Videographic Measurements of Optic Nerve Topography in Glaucoma

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Topographic measurements of the optic nerve head were made with computerized videographic image analysis (Rodenstock Analyzer) in one eye each of 36 normal controls, 41 glaucoma suspects and 46 glaucoma patients matched for age. Glaucoma suspects had elevated intraocular pressures and normal visual fields in both eyes. Glaucoma patients had typical visual field defects. Disc measurements were corrected for the optical dimensions of individual eyes. One-way analysis of variance revealed statistically significant differences among the diagnostic groups for cup-disc ratio \( (P = 0.0006) \), disc rim area \( (P < 0.0001) \) and cup volume \( (P = 0.0001) \). Mean \( \pm \text{SEM} \) disc rim area was 1.14 \( \pm \) 0.04 mm\(^2\) for controls, 1.10 \( \pm \) 0.04 mm\(^2\) for glaucoma suspects and 0.87 \( \pm \) 0.05 mm\(^2\) for glaucoma patients. Mean \( \pm \text{SEM} \) optic nerve cup volume was 0.35 \( \pm \) 0.02 mm\(^3\) for controls, 0.44 \( \pm \) 0.04 mm\(^3\) for glaucoma suspects and 0.60 \( \pm \) 0.05 mm\(^3\) for glaucoma patients. Planimetric measurements of disc rim area were made from manual tracings of stereoscopic disc photographs of the same eyes. There was a statistically significant correlation between the computerized videographic measurements and the manual photographic measurements of disc rim area \( (r = 0.73, P < 0.0001) \). The broad range of values for these optic nerve structural parameters in normal eyes and their overlap with values in glaucomatous eyes prevents their use to reliably predict which patients are normal and which have glaucomatous visual field loss. New parameters are required to fully describe the depth information generated with new quantitative techniques. Invest Ophthalmol Vis Sci 29:1294-1298, 1988

Some clinical studies suggest that structural changes of the optic nerve head precede measurable visual field abnormalities in early glaucoma.\(^1\)\(^-\)\(^7\) Considerable loss of optic nerve fibers can occur in patients with elevated intraocular pressure before visual field abnormalities are detected.\(^8\) The earliest disc changes in patients with glaucoma probably cannot be adequately identified by clinical estimates of the cup-disc ratio.\(^9\) Careful examination of stereoscopic disc photographs seems to be the best routine way to detect subtle interval changes of the optic disc.\(^3\)\(^,\)\(^4\)\(^,\)\(^7\) The qualitative and subjective nature of these comparisons has initiated a search for more quantitative methods.

We used computerized image analysis (Rodenstock Analyzer) to measure cup-disc ratio, disc rim area, and disc cup volume in age-matched normal controls, glaucoma suspects and in patients with visual field loss from glaucoma. The automated measurements of disc rim area were also compared with manual measurements of disc rim area made from stereoscopic disc photographs.

**Materials and Methods**

Patients of the Yale Glaucoma Service were used in this study. All patients over the age of 40 who were evaluated for glaucoma before December 1, 1986 and who had automated perimetry (Octopus Program 32; Interzeag, Schlieren, Switzerland), stereoscopic optic disc photographs, and computerized image analysis (Rodenstock Analyzer; Rodenstock Instrumente, GmbH., Munich, West Germany) were included. Computerized image analysis was performed in patients with reasonably clear media (20/40 or better) who could be diluted to 5 mm or more. Those who had elevated intraocular pressure (consistently >21 mm Hg in both eyes) and unequivocally normal visual fields in both eyes (no loss compared to age-matched controls) were considered glaucoma suspects (GS). Those with elevated intraocular pressures (or a history of elevated intraocular pressure before
treatment) and typical glaucomatous visual field defects were considered glaucomatous (GL). Typical glaucomatous defects were defined as at least three contiguous points with ten decibel loss or greater compared to age-matched controls in the superior or inferior Bjerrum areas, or a 10 decibel difference across the horizontal nasal midline at two or more locations. The visual field mean defect and corrected loss variance was calculated for each field. Normal control subjects (NL) had no history of eye disease and were recruited from hospital staff and spouses or friends of patients; none had presented to the Eye Center for evaluation. Those included were over the age of 40 and had a normal eye examination and normal visual fields tested with automated threshold perimetry. Informed consent was obtained from each person after photographic procedures were fully explained.

