Comparison of Standard White-on-White Automated Perimetry and Short-Wavelength Automated Perimetry in Early Glaucoma Patients

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Background: To evaluate the relationship between short-wavelength automated perimetry (SWAP) and the standard white-on-white automated perimetry (W-W) in detection of early glaucomatous visual field deficits.

Methods: Twenty-four patients suspected of having glaucoma and who had experience with automated visual field tests were evaluated by SWAP and standard W-W perimetry. Results of the mean deviation (MD), pattern standard deviation (PSD), pattern deviation probability plot, test reliability, and test time were compared.

Results: The average MD in the SWAP group was significantly higher than that in the W-W group (SWAP: -6.55 db, W-W: -2.69 db, $p<0.001$). A significant difference also existed in PSD between the 2 groups (SWAP: 3.49 db, W-W: 2.40 db, $p<0.001$). The test time was longer in the SWAP group than in the W-W group (SWAP: 15 min, 6 s; W-W: 13 min, 8 s, $p<0.001$). There was no significant difference between the 2 groups in test reliability or in the number of points that were depressed below the 1% and 5% sensitivity levels on the pattern deviation probability plot.

Conclusions: This study showed that greater MD and PSD were demonstrated with SWAP. The test time was longer for SWAP. However, in order to conclude that SWAP is an early indicator of glaucomatous damage, longer follow-up and further analyses are required.

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Key words: early glaucoma, short-wavelength automated perimetry, white-on-white automated perimetry.

A diagnosis of glaucoma requires a clinical triad: elevated intraocular pressure, structural alteration of the optic disc, and visual field deficits. As a psychophysical test of optic nerve function, visual field testing plays an important role in the assessment of glaucoma. For the past few decades, white-on-white automated perimetry (W-W) has been considered the test of reference for glaucoma diagnosis and monitoring. However, since demonstrable visual field deficits occur after structural changes in the optic disc,[1,2] it is now considered subordinate to optic nerve head description.

Recently, several studies have reported that foveal blue and blue-yellow color vision deficits are present in patients with ocular hypertension and glaucoma, and that these deficits appear to be early

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indicators of glaucomatous damage.[3-7] Patients with ocular hypertension who had blue and blue-yellow color vision deficiencies had a much higher incidence of glaucomatous visual field loss 5 years later, compared with those with normal color vision results.[7] Using special techniques that selectively examine the sensitivity of short-wavelength-sensitive cones, it is possible to detect glaucomatous visual field deficits at an earlier stage. Several studies have shown that short-wavelength automated perimetry (SWAP) is more sensitive than W-W in detecting early glaucomatous defects, and it also shows greater progression of existing glaucomatous defects.[3,8,9]

The purpose of this study was to evaluate differences in presentations between W-W and SWAP in early glaucoma patients, and to determine whether SWAP changes precede those of W-W.

METHODS

We prospectively collected 24 eyes of 24 subjects (14 males and 10 females) diagnosed as suspected of having glaucoma, who had to meet the following inclusion criteria: (1) best-corrected visual acuity of 20/30 or better; (2) intraocular pressure 21 mmHg; (3) clear ocular media; (4) normal ocular examination except for a suspicious optic disc; (5) no other ocular or systemic condition that may have affected their visual fields; and (6) 2 or more normal or equivocal visual field tests on standard white-on-white automated perimetry. Their average age was 38±12 (range, 14-57) years.

For these subjects, we first arranged SWAP, followed by W-W, separated by a 30-min rest. Both eyes were respectively tested. In 11 patients, significant glaucomatous visual field deficits on W-W perimetry were demonstrated in 1 eye, but the fellow eye showed no change yet. The "seemingly normal" fellow eyes were chosen for analysis.

SWAP was performed with a Humphrey Field Analyzer (HFA II 750i, Humphrey Systems, Dublin, CA), using the program 30-2 with full-threshold performance. A size V light stimulus was chosen, with a 440-nm-wavelength blue spot projected onto a 530-nm-wavelength yellow background at a maximal brightness of 100 dc/m^2. W-W was also performed with the Humphrey Field Analyzer (HFA II 750i), using the same (30-2, full-threshold) program. A size III stimulus was chosen with a maximal intensity of 10,000 asb, a duration of 200 ms, which projected onto a background bowl illuminated at 31.5 asb.

