

CLINICAL SCIENCE

Use of high spatial resolution perimetry to identify scotomata not apparent with conventional perimetry in the nasal field of glaucomatous subjects

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Aim: To examine whether high spatial resolution perimetry (HSRP) could identify fine scale scotomata which may not be apparent with conventional perimetry. The HSRP was performed in the nasal field, as this location is a recognised site for the early occurrence of glaucomatous defects.

Method: 16 early glaucoma eyes, 17 glaucoma suspect eyes, and 20 age matched healthy control eyes underwent conventional automated perimetry using the 24-2 program of the Humphrey field analyser (HFA) and HSRP. The HSRP was performed in the nasal field by testing 9×9 degrees of 100 tested points separated by 1 degree and the results compared with the HFA 24-2 program.

Results: Mean HSRP thresholds were significantly abnormal in the suspect and glaucoma eyes, with elevated levels of asymmetry between the superior and inferior nasal field. Overall, 7/17 (41%) suspect eyes (95% confidence interval 5/17 (29%) to 7/17 (41%)) had nasal scotomata on HSRP, although their HFA 24-2 fields failed to identify any defects. In glaucomatous eyes, 15/16 (94%) eyes had HSRP scotomata (95% CI 14/16 (88%) to 15/16 (94%)). In 12 these coexisted with HFA 24-2 defects at the same location, while in three eyes only HSRP identified scotomata in the nasal field.

Conclusion: HSRP can identify scotoma in glaucomatous eyes in the nasal field which may be missed with the lower spatial resolution of conventional perimetry.

The nasal step is a characteristic glaucomatous field defect elicited in kinetic perimetry, arising as a result of a difference in the sensitivity above and below the horizontal midline. This gives rise to a "step" in the isoptre, a defect which was first reported by Rönne in 1909.¹ Subsequent studies of kinetic perimetry have consistently shown that this defect is an early feature of glaucoma, with reported incidences of nasal steps as isolated manifestations of glaucoma varying from 1% to as much as 50%.^{2–6}

In static perimetry, the equivalent of a nasal step is a difference in the sensitivity above and below the horizontal midline.

Caprioli and Spaeth identified peripheral nasal defects in 10% of glaucoma suspects with normal central (<30 degree) fields using static automated perimetry, although their findings were difficult to interpret because of the high false positive rate in their controls.⁷ A study by Stewart also reported glaucomatous defects between 30–50 degrees nasally in 11% of glaucoma suspects.⁸

Both studies identified peripheral nasal field defects in the presence of a normal central field when tested with conventional automated perimetry.

However, a major limitation with the use of conventional automated perimetry is that it is insensitive to early glaucomatous damage. Evidence for this is provided by clinical,^{9–10} histological,¹¹ and psychophysical studies^{12–18} which have identified glaucomatous abnormalities before field abnormalities can be reliably detected using conventional automated perimetry.

One hypothesis which accounts for the poor sensitivity of conventional perimetry in early glaucoma is the "selective cell death hypothesis".¹⁹

Quigley and colleagues hypothesised a selective cell death of the larger diameter optic nerve fibres in early glaucoma.¹⁹ Since magnocellular cells are associated with larger mean diameters, the selective cell death hypothesis implies a preferential loss of magnocellular function in early glaucoma. Selective tests of magnocellular function include motion, flicker,

and frequency doubling perimetry. These have all identified abnormalities in early glaucoma.^{12–13–15–16–18}

Alternatively, the poor sensitivity of conventional perimetry may be a consequence of the non-selective nature of the stimulus used in luminance perimetry, which stimulates a broad spectrum of retinal ganglion cells. The large overlap in ganglion cell receptive fields results in considerable redundancy that may mask early losses if all classes of ganglion cells are stimulated.²⁰

An additional factor contributing to the poor sensitivity of conventional perimetry in detecting early glaucoma is its relatively low spatial resolution, with 6 degrees separating adjacent test locations in the 24-2 and 30-2 programs of the Humphrey field analyser (HFA, Zeiss Humphrey Systems, Dublin, CA, USA). Several studies have addressed this problem by performing perimetry at a higher spatial resolution, and have identified scotomata in glaucoma patients beyond the resolution of conventional perimetry.^{16–21–24} These findings suggest that the spatial resolution of conventional perimetry is not high enough to identify early glaucomatous damage.

Previous publications have reported a technique for performing high spatial resolution perimetry (HSRP) in a number of diseases.^{25–28} The technique obtains a threshold plot of 100 HFA test points separated by 1 degree to generate a 10×10 grid and allows the field to be sampled at much greater resolution than conventional perimetry. The technique is clinically practical and can be performed on an unmodified HFA.

