peared much easier to flatten than the stroma. It appeared relatively easy to flatten the swollen elevated epithelium with a small force that did not mirror the true intraocular pressure. The Goldmann applanation tonometer when applied to edematous corneas almost always read low, and errors between 10 and 30 mm. Hg were not uncommon. The Goldmann instrument unquestionably represented the standard of accuracy in patients with normal corneas but was misleading when the circular reflexes were even slightly irregular due to corneal edema.

REFERENCES

The glaucomatous visual field

Stephen M. Drance

Key words: visual field defects, chronic simple glaucoma, nerve fiber bundle defects, profile static perimetry

The characteristic visual field defects in chronic simple glaucoma occur as a result of damage to bundles of nerve fibers. Chronic simple glaucoma, while the most frequent cause, is not the only cause of nerve fiber bundle defects. The many
Fig. 1. Upper baring of the blind spot in a patient with slight lens opacity but no evidence of glaucoma. The profile perimetry 135 to 315 degrees shows a slightly lower sensitivity to light in the upper temporal part of the visual field but no evidence of a nerve fiber bundle defect.

causes of such defects have been divided by Harrington\textsuperscript{1} into those occurring at the disc and those resulting from lesions of the anterior nerve and lesions of the posterior nerve and chiasm (Table I). It is therefore important to bear in mind that not all arcuate scotomata are due to glaucoma.

A knowledge of the visual field changes and their progression in chronic simple glaucoma is necessary in order that appropriate perimetric techniques can be used to delineate the earliest nerve fiber bundle defects which indicate glaucomatous damage and to plot the size and density of such defects so that progression can be accurately recorded.

The recent advances of profile, static perimetry have enabled the re-evaluation of the glaucomatous visual field because these tests, although time consuming, give more reproducible results and smaller defects can be accurately recorded. It must be stressed, however, that all changes in the visual field can be found by painstaking quantitative kinetic perimetry on the tangent screen, providing the appropriate areas are searched in appropriate manner to allow the detection of small defects.

Baring of the blind spot has been described as one of the early changes of the glaucomas, but as has been shown by the work of Aulhorn and Harms\textsuperscript{2} and Drance and associates,\textsuperscript{3} the area around the blind spot has the flattest slope, and therefore threshold targets can be made to bare the blind spot in a nonspecific fashion. Targets which are suprathreshold in youth may become threshold due to miosis, lens opacity, refractive error, and aging in the same individual at a later stage in life. It is therefore quite feasible,
Fig. 3. Dense relative paracentral scotoma in the Bjerrum region above the blind spot. The scotoma is surrounded by a less-dense scotoma, separated from the blind spot as shown in the circular static perimetry (lower right), with a circumferential course.

Table I. Lesions producing arcuate scotomata

<table>
<thead>
<tr>
<th>Lesions at the disc</th>
<th>Lesions of the anterior nerve</th>
<th>Lesions in the posterior nerve and chiasm</th>
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<tbody>
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<td>1. Juxtapapillary choroiditis</td>
<td>1. Ischemic infarct and segmental atrophy in the optic nerve due to arterial occlusion</td>
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<tr>
<td>2. Myopia and peripapillary atrophy</td>
<td>2. Carotid and ophthalmic artery occlusion</td>
<td>1. Meningioma at the optic foramen</td>
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<td>3. Coloboma and pits of the optic nerve head</td>
<td>3. Cerebral arteritis</td>
<td>2. Meningioma of the dorsum sellae</td>
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<td>5. Papilledema with increased intracranial pressure</td>
<td>5. Electric shock</td>
<td>4. Opticochiasmatic arachnoiditis</td>
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<td>7. Papillitis</td>
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<td>8. Retinal arterial plaque on the disc</td>
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<td>9. Papilledema in malignant hypertension</td>
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<td>10. Occlusion of central retinal artery</td>
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with standard targets, to produce baring of the blind spot, and this is usually present superiorly. It is in fact true that if one can find the appropriate threshold target, one can bare the blind spot in almost any normal eye (Fig. 1).

