The topographical relationship between optic disc
and visual field in glaucoma

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Abstract. The spatial relationship between anatomy and function in glaucoma was studied in 15 selected cases of focal damage. Based on planimetric data of the optic disc the anatomical site of damage was defined as the sector with the thinnest neuroretinal rim. Perimetric data were evaluated with regard to 21 regions of the 'Perimetric Nerve Fibre Bundle Map' (Weber & Ulrich 1990a). The site of damage was defined as those regions with at least 50% of depressed points. The site of the affected rim and the number of the corresponding Perimetric Nerve Fibre Bundles showed a linear correlation over a limited range of the superior and inferior pole of the disc. A 'functional disc map' could be established for 6 perimetric regions.

Key words: glaucoma - perimetry - optic disc - neuroretinal rim - nerve fibre bundles - topography.

Anatomical changes typical of glaucoma are progressive cupping of the optic disc, narrowing of the neuroretinal rim and damage to the retinal nerve fibre layer. From the functional point of view, visual field defects develop in paracentral and peripheral areas and become gradually more obvious; finally, the fixation point is affected and central visual acuity is impaired. The relationship between functional defects and anatomical changes has been the subject of much research in the past. In 1974, Read & Spaeth put forward the interesting hypothesis that functional impairment was preceded by damage to anatomical structures. This assertion has subsequently received much support from various studies (Hart et al. 1978; Quigley & Green 1979; Airaksinen et al. 1985).

Quite apart from the quantitative aspect, the relationship between anatomical damage and functional change also has a topographical aspect. Rønne (1913) was the first to realize the connection between the arcuate scotoma described by Bjerrum in 1889 and the anatomical course of the nerve fibres on the retina. Since then it is well known that upper arcuate scotomas are associated with damage to inferior nerve fibre bundles and loss of the neuroretinal rim at the inferior papillary pole; conversely, lower arcuate scotomas correspond to changes at the superior papillary pole.

Based on this observation, the quantitative relationship between topographically corresponding functional and anatomical areas was investigated separately; just as might be expected, a much better statistical correlation became apparent (Dannheim & Obrecht 1989).

Until now, few attempts have been made to investigate the topographical relationship precisely. Based on clinical experience, Read & Spaeth (1974) presented a 'mapping of the disc' that distinguished between a 'Bjerrum rhomboid' between 11.30 and 1 o'clock (with respect to the left eye), a zone of peripheral nasal contraction between 1 and 2 o'clock, and similar areas in the lower half of the disc. The remaining disc regions refer to the temporal visual field and the macular fibres, respectively. The corresponding areas in the visual field were not described cartographically.

Wirtschafter et al. (1982) suggested a division of the visual field into 15 sectors. The boundary lines
were obtained by projecting illustrations of the course of retinal nerve fibre layers in the primate eye onto an appropriately scaled visual field. The borders were arbitrarily adjusted to geometrical curves like straight lines, parabolas, and ellipses. The 15 sectors have a clock hour notation with regard to the optic disc. The origin of this correlation was arbitrary, too. Clinical proof could not be obtained up till now.

The lack of a reproducible investigation on the spatial correlation between anatomy and function is obvious. Such a study has several basic requirements.

1. A topographical determination of the damage should be possible. This requires cases with focal damage visible both at the optic disc and in the visual field.

2. Exact measurements are needed. Nowadays, planimetry of the optic disc and automated static perimetry are appropriate techniques.

3. A grading of the damage is needed. This should be the width of the neuroretinal rim at the disc and the defect depth in the visual field.

4. For the sake of reproducibility, topography has to be transformed into numerical values. At the optic disc, the angle of the measured rim position is an accurate value. Concerning the visual field, several test locations may be connected to the same rim position. A predefined of particular

Material and Methods

Sixty-six eyes of 41 patients were examined perimetrically and papillometrically at the University Eye Clinic of Hamburg. Twenty-nine eyes had confirmed primary open-angle glaucoma or low-tension glaucoma, the other 39 had suspected glaucoma.