HSRP in glaucoma has been shown to identify scotomata beyond the spatial resolution of conventional perimetry in a

Abbreviations: FMM, fine matrix map; GHT, glaucoma hemifield test; HFA, Humphrey field analyser; HSRP, high spatial resolution perimetry; ONH, optic nerve head; POAG, primary open angle glaucoma; RNFL, retinal nerve fibre layer

Table 1 Characteristics of study group. Values shown are mean (SD). Figures in parentheses indicate minimum and maximum values

	Control eyes (20 eyes)	Suspect eyes (17 eyes)	Glaucoma eyes (16 eyes)	p Value
Age (years)	65.3 (5.7) (55–75)	61.6 (10.4) (44–74)	67.4 (7.7) (53–83)	0.12*
Refraction (D)	0.3 (1.8) (–3.3–4.8)	–0.3 (3.2) (–6–3.8)	0.9 (1.0) (–1–2.8)	0.34*
HFA 24-2 mean deviation (dB)	0.9 (1.0) (–1.4–2.4)	–0.2 (1.1) (–2.5–1.8)	–2.1 (1.4) (–4.0–1.2)	0.001†

*Kruskal-Wallis test.

†Mann-Whitney U test (glaucoma versus control eyes, suspect versus control eyes).

number of locations other than the nasal field, with good reproducibility and within a clinically acceptable test time.^{16 24}

The purpose of this study was to examine whether HSRP could identify fine scale scotomata which may not be apparent with conventional perimetry. The HSRP was performed in the nasal field, as this location is a recognised site for the early occurrence of glaucomatous defects.

METHODS

The study was approved by the Moorfields Hospital ethics committee and followed the tenets of the Helsinki agreement.

Eligibility criteria

Healthy control subjects

Twenty healthy subjects comprised the control group. These were recruited from an established cohort of normal subjects (spouses, volunteers) used as the control group for a number of prospective studies in the ocular hypertension clinic of Moorfields Eye Hospital.

Inclusion criteria were normal ocular examination with an IOP less than 21 mm Hg, visual acuity better than 6/12, refraction ≤ 7 dioptres (D) ametropia, and a normal HFA 24-2 field test, repeated on at least three occasions. For this study we defined a normal HFA 24-2 field as a normal or borderline glaucoma hemifield test in the absence of any clusters of depressed locations in either hemifield. The cluster definition of a scotoma on the HFA 24-2 required a minimum of three adjacent points within a hemifield depressed by at least 5 dB from normal age expected values, with one point depressed by 10 dB. This definition has been widely used in previous studies.^{29 30}

Exclusion criteria were previous ocular surgery, diabetes, family history of glaucoma in a first degree relative, or systemic β blocker medication.

Glaucoma suspects

Twenty glaucoma suspects were recruited from the Moorfields ocular hypertension clinic. Inclusion criteria were visual acuity better than 6/12, refraction ≤ 7 D ametropia, documented intraocular pressure >21 mm Hg in the presence of a normal HFA 24-2 field test according to the above definition, repeated on at least three occasions.

Exclusion criteria were previous ocular surgery or history of diabetes.

Early primary open angle glaucoma eyes

Sixteen patients with early primary open angle glaucoma (POAG) were recruited from the glaucoma clinic or the ocular hypertension clinic. The latter were patients in whom a reproducible field defect had developed while under review.

Inclusion criteria were visual acuity better than 6/12, refraction ≤ 7 D ametropia, documented intraocular pressure >21 mm Hg on at least one occasion in the presence of an open angle, and a glaucomatous visual field defect on the HFA 24-2 field test reproducible on at least three consecutive occasions. All 16 eyes had early arcuate scotomata. In 12 these extended to the nasal field on the HFA 24-2 test.

Exclusion criteria

Significant ocular pathology other than glaucoma, previous ocular surgery or trauma, history of diabetes, or topical miotic agents.

All study participants contributed only one eye to the study, chosen at random if both were eligible. The characteristics of the study population are summarised in Table 1.

Visual field testing

All subjects underwent conventional perimetry with the HFA 24-2 program, followed by HSRP using the Humphrey field analyser model 630. Tests were performed on the same day using the same machine, with the tests separated by a suitable rest period. All perimetry was performed using the full threshold algorithm with standard 4-2 double reversal strategy. Eye movements were continuously monitored using a closed circuit camera in the standard fashion. All fields were reliable, defined as fewer than 30% fixation losses, 30% false negatives and 15% false positives. All subjects were practised perimetric observers.

High spatial resolution perimetry

The technique for performing HSRP has been extensively described in previous publications.^{24 26} To perform HSRP, the “custom grid” program of the HFA was used to define four custom test programs, each consisting of 5×5 locations separated by 2 degrees, with the coordinates of each custom test program offset to the other by 1 degree in the x, y, or x and y axis. Subjects were tested using the four custom test programs applied in succession in a randomised order with a short standardised rest period between each. The test time was approximately 20 minutes, excluding the brief rest between grids, and was tolerated by all subjects.

A size III stimulus was used on a standard HFA bowl illumination of 31.5 apostilbs.

