relative to SAP for detection of glaucoma. Sample et al.15 compared SAP, FDT1 (the first generation of FDT), full-threshold SWAP, and high-pass resolution perimetry and found that FDT perimetry had higher sensitivities than all other tests for all visual field parameters.19 The introduction of the second generation of FDT, the Matrix FDT perimetry, improved the ability to correlate with SAP by giving a comparable spatial assessment (24-2). Racette et al.20 showed that the performance of FDT1 was similar to that of Matrix FDT perimetry and that Matrix FDT perimetry was better than SAP in discriminating glaucomatous from normal eyes.20 In contrast, Spry et al.21 and Burgansky-Eliash et al.22 did not find superiority of Matrix FDT perimetry over SAP.

In earlier studies, Sample et al.4,7 and Johnson et al.6,7 reported that full-threshold SAP is more sensitive in detecting glaucomatous visual field loss than is full-threshold SAP, although, in a more recent study, Sample et al.19 did not find a

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**Table 1. Demographics and Visual Field Measurements of the Normal and Glaucoma Groups**

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Glaucoma</th>
<th>P</th>
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<tbody>
<tr>
<td>Subjects, n</td>
<td>37</td>
<td>95</td>
<td>—</td>
</tr>
<tr>
<td>Age, y ± SD</td>
<td>53.78 ± 8.99</td>
<td>54.23 ± 14.36</td>
<td>0.83</td>
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<tr>
<td>Spherical error, D ± SD</td>
<td>0.51 ± 1.49</td>
<td>-1.60 ± 3.46</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Cirrus HD-OCT average RNFLT, μm ± SD</td>
<td>97.84 ± 7.53</td>
<td>69.69 ± 11.32</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>SAP MD, dB ± SD</td>
<td>-0.48 ± 1.03</td>
<td>8.13 ± 7.65</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>SAP PSD, dB ± SD</td>
<td>1.46 ± 0.30</td>
<td>6.13 ± 4.46</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Matrix FDT perimetry MD, dB ± SD</td>
<td>0.27 ± 2.25</td>
<td>-9.10 ± 6.65</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Matrix FDT perimetry PSD, dB ± SD</td>
<td>2.65 ± 0.45</td>
<td>5.69 ± 2.17</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>SITA SWAP MD, dB ± SD</td>
<td>-3.61 ± 3.14</td>
<td>-11.13 ± 7.65</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>SITA SWAP PSD, dB ± SD</td>
<td>2.49 ± 0.51</td>
<td>5.56 ± 2.66</td>
<td>&lt;0.001</td>
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**Figure 1.** Proportional agreement of visual field defects detected by SAP, Matrix FDT perimetry, and SITA SWAP. The number of subjects (eyes) with visual field defects detected by each of the perimetric tests is shown in parentheses.
difference between full-threshold SWAP compared to SAP. Likewise, van der Schoot et al. demonstrated no superiority of SWAP over SAP in detecting visual field progression in patients with ocular hypertension. It has been suggested that the adoption of SITA strategy in SAP may have improved its diagnostic sensitivity by shortening the test duration and tightening the confidence limits. The development of SITA SWAP significantly reduced the test time, widened the dynamic range of threshold sensitivity, decreased the threshold variability, and corrected for lens density. Nevertheless, Ng et al. compared full-threshold SWAP and SITA SWAP and did not find significant differences in sensitivity and specificity between the two strategies. This result is in agreement with the results of Bengtsson and Heijl, demonstrating similar diagnostic sensitivity of full-threshold SWAP, SITA SWAP, and SAP (SITA fast).

To our knowledge, only one study has directly compared the latest visual field technologies of FDT and SWAP. Tafreshi et al. compared SAP, Matrix FDT perimetry, and SITA SWAP and detected no significant differences in their diagnostic performance. Their results are different from ours, in which we found a higher sensitivity for Matrix FDT perimetry than SITA SWAP in detecting glaucomatous visual field defects.