A computerized image analysis system (Rodenstock Analyzer) was used to make quantitative depth measurements of the optic nerve head. Descriptions of this instrument and the reproducibility of its measurements have been published. The optical head provides a simultaneous stereoscopic videographic image of the optic disc with an image-intensified video camera. A frame grabber (256 × 256 × 8 bit buffer) digitizes and freezes fundus images for evaluation by the operator. Images may be rejected or saved on a floppy diskette or fixed disc. To obtain depth measurements across the optic nerve surface, a set of seven parallel stripes is projected onto the fundus; two such images are processed to make depth measurements and provide 14 vertical stripes along which measurements are made. Approximately nine to ten of these span an average-sized optic nerve head. The stripes provide features on otherwise featureless areas of the optic disc so that effective image analysis can be performed. The instrument simultaneously records a pair of stereoscopic disc images with striped patterns whose deformations contain depth information. The computer selects corresponding line segments within the two stereoscopic half-images and computes their cross-correlation function to determine depth. These depth measurements are processed to extract structural parameters after the disc edge is defined. The disc edge is defined by an ellipse which is positioned by the operator. A computer algorithm identifies the margin of the cup as a locus of 360 points, one on each of 360 radial profiles which lie 150 μm below and nearest the disc edge. The disc rim area is the area between the cup rim margin and the disc edge. The cup-disc ratio is the average of all cup-disc ratios calculated for each of the 360 radial profiles. The optic nerve cup volume is the volume below an imaginary plane constructed at the average level of the peripapillary retina and bounded by the disc edge. All dimensions are corrected for optical magnification or minification with sonographic measurements of the axial eye length or with keratometric and refractive measurements.

Stereoscopic optic disc photography was performed with a Zeiss fundus camera equipped with a ×2 adaptor. Photographs were taken on Kodachrome slide film. The best stereoscopic pair was selected for each disc, and the right-hand stereophotograph was duplicated and projected onto a sheet of paper. The disc edge and perceived cup edge was traced by one of us (JC) while the stereoscopic pair was viewed; only depth clues were used, and color differences were ignored. The location of the cup edge was defined as being at the level of the internal scleral opening when viewed stereoscopically. The disc area was set to equal the previously calculated disc area for each eye as described above. A computerized digitizing pad was used to measure the disc rim area which was corrected to an absolute value in mm².

Statistical analysis was performed with the goodness of fit test, student t-test, one-way analysis of variance (ANOVA), and Duncan’s multiple range test.

Results

Statistics for age, refractive error, optic disc parameters and visual field indices are given in Table 1. Analysis of variance demonstrated no statistically significant differences for age or refractive error (spherical equivalent) among the groups.

The mean total disc area did not differ among the groups (ANOVA, P = 0.35). ANOVA revealed statistically significant differences among the groups for cup-disc ratio (P = 0.0006), disc rim area (P < 0.0001), and cup volume (P = 0.0001).

The Duncan multiple range test was used to test for simultaneous statistically significant differences (P < 0.05) between the independent means of each disc parameter among the patient groups. Mean cup-disc ratio, mean cup volume and mean disc rim area were significantly different between the NL and GL group, and also between the GS and GL group. There is considerable overlap of the measurements for each of these structural parameters among the patient groups (see Figs. 1–3).

