

Neural Rim Characteristics of Healthy South Indians: The Chennai Glaucoma Study

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PURPOSE. To report neural rim dimensions for South Indians and examine rim shape with relevance to clinical evaluation.

METHODS. Healthy phakic participants ($n = 623$) of the Chennai Glaucoma Study with normal frequency-doubling perimetry underwent complete eye examinations including optic disc digital stereophotography. Planimetry was performed under stereoviewing conditions using custom software. Rim area, shape, and associations were examined. Rim area asymmetry was studied in a subgroup of 565 subjects.

RESULTS. Mean neuroretinal rim area was 2.29 ± 0.39 mm². Disc area ($P < 0.001$) and type of cupping ($P < 0.001$) were associated with rim area. Mean rim area asymmetry was 0.18 ± 0.15 mm²; 95% of subjects had asymmetry < 0.5 mm². Disc area asymmetry (0.359 , $P < 0.0001$) and intraocular pressure (IOP) asymmetry ($P = 0.004$) were related to rim area asymmetry. On average, the inferior rim was thickest and the temporal was thinnest. Mean inferior by superior rim width was 1.18 ± 0.17 ; 2.5 percentile, 0.9. Thirty-eight (7.1%) subjects had the superior rim thicker than the inferior rim, the occurrence of which was associated with disc torsion ($P = 0.002$) and male sex ($P = 0.04$). Of the clinically relevant rim width measures in glaucoma (i.e., inferior, superior, and temporal) the temporal rim was thinnest in 469 (87.8%) eyes. Horizontally oval disc shape ($P < 0.0001$), type of cupping ($P = 0.006$), and astigmatism ($P = 0.001$) were associated with the presence of thicker temporal than superior/inferior rims.

CONCLUSIONS. The report provides hitherto unreported neural rim measurements among healthy South Indians. The ISNT rule (inferior rim thicker than superior rim, thicker than nasal rim, thicker than temporal rim) was violated in a significant minority. Physiological associations with such violations are described. (*Invest Ophthalmol Vis Sci.* 2008;49:3457-3464) DOI:10.1167/iovs.07-1210

The neural rim, composed of the axons of retinal ganglion cells, is the most important part of the optic disc, and its meticulous examination is vital to the diagnosis of glaucoma. Quantitative evaluation of the size and shape of the neural rim provides important diagnostic information in the context of

glaucoma and other optic neuropathies. However, as is true of most biological measures, human optic discs exhibit a great range of variability in relation to shape, size, and relationships between their constituent parts.¹⁻³ For rim areas, Ramrattan et al.¹ reported a threefold variation in their study participants of the Rotterdam Eye Study, and Jonas et al.⁴ reported almost a sixfold variability in their study of 457 normal Caucasian eyes.

Racial differences in optic disc morphology, in terms of disc size and rim area, are well known and recognized.^{2,5} Therefore, studies of normal individuals in each racial or ethnic group would provide important insight into similarities and differences in optic disc morphology between people. Jonas et al.⁶ reported results of morphometric evaluation of 70 subjects who participated in the Vellore Eye Study. The present study reports planimetric neural rim data from a large population-based study and examines neural rim shape in this group with relevance to clinically used measures to evaluate the neural rim.

METHODS

The present study was part of the Chennai Glaucoma Study (CGS), a population-based survey of glaucoma in Southern India. The study was previously approved by the Institutional Review Board, and written informed consent was obtained from all participants. The study was conducted in accordance with the tenets of the Declaration of Helsinki.⁷

The methodology of the CGS has been described in detail in a previous publication.⁸ In brief, the study had rural and urban components. The urban component included five randomly chosen clusters in Chennai city. Permanent residents ($n = 960$) 40 years of age or older were enumerated from each cluster. Persons examined from the last two clusters were included in the present study, as only participants from these two clusters had the keratometry readings necessary to correct for ocular magnification.

