The Structure-Function Relationship in Eyes With Glaucomatous Visual Field Loss That Crosses the Horizontal Meridian

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Objective: To evaluate the relationship between visual field loss and glaucomatous optic discs in eyes in which field loss spreads across the horizontal meridian.

Subjects and Methods: Ninety-six patients with glaucoma (9 advanced, 60 moderate, and 27 early) with 2 successive abnormal fields were included. Standard achromatic automated perimetry defects were identified with a nerve fiber bundle map to identify abnormal sectors. Crossover was present if the superior and inferior sectors at the horizontal meridian (nasal, central, or temporal) were both abnormal. Optic disc damage was assessed by masked grading of simultaneous stereophotographs.

Results: Only 30% (29) of glaucomatous eyes showed crossover, and only 2 of those eyes had early loss. The most frequent pattern of visual field loss (41% of eyes) was single hemifield damage with defects in contiguous sectors. Regardless of the pattern or severity of visual loss, most eyes (66 [69%] of 96) had both superior and inferior optic disc damage.

Conclusions: Early glaucomatous visual field loss rarely crosses the horizontal meridian, but defects in both hemifields at the horizontal meridian are more common in more advanced field loss. In 26 (90%) of 29 eyes with crossover, it could be explained by changes at the optic nerve head.

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It is commonly thought that visual loss does not progress across the horizontal meridian until the later stages of glaucoma. That is, visual loss is believed to spread within a hemifield until the disease is more advanced. To our knowledge, no studies employing automated static threshold tests have explicitly addressed how often visual field loss spreads across the horizontal meridian in patients with glaucoma.

Visual field loss correlates with the appearance of the optic disc and retinal nerve fiber layer, and functional defects are topographically related to these structural changes. Simultaneous stereophotographs are commonly used in the clinical setting to evaluate optic disc integrity and monitor progression of glaucomatous optic neuropathy. Optic disc damage identified by stereophotographs correlates with functional loss, and field defects have been predicted based on optic disc photographs.

The purpose of the present study was to determine the frequency of visual field defects that cross at the horizontal meridian on standard automated perimetry and to relate this pattern to optic disc abnormalities on stereophotographs in eyes with early, moderate, and advanced glaucoma.

Overall, visual field defects spread across the horizontal meridian in only 29 (30%) of 96 eyes. Crossover was rare in eyes with early loss (2 [7%] of 27) and relatively more common in eyes with moderate (21 [35%] of 60) and advanced (6 [67%] of 9) visual loss. When visual loss did spread across the horizontal meridian, 20 (69%) of 29 eyes had crossover in the nasal region and 18 (62%) of these eyes had contiguous defects.

The most common pattern of loss among the 96 eyes was a pattern of de-
SUBJECTS AND METHODS

SUBJECTS

We performed a retrospective analysis of visual field data from a prospective longitudinal study of patients with primary open-angle glaucoma at the University of California, San Diego, Glaucoma Center. All patients gave informed consent to participate in this research, and the study was approved by the University of California, San Diego, Human Subjects Committee and conformed to the Declaration of Helsinki.

Each subject underwent a complete ophthalmological examination, which included a review of the relevant medical history, best-corrected visual acuity, slitlamp biomicroscopy (including gonioscopy), applanation tonometry, dilated funduscopy, and fundus photography. Patients had to have a best-corrected visual acuity of 20/40 or better, a spherical refraction within ±5.0 diopters (D), and a cylinder within ±3.0 D. Patients were excluded if they had a history of intraocular surgery (except uncomplicated cataract surgery), other intraocular diseases, other diseases affecting the visual field (pituitary lesions, demyelinating diseases, acquired immunodeficiency syndrome, or diabetes mellitus), a “generalized depression” or “sensitivity too high” result on the Glaucoma Hemifield Test, or problems other than glaucoma affecting color vision.

Standard automated perimetry with a Goldmann size III (0.43°) stimulus on a 31.5-apostilb background was performed. The Humphrey 24-2 program (Humphrey-Zeiss, Dublin, Calif) was used for perimetric testing. Of the 256 patients with glaucoma, 96 eyes from 96 patients had 2 successive abnormal and reliable standard visual fields and met the inclusion and exclusion criteria outlined above. Visual fields were reliable if they had false-positive, false-negative, and fixation losses of 25% or less. A visual field was designated abnormal if the corrected-pattern SD was outside 93% or the Glaucoma Hemifield Test was outside 99.3% of age-specific norms. Except when otherwise stated, the results are based on the first 2 abnormal fields to show spread of visual loss across the horizontal meridian. When crossover was not present, we used the first 2 abnormal visual fields available from each patient. The mean ± SD number of years between the 2 visual field tests was 0.89 ± 0.77. We determined the severity of visual loss on the first of the 2 fields included in the study for each patient. There were 27 early, 60 moderate, and 9 advanced cases (Table 1). Age ranged from 29 to 88 years with a mean ± SD of 63.7 ± 12.0 years.

