**Objectives:** To determine if short-wavelength automated perimetry (SWAP) provides evidence that indicates early functional losses in ocular hypertensive subjects and to establish a direct comparison with early structural abnormalities in the retinal nerve fiber layer (RNFL).

**Methods:** A total of 160 eyes belonging to 83 patients with ocular hypertension (intraocular pressure >21 mm Hg and normal results on standard automated perimetry evaluation), on which a SWAP and RNFL study were performed, were examined. One hundred twenty-eight age-matched subjects without ocular hypertension were evaluated to establish the 95% and 99% confidence intervals at each of the 76 exploration points of the SWAP test.

**Results:** The RNFL study results were normal in 83 cases (51.8%) and pathologic in 77 cases (48.1%). The SWAP results were pathologic in 57 cases (35.6%). Significant differences (P<.001) were observed when comparing the distribution of normal and pathologic SWAP results among the types of defects in the RNFL (focal wedge, diffuse atrophy, and mixed atrophy).

**Conclusions:** Short-wavelength automated perimetry is a useful test for the early detection of visual field losses. It is more sensitive than standard automated perimetry and provides a high association with RNFL assessment, which has proved capable of detecting signs of glaucomatous damage several years before the onset of the typical visual field defects.


Currently, the main objective in glaucoma diagnosis is to detect changes in visual function at early stages of the disease. Therefore, treatment will be initiated before the characteristic changes in the optic nerve or in the visual field appear.1

With this aim, several methods have been designed to evaluate the earlier structural and functional abnormalities in glaucoma. But so far, only retinal nerve fiber layer (RNFL) abnormalities and neuroretinal rim changes, measured through longitudinal studies, have proved capable of detecting the presence and progression of the glaucomatous damage.

In recent years, a new perimetric test—short-wavelength automated perimetry (SWAP)—has been developed and appears to be superior than standard automated perimetry in the detection of visual field defects in patients suspected of having glaucoma, thus becoming an early indicator of functional glaucomatous losses.4-6

The aims of this study were to determine if SWAP provides evidence that suggests early functional losses in patients with ocular hypertension and to establish a direct comparison with structural abnormalities in the RNFL assessment.

A total of 160 eyes of 83 patients were included in this study (46 men and 37 women). Mean age (± SD) was 45.4 (± 7.51) years; mean visual acuity was 20/25; and mean intraocular pressure was 23.72 (± 2.23) mm Hg.

In the RNFL study of the 160 eyes with ocular hypertension, the fiber assessment was distributed in the following way: focal wedge defects occurred in 13.8% (22 cases); diffuse atrophy in 26.2% (42 cases); mixed atrophy in 8.1% (13 cases); and a normal RNFL in 51.9% (83 cases) (Figure 1). Thus, 51.9% (83 cases) were considered normal results and 42.2% (77 cases) pathologic results.

Based on the perimetric criteria described, the SWAP results were pathologic in 57 cases, which represents 35.6% of the total sample.
PATIENTS AND METHODS

PATIENT SELECTION

All patients were recruited prospectively from the Glaucoma Department, Department of Ophthalmology, Hospital Miguel Servet, Zaragoza, Spain. The age range for all patients was from 30 to 60 years, with 23 subjects between the ages of 30 and 39 years, 29 subjects between the ages of 40 and 49 years, and 31 subjects between the ages of 50 and 60 years.

Ocular hypertension was defined as best corrected visual acuity of 20/30 or higher in each eye; intraocular pressure greater than 21 mm Hg on at least 2 occasions (measured by applanation tonometry); refractive errors of less than 3.00 spherical and 3.00 diopter cylindrical equivalent; normal result on standard achromatic automated perimetry examination (central threshold test; Goldmann size III (4 mm²; white color; stimulus duration, 0.2 seconds; background, 31.5 apostilbs [3.15 millilambert]); STATPAC [statistical package]; Humphrey Instruments, San Leandro, Calif); and normal appearance of the optic nerve head.

Informed consent was obtained from all patients. The nature and possible consequences of the procedures were fully explained to them.

Exclusion criteria were personal history of ocular disease, surgery, or trauma; any media opacities; systemic disease with ophthalmic repercussions; inability to perform any of the tests included in the exploratory procedure (RNFL imaging or SWAP); and low quality of the RNFL images.

EXPLORATORY PROCEDURE

All patients underwent the following protocol: SWAP was performed with a modified Humphrey field analyzer, series 1, using the program 30-2 test procedure, which measures the differential light sensitivity at 76 points in the central 30° field. The modifications needed to perform the test are included in the Humphrey field analyzer by the manufacturer. The test uses a bright yellow background of 100 candela per square meter (Shott OG-530 filter, Ealing, Electro-Optical Inc, Holliston, Mass), blue stimuli (440 nm), a Goldmann size V stimulus (Haag-Streit, Bern, Switzerland), and a dynamic range of 0 to 36 dB. This program performs increment threshold determinations at 76 locations within the central 30° radius of the visual field.