Eligible residents were contacted by social workers to collect demographic information and confirm eligibility and were asked to participate in a comprehensive ophthalmic examination at the base hospital. Written informed consent was obtained from all participants at the examination center. A detailed medical and ophthalmic history was recorded. The participants then underwent visual acuity testing with a logarithm of minimum angle of resolution (log MAR) 4-m charts (Light House Low Vision Products, New York, NY) and objective and subjective refraction. Spherical equivalent refraction was calculated as spherical error plus half of the cylindrical error. A minus cylindrical error was noted. The participants then underwent slit lamp examination and applanation tonometry, pachymetry, gonioscopy, frequency-doubling perimetry (C-20-1 screening and N-30 threshold, FDP; Carl Zeiss Meditec, Inc., Dublin, CA), and detailed lens, optic disc, and fundus examination after pupillary dilation. All subjects with sufficient media clarity to permit good-quality fundus photographs underwent fundus photography. A fundus camera (FF450-plus with VISUPAC; Carl Zeiss Meditec) with digital image-archiving system was used. Photography included one stereo-pair (nonsimultaneous) of 20° optic disc photographs for each eye. Axial length measurement was performed using an ultrasonic biometer (Ocuscan; Alcon Laboratories, Fort Worth, TX) on every fifth subject, the first subject in the series having been selected at random.

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In addition, subjects from the last two clusters also underwent keratometry (Bausch & Lomb Ophthalmic Instruments, Rochester, NY) before any contact procedures. Among persons from the last two clusters examined, further eligibility criteria for the current planimetric study were absence of any cataract (based on the Lens Opacities Classification System [LOCS II]⁹ grading), media haze or other ocular abnormality, and reliable, normal FDP screening examinations. Reliability criteria for FDP were no fixation errors or false positives.

Patients with glaucoma were excluded from the present study. For the CGS, glaucoma was diagnosed based on the recommendations of the International Society for Geographic and Epidemiologic Ophthalmology (ISGEO).^{10,11} Ocular hypertensives (high IOP plus normal Humphrey 24-2 visual fields) were, however, included.

Other exclusion criteria from the planimetric study were any cataract or other media haze, aphakia, pseudophakia, nonavailability of keratometry measurements, poor-quality optic disc photographs including blurred photographs and/or poor stereo and any defect(s) on FDP and myopia > -8.0 D.

The labeled optic disc photographs were exported from the VISUPAC system as high-quality JPEG images and saved in an external storage device to be analyzed later.

Planimetry was performed using custom planimetry software, which was developed specifically for this purpose (MatLab ver. 7; Mathworks Inc., Natick, MA). The custom software was tested against the commercial VISUPAC software. Vertical and horizontal disc diameters and disc areas were marked on 50 optic disc pictures (of 50 subjects) and the values were noted. The pictures were then exported as described, and the same measurements were made using the custom software. Excellent correlation was found between the two measurement methods. The mean difference between the results of the two methods of vertical linear measures was 0.005 ± 0.004 , intraclass correlation coefficient (ICC) 0.99; for horizontal lines it was 0.001 ± 0.004 , ICC 0.99; and for area measures it was 0.011 ± 0.02 , ICC 0.99.

Planimetry

Stereo pairs of photographs were displayed side by side on a 15-in. monitor. The Screenscope (Berezin Stereo Photography products, Mission Viejo, CA) is a stereo viewer that permits use on digital stereo photographs on a computer screen and was used for this study. All markings were made on the photograph on the right side, under direct stereoviewing conditions. Disc area, cup area, vertical and horizontal

disc and cup diameters as well as superior, inferior, nasal, and temporal neural rim widths were measured. Four types of cupping were identified based on a modification of the classification described by Jonas et al.⁴—no cupping, well demarcated cups with steep sides, cups with partially sloping temporal rim, and cups with entire temporal rim sloping (including superotemporal, horizontal temporal, and inferotemporal rim; Fig. 1). Other features noted were torsion of the disc, direction and degree of torsion if present, disc tilting, and the presence of cilioretinal arteries. Corrections for ocular magnification were made based on keratometry and refraction (Littmann's correction).¹²

Definitions

Disc margin: The inner edge of the peripapillary scleral ring of Elschnig.