Software was used to merge the four custom test programs to generate a single fine matrix map (FMM) of the thresholds of 100 test locations separated by 1 degree covering an area of 9×9 degrees in the nasal field. This extends from the HFA 24-2 coordinates $-19, -4$ to $-28, 5$ for a right eye, and extends above and below the horizontal midline. The test location overlaps four test points on the HFA 24-2 program (including the two locations in the nasal field at $-27, 3$, and $-27, -3$). Accuracy of fixation is monitored in the same way as conventional perimetry.

HSRP was performed without near correction in accordance with the protocol of our previous studies.^{16 24 27 28} The refraction at this eccentricity is difficult to ascertain and near correction could induce prismatic and edge effects which would be difficult to standardise during the test procedure. However, the distribution of refractive errors was comparable between the groups of eyes tested and did not differ significantly (Table 1).

Analysis

The data were imported to software (SPSS for Windows, release 10, SPSS Inc, Chicago, IL, USA) for statistical analysis. All variables were tested for normality, and analysis of variance (ANOVA) followed by post hoc testing was used to identify

Table 2 Summary statistics of HSRP thresholds by group. Values shown are mean (1 SD) in dB. Figures in parentheses indicated minimum and maximum values

	Normal eyes (20 eyes)	Suspect eyes (17 eyes)	Glaucoma eyes (16 eyes)	Normal v suspect	Normal v glaucoma
Mean threshold (MT)	28.0 (1.7) (24.2–30.4)	25.9 (3.2) (18.8–30.5)	22.1 (4.1) (12.4–27.1)	p < 0.03*	p < 0.001*
Uniformity index (UI)	1.5 (0.2) (1.1–2.1)	2.4 (1.4) (1.2–7.4)	3.8 (1.9) (1.3–8.6)	p < 0.001*	p < 0.001*
Asymmetry index (AI)	0.4 (0.2) (0.0–0.7)	1.2 (2.2) (0.2–8.4)	2.2 (2.3) (0.0–7.5)	p < 0.009*	p < 0.001*

*Mann-Whitney U test.

significant differences between pairs of groups. If data distributions were non-parametric, equivalent non-parametric tests were used. The level of statistical significance was set to $p < 0.05$.

High spatial resolution perimetry

The method of analysis of the threshold data from HSRP has been reported in previous publications.^{16,24} Firstly, the mean threshold of the 100 test locations was calculated to obtain a global summary measure of the thresholds. Two additional measures were calculated to describe the uniformity of thresholds within each FMM, called the uniformity index and the asymmetry index.

The uniformity index is the standard deviation (SD) of the threshold values and gives an overall measure of the degree of uniformity, similar to the pattern standard deviation of the HFA 24-2 test.

The asymmetry index was derived to quantify the degree of threshold difference for each test location in the superior nasal field and its corresponding equivalent location in the inferior nasal field. This index was calculated as the mean of the pairwise threshold differences (superior – inferior) between corresponding locations in the superior and inferior nasal field. In control eyes, differences between the superior and inferior nasal fields were minimal (superior – inferior mean (1 SD) difference = -0.4 (0.4) dB). The negative mean value indicates a minimally higher threshold sensitivity in the inferior field. This difference is a physiological reflection of the anatomical and functional asymmetry of the retina and has been reported previously.³¹ To allow scores to be compared between groups we calculated the “normalised asymmetry index” for each subject, expressed as the absolute difference normalised with respect to the mean difference of the controls.

The normative ranges of the HSRP summary measures (mean threshold, uniformity index, asymmetry index) were investigated for the possible influence of factors such as age and refraction by performing linear regression on the control data. Forward stepwise linear regression was performed separately with each summary measure as the dependent variable using factors such as age, refraction, sex, and eye side as independent variables. Factors that contributed significantly to a linear relation were taken as those with a significance level < 0.05 and $R^2 > 0.1$.

Summary measures uniformity index and asymmetry index were independent of age, refraction, sex, and eye side. For each subject, the uniformity index or asymmetry index was defined as abnormal if it exceeded the upper limit of the 95% confidence limits of the controls (“control limits”) defined as control mean plus or minus $1.96 \times \text{SD}$.

Analysis of mean threshold showed a significant dependence on age ($R^2 = 0.41$, $p = 0.003$) and the normal limits for mean threshold were therefore defined as the 95% individual prediction intervals of the regression analysis of the control data on age.

A scotoma on the HSRP was defined if at least two out of three summary measures were outside control limits.