The disagreement among studies is probably related to the differences in subject selection, the definition of visual field abnormality, and the reliability of the reference standard. Subject selection has a substantial impact in the evaluation of diagnostic performance. A study group with more patients with advanced disease is likely to attain a higher value of diagnostic sensitivity. In the present study, as an example, the sensitivities and AUCs were all reduced in the three visual field tests when the analysis excluded patients with moderate and advanced glaucoma. Notably, in the comparison between Matrix FDT perimetry and SITA SWAP (Table 2), a significant difference in sensitivity was evident only when the analysis

| Table 2. Diagnostic Performance of SAP, Matrix FDT Perimetry and SITA SWAP for Detection of Glaucoma |
|-------------------------------------------------|-----------------|-----------------|
| All Glaucoma (n = 95)                            | Early Glaucoma (n = 56) |
| SAP                                            | Matrix FDT Perimetry | SITA SWAP       |
| Sensitivity, % (95% CI)                         | 68.4 (58.5–76.9)   | 69.5 (59.6–77.8) |
| Specificity, % (95% CI)                         | 100.0 (90.6–100.0) | 97.3 (86.2–99.5) |
| Matrix FDT Perimetry                            | 58.9 (48.8–68.3)   | 97.3 (86.2–99.5) |
| SITA SWAP                                       | 46.4 (34.0–59.3)   | 97.3 (86.2–99.5) |
| SAP                                            | Matrix FDT Perimetry | SITA SWAP       |
| Sensitivity, % (95% CI)                         | 51.8 (39.0–64.3)   | 33.9 (22.9–47.0) |
| Specificity, % (95% CI)                         | 100.0 (90.6–100.0) | 97.3 (86.2–99.5) |
| Matrix FDT Perimetry                            | 97.3 (86.2–99.5)   | 97.3 (86.2–99.5) |
| SITA SWAP                                       | 33.9 (22.9–47.0)   | 33.9 (22.9–47.0) |

Figure 2. AUCs of MD (A, B) and PSD (C, D) for SAP, Matrix FDT perimetry, and SITA SWAP were compared, including all (A, C) and early (B, D) glaucoma patients.
excluded patients with moderate and advanced glaucoma. In fact, Tafreshi et al.\textsuperscript{28} also reported higher sensitivity of Matrix FDT perimetry than of SITA SWAP when visual field abnormality was defined with reference to the values of total deviation, MD, and PSD. Statistically significant differences may have been found in their study if the comparisons had been confined to patients with early visual field loss. Matrix FDT perimetry may not outperform SITA SWAP in patients who already have moderate to advanced visual field defects.

Different definitions of visual field abnormality have been used in studies comparing perimtries. Although the Hodapp-Parrish-Anderson criteria are well-recognized for defining glaucomatous visual field loss,\textsuperscript{13} MD and PSD values are commonly adopted to evaluate diagnostic performance of visual field tests. It is important to note that different definitions of visual field abnormality may generate different conclusions from the same study. In the study by Leeprechanon et al.\textsuperscript{29} comparing full-threshold SWAP and Matrix FDT perimetry, the SWAP MD and Matrix FDT perimetry PSD had the greatest AUCs (0.74 and 0.67, respectively), and the difference between the two AUCs was not significant ($P = 0.37$). However, when visual field abnormality was defined with reference to the number and severity of defects in the pattern deviation plot, Matrix FDT perimetry was in fact more sensitive (72%) than full-threshold SWAP (54%; $P = 0.02$) at a similar specificity (53% and 44% [$P = 0.12$], respectively). A similar situation was also observed in the present study. In the comparison of AUCs between SAP and SITA SWAP, significant differences were detected between SAP MD and SITA SWAP MD ($P < 0.001$; Figs. 2A, 2B). Significant differences in diagnostic sensitivity between SAP and SITA SWAP, however, were not apparent when visual field abnormality was defined with reference to the pattern deviation plot (Table 2). The sensitivity and specificity of a particular definition of visual field abnormality may also vary with the status of the disease. For example, PSD is a less sensitive parameter in advanced glaucoma, whereas MD could be less specific in patients with coexisting cataract. Considering different defining criteria of visual field abnormality would be important in the interpretation and comparison of diagnostic performances of various types of perimetric testing.