Cup margin: When the cup was steep and punched out, the demarcation was clear; when the cup was conical, the plane midway between the surface of the disc and the depth of the cup was used as a reference plane.¹³

Neural rim: the area between disc margin and cup margin.

Superior, temporal, inferior, and nasal rim width: measured at 12, 3, 6, and 9 o'clock positions, respective, in relation to the optic disc center and not measured in discs with no cups.

Torsion: the optic disc was considered torted when the vertical axis of the optic disc was rotated $>15^\circ$ from the vertical meridian.¹⁴

Tilting: the optic disc was considered tilted when there was (three-dimensional) angulation of the (anteroposterior) optic cup axis.¹⁴

All planimetric measurements were made by a single observer, who is a glaucoma specialist.

Statistical Analysis

Statistical analysis was performed with commercial software (SPSS for Windows; SPSS Inc., Chicago, IL). In general, associations between two numerical variables were examined by using Pearson's correlation. Associations between two variables—one of them numerical and the other categorical—were determined by *t*-test. The associations between categorical variables were explored with the χ^2 test. For multivariate analysis, when the dependent variable was numerical, multiple

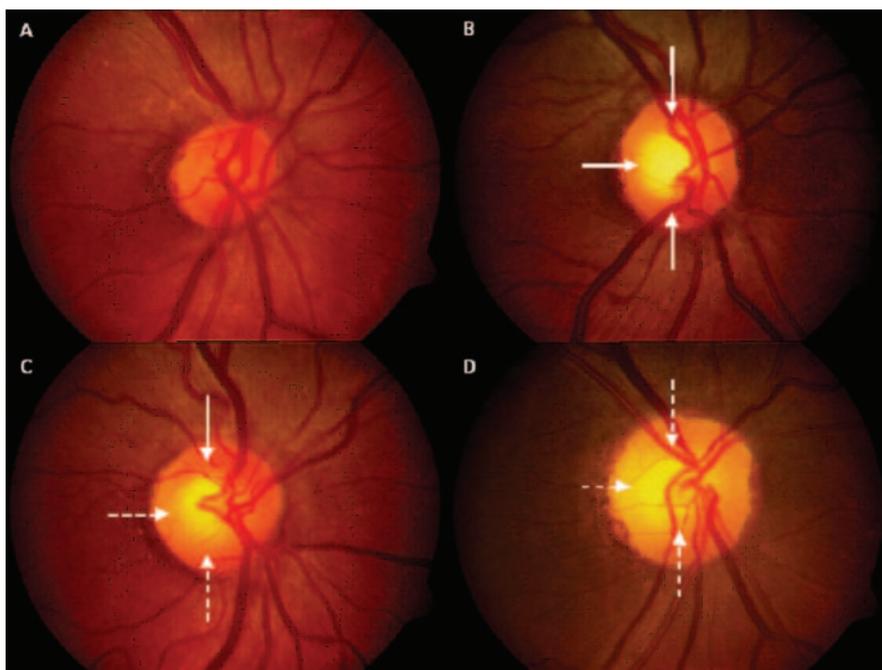


FIGURE 1. Examples of four types of cupping. (A) Disc with no cup; (B) disc with well-demarcated cup; (C) disc with partly sloping rim; (D) disc with fully sloping temporal rim. Steep rims marked with *straight-line arrows*, sloping rims marked with *dotted-line arrows*.