The presence of scotomata on the HSRP was assessed in relation to the presence or absence of scotoma on the HFA 24-2 field at the test site. This was defined as the presence of at least one of the four HFA 24-2 locations depressed by at least 5 dB from normal age expected values, directly adjacent or within a cluster of a scotoma according to our definition (see Methods). The HFA 24-2 fields were further analysed for the presence of scotoma according to a probabilistic definition, defined as at least one depressed nasal HFA 24-2 location within a hemifield cluster of three or more abnormal points on the pattern deviation plot, with at least one location having a probability of abnormality at $p < 0.01$, and two locations at $p < 0.05$.²⁴

Quantitative analysis was performed on the raw data. However, for display purposes, spatial image processing of the HSRP thresholds was performed using a Gaussian filter to generate three dimensional surface plots in accordance with previous studies.^{16,24}

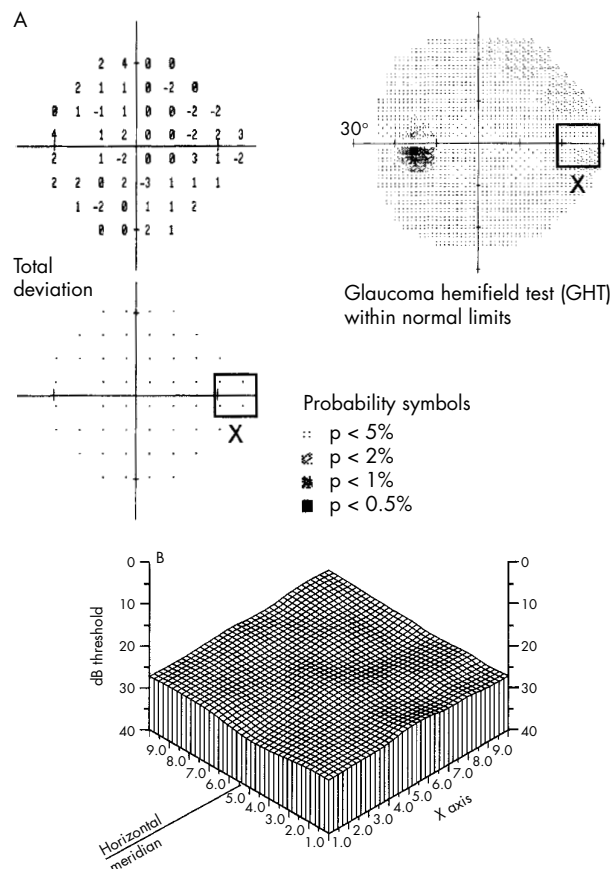


Figure 1 (A) HFA 24-2 from a normal control. Box indicates site of HSRP in nasal field. (B) HSRP matrix map is normal with uniform threshold profile. Areas of scotoma would result in hills and valleys on the threshold plot, and would give rise to a high uniformity index. For the groups, the uniformity index was significantly higher in the glaucomatous eyes ($p < 0.001$) and suspects ($p < 0.001$) compared to controls.

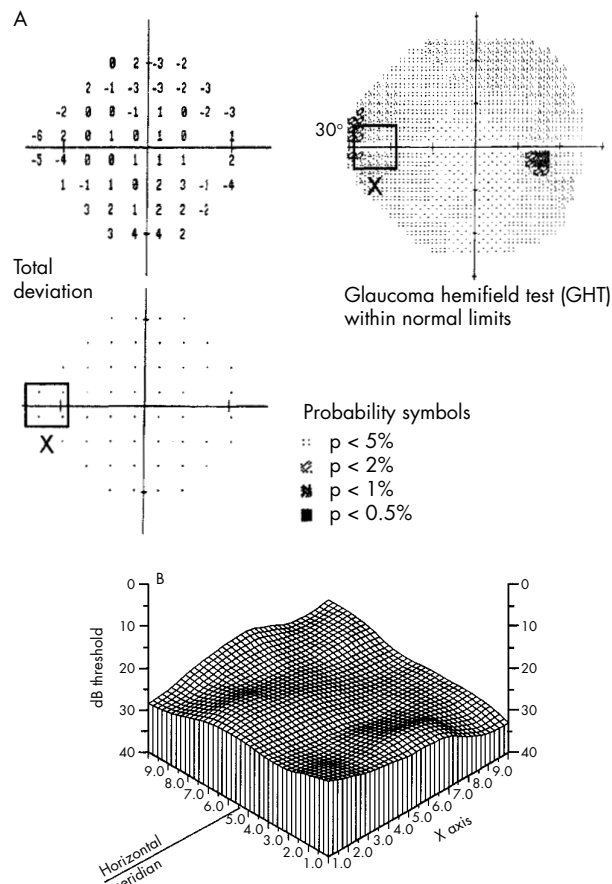


Figure 2 (A) HFA 24-2 from a glaucoma suspect. Box indicates site of HSRP in nasal field within an area of normal HFA 24-2 field. (B) Abnormal HSRP matrix map. Subtle elevations represent areas of abnormally depressed thresholds.

RESULTS

Table 2 shows summary data of the HSRP by group. The mean threshold was significantly lower in the glaucomatous eyes ($p < 0.001$) and suspects ($p = 0.03$) compared with controls.

In controls, threshold plots were uniform and as a consequence the uniformity indices were low (Fig 1).

This non-uniformity of the visual field is shown in the HSRP threshold plots from suspects. Scotoma is shown by elevations and is not apparent at the lower spatial resolution of the HFA 24-2 (Figs 2 and 3).