For both SWAP and W-W, the machine with a built-in automatic gaze tracking system measured the patient's gaze direction at the time of stimulus presentation. During the test, blind spot fixation was monitored not only by the Heijl-Krakau method but also by an experienced perimetrist. The reliability of each visual field test was assessed, and the test was considered reliable only if fixation losses, and false-positive and false-negative rates were less than 25%. Those exceeding 25% were considered unqualified and were excluded.

The visual field charts were reviewed for mean deviation (MD), pattern standard deviation (PSD), test reliability (fixation losses, and false-positive and false-negative rates), and test time. In the pattern deviation probability plot analysis, after excluding the edge points on the upper, temporal, lower periphery, and blind spot poles (the one above and the one below the blind spot), 60 spots remained. The numbers of points depressed below the 5% and 1% sensitivity levels were counted.

The mean and standard deviation of the MD, PSD, test reliability, test time, and the numbers of points that were depressed below the 5% and 1% sensitivity levels on the pattern deviation probability plot were calculated. Statistical differences for MD, PSD, and test time were evaluated using paired *t*-test. As to differences in test reliability, the Wilcoxon signed rank test was used for analysis.

RESULTS

The average MD in the SWAP group was 6.55 ±3.31 db, and in the W-W group was 2.69±1.76 db ($p<0.001$). The average PSD in the SWAP group was 3.49±0.80 db, and was 2.40±0.95 db in the W-W group ($p<0.001$). The average test time in the SWAP group was 905.68 (15 min, 6 s)±70.03 s, and was 788.26 (13 min, 8 s)±69.93 s in the W-W group ($p<0.001$) (Table 1).

For the reliability analysis, the average fixation loss in the SWAP group was 6.57%±7.98%, and was 6.41%±8.43% in the W-W group ($p=0.95$); the false-positive rate was 0.72%±1.95% in the SWAP group and 2.37%±5.00% in the W-W group ($p=0.07$); and the false negative rates were 2.14%±

Table 1. Test Results and Reliabilities of SWAP and W-W

	SWAP	W-W	*p* Value
MD (db)	6.55± 3.31	2.69± 1.76	< 0.001
PSD (db)	3.49± 0.80	2.40± 0.95	< 0.001
Test time (s)	906±70.03	788±69.93	< 0.001
Fixation losses†	6.57± 7.98	6.41± 8.43	0.95
False-positive rate†	0.72± 1.95	2.37± 5.00	0.07
False-negative rate†	2.14± 4.06	1.28± 3.70	0.57
No. of points < 5%	3.42± 3.12	3.29± 3.13	0.84
No. of points < 1%	0.67± 1.13	0.71± 1.04	0.85

† By the Wilcoxon signed rank test.

4.06% and 1.28%±3.70%, respectively ($p=0.57$). The average number of test points that was depressed below the 5% sensitivity level on the pattern deviation probability plot was 3.42±3.12 in the SWAP group and 3.29±3.13 in the W-W group ($p=0.84$); and that below 1% was 0.67±1.13 in the SWAP group and 0.71±1.04 in the W-W group ($p=0.85$).

Our data revealed that there were statistically significant differences in MD, PSD, and test time between the 2 groups, but there was no statistically significant difference in test reliability or the numbers of test points that were depressed below the 5% and 1% sensitivity levels on the pattern deviation probability plot.

DISCUSSION

The concept that SWAP can detect glaucomatous visual field changes earlier than standard W-W perimetry has been well established.[3,8,10-13] According to a study of Johnson et al., blue-on-yellow perimetry can be an early indicator of glaucomatous damage, and is predictive of impending glaucomatous visual field loss for standard W-W perimetry in ocular hypertensive patients.[3] In addition, the study also showed that SWAP deficits progressed more rapidly in early glaucoma patients.[8] Nowadays, the 2 mainstream computerized automated perimetry systems, including the Humphrey and the Octopus systems, have incorporated a blue-on-yellow visual field test as a regular mode. Being a major advance in the field of computerized automated perimetry, SWAP provides new perspectives for both clinicians and patients.

