Visual field testing is an essential component of glaucoma assessment, in terms of detection as well as in monitoring the progression of the disease. Automated static threshold perimetry is now the gold standard for assessment of the glaucoma patient, while manual kinetic or static perimetry are rarely used. However, the term ‘automated’ is a misnomer and should not be taken to infer that the practitioner has no role to play in the interpretation of the results of the visual field. Indeed, this is one of the major challenges facing the practitioner.

INTERPRETATION OF VISUAL FIELD PLOTS IN GLAUCOMA

The threshold plots from automated static perimeters often contain a seemingly overwhelming amount of information including raw data, maps and indices that can be difficult to interpret. The main problem lies in differentiating a normal field from that of a patient with early glaucoma and in separating small, real defects from those arising due to a variation in the patient’s responses. To achieve this, it is essential to identify the components of the plot that are important in making the diagnosis and those that can be largely ignored.

The first component to look at is the patient’s reliability. Fixation losses should be less than 20 per cent, false positives and negatives less than 33 per cent; if they are not, it is advisable to reinstruct the patient and retest. Next, look at the raw numbers at the stimulus locations across the field, remembering that decibels (dB) on one instrument are not comparable to another. As a rule of thumb, add six decibels to the values for the Medmont for comparability with the Humphrey Field Analyser (HFA). Note any clusters of non-edge points that are significantly depressed (more than six decibels from normal with a total loss of 30 dB relative to the age-matched normal), the depth of an individual defect (greater than 10 dB abnormal) and any asymmetry between the eyes.

Finally, the statistical evaluations and global indices give an indication of whether a result really is a defect, by displaying its comparison with age-matched normal data. It is useful to scan the total deviation plots for outliers in the numerical plots and any clusters of high p values in the probability maps. The pattern deviation map on the HFA should be compared to the total deviation map to see if diffuse loss has been eliminated, and any...
supra-threshold values noted. It is always useful to review the raw numerical plots to look at the suspicious areas indicated by these maps. The global indices give an indication of any generalised depression in the visual field (average defect [AD]/mean defect [MD]) and localised changes (pattern defect [PD]/pattern standard deviation [PSD]), while reliability within a given test session is given as the short-term fluctuation. If any of the indices are flagged as abnormal, look at the raw numbers again to get a sense of the configuration of the loss. Because of interpolation, grey scales can easily mislead and should be inspected last.

Glaucomatous visual field losses are initially characterised by early paracentral scotomas (that may or may not be extensions from the blind spot) and/or nasal steps. Over time they elongate along the nerve fibre bundles to form arcuate defects. Temporal wedges are also significant and should be monitored closely.1

Figures 1 and 2 represent the left visual field of a 63-year-old white female with primary open angle glaucoma, measured with the HFA (Figure 1) and Medmont (Figure 2) perimeters. The right visual field was essentially the same with both instruments. The HFA (Figure 1), using the SITA-standard strategy, gives a reliable plot and indicates a typical early visual field loss. The total deviation and pattern deviation plots show a small superior nasal step and a reduction in sensitivity close to fixation. The MD index reflects this early loss in sensitivity and the PSD index a change in the shape of the hill of vision. The Glaucoma Hemifield Test (GHT) flags the field as being outside normal limits, that is, the difference in sensitivity between the superior and inferior fields is greater than that found in an age-matched normal patient and reflects early glaucomatous change. The Medmont plot, using the static testing facility (Figure 2), denotes a more extensive loss of sensitivity with an arcuate scotoma arising in the nasal field, even close to fixation. The pattern index is clearly flagged as being abnormal.

A second example (Figures 3 to 5) is of a 57-year-old white male, again with primary open angle glaucoma. The HFA plot (Figure 3) shows a large nasal step, sensitivity losses close to fixation and the development of an arcuate nerve fibre layer defect. An arcuate defect of a similar nature to that of the Humphrey plot and situated within 10 degrees of fixation is present in the static Medmont field (Figure 4). However, with the second Medmont plot (Figure 5) using the auto-flicker technique, this inferior

Figure 1. Visual field results (Humphrey 24-2) using the SITA-standard strategy for a patient with early glaucomatous field loss. Results show an early superior nasal step and paracentral loss with deviation plots and indices flagged as abnormal.