The threshold asymmetry between the superior and inferior fields, expressed as normalised asymmetry index, was significantly higher in the glaucomatous eyes ($p = 0.001$) and the suspects ($p = 0.009$) (Table 2). This can be seen graphically in the HSRP threshold plot of Figure 3B: the elevations represent reduced threshold sensitivity in the superior compared to inferior nasal field. This is equivalent to the "nasal step" field defect that can be identified with kinetic perimetry.

Although the suspect eyes had significantly lower mean deviation (MD) (Table 1), none had any discernable scotomata on the HFA 24-2 plot according to the conventional 5 dB cluster definition.

However, analysis of the HSRP thresholds showed that summary measures were outside normal limits in 5/17 (mean threshold), 10/17 (uniformity index), and 7/17 (asymmetry index) eyes. In 7/17 (41%) eyes (95% CI 5/17 (29%) to 7/17 (41%)), at least two out of three summary measures were abnormal with evident scotomata on the threshold plots (Fig 2B and 3B). Of these seven eyes, only two had scotoma within the nasal field of HFA 24-2 plot using the probabilistic definition.

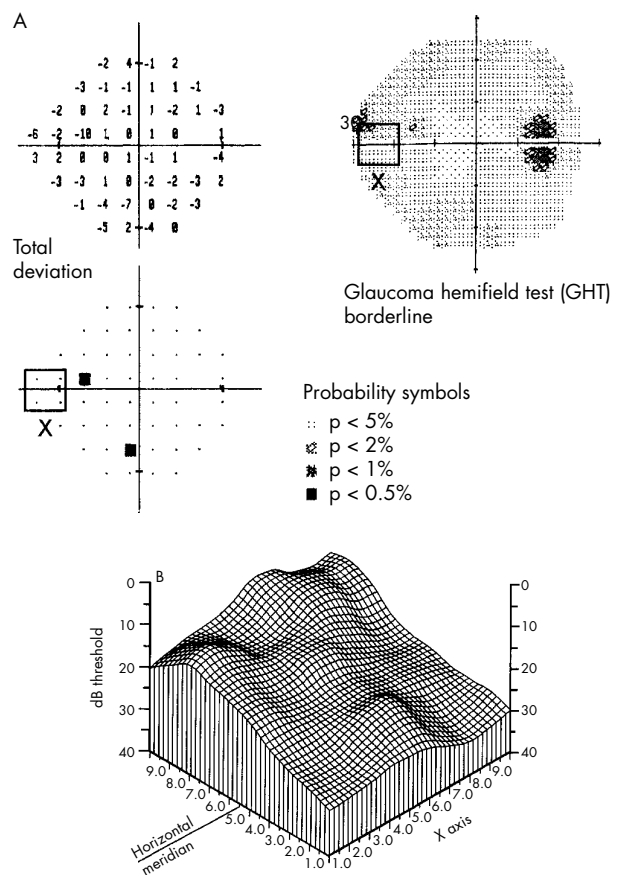


Figure 3 (A) HFA 24-2 from a glaucoma suspect eye. Box indicates site of HSRP in nasal field within an area of normal HFA 24-2 field. (B) Abnormal HSRP matrix map. The greater elevation in the superior nasal field represents reduced threshold sensitivity compared to inferior nasal field. This represents an abnormally high degree of asymmetry in sensitivity between the superior and inferior fields.

In glaucomatous eyes, 15/16 (94%) eyes had HSRP scotomata (95% CI 14/16 (88%) to 15/16 (94%)).

HSRP results were analysed in terms of whether there was a scotoma on the HFA 24-2 field at the test site using the conventional 5 dB definition. The HSRP overlapped an area unaffected by scotoma on the HFA 24-2 at the test site in 4/16 eyes.

Of these, three eyes had scotoma on the HSRP with summary measures outside normal limits. An example is shown in Figure 4: one eye had scotoma on the HFA 24-2 pattern deviation plot according to the probabilistic definition.

The remaining 12 eyes had scotoma extending to the nasal field on the HFA 24-2.

All had abnormal HSRP with at least one summary measure outside normal limits (10/12 (mean threshold), 12/12 (uniformity index), and 9/12 (asymmetry index)).

Eleven of 12 eyes had two or more abnormal summary measures.

For the controls, 19/20 had summary measures within normal cut-offs. One had a uniformity index outside control mean +1.96 SD with normal mean threshold and asymmetry index.

HSRP test times for the suspect and glaucoma groups were 21.6 (4.2) and 23.5 (4.1) minutes (mean (1 SD)) respectively. These were significantly prolonged compared to the control group mean of 17.7 (1.6) minutes ($p < 0.01$). For comparison, HFA 24-2 mean test times were 13.4 (2.6) (suspect group), 13.4 (1.9) (glaucoma group), and 12.5 (1.9) minutes (control group).