In all patients, photographs of the optic disc were taken with a Topcon stereo fundus-camera. These photographs were projected from below onto a rear projection screen and inspected with a stereo viewer. The margin of the disc and the cup were traced with a pen on a digitalized graphics tablet. Although the depth of the excavation could not be measured using this type of two-dimensional planimetry, the stereoscopic impression facilitated the definition of these margins (Dannheim 1988). The data were processed on a personal computer using the program 'Planidata' which was developed by one of the authors (D. Dannheim). From the numerous planimetric features of this program, we used the calculation of the relative width of the neuroretinal rim, the rim/radius ratio. This value was computed for 360 radii with a 1 degree spacing and with regard to the geometrical center of the disc. Beside the natural disc plot, a rectangular presentation of the rim/radius ratio vs degree was available (Fig. 2).

The visual fields were assessed with an Octopus Perimeter 201 using the program G1 (Flammer et al. 1986) which measures the static threshold at
59 points by double bracketing. Repetitive measurement by single bracketing (called phase 2 of the program) was a matter of routine. The results were analysed with regard to the 'Perimetric Nerve Fibre Bundles' (PNFB, Fig. 1). The evaluation was simplified by a visual field print-out that represents the data for each region separately (Fig. 2). This type of data processing is available on the perimetric data program ‘Peridata’ (Weber 1989).

The relation of anatomical to functional sites is only possible in cases of focal damage. This pseudo-experimental situation can be obtained from clinical data by means of selection. Fifteen eyes (12 patients) met these criteria.

Evaluation of perimetric data: All PNFB where at least 50% of the test points showed at least 10 dB relative defect depth (after subtracting general deviations) were considered to be damaged bundles. The relevant zone of damage was the largest group of contiguous affected PNFB.

Evaluation of optic disc data: The relevant zone of damage on the disc was a sector of corresponding size that included the meridian with the thinnest rim. The determination of the size of the sector was based on the arbitrary assumption that each of the 21 PNFB corresponded to a disc sector of equal size. Thus, one PNFB would correspond to a sector of 17.1° (360°/21). The position of the affected sector was evaluated in each case in an iterative process: Starting at the angle with the thinnest rim, the sector with a rim/radius ratio below a particular criterion was determined. This criterion was altered until the size of the sector was equal to the assumed size.

The correlation between the visual field and the disc changes was based on the centre of the dam-
aged zones. Concerning perimetry, this was the arithmetic mean of the first and the last PNFB number. Regarding the optic disc, it was the mean of the borderline angles on either side of the affected sector. The scaling of the angle was a mirror image for the left and right eye, respectively. It started at the horizontal nasal equator. In the left eye scaling increased clockwise, in the right eye counter-clockwise.

Thus, each eye yielded a pair of topographical values. The relationship between the two values was depicted graphically in a scattergram.

Results

The zone of functional damage involved 1 to 6 neighbouring PNFB (mean 3.2). In 10 out of 15 eyes a sector of equivalent size (17.1° to 102.6°) with a thinning of the neuroretinal rim was found in the papillary data (Fig. 2). In the remaining 5 cases the sector of well-localised thinning of the rim was either larger or smaller than the angle defined by the perimetric damage (Fig. 3). In all cases, damage of the rim was both obvious and focal.

The centres of the affected perimetric areas were concentrated on two particular regions: In 7 eyes it was located between the PNFB 5 to 8, in 8 cases between the PNFB 15 to 16. None of our subjects showed centrocecal or temporal PNFB defects.

The centres of the affected rim positions were limited to angles between 66° thru 118.5° and 227° thru 273°, respectively.

Fig. 4 shows the relationship between the perimetric and papillary site of damage. Each square stems from one eye. The value on the x-axis is the location of papillary damage. The y-axis shows the region of perimetric damage. Shaded squares represent eyes with equivalent, empty squares eyes...
Scattergram showing the relationship between the centre of the damaged rim area (x-axis) and the centre of the perimetric area of damage (y-axis) in 15 eyes with glaucoma. The lines of regression were graphically determined. See also Table 1.

with differing extent of damage. The accumulation of pairs of values at the superior and inferior disc poles and the corresponding perimetric regions allows the construction of regression lines only in limited areas. Two lines were graphically estimated and drawn into Fig. 4. The gradient was 30° for the first line (involving PNFB 7 and 8) and 15° for the second line (involving PNFB 14 through 17). Particular coordinates of these regression lines are given in Table 1.