Baring of the blind spot does accompany nerve fiber bundle defects, but it is a change which is not specific enough to be useful in the detection of early glaucoma unless it is accompanied by a method of examination which determines the appearance of the nerve fiber bundle defect responsible for the baring.

Relative scotomata arising from blind spots and therefore producing baring of
the blind spot to a particular isopter, situated superonasally but not reaching the nasal horizontal meridian, can be due to a refraction scotoma. This always occurs in myopic individuals in whom the lower part of the fundus has an unusually pale appearance, and there is often an inferior conus or other congenital abnormality of the nerve head. The addition of concave lenses to those necessary for axial correction abolish these scotomata (Fig. 2).

Nerve fiber bundle defects

Sector-shaped defects in the visual field are nerve fiber bundle defects. In chronic simple glaucoma, the superotemporal and inferotemporal parts of the nerve head seem to be most vulnerable to damage. Other parts of the nerve head may also be damaged. The nerve fiber bundle defects most frequently involve the arcuate fibers which arch above and below the fovea. These fibers end along the horizontal meridian which extends from fixation to the nasal periphery of the field. Peripheral field defects along the nasal horizontal meridian should always be searched for. Sector-shaped scotomata elsewhere in the field should also be kept in mind. The size, shape, and location of the nerve fiber bundle scotoma will depend on the extent and site of the damage to nerve fiber bundles at the optic nerve head.

Paracentral circumscribed defects can occur either in the temporal or in the nasal part of the Bjerrum area and tend to be elongated circumferentially along the course of the nerve fibers. On the temporal side of the central field, they classically occur in the Bjerrum region between 10 and 20 degrees from fixation in
the area which constitutes the upward or downward arcuate projection of the appropriate pole of the blind spot (Fig. 3). On the nasal side, the scotomata can come almost to fixation (Fig. 4) or alternately be as much as 20° or even 30° away from fixation (Fig. 5). The Bjerrum region on the nasal side is very wide in accordance with the course of the arcuate fibers. The defects are often absolute when first discovered or show deep relative nuclei surrounded by areas of less dense involvement. Dense nuclei are often multiple and lie along the course of nerve fibers (Fig. 6). Paracentral scotomata are often delineated by the nasal horizontal meridian (Fig. 7). A relative disturbance can be traced to a varying extent toward the blind spot indicating its arcuate nature (Fig. 8).

With the use of static profile perimetry absolute or deep relative scotomata can be plotted in the course of the nerve fiber bundles which terminate in the horizontal nasal meridian at the site of a nasal step (Fig. 9). The shape of the nasal step and its width depend on many factors. In the periphery of the visual field, the nasal steps are often wedge shaped (Fig. 10). In the midperiphery they tend to be more like a right angle (Fig. 11). Closer to fixation, the nasal steps assume the characteristics of an obtuse angle, and this is consistent with the shape of the nerve fiber bundles reaching the horizontal nasal meridian at that point (Figs. 10 and 11). Nasal steps are not necessarily found in all isopters (Fig. 11). The width of the nasal step in degrees is also variable and no arbitrary rule which assigns significance to a particular size of nasal step is strictly accurate. Nasal steps are frequently found in association with arcuate or paracentral scotomata, and are only rarely (1.6 per cent) significant isolated findings. When facilities for accurate analysis of the central field do not exist, nasal steps in the periphery may appear to be the only signs of damage, but in reality they should point to more exhaustive analysis and a search of the central field. They are also useful corroborative signs when other defects are doubtful. The finding and significance of nasal steps in the central and peripheral field should not be underrated. The peripheral field is unfortunately neglected in glaucoma work.