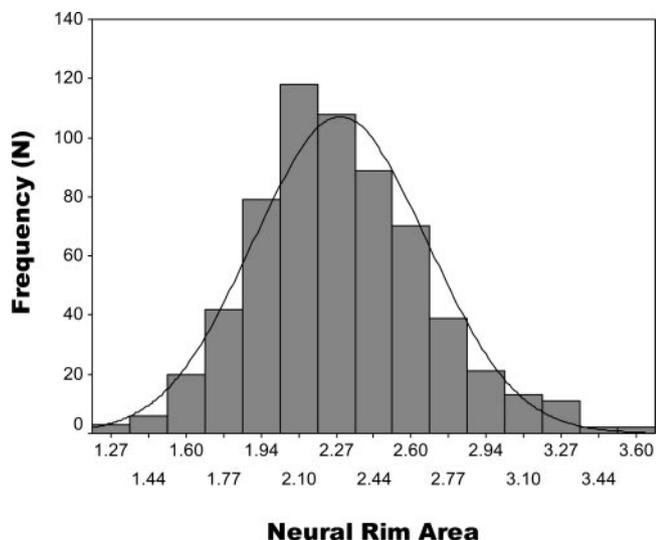


FIGURE 2. Frequency distribution of neural rim area with superimposed normal curve (Kolmogorov-Smirnov test for normality, $P = 0.14$).

linear regression was used with dummy coding for categorical explanatory variables. When the dependent variable was categorical, logistic regression was used.

Inter-eye differences are presented as absolute values (larger minus smaller values) and as right- minus left-eye values. Right- minus left-eye values were used to explore associations and to preserve side orientation with respect to all parameters examined.

Significance was assessed at the $P < 0.05$ level.

RESULTS

A total of 1920 eligible residents were enumerated for the planimetric study, and 1547 (80.57%) responded. Of those, 896 persons were excluded based on the exclusion criteria described in the Methods section: cataract, aphakia, pseudophakia, glaucoma or other ocular disease, abnormal FDP, poor performance of FDP, high myopia, nonavailability of keratometry readings, or poor-quality disc photographs. At least one eye was eligible in 678 persons; in 623 persons, right eyes were eligible; and in 645 persons, left eyes were eligible for inclusion and analysis. Neural rim dimensions and correlations are presented for right eyes only ($n = 623$), to maintain clarity and avoid repetition. Inter-eye asymmetry data are presented for a subset of 565 patients for whom both eye data were available.

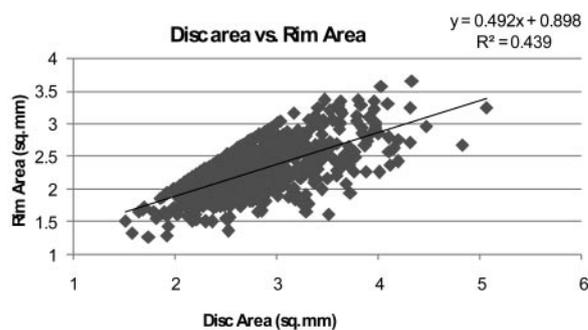


FIGURE 3. Scatterplot of rim area versus disc area ($n = 623$) with regression line. Also displayed (top right) are the regression equation and r^2 value (coefficient of determination).

The mean age of the 623 participants was 48.3 ± 6.9 years. The mean age of all participants from the two clusters ($n = 1547$) was 53.58 ± 10.61 years ($P < 0.0001$).

Of the participants, 369 (59.2%) were women. The mean spherical equivalent refractive error was 0.44 ± 1.15 D (-7.25 - 5 D). The mean cylindrical error was -0.37 ± 0.48 D, and mean intraocular pressure (IOP) was 15.9 ± 3.7 mm Hg.

Neural Rim Area

The mean neuroretinal rim area was 2.29 ± 0.39 mm² (median, 2.25 mm², 2.9 times variability). Figure 2 demonstrates the normal distribution of the neural rim area.

Associations with Neural Rim Area

The rim area showed a strong positive correlation with the disc area ($r = 0.67$, $r^2 = 0.44$, $P < 0.0001$). For every 1-mm² increase in disc area, the rim area increased by 0.5 mm² (Fig. 3).