In this study, the results of the 2 different visual field tests were mainly evaluated by MD and PSD. Moreover, we also calculated the numbers of points with sensitivities lower than 5% and 1% on the pattern deviation probability plot. Most clinicians used to interpret visual field defects by the pattern deviation plot, because generalized visual field defects on the total deviation plot map can be related to conditions other than glaucoma, such as cataracts and miotic effects. Using the pattern deviation approach, these biases can be removed.[14] Compared with previous studies,[3,10,14-18] our data also showed statistically significant differences in the MD and PSD between SWAP and W-W.[3,10,15-18] We hypothesize that the greater PSD in SWAP may be due to increased variability of retinal sensitivity.

There was no statistically significant difference in the comparison made using the pattern deviation probability plot. This could possibly have been caused by multiple factors. First, the follow-up period was not long enough, and confounding factors might have existed when 1 visual field was used for comparison. Second, although the patients included in this study were suspected of having glaucoma, there might actually have been a combination of diagnoses. Nine of the 24 eyes tested were seemingly normal fellow eyes (with the other eye having definitely been diagnosed with glaucoma), but when they were evaluated separately, there still was no difference in the point analysis. Most of the literature has reported a difference in the pointwise analysis when compared to their own normal control group, not the normative database provided within the machine.[17] The machine-built database might have a normal range that is too wide to detect the lower cut-off limit; this would cause the SWAP results to have been underestimated.

When nuclear sclerosis develops with increasing age, the progressive yellowness of the lens reduces the intensity of blue light within the eye.[19] It has been shown that chromatic effects of the lens become increasingly important in subjects older than 65 years.[19] Since all patients in this study were young to middle-aged (mean age, 38±12 years; range, 14-57 years) with best visual acuity better than 20/30, this effect may have been precluded.

This study revealed a longer test time for SWAP. Although most of our patients were quite experienced in undergoing standard W-W visual field tests, they were new to SWAP. Unfamiliarity increased the test time, and it has been reported that the retinal sensitivity decreases as the test duration

increases.[20-22] In addition, a learning effect was noted to exist up to the tenth test in SWAP, which usually disappears after the second or third examination with standard W-W perimetry.[17] Comparing the 2 visual field strategies simply using the first-time result might have been a little crude in this study. According to the literature, a reduction in retinal sensitivity can lead to contamination of the generalized depression component and underestimation of the focal visual field defects.[16]

Although the idea that SWAP can detect early glaucomatous changes has been widely disseminated, the diagnostic efficiency seemed to be poorer than that of standard W-W perimetry, and it requires greater accommodation by patients. Furthermore, the validity of the normative database in the statistical package built into the Humphrey machine (STATPAC) is questionable.[17] Further studies are needed to establish the normative database of our own population and to set the criteria for SWAP reading.

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光電動視野計和白光電動視野計在早期青光眼病患之比較

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背 景： 青光眼的診斷依據爲眼壓，視神經盤變化，及視野缺損。傳統上視野的評估是靠白光電動視野計，但是臨床上當視野呈現出缺損時，多半已伴隨視神經盤之明顯變化，使得白光視野計無法早期診斷青光眼。近年來，越來越多的證據顯示，由於作用在對短波長藍光敏感之視網膜錐狀感光細胞，藍光電動視野計比起白光電動視野計更能夠在疾病早期呈現出青光眼之視野缺損，並預測日後的視野變化。本篇的目的在於比較早期青光眼病患其藍光電動視野計和白光電動視野計測量值之差異，並探討藍光電動視野計是否能夠用於早期診斷青光眼。

方 法： 本篇就兩種電動視野計測試結果之平均缺損 (mean defect, MD)，pattern standard deviation (PSD)，測試時間，區塊敏感度圖形分析 (pattern deviation probability plot)，及測試之可信度 (fixation losses, false positive rate, false negative rate)，在24位早期青光眼病患進行比較。

結 果： MD, PSD及測試時間在藍光電動視野計組皆比白光電動視野計組多。而在區塊敏感度圖形分析及測試之可信度方面無顯著差異。

結 論： 本篇研究發現MD及PSD的值在藍光電動視野計組皆較白光電動視野計組高，且測試時間在藍光電動視野計組亦較長。然而，若欲用於早期診斷青光眼，則更長期的追蹤，更進一步的分析並建立本土資料庫是必須的。
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關鍵字： 早期青光眼，藍光電動視野計，白光電動視野計。

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