Figure 2. Visual field results (Medmont) using a static testing strategy for the same patient as in Figure 1, denoting a more extensive loss of sensitivity with an arcuate scotoma arising in the nasal field, even close to fixation. The pattern index is clearly flagged as being abnormal.
Visual fields in glaucoma

Wood, Swann and Stavrou

Figure 3. Visual field results (Humphrey 24-2) using the SITA-standard strategy for a patient with more advanced glaucomatous loss than that depicted in Figures 1 and 2. There is a clear inferior nasal step, which respects the horizontal midline. This is clearly evidenced in the total and pattern deviation maps and reflected in the visual field indices that are significantly different from normal.

Figure 4. Visual field results (Medmont) using a static testing strategy for the same patient as in Figure 3. Note that the pattern of loss is very similar to that of the HFA plot with a marked inferior nasal step.

Figure 5. Visual field results (Medmont) using an autoflicker testing strategy for the same patient as in Figure 3. The loss appears to be much more extensive than for the static results with the inferior nasal step extending beyond that quadrant and a superior arcuate loss becoming apparent. These results are reflected by the age-normal map and the indices.

PATIENT FACTORS

Automated perimetry is limited by the fact that the outcome of a given examination can be affected by a number of factors. These include factors specific to the patient, and those particular to the measurement technique itself. Such factors can limit the ability to differentiate a given visual field from age-matched normal values, and limit the usefulness of the visual field to monitor progression of field loss. In particular, many of these factors can mimic or mask the appearance of glaucomatous field defects and must be recognised.
Pupil size
Small pupils are common, especially in elderly patients, and can result in false scotomas and depressions within the visual field. The size of the pupil will affect retinal illumination and thus the adaptive state of the retina (important at mesopic levels), diffraction, aberrations, ametropia and retinal image size. For patients with small pupils, dilation or the use of large target sizes can be considered. Edgar and colleagues looked at the effect of pupil size in young normal subjects. They found that miosis causes significant worsening in MD and PSD indices and a decrease in short-term fluctuations. The MD loss increased with eccentricity. There was no significant change to MD or PSD as a result of dilation. However, Kudrna, Stanley and Remington and Mendivil, who studied the effect on glaucoma patients, found MD and foveal thresholds significantly worsened following dilation.

Media opacities
Media opacities are also common in elderly patients and have effects similar to those of age-related miosis, where visual field defects are exaggerated and there is a general depression of the visual field. Figures 6 and 7 show the left visual fields of a 56-year-old male patient with cortical cataracts before and after surgery. Visual acuity prior to surgery was 6/30 and visual fields demonstrated a general reduction as evidenced by the total deviation map and the GHT statistic. Following surgery, visual acuity was 6/6 and the visual fields showed no abnormal points in the deviation plots and the visual field indices are given as normal. In this case, the cataract merely had the effect of sinking the hill of vision. However, some studies have also suggested that cataracts can mask the effects of glaucomatous visual field loss, as a significant improvement in MD and a worsening of PSD can occur following cataract extraction. Dilating the pupils is an option and results in increased contrast between the test object and the background. However, it is essential that the pupils are dilated for subsequent visual field tests.

Anatomical considerations
The eyelashes and eyelids can cause a depression in sensitivity in the superior visual field, which can mimic the effects of a superior hemifield defect commonly seen in glaucoma patients. For patients with a marked ptosis, taping the lids open may be the only option. This should be attempted with care.

Learning effects
Learning effects occur when the patient is unfamiliar with the procedures and because they have a limited awareness of their peripheral field. For static auto-
Visual fields in glaucoma  Wood, Swann and Stavrou

...ated perimetry, it is advisable to give the patient a practice session with a screening test before proceeding with threshold testing. Heijl and Bengtsson\(^7\) found that learning had a large and unpredictable effect on the visual fields of glaucoma patients, where more sensitive points showed more improvement than defective areas and peripheral test locations improved more than central ones. The latter finding is consistent with previous studies of visually normal subjects.\(^8\) In most patients, the learning effects occurred between the first and second sessions, so it is recommended that testing should be based on more than one field. Retesting is strongly recommended for an equivocal result where the patients have not had their fields tested previously.