PROCEDURE

For each visual field, we identified which field sectors were abnormal on a perimetric nerve fiber bundle map described by Weber et al.11,14 (Figure 1). This map was derived empirically from the analysis of a large number of patients with localized nerve fiber layer and wedge defects. Visual field locations corresponding to the same retinal nerve fiber bundle are grouped into sectors. The map was slightly modified from the original by combining adjacent sectors containing single visual field locations (labeled sectors 1/2, 9/10, 12/13, and 20/21). This reduced the overemphasis on sectors with only 1 field location. Sectors with only 2 visual field locations (ie, sectors 20/21, 1/2, 3, 19, and 18) had to have at least 1 of the visual field locations at a pattern deviation of less than 5% for the sector to be abnormal. For the remaining sectors, 2 or more visual field locations within the sector with a pattern deviation of less than 5% were necessary for the sector to meet the criteria for abnormality.

Characterizing the Pattern of Visual Loss

After mapping the visual field defects, we determined whether visual loss had spread across the horizontal meridian (hereafter referred to as crossover). Crossover was present if (1) both the superior and inferior sectors adjacent to the horizontal meridian were abnormal in the nasal (sectors 8 and 14), central (sectors 9/10 and 12/13), and/or temporal regions (sectors 20/21 and 1/2) (Figure 2) and (2) crossover was repeated in the same region on both fields. We also determined whether additional areas of field defects were in adjacent perimetric nerve fiber bundles or spatially separated regions of the field. We identified 5 patterns of visual loss (Figure 3): A, crossover with contiguous defects; B, no crossover with contiguous defects; C, crossover with noncontiguous defects; D, no crossover with noncontiguous defects; and E, no confirmed defects.

Optic Disc Stereoscopic Photographs

Simultaneous stereoscopic photographs (Topcon Simultaneous Stereo Camera TRC-SS; Topcon America Corp, Paramus, NJ) were obtained for all patients and reviewed with a simultaneous stereoscopic viewer. Masked simultaneous stereophotographs closest to the visual field date were examined independently for excavation, focal, and diffuse rim-thinning and nerve fiber layer defects by at least 2 experienced reviewers (C.V. and A.G.B.). In cases of disagreement, consensus was reached by 2 graders. The superior and/or inferior optic discs were designated abnormal if excavation, rim-thinning, and/or nerve fiber layer defects were present in that hemifield. The decisions of the senior grader were employed in cases of disagreement about the location of the abnormality. This was necessary in only 6 of 96 eyes. The mean ± SD number of years from the date of the stereophotographs to the date of the field used was 0.38 ± 0.51 years.
graphs revealed rim thinning and/or excavation in both superior and inferior segments of the optic disc in all but 2 (11%) of these 18 eyes (Table 3). Of those 2 eyes, 1 had a normal stereophotograph, and 1 had primarily an inferior field defect and inferior rim thinning of the optic disc. The eye with a primarily inferior field defect was also the only case of early visual loss in this group. The majority of eyes (14 [78%]) had moderate loss, whereas 3 eyes (17%) had advanced loss.

Similarly, a pattern of crossover with noncontiguous defects (pattern C) might be expected to be associated with damage to both superior and inferior optic discs. Damage was present in both the upper and lower optic discs of these eyes (Table 3). Three of the remaining eyes had normal stereophotographs. One eye had defects in both superior and inferior visual fields but only inferior optic disc damage. One eye showed primarily an inferior visual field defect but superior optic disc damage. This patient had early visual loss. Most of these eyes (7 [64%] of 11) had moderate visual loss. Twelve (13%) of the 96 eyes had normal stereophotographs. Eyes with a pattern of noncontiguous defects with crossover (Figure 3C) had a higher frequency of normal stereophotographs than the other patterns (27% of eyes) (Table 3 and Table 4).

**COMMENT**

It is rare for defects to spread across the horizontal meridian in early glaucoma (only 2 [7%] of 27 eyes had early visual loss). Of the 2 eyes with early visual loss and crossover, 1 eye had a primarily inferior field defect with inferior optic disc damage, and 1 eye had a primarily inferior field defect with superior optic disc damage. Even in the group as a whole, crossover was relatively uncommon in the patients with glaucoma (30% of eyes). When visual loss did spread across the horizontal meridian, crossover typically occurred in the nasal region and was associated with damage to both superior and inferior optic discs, and defects were often also in contiguous perimetric nerve fiber bundles. It should be noted that we specifically chose visual fields that showed crossover if this pattern was evident on any of the patient’s visual fields. Our results will reflect this selection process.