Rim area was significantly different between the different types of cups (Table 1) and showed weak positive correlations with age ($r = 0.11$, $P = 0.006$) and height ($r = 0.1$, $P = 0.016$). The mean rim area was also 3.1% greater in men than in women (mean rim area in men, 2.33 ± 0.4 ; mean rim area in women 2.26 ± 0.38 , $P = 0.038$). The associations of rim area with spherical equivalent refraction, axial length, central corneal thickness (CCT), intraocular pressure (IOP), torsion or tilting of the disc, disc shape represented by the ratio of vertical disc diameter (VDD) to horizontal disc diameter (HDD), and presence of cilioretinal arteries were nonsignificant.

Multivariate analysis with multiple linear regression showed that only disc area (r^2 change, 0.44; $P < 0.001$) and type of cupping (r^2 change, 0.195; $P < 0.001$) retained statistically significant associations with rim area. Rim area to disc area

TABLE 1. Comparison of Rim Area by Type of Cupping

Type of Cup	n	Mean Rim Area \pm SD* (mm ²)	95% CI* (mm ²)	P*	Mean \pm SD† RA/DA	95% CI† (mm ²)	P†
No cup	89	2.39 \pm 0.35	2.32-2.46	<0.001	1	—	<0.001
Steep cup	317	2.19 \pm 0.36	2.15-2.23	<0.001	0.77 \pm 0.09	0.76-0.78	<0.001
Partly sloping temporal rim	71	2.21 \pm 0.42	2.11-2.31	<0.001	0.76 \pm 0.09	0.74-0.78	<0.001
Fully sloping temporal rim	146	2.48 \pm 0.39	2.41-2.54	<0.001	0.85 \pm 0.08	0.84-0.86	<0.001

Tukey post hoc multiple comparison test revealed significant difference in total RAs and RA/DA between all pairs except steep cup and partly sloping temporal rim. RA, rim area; DA, disc area.

* Data represent total RA. P calculated using one-way ANOVA.

† Data represent RA adjusted for DA (RA/DA). P calculated using one-way ANOVA.

TABLE 2. Neural Rim Area Asymmetry

Difference* (mm ²)	Subjects (n)	Percentage	Cumulative Percentage
0-0.1	217	38.41	38.41
0.11-0.2	155	27.43	65.84
0.21-0.3	107	18.94	84.78
0.31-0.4	45	7.96	92.74
0.41-0.5	19	3.36	96.1
0.51-0.6	8	1.42	97.52
0.61-0.7	5	0.88	98.4
0.71-0.8	4	0.71	99.11
0.81-0.9	4	0.71	99.82
0.91-1.0	1	0.18	100.0

n = 565.

* Absolute value (i.e., larger minus smaller value).

ratio (representing rim area adjusted for differences in disc area) was compared between cup types and was found to differ significantly (Table 1).

Neural Rim Area Asymmetry

Mean absolute rim area asymmetry was 0.18 ± 0.15 mm² (median 0.14 mm², 95th percentile 0.48 mm². Frequencies at different levels of asymmetry are summarized in Table 2.

Associations with Neural Rim Area Asymmetry

Rim area asymmetry correlated with disc area asymmetry (r = 0.59, P < 0.0001) and IOP asymmetry (r = -0.12, P = 0.005). Insignificant associations were observed with asymmetry of spherical equivalent refractive error, asymmetry in morphologic type of cupping, CCT asymmetry, age, and sex.

On multivariate analysis, disc area asymmetry (r² change 0.359, P < 0.0001) and IOP asymmetry (r² change 0.009, P = 0.004) were significantly related to rim area asymmetry (Figs. 4, 5).

Neural Rim Width

Comparison of mean width of the neuroretinal rim at the superior, temporal, inferior, and nasal positions are presented in Table 3. Discs with no cupping (n = 89) were excluded for all analyses of neural rim widths.