**Fatigue effects**
As the visual field examination continues, the patient’s ability to respond to stimulus presentations is impaired due to fatigue, resulting in high, short-term fluctuations and reduced sensitivity. Misclassification of patients may also occur with longer duration threshold testing,\(^9\) as fatigue causes a significant worsening in MD. Hence, the best solution is to give the patient frequent rests throughout an examination that is likely to be prolonged.

**Defocus**
If an inappropriate refractive correction is used for the working distance of the perimeter, a refractive scotoma can result, because the targets are defocused. The effect of defocus will vary according to stimulus size, background luminance and stimulus location. A true refractive scotoma can result from localised elevations or depressions in the retina creating artificial hypermetropia or myopia. In these cases, the optimum refraction may vary across the visual field. The rim of the correcting lens can also cause a full or partial ring scotoma, which can simulate the appearance of a glaucomatous field defect.\(^10\) Hence, it is important to avoid these effects through proper positioning of the patient in the instrument and correct positioning of the lens and lens holder.

**Fixation**
Accurate fixation is important to ensure that thresholds are being measured at consistent locations. The fixation target should be fairly bright and small enough to encourage accommodation. A patient’s fixation is monitored using the Heijl-Krakau technique, where the blind spot is plotted initially and then suprathreshold stimuli are presented within this area at intervals throughout the test. In some instruments such as the HFA, the patient’s fixation can also be monitored visually by the examiner via a monitor or telescopic system.

**NON-Routine testing**
In practice, situations arise in which, having followed all of the previous strategies, a patient will show fundus signs indicating glaucoma, such as a retinal nerve fibre layer defect, but threshold fields appear normal. A repeated test using the same technique still results in a normal field. What are the options?

Further testing with a custom grid, placing many points in the area of the visual field corresponding to the detected nerve layer loss, should be considered. A Humphrey 24-2 or 30-2 test is appropriate in a glaucoma patient or glaucoma suspect, but with the stimuli six degrees apart, a scotoma of considerable size can be missed. Custom grids can present stimuli two degrees apart and have been shown to have a better chance of picking up early glaucomatous changes.\(^11\) Other workers\(^12\) have similarly recommended using either the Medmont central 10 degrees program or Humphrey 10-2 program in glaucoma patients in order to detect paracentral losses close to fixation.

An example of this (Figures 8 to 10) shows the fields of a 53-year-old white male with primary open angle glaucoma. The disease was well-established in the left eye but at a very early stage in the right eye. There was a nerve fibre layer defect emerging from the right optic disc at seven o’clock, although the visual fields with conventional white on white perimetry were normal.

**ALTERNATIVE TESTING STRATEGIES**
The use of short wavelength and flicker modalities can also be considered, depending on the type of machine available in a practice. Three of these optional techniques, which are now beginning to be more widely accepted, are short wavelength automated perimetry, flicker perimetry and the frequency doubling technique.

**Short wavelength automated perimetry**
Short wavelength automated perimetry (SWAP) is a perimetric technique in which large (Goldmann size V equivalent)
narrow band, blue stimuli are presented on a bright yellow background. The technique is now commercially available on the newer models of the HFA. A growing body of evidence suggests that SWAP defects are more extensive than defects measured with standard perimetry for patients with glaucoma, and precede the development of visual field loss by up to five years in high-risk glaucoma patients.\textsuperscript{13-15}

There have been a number of hypotheses advocated to explain why SWAP defects might precede those measured by standard techniques. The reduced redundancy theory is one of the more widely accepted. It suggests that because there are fewer short wavelength sensitive (SWS) cones and blue-on ganglion cells (the ganglion cells which mediate the SWS signals), any damage that occurs in these cell types will be apparent at an earlier stage of the disease.\textsuperscript{16} This theory is to some extent supported by findings from flicker perimetry, which also has been shown to detect glaucomatous damage before standard techniques. The sensation of flicker is mediated by the magnocellular cells (M cells) that, though not the same subpopulation as SWS cells, share the common characteristic of having a low redundancy.\textsuperscript{17-19}