Another factor that influences the performance of a diagnostic test is the reliability of the reference standard. Although evaluation of the optic disc with stereophotographs provides independence from visual field measures and is a commonly adopted reference standard in diagnostic studies of perimtries, subjective assessment of the optic disc can be unreliable. Interobserver agreement in diagnosing and monitoring glaucomatous optic disc changes has been shown to be low.\textsuperscript{30–34} Misclassification is likely to occur, particularly for patients with early disease. Correct and objective classification between early glaucomatous and normal eyes is thus germane to the comparison of diagnostic performances of various types of perimetric testing. In this study, an objective measure based on the RNFL thickness deviation map score (0–5) was used as the reference standard.\textsuperscript{15} Although a map score of 5 was shown to have a higher specificity than a map score $\geq 4$ for detecting visual field defects by SAP, the higher specificity could be at the expense of lower sensitivity to detect mild glaucomatous damage not evident in SAP. For this reason, a map score of $\geq 4$ was used to define glaucoma.

There are shortcomings in the study. The criteria used to define visual field defects in the pattern deviation plot were developed for SAP and thus may not be optimal for Matrix FDT perimetry and SITA SWAP. The results may thus be biased...
toward better performance of SAP. Polo et al.3,2 showed that the optimum perimetric criteria for full-threshold SWAP was a cluster of four points lower than P < 0.5 or a cluster of three points lower than P < 1%. The optimum criteria for SITA SWAP and Matrix FDT perimetry, however, have not been investigated, and no criteria have been proposed to define visual field defects derived from these perimeters. We therefore compared the three perimetrys using the same criteria, and the presence of visual field defects was confirmed in at least two visual field tests, to reduce false-positive test results. Interpretation of the results requires understanding of the limitations in such a comparison. As each of the perimetrys has a different group of normal subjects, a different sample size, and different methods for deriving the reference database and statistical package for analysis, results obtained from one perimetry may not be directly comparable to the others. In addition, decibel values for each perimetry are not equivalent. SAP and SITA SWAP use Weber contrast (ΔL/L) whereas Matrix FDT perimetry uses Michelson contrast (Lmax – Lmin/Lmax + Lmin), where L is luminance. Nevertheless, it is notable that results derived from the pattern deviation plot were generally consistent with those analyzed using the MD and PSD values.

Although the RNFL thickness deviation map provides a clear visualization of the RNFL defects, the accuracy of RNFL measurement is influenced by the performance of the segmentation algorithm and the inclusion of retinal blood vessels.5,34 The study is also limited by the fact that all participants were Chinese, whereas the normative data of the three perimetries were collected mostly from non-Asians. The diagnostic sensitivity and specificity calculated from individual tests may not be optimized for Asian populations; yet, the ethnic differences are unlikely to have affected the relative diagnostic performances of the three types of perimetry. Although glaucoma patients were consecutively recruited, the number of subjects eligible for inclusion was limited by the relatively stringent criteria (able to perform visual field testing reliably in all three perimetrys, OCT image signal strength of at least 7, and no history of other eye diseases except mild cataract). For this reason, the mean age of glaucoma patients in this study was relatively young (54.2 years). The relative diagnostic performance of perimetries might be different in an older population. Although the new normative database in SITA SWAP may account for some catactral changes,26 further studies are needed to validate its performance in older age groups. Last, the sample size was powered to detect a difference in AUC of 0.14. Insignificant differences in diagnostic sensitivity among perimetries might have become significant if the sample size had been larger.

In summary, Matrix FDT perimetry is more sensitive to SITA SWAP in detecting glaucomatous visual field loss at a similar level of specificity. This finding is pertinent to diagnosing glaucoma, but not necessarily to detecting disease progression. A longitudinal study comparing the performance of SAP, Matrix FDT perimetry, and SITA SWAP to detect progressive events would be relevant to corroborate the current findings.

References