Discussion

From the beginning one must doubt the validity of a correlation of purely functional results of a subjective method of examination with an extremely variable pathological-anatomical structure such as the glaucomatous optic disc. This may explain why no similar study has been carried out so far. Meeting 4 basic requirements - selected cases with focal damage, exact measurements, defined grading of damage, and numerical transformation of topography - made a solution more easily conceivable.

The results recorded for 6 out of 21 PNFB or one quarter of the disc rim, respectively, seem plausible in the light of hitherto available information (Fig. 5). The zones in which we could establish a clear relationship correspond exactly to the ‘Bjerrum Rhomboid’ of Read & Spaeth (1974), located in our scale between 75° and 120° or between 240° and 285°, respectively. As these authors drew no sketch it is impossible to establish whether this also corresponded to the same areas of the visual field.

The many restrictions imposed upon our study make it necessary to speak of preliminary results:

- Fifteen eyes make a small sample. Although we examined 66 eyes, a considerable reduction was necessary to get the pseudoexperimental situation of clear, focal damage (see above). A larger number is indeed desirable, and should be aimed at in future studies.

- With the fundus-camera which we used it is, unfortunately, impossible to focus both disc and foveola simultaneously. Therefore, from the point of view of papillometry, the amount of rotation is unknown. On the basis of experience the range is under 10%. We have now begun a study which aims at presenting an accurate answer to this question.
- The visual field program with 59 points is not ideal, as less than 3 points per PNFB on average are available. A specialized program tailored to search for small glaucomatous scotomas would be more useful. The glaucoma program 30-S with 129 centrally condensed points (Weber & Kosel 1986) is such a program. Unfortunately, this was not available at the clinic where the examinations were carried out.

- The correlation is only based on central visual field data. The peripheral field was not quantitatively tested and therefore not evaluated. So far, no method has been found which measures threshold values in the periphery quantitatively in an acceptably short span of time. Neither the precise normal values, nor the course of the nerve fibres in the periphery is known for this very reason. The newly developed technique of measurement, the 'dynamic strategy' (Weber 1990b), may constitute a step forward in this direction. Not yet published trials, recently carried out, lead to radical time saving, especially in the periphery.

- The hypothesis used in the measurement of the papillary angle of damage was based on the assumption that PNFB take up 17.1° of the disc. In actual fact we found a distance of 15° and 30°, respectively. The influence of angular deviation on the result was lessened by only including the centre of the damaged disc sector. If the shape of a notching is symmetric, a change in the angular interval leads to a discordant symmetric displacement of beginning and end of the sector; the centre angle remains constant. The only cause of bias is asymmetry of the notching. Even so, asymmetry is possible, and this method must be subject to gradual improvement if it is to constitute the basis of consecutive studies and enable a closer evaluation of angular interval.

Our selection of glaucoma cases was based on focal disc damage. We assume that a more extended damage to the optic disc follows the same rules. It should be pointed out, however, that we assessed only narrowing of the rim tissue. Pallor of the disc was not recorded.

Our study, as well as future studies with this method face the problem that localised damage in glaucoma is most extensive in the area of the superior and inferior papillary pole (Jonas et al. 1987). It might just be possible, however, to establish a clear relationship between the remainder of papillary positions and PNFB if a much larger number of cases were taken into consideration. Nevertheless, the anatomical relationship of the centrocecal visual field poses a special problem: The place of entry of their nerve fibres, the temporal papillary margin, loses signs of vitality early. But while the appearance of the disc would seem to indicate loss of function, this part of the field is often still preserved (Read & Spaeth 1974). Therefore, it is probable that some persistent uncertainties on the 'functional disc map' (Fig. 5) will remain.

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References


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