There was a positive correlation between disc rim area measurements performed manually and those performed with computerized image analysis (Fig. 4). Linear regression analysis provided a best fit with slope = 0.87, y-intercept = 0.27 mm², and correlation coefficient (r) = 0.73 (P < 0.0001). The correlation coefficients for each of the patient groups taken separately were: 0.56 for NL, 0.66 for GS and 0.72 for GL. Eight outliers were identified from the scatterplot.
Table 1. Statistics for age, refractive error, optic disc parameters and visual field indices

<table>
<thead>
<tr>
<th></th>
<th>Normal (n = 36)</th>
<th>Glaucoma suspect (n = 41)</th>
<th>Glaucoma (n = 46)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>62.8 ± 1.6</td>
<td>59.7 ± 1.5</td>
<td>63.7 ± 1.3</td>
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<tr>
<td>Refractive error</td>
<td>0.2 ± 0.3</td>
<td>-0.3 ± 0.4</td>
<td>-0.3 ± 0.4</td>
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<tr>
<td>(spherical equivalent, diopters)</td>
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<tr>
<td>Optic Disc</td>
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<tr>
<td>Disc area (mm²)</td>
<td>1.71 ± 0.05</td>
<td>1.79 ± 0.07</td>
<td>1.70 ± 0.05</td>
</tr>
<tr>
<td>Cup-disc ratio</td>
<td>0.49 ± 0.03</td>
<td>0.54 ± 0.03</td>
<td>0.64 ± 0.03</td>
</tr>
<tr>
<td>Disc rim area (mm²)</td>
<td>1.14 ± 0.04</td>
<td>1.10 ± 0.04</td>
<td>0.87 ± 0.05</td>
</tr>
<tr>
<td>Disc cup volume (mm³)</td>
<td>0.35 ± 0.02</td>
<td>0.44 ± 0.04</td>
<td>0.60 ± 0.04</td>
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<tr>
<td>Visual field</td>
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<tr>
<td>Mean defect (dB)</td>
<td>-0.4 ± 0.3</td>
<td>7.4 ± 1.0</td>
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<tr>
<td>Corrected loss variance (dB²)</td>
<td>4.9 ± 1.9</td>
<td>22.8 ± 3.9</td>
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</tbody>
</table>

* Data are presented as the mean ± SEM.

(Fig. 4); the ratio of the manual to the computerized measurements was less than 0.6 for these eyes. Seven eyes were from subjects with glaucoma, and one was from a glaucoma suspect. All eight had the single characteristic of a concave or flat disc rim which sloped continuously upward to the disc edge. The sloped disc rim in these cases was not included in the manual rim area measurement, but portions within 150 µm in depth from the disc edge were included in the computerized measurement. For this reason, the disc rim area determined by image analysis was larger than that measured with the manual technique.

**Discussion**

Ophthalmologists have traditionally used estimates of cup-disc ratio to evaluate the optic nerve for glaucomatous damage. Bengtsson showed that the diameter of the optic nerve cup depends on the size of the optic disc, and suggested that the breadth of the disc rim might be a more useful measure of glaucomatous optic nerve damage.16 Radius and Pederson17 found a correlation between the amount of rim tissue and the number of axons present in the optic nerves of primate eyes with experimentally induced glaucoma. Absolute measurements of optic nerve topography may provide an estimate of the number of nerve fibers contained in the optic nerve head and may assist the detection of early glaucomatous nerve damage. The disc rim is narrowed in patients with visual field defects from glaucoma.18 Balazsi et al19 made absolute measurements of the disc rim, which the authors termed “neuroretinal rim.” The location of the disc rim and disc edge were traced on a projected image while a corresponding stereoscopic pair was viewed. The traced disc rim area was measured with a computerized planimeter. Enlarged black and white

![Fig. 1. The distribution of cup-disc ratios for normal subjects (n = 36), glaucoma suspects (n = 41) and patients with glaucoma (n = 46). There are statistically significant differences between the means of the normal and glaucoma groups and between the means of the glaucoma suspect and glaucoma groups. Large overlap of the values among the patient groups is apparent.](image1)