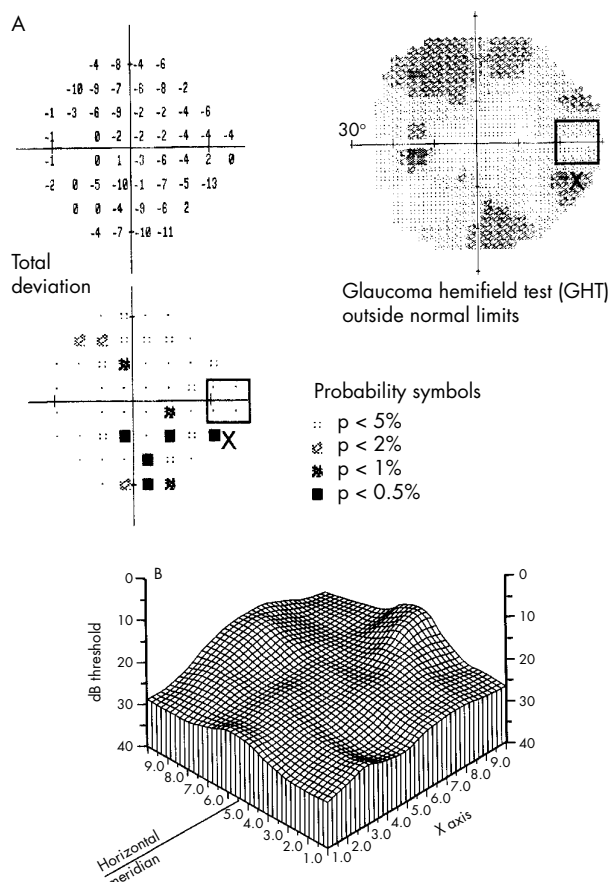


Figure 4 (A) HFA 24-2 from a glaucomatous eye showing inferior arcuate scotoma. Box indicates site of HSRP in nasal field within an area of non-scotomatous HFA 24-2 field. (B) Abnormal HSRP matrix map with scotoma represented by elevations in the threshold plot.

DISCUSSION

The purpose of this study was to examine whether high spatial resolution perimetry (HSRP) can identify fine scale scotomata not apparent with conventional perimetry. The results demonstrate that both suspect and glaucomatous eyes have scotomata in the nasal field which are not apparent at the lower spatial resolution of conventional perimetry. The technique used in this study for performing HSRP encompasses a grid of 9 degrees and can be applied anywhere in the visual field. Previous publications have reported fine scale scotomata in locations other than the nasal visual field—for example, in areas adjacent to an existing scotoma or in areas corresponding to retinal nerve fibre layer (RNFL) defects.^{16, 24} Other researchers have used high spatial resolution perimetry to identify scotomata in glaucoma suspects which are not detected with conventional perimetry.^{21–23}

The major drawback of HSRP is the additional test time required. This disadvantage makes it impractical for routine clinical use. Furthermore, in view of the longer test time, patient fatigue must be considered as a possible cause of poor performance on the HSRP, especially if it is performed after a conventional HFA 24-2 test. Nevertheless, in selected patients, HSRP may be clinically useful as a supplementary method of confirming overt visual field loss in eyes with glaucomatous features such as disc cupping or RNFL defects with normal or equivocal HFA 24-2 fields (so called “pre-perimetric glaucoma”).

Evidence suggests that the nasal field remains a promising site to investigate, as numerous studies have identified nasal field defects as an isolated manifestation of glaucoma using kinetic and static perimetry.^{2–8}

Scotomata in the peripheral nasal field (>30 degrees) have been reported in glaucoma in suspects who appear to have normal central fields, as tested using conventional automated perimetry.^{7, 8} Our findings provide further evidence that the inadequate spatial resolution of conventional perimetry is a principal limitation in detecting early glaucoma.

Our findings also suggest that the nasal field is a worthwhile location to investigate for the early occurrence of visual field loss, and it is worth considering the possible reasons that may account for this.

One factor to consider is the sector of the optic nerve head represented by the nasal field. A recent study has produced a map relating the HFA 24-2 visual field test locations to the corresponding regions of the optic nerve head (ONH).³² According to this map, the paracentral area of the visual field (which includes the nasal region tested in our study) would be represented by sectors nearer the poles of the ONH than previously thought.^{33, 34} Thinning of the neuroretinal rim at the ONH poles is characteristic of glaucoma, and several authors have reported that vertical enlargement of the cup may be an early sign of glaucoma.^{35–37} Vertical expansion of the cup is often noted to be asymmetric.^{37, 38} This may result in notching of the neuroretinal rim if marked asymmetry of expansion occurs towards one of the poles.^{35–40} The frequent occurrence of thinning of the neuroretinal rim in early glaucoma provides a rationale for detailed testing of the nasal field in the absence of overt loss on the 24-2 program of the HFA.