Photographic image evaluations of the RNFL were considered along the periphery of the 30° visual field.11,12 The SWAP data were corrected by ocular media transmission losses measured for each eye. The criteria used to establish an abnormal perimetry result consisted of deficits that produced a cluster of 3 or more points that were lower than the normal 3% probability level or a cluster of 2 or more points that were lower than the normal 1% probability level. These points should not be located along the periphery of the 30° visual field (24 points excluded), or in the blind spot poles (2 points excluded).

Retinal Nerve Fiber Layer

Photographic image evaluations of the RNFL were considered as normal or abnormal. Glaucomatous damage was defined by the presence of focal wedge defects or diffuse or mixed atrophies.

Figure 2 summarizes the distribution of the different RNFL types related to the perimetric results in the study group. Significant differences were observed comparing the distribution of normal and pathologic perimetric study results among the types of defects in the RNFL (P < .001 by χ² test). When the perimetric result was defined as normal, 74 (71.8%) of 103 eyes had fibers that were normal. On the other hand, the pathologic fields were mainly in 48 (84%) of 57 eyes with RNFL defects.

Table 1 summarizes the distribution of the SWAP results depending on the type of RNFL defect recorded. The percentage of abnormal visual field results was higher in the groups with RNFL defects than in the groups with normal RNFLs. There were statistically significant differences between the pathologic SWAP perimetric study results in the group with normal RNFLs and each of the different groups with abnormal RNFLs (P < .05 by χ² test).

The comparison between SWAP and RNFL results, classified as normal or altered, also resulted in statistically significant association (P < .001 by χ² test) (Table 2). Using the RNFL as early glaucoma criteria, SWAP sensitivity and specificity values were 62% and 89%, respectively.

Figure 3 shows an example of an ocular hypertensive eye that had a RNFL defect and the corresponding SWAP visual field.
Short-wavelength automated perimetry is a perimetric test designed to isolate and quantify the activity of short-wavelength–sensitive pathways.5,6,8,11

As can be seen from the results of our study, 57 (35.6%) of 160 pathologic SWAP results were observed in the sample of patients with ocular hypertension and normal standard automated perimetry results. These results are in agreement with those reported by Sample and Weinreb13 who found, using similar technical perimetric parameters, that 43% of their population of patients suspected of having glaucoma had pathologic perimetric results (SWAP results). Likewise, other authors4,5,14-16 have also found short-wavelength sensitivity losses in patients with ocular hypertension, which...
confirms the usefulness of this test in the assessment of early functional glaucomatous damage.

Retinal nerve fiber layer evaluation is a technique with high sensitivity and specificity in the early diagnosis of glaucomatous damage. By means of this technique, the presence of signs of glaucomatous damage is discovered several years before the development of reproducible field abnormalities on standard automated perimetry. At present, there is no study in the literature in which the structural alterations observed in the RNFL are compared with the functional losses found by using SWAP in a group of subjects suspected of having glaucoma.

In our study, the RNFL was normal in 83 eyes (51.9%) and pathologic in 77 (42.2%) (wedge defects, 22; diffuse atrophy, 42; mixed atrophy, 13); these data are similar to the percentages reported by other authors. The SWAP distribution in the different groups defined by RNFL imaging confirmed that the greater percentage of pathologic perimetric results was obtained in eyes with an altered RNFL. This association confirmed the validity of the test in detecting functional changes in glaucoma in the early stages of the disease.

It is also interesting to observe the distribution of the different fiber patterns in relation to the type of perimetry, which displays the association that exists between SWAP and RNFL evaluation. The presence of RNFL defects was associated significantly with the higher ratio of eyes with pathologic perimetrics.

Similar associations have been discovered between the RNFL condition and the presence of visual field losses in the standard automated perimetry. Abecia et al reported a significant association between the severity of the RNFL defects and the defects revealed by standard automated perimetry measurements. A report by Quigley et al rating the RNFL showed a higher incidence of abnormal perimetric results with greater severity of RNFL defects.

The SWAP sensitivity and specificity to identify patients with pathologic RNFLs in our sample were 62% and 89%, respectively. The percentage of perimetric results considered to be pathologic, with a normal RNFL, is sufficiently low (10.8%) to accept the SWAP abnormality criteria in patients suspected of having glaucoma. With regard to sensitivity, we consider 62% sufficient since we are dealing with patients who display RNFL alterations and normal standard automated perimetry results.

In conclusion, it can be established that SWAP is a useful test in the early detection of incipient losses in the central visual field. Short-wavelength automated perimetry also correlates positively with the RNFL assessment, which has proved capable of detecting signs of glaucomatous damage several years before the appearance of typical central visual field defects in conventional perimetry. Having observed the association between SWAP results and RNFL condition, and in agreement with several longitudinal studies, there is enough evidence to suggest that SWAP detects functional losses several years before standard automated perimetry.

Nevertheless, a long-term prospective follow-up of these patients will be conducted to study the progression of the SWAP defects found in patients with ocular hypertension and to confirm the value of SWAP to predict the future development of visual field losses found by standard automated perimetry.

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