![Fig. 2. The distribution of disc rim areas for normal subjects (n = 36), glaucoma suspects (n = 41) and patients with glaucoma (n = 46). There are statistically significant differences between the means of the normal and glaucoma groups and between the means of the glaucoma suspect and glaucoma groups. Large overlap of the values among the patient groups is apparent.](image2)
stereoscopic prints were used by Airaksinen and co-workers to make similar measurements in normal, glaucoma suspect and glaucoma patients. The perceived position of the cup edge was traced and corrected area measurements were made. Means (±SEM) for disc rim area were measured in this way were 1.40 ± 0.03 mm² in 33 normals, 1.31 ± 0.04 mm² in 25 glaucoma suspects, and 0.89 ± 0.05 mm² for 38 glaucoma patients. There were statistically significant differences between the means, but the values overlapped considerably among the patient groups. Measurements of cup volume are not possible with this technique.

We used a computerized system for image analysis of simultaneous stereoscopic videographic images of the optic nerve head (Rodenstock Analyzer) to make optically corrected measurements of disc size, cup-disc ratio, disc rim area and disc cup volume. The reproducibility of the measurements (average coefficient of variation) obtained with the version of the system used in this study is 6.1% for cup disc ratio, 6.3% for disc rim area, and 9.2% for cup volume.

There were significant differences between mean measurements of each of these parameters between normals and glaucoma patients, and between glaucoma suspect and glaucoma patients, but not between normals and glaucoma suspects. The broad range of values for disc rim area in normal eyes and their overlap with values in glaucomatous eyes prevents the use of this parameter to reliably predict which patients are normal and which have glaucomatous field loss, and seems only slightly better than measurements of cup-disc ratio or cup volume in this regard.

The cup margin as defined by the computer program does not necessarily correspond to the clinical perception of the cup margin. There are some discs for which the measurement of disc rim area with the automatic and manual techniques differs. This is not surprising, since the definitions of the cup margin with the two methods are quite different. Subjective perception of the cup margin is difficult to standardize, and may involve such things as the rate of change of slope, depth, location and pattern of vessels, visibility of the lamina, and sometimes differences in color. Automatic localization of the cup edge can be standardized, and in this analysis was defined as lying 150 μm below the disc margin. Eyes in which there was a discrepancy between the manual and automatic measurements had characteristically concave or flat disc margins which sloped upward to the disc edge. In these cases, areas of the cup edge were manually marked coincident with the disc edge, while the automatic technique included some portions (those within 150 μm in depth from the disc edge) of the disc rim substance in the calculation for disc rim area. Nevertheless, the overall correlation between the manual and automatic techniques for measurements of disc rim area was quite good (Fig. 4).

The structural parameters reported here have been derived from quantitative measurements of surface contour and were originally calculated to conform to

**DISC RIM AREA (mm²)**

![Graph showing the distribution of cup volumes for normal subjects (n = 36), glaucoma suspects (n = 41) and patients with glaucoma (n = 46). There are statistically significant differences between the means of the normal and glaucoma groups and between the means of the glaucoma suspect and glaucoma groups. Large overlap of the values among the patient groups is apparent.](image)

**Fig. 3.** Measurements of disc rim area obtained with manual tracing and planimetry are plotted against those obtained with computerized image analysis (Rodenstock Analyzer). There is a statistically significant correlation between these two sets of measurements (r = 0.73, P < 0.0001). The dotted lines indicate the 95% confidence interval for the linear regression. There are eight outliers for which the disc rim area measurement with the manual technique was much smaller than with the computerized technique. Please see text for details.

![Graph showing the distribution of disc rim area measurements for normal subjects (NL), glaucoma suspects (GS), and patients with glaucoma (GL).](image)
our present clinical descriptions of the optic nerve head. However, these parameters now seem inadequate to detect small changes in surface contour of the disc and surrounding nerve fiber layer. It may be necessary to abandon these summary structural parameters so that measurements of surface contour of the disc and nerve fiber layer may be used to best advantage. Comparisons of sequential quantitative measurements of surface contour may more effectively detect early structural damage from glaucoma.

Key words: optic nerve, glaucoma, image analysis, cup-disc ratio, disc rim area, disc cup volume

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References