However, there are some reported disadvantages in using SWAP, including a greater sensitivity to the reduced ocular transmission of the aging lens and a greater variability in responses.\textsuperscript{20} However, a large number of investigators feel that these problems are outweighed by the very positive benefits of earlier detection of ocular disease.\textsuperscript{21}

**Flicker perimetry**

As discussed above, perimetry using flickering targets has been reported to be more sensitive in a range of visual pathway diseases, including glaucoma. Tyler\textsuperscript{22} conducted some of the early clinical research in this area and reported losses in foveal and peripheral flicker sensitivity for patients with glaucomatous damage. Such losses showed selectively greater involvement for high temporal frequencies (30 to 40 Hz). Flicker has been used clinically by Lachenmayr and colleagues,\textsuperscript{23,24} who measured critical flicker fusion frequency (CFF), the maximum flicker rate at which a subject still perceives flicker, and reported larger defects for this than for standard perimetry in patients with glaucoma and ocular hypertension. Similarly, using relatively large LED targets, Austin, O’Brien and Wishart\textsuperscript{25} reported that in ocular hypertension and glaucoma patients, flicker losses were greater for temporal frequencies of 10 and 15 Hz and that these changes preceded those found by static perimetry.

The ability to present flickering targets is now available on the Medmont perimeter, where the frequency of the flicker can be varied if required by the examiner. A flicker rate of 18 Hz is often used. However, more recent work has indicated that it is better to have the flicker rate of the targets decrease with increasing frequency.
eccentricity using the Autoflicker option of the test. Indeed, using this test on the Medmont, Rota-Bartelink and colleagues demonstrated significantly greater defects with flicker compared with static perimetry for patients with early primary open angle glaucoma. Figure 5 also demonstrates this effect.

Importantly, the test involves the subject responding to the presence of flicker as opposed to simply detecting the targets. Hence, it is essential that the patient instructions are appropriate. The subject should be instructed to respond only to the flickering or shimmering of the target, otherwise in our experience a high number of false positives will occur.

**Frequency doubling technique**

The Frequency doubling technique (FDT) was developed to selectively test the M pathways, which are believed to be preferentially damaged in early glaucoma. To achieve this, the FDT incorporates a low spatial (0.25 c/deg) and high temporal (25 Hz counterphase flicker) frequency stimulus. For this stimulus combination, the stimulus display appears to have twice as many light and dark bars as are physically present. Hence, the term frequency doubling. This is believed to arise because of the difference in conduction time between the M and parvocellular (P) pathways of the visual system. The presence of nasal steps and hemifield defects can be elicited with the presentation of the FDT stimuli at 17 visual field locations within 20 degrees of fixation, four in each quadrant and one in the central five degrees.

There is now a growing body of evidence suggesting that the FDT can detect glaucoma at an earlier stage than conventional white on white perimetry and as the duration of testing is shorter and the FDT is portable, it may be used as an effective screening tool.

**CONCLUSION**

In terms of the interpretation of visual field plots, a systematic approach should be taken. First, ensure that the reliability of the patient is within the recommended limits, then view the raw numbers, statistical maps and finally the indices, while avoiding placing too much weight on the appearance of the grey scale plots. Awareness of patient factors such as pupil size, media opacities and the trial lens rim is essential, as these can often mimic the appearance of glaucomatous field loss.

In terms of testing protocols, the same threshold test should not be used in every case. Customised tests and grid patterns of stimuli may be used to investigate specific areas within the visual field to maximise the rate of detection of visual field loss, especially with very early changes. Custom grids can be allied to fundsus changes, visible using the ophthalmoscope. Where results are equivocal or unexpectedly normal, retesting can be advantageous. Alternatively, it may be useful to test using SWAP or flicker strategies as the evidence suggests that visual field defects can be detected at an earlier stage with these techniques, and it is well acknowledged that early intervention provides the best visual prognosis for the patient.

**REFERENCES**

Visual fields in glaucoma
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