The most common pattern of visual loss showed defects in contiguous sectors that did not cross at the horizontal meridian. Defects in field locations testing arcuate and nasal nerve fiber bundles were most frequent in these eyes, reflecting the classic glaucomatous arcuate, paracentral, and nasal step defects.16–20 As previously reported, defects near the horizontal meridian in the temporal visual field were relatively uncommon, and field loss was more common in the upper than the lower hemifield for eyes with this pattern of loss.1,20 Damage to the nasal side of the disc (temporal visual field) might be more likely to affect vision above and below the horizontal me-
7 (18%) of 39 eyes with early focal visual field loss had
in some patients. For instance, Emdadi et al23 noted that
be apparent on visual fields prior to structural changes
normal stereophotographs. Glaucomatous changes may
13% of eyes with confirmed abnormal visual fields had
This issue directly. However, in the present study,
confirmed visual field loss, we cannot ad-
superior and inferior field defects were equally fre-
for observing crossover. With the other patterns of loss,
 temporibus visual field defects were relatively un-
common, and the 24-2 test pattern only tests 4 locations
in the temporal field, so there were fewer opportunities
for observing crossover. With the other patterns of loss,
superior and inferior field defects were equally fre-
quent.

Previous studies have noted that optic disc abnor-
malities precede visual field loss.21-22 Because all eyes in
this study had confirmed visual field loss, we cannot ad-
dress this issue directly. However, in the present study,
13% of eyes with confirmed abnormal visual fields had
normal stereophotographs. Glaucomatous changes may
be apparent on visual fields prior to structural changes
in some patients. For instance, Emdadi et al23 noted that
7 (18%) of 39 eyes with early focal visual field loss had

*Data given as number (percentage) of eyes.

no detectable optic nerve damage by confocal scanning
laser ophthalmoscopy.

It has been proposed that progressive field loss
may sometimes be due to additional retinal ganglion
cell death by secondary factors resulting from the death
of neighboring ganglion cells,24-29 although not every-
one agrees.30 In this case, one might expect early visual
field loss near the horizontal meridian to more readily
progress to the adjacent hemifield. Crossover might
then be associated with damage only to the superior or
inferior optic disc. It should be noted that atrophy at
the optic disc following secondary degeneration of reti-
nal ganglion cells is difficult to distinguish from pri-
mary loss at the optic disc. Only 1 patient showed this
pattern of loss, and the patient had early visual loss.
There was, therefore, little evidence in the present study
of the effects of retinal secondary neurodegeneration on
the standard automated perimetry fields. With current
visual field techniques, secondary degeneration might
be hard to detect against the background of primary
loss. A visual function–specific test, such as short-
wavelength automated perimetry or frequency-doubling
technology, which is more sensitive than standard auto-

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Table 3. Relationship Between Presence or Absence of Contiguous Defects and Structural Damage in 29 Eyes With Crossover*

<table>
<thead>
<tr>
<th>Crossover Location</th>
<th>Stereophotographs of the Optic Disc, No. of Eyes</th>
<th>Visual Field</th>
<th>One Hemifield, Rim Thinning</th>
<th>Both Hemifields, Rim Thinning</th>
<th>Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contiguous</td>
<td></td>
<td>Superior</td>
<td>Inferior</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Superior</td>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Both hemispheres</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Noncontiguous</td>
<td></td>
<td>Superior</td>
<td>2</td>
<td>1 Superior</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Superior</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Both hemispheres</td>
<td>7</td>
<td>1 Inferior</td>
<td>1</td>
</tr>
</tbody>
</table>

*Crossover is used to mean if visual loss had spread across the horizontal meridian.

Table 4. Relationship Between Presence or Absence of Contiguous Defects and Structural Damage in 55 Eyes Without Crossover*

<table>
<thead>
<tr>
<th>Defects Location</th>
<th>Stereophotographs of the Optic Disc, No. of Eyes</th>
<th>Visual Field</th>
<th>One Hemifield, Rim Thinning</th>
<th>Both Hemifields, Rim Thinning</th>
<th>Normal</th>
</tr>
</thead>
<tbody>
<tr>
<td>No crossover, contiguous</td>
<td></td>
<td>Inferior†‡</td>
<td>13</td>
<td>1 Superior</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Superior†‡</td>
<td>26</td>
<td>5 Inferior</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Both hemispheres</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>No crossover, noncontiguous</td>
<td></td>
<td>Inferior†‡</td>
<td>3</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Superior†‡</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Both hemispheres</td>
<td>11</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>No defective sectors</td>
<td></td>
<td>None†‡</td>
<td>12</td>
<td>1 Inferior</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 Superior</td>
<td>2</td>
</tr>
</tbody>
</table>

*Crossover is used to mean if visual loss had spread across the horizontal meridian.
†One stereophotograph was of unacceptable quality.
‡Three stereophotographs were of unacceptable quality.

References