An arcuate scotoma in the temporal
portion of the field is narrower because all nerve fiber bundles converge onto the nerve head. It becomes wider on the nasal side and may come almost to fixation along the nasal horizontal meridian. The scotoma can be very wide along this meridian. It is often accompanied by nuclei, separate from it, situated along the nasal horizontal meridian peripherally to the arcuate scotoma. Such scotomata may be responsible for nasal steps in the peripheral isopters (Figs. 7 and 12). The arcuate scotoma, bounded by its clear-cut nasal horizontal border, often extends to the blind spot. It may be separated from the blind spot by an area of normal function (Fig. 8) or alternately joined to the blind spot by an area of relative impairment. Arcuate scotomata do not usually arise from the blind spot and, when they extend to the blind spot, are not densest at the blind spot. Arcuate scotomata above and below form ring scotomata and usual-

ly show a nasal horizontal step between them. Occasionally arcuate scotomata cease abruptly at the vertical meridian but any scotomata with vertical edges should be treated with suspicion, as they may be produced by neurologic lesions involving the visual pathways.

There has been little interest in sector-shaped defects other than the Bjerrum scotoma which breaks through to the periphery. The reason for this is that by far the most frequent changes occur in the nasal field. The presence of sector-shaped defects, which extend toward the periphery of the visual field but not along the nasal horizontal meridian, must be borne in mind (Figs. 13 to 15). This is particularly true of the temporal field, where normal perimetric procedures often do not search the peripheral field. Temporal peripheral sector-shaped defects are more
commonly missed than are nasal ones. The shape of the sector scotomata corresponds exactly to the course of the nerve fibers and may, if the appropriate bundles are involved, have a temporal horizontal boundary (Fig. 14). In view of the difference in course of the nerve fiber bundles on the temporal side of the field, a horizontal delineation occurs much less frequently than on the nasal side.

**Method of screening for the presence of glaucomatous visual field defects**

Any method which is designed to screen for early visual field defects in glaucoma must have a high sensitivity, which means that it must detect as many of the visual field defects present as possible and it must also have a high specificity so that not too many false positives are produced by the screening procedure. The
method must be rapid, nontiring to the patient, and easily reproducible. Armaly described such a screening method which involves the use of the Goldmann perimeter with threshold targets. It consists of plotting the blind spot and 72 points in the central field, so that defects are likely to be picked up as abnormal responses (Fig. 16). The technique was modified by Rock and associates to include the more peripheral nasal portions of the visual field, because peripheral nasal steps, which occur commonly, were missed. This method was recently evaluated in people with no visual field defects and in glaucomas with early and advanced visual field defects. The screening method was found to have a very high specificity (87 per cent) and also a high sensitivity (90 per cent). It was easy to perform and took approximately five minutes for each eye.

The Friedmann field analyzer is also suitable for glaucomatous screening. The screening technique, as described, can
Fig. 13. Glaucoma field showing upper arcuate scotoma. There is an absolute sector-shaped scotoma inferiorly encroaching on the nasal and temporal field.

Fig. 14. Glaucoma field showing temporal sector defect with a horizontal border. The nasal field shows no defect.
also be done on the tangent screen providing one can make targets disappear. This can be done by having a flat wand with the target on one of its sides so that by turning the wand the target can be hidden from the patient.

**Progression of the visual field**

Progression of the visual field defect in chronic simple glaucoma may be due to sudden, steplike, fresh nerve fiber bundle defects. These are most likely to occur in proximity to previous defects, as the affected part of the optic nerve head is poorly perfused and vulnerable to further changes. Fresh absolute or deep relative nuclei in the course of the same nerve fiber bundle coalesce and convert isolated paracentral scotomata into arcuate scotomata (Figs. 17 and 18). Damage to adjacent nerve fiber bundles results in widening of the original field defect. Widening toward the periphery can lead to a breakthrough of the scotoma toward the peripheral isopters. Fresh scotomata can also occur in parts of the visual field previously unaffected. Such fresh visual defects may gradually lead to an upper and a lower

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**Fig. 15.** Typical superior arcuate scotoma. Sector-shaped involvement of temporal field with absolute nuclei.