Furthermore this asymmetry of rim thinning is likely to account for the high asymmetry of threshold identified between the inferior and superior nasal fields in glaucomatous eyes. Other researchers have reported high degrees of threshold asymmetry in the nasal field in glaucoma.^{5, 31}

Potential sources of bias and error

The sample sizes in this study were relatively small and consequently the cut-off values used to define the normal control limits are likely to be significantly dependent on the sample sizes and the exclusion and inclusion criteria used. This must be recognised as a potential source of bias. Both control and glaucoma groups were enrolled from an ongoing study (the Moorfields Ocular Hypertension study) and the controls would have been selected on the basis of a repeatedly normal field. Selecting controls on the basis of a normal field is a possible source of selection bias that may overemphasise the true differences between the groups. Bias could have been minimised if an independent measure, such as the optic disc, had been used to classify the normal, suspect, and glaucomatous groups. However this is still problematic because of the lack of any agreed standard for reliably classifying subjects into normal or abnormal using quantitative disc analysis.

A further source of bias to consider is sampling bias. In our study, HSRP sampled the area of field many more times than the 24-2 program of the HFA (100 versus 4). Testing many more locations in areas where there is likely threshold variability associated with early disease increases the likelihood of discovering defects.

The final potential source of error is the influence of refractive error on the HSRP thresholds in the nasal field. While the influence of refractive error cannot be excluded, there are reasons to suppose that it is unlikely to be a major factor in accounting for the differences between the groups. Firstly, the refractive errors of the subject groups were equivalent. Secondly, our analysis did not identify any relation between HSRP thresholds and the degree of refractive error in the controls. Thirdly, previous studies have shown that in general, the effect of refractive error is to globally suppress field sensitivities.⁴¹ However, two of the HSRP indices this study used reflect focal sensitivity differences, either within the entire area of field tested (uniformity index) or across the superior and inferior fields (asymmetry index). Refractive

errors would not be expected to account for these localised threshold abnormalities, as in general the effect of refractive error is to smear out localised abnormalities.

In summary, a substantial proportion (88%) of glaucomatous eyes and 41% of glaucoma suspects had fine scale scotomata in the nasal field identified with our technique. These may be missed by the low spatial resolution of conventional perimetry. Longitudinal follow up is under way to identify whether those eyes with fine scale scotomata are more likely to develop enlargement of scotomata which can be detected with conventional perimetry.