**Fig. 16.** Armaly's method of screening for glaucoma on the Goldmann perimeter. (From Armaly, M. F.: Am. Arch. Ophthalmol. 81: 25, 1969.)
Fig. 17. Multiple absolute nuclei in an arcuate scotoma. Profile 45 degrees shows the absolute nucleus to be very narrow.

Fig. 18. Progression of field defect shown in Fig. 17 showing the coalescence of absolute nuclei into larger and wider absolute scotoma.

Fig. 19. Left eye (OS): temporal island as the last remaining part of a glaucomatous field. Right eye (OD): advanced glaucomatous field defect showing a change beyond a ring scotoma with remaining central field and temporal field rest.

Arcuate scotoma with a characteristic ring shape which usually retains a nasal step because of the asymmetry of the bundles involved. The ring widens to involve the more peripheral areas and spreads toward the center. Fixation is spared for a long time, and even when the upper or lower scotoma encroaches on the nasal side to
Fig. 20. Unusual sequence of an absolute paracentral scotoma (profile 135 degrees) gradually disappearing over a two-year period. The baring of blind spot (lower left) is no longer accompanied by a scotoma (profile 135 degrees, lower right).

within a degree or two of fixation, foveal function may remain normal with good visual acuity. When a central island of vision is the only field remnant, a nasal step can usually still be plotted. The central island of vision is often accompanied by a temporal visual field rest which may disappear before the central vision is finally abolished (Fig. 19). However, it may remain as the only field remnant. A change in density of existing scotomata and conversion of relative scotomata into absolute defects is another way of progression. This may occur as a result of a gradual deterioration of function or sudden step-like episodes involving fresh nerve fibers.

Static profile perimetry is most useful for recording changes in the visual field of chronic simple glaucoma. The time involved in plotting static profiles is worthwhile in this disease because of the greater reliability of the patient’s responses. Deterioration can be plotted with greater confidence and further therapy, medical or surgical, can be planned.

Isolated paracentral scotomata in the Bjerrum area can disappear with successful medical or surgical reduction in intra-
ocular pressure (Fig. 20). This change is slow and rather infrequent, but indicates that certain defects are reversible.

The majority of visual field defects unfortunately remain either unchanged or show progression. The progression is often related to poor medical or surgical intraocular pressure control. Other factors apart from the pressure level must be considered.

Progression of a visual field defect is probably the most important indication for more intensive medical or surgical therapy. Therefore, progression must be properly evaluated. In many glaucoma patients, changes in the contour of the isopter are due to progressive lens opacities, which also result in reduction of visual acuity. Changes of the isopter may therefore be a misleading sign of progression of glaucomatous damage. They may be merely due to miotic pupils or developing opacities of the media. Static, profile perimetry is well suited to an analysis of visual field progression. Careful quantitative kinetic perimetry can be used for the same purpose.

Changes in medication which alter the refraction or pupillary diameter must not be disregarded, and visual fields should be replotted so that new base lines are established. Progression should then be measured from the new base line fields.

I am indebted to Mrs. M. Fairclough, Miss J. Bryett, and Miss C. Wheeler for the excellence of the visual fields.

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Interpretive gonioscopy in glaucoma

H. Dunbar Hoskins, Jr.

Gonioscopy is necessary for determining the mechanisms causing increased intraocular pressure in the patient with glaucoma. There are useful methods which simplify the gonioscopist's task. Particular emphasis is placed upon positioning the lens, pressure gonioscopy, and special illumination techniques as they apply to the glaucoma patient.

Key words: glaucoma, gonioscopy, intraocular pressure, lens positioning, illumination techniques

Since Uribe Troncoso developed the first gonioscope, ophthalmologists have been interested in the detailed study of the iridocorneal angle. Development of techniques and innovations have since im-