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REFERENCES

- Rönne H. Ueber das Gesichtsfeld beim Glaukom. *Klin Monatsbl Augenheilkd* 1909;**47**:12–33.
- Armaly MF. Visual field defects in early open angle glaucoma. *Trans Am Ophthalmol Soc* 1971;**60**:147–62.
- LeBlanc EP, Becker B. Peripheral nasal field defects. *Am J Ophthalmol* 1971;**72**:415–19.
- Drance SM, Susanna R, Fairclough M. Early defects in the visual field in glaucoma. *Klin Monatsbl Augenheilkd* 1978;**173**:519–23.
- Zingirian M, Calabria G, Gandolfo E. The nasal step in normal and glaucomatous visual fields. *Can J Ophthalmol* 1979;**14**:88–94.
- Werner EB, Beraskow J. Peripheral nasal field defects in glaucoma. *Ophthalmology* 1979;**86**:1875–8.
- Caprioli J, Spaeth GL. Static threshold examination of the peripheral nasal visual field in glaucoma. *Arch Ophthalmol* 1985;**103**:1150–4.
- Stewart WC. Static versus kinetic testing in the nasal peripheral field in patients with glaucoma. *Acta Ophthalmol (Copenh)* 1992;**70**:79–84.
- Zeyen TG, Caprioli J. Progression of disc and field damage in early glaucoma. *Arch Ophthalmol* 1993;**111**:62–5.
- Wollstein G, Garway-Heath DF, Poinoosawmy D, et al. Glaucomatous optic disc changes in the contralateral eye of unilateral normal pressure glaucoma patients. *Ophthalmology* 2000;**107**:2267–71.
- Quigley HA, Dunkelberger GR, Green WR. Retinal ganglion cell atrophy correlated with automated perimetry in human eyes with glaucoma. *Am J Ophthalmol* 1989;**107**:453–64.
- Fitzke FW, Poinoosawmy D, Ernst W, et al. Peripheral displacement thresholds in normals, ocular hypertensives and glaucoma. In: Greve EL, Heijl A, eds. *Seventh international visual field symposium*. Dordrecht: Martinus Nijhoff, 1987:447–52.
- Casson EJ, Johnson CA, Shapiro LR. Longitudinal comparison of temporal-modulation perimetry with white-on-white and blue-on-yellow perimetry in ocular hypertension and early glaucoma. *J Opt Soc Am A* 1993;**10**:1792–806.
- Johnson CA, Adams AJ, Casson EJ, et al. Blue-on-yellow perimetry can predict the development of glaucomatous visual field loss. *Arch Ophthalmol* 1993;**111**:645–50.
- Baez KA, McNaught AI, Dowler JG, et al. Motion detection threshold and field progression in normal tension glaucoma. *Br J Ophthalmol* 1995;**79**:125–8.
- Westcott MC, Fitzke FW, Hitchings RA. Abnormal motion displacement thresholds are associated with fine scale luminance sensitivity loss in glaucoma. *Vis Res* 1998;**38**:3171–80.
- Chauhan BC, House PH, McCormick TA, et al. Comparison of conventional and high-pass resolution perimetry in a prospective study of patients with glaucoma and healthy controls. *Arch Ophthalmol* 1999;**117**:24–33.
- Sample PA, Bosworth CF, Blumenthal EZ, et al. Visual function-specific perimetry for indirect comparison of different ganglion cell populations in glaucoma. *Invest Ophthalmol Vis Sci* 2000;**41**:1783–90.
- Quigley HA, Dunkelberger GR, Green WR. Chronic human glaucoma causing selectively greater loss of large optic nerve fibers. *Ophthalmology* 1988;**95**:357–63.
- Johnson CA. Selective versus nonselective losses in glaucoma. *J Glaucoma* 1994;**3**:S32–44.
- Airaksinen PJ, Heijl A. Visual field and retinal nerve fibre layer in early glaucoma after optic disc haemorrhage. *Acta Ophthalmol (Copenh)* 1983;**61**:186–94.
- Weber J, Dobek K. What is the most suitable grid for computer perimetry in glaucoma patients? *Ophthalmologica* 1986;**192**:88–96.
- Tuulonen A, Lehtola J, Airaksinen PJ. Nerve fiber layer defects with normal visual fields. Do normal optic disc and normal visual field indicate absence of glaucomatous abnormality? *Ophthalmology* 1993;**100**:587–97.
- Westcott MC, McNaught AI, Crabb DP, et al. High spatial resolution automated perimetry in glaucoma. *Br J Ophthalmol* 1997;**81**:452–9.
- Chuang EL, Sharp DM, Fitzke FW, et al. Retinal dysfunction in central serous retinopathy. *Eye* 1987;**1**:120–5.
- Fitzke FW, Kemp CM. Probing visual function with psychophysics and photochemistry. *Eye* 1989;**3**:84–9.
- Chen JC, Fitzke FW, Bird AC. Long-term effect of acetazolamide in a patient with retinitis pigmentosa. *Invest Ophthalmol Vis Sci* 1990;**31**:1914–18.
- Chen JC, Fitzke FW, Pauleikhoff D, et al. Functional loss in age-related Bruch's membrane change with choroidal perfusion defect. *Invest Ophthalmol Vis Sci* 1992;**33**:334–40.
- Graham SL, Drance SM, Chauhan BC, et al. Comparison of psychophysical and electrophysiological testing in glaucoma. *Invest Ophthalmol Vis Sci* 1996;**37**:2651–62.
- Collaborative Normal-Tension Glaucoma Study Group. The effectiveness of intraocular pressure reduction in the treatment of normal-tension glaucoma. *Am J Ophthalmol* 1998;**126**:498–505.
- Jenni A, Hirsbrunner HP, Fankhauser F. The nasal step in the normal and glaucomatous visual field. In: Heijl A, ed. *Perimetry update*. Amsterdam: Kugler & Ghedini, 1989:305–11.
- Garway-Heath DF, Poinoosawmy D, Fitzke FW, et al. Mapping the visual field to the optic disc in normal tension glaucoma eyes. *Ophthalmology* 2000;**107**:1809–15.
- Wirtschafter JD, Becker WL, Howe JB, et al. Glaucoma visual field analysis by computed profile of nerve fiber function in optic disc sectors. *Ophthalmology* 1982;**89**:255–67.
- Weber J, Dannheim F, Dannheim D. The topographical relationship between optic disc and visual field in glaucoma. *Acta Ophthalmol (Copenh)* 1990;**68**:568–74.
- Kirsch RE, Anderson DR. Identification of the glaucomatous disc. *Trans Am Acad Ophthalmol Otolaryngol* 1973;**77**:OP143–56.
- Gloster J. Vertical ovalness of glaucomatous cupping. *Br J Ophthalmol* 1975;**59**:721–4.
- Portney GL. Photogrammetric analysis of the three-dimensional geometry of normal and glaucomatous optic cups. *Trans Am Acad Ophthalmol Otolaryngol* 1976;**81**:239–46.
- Read RM, Spaeth GL. The practical clinical appraisal of the optic disc in glaucoma: the natural history of cup progression and some specific disc-field correlations. *Trans Am Acad Ophthalmol Otolaryngol* 1974;**78**:OP255–74.
- Spaeth GL, Hitchings RA, Sivalingam E. The optic disc in glaucoma: pathogenetic correlation of five patterns of cupping in chronic open-angle glaucoma. *Trans Am Acad Ophthalmol Otolaryngol* 1976;**81**:217–23.
- Hitchings RA, Spaeth GL. The optic disc in glaucoma. I: Classification. *Br J Ophthalmol* 1976;**60**:778–85.
- Goldstick BJ, Weinreb RN. The effect of refractive error on automated global analysis program G-1. *Am J Ophthalmol* 1987;**104**:229–32.



Use of high spatial resolution perimetry to identify scotomata not apparent with conventional perimetry in the nasal field of glaucomatous subjects

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