Comparison of Superior and Inferior Rims

The mean ratio of the inferior to superior rim width was 1.18 ± 0.17, indicating that on average, the inferior rim was 18%

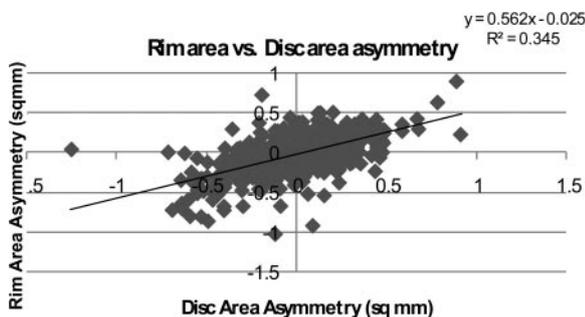


FIGURE 4. Scatterplot of rim area asymmetry versus disc area asymmetry (n = 565) with regression line. Right- minus left-eye values are used for asymmetry of both measures. Also displayed (top right) are the regression equation and r² value (coefficient of determination).

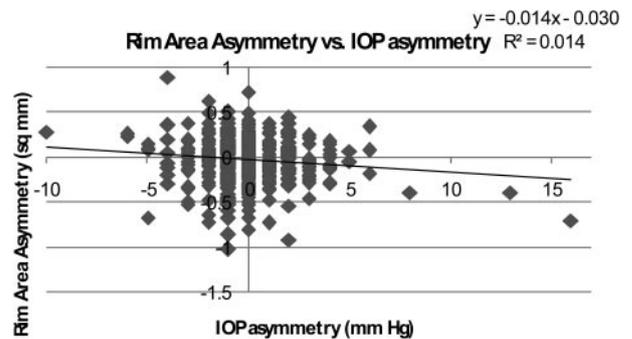


FIGURE 5. Scatterplot of rim area asymmetry versus IOP asymmetry (n = 565) with regression line. Right- minus left-eye values are used for asymmetry of both measures. Also displayed (top right) are the regression equation and r² value (coefficient of determination).

thicker than the superior rim (2.5 percentile = 0.9, 97.5 percentile = 1.62). Thirty-eight (7.1%) patients had superior rims thicker than the inferior rim (examples in Figs. 6A, 6B). The associations of thicker superior rims with ocular and other variables are summarized in Table 4.

Temporal Rim

In 426 (79.77%) eyes, the temporal rim was the thinnest one. In 43 (8.05%) eyes, the nasal rim was thinner than the temporal; in 44 eyes (8.24%), the superior rim was thinner, and in 5 eyes (0.94%), the inferior rim was thinner. In the remaining 16 eyes (3%), more than one of the other three rims was thinner than the temporal.

Considering the clinically most relevant rim width measures in the context of glaucoma, the relationships of temporal with superior and inferior rims was evaluated, and the nasal rim was excluded from the analysis. Excluding the nasal rim, the temporal rim was thinnest in 469 eyes (87.8%). Associations with the presence of thinner superior/inferior than temporal rims are summarized in Table 5. Examples are presented in Figures 6C and 6D.

DISCUSSION

The optic disc owes its importance to the neuroretinal rim, the assessment of which is the single most important component of a glaucoma work-up. In this study, we examined neural rim characteristics—size, configuration, asymmetry, and associations—in a relatively large, perimetrically normal, population-based sample of South Indians. We present normative values of rim area and asymmetry for this ethnic group. We confirm previously reported associations of rim area with disc area in this group and demonstrate the dependence of rim area on

TABLE 3. Comparison of Mean Rim Width at Superior, Temporal, Inferior, and Nasal Positions

Position	Mean Rim Width (mm)	SD	P*
Superior (n = 534)	0.53	0.11	<0.0001
Temporal (n = 534)	0.44	0.12	<0.0001
Inferior (n = 534)	0.61	0.11	<0.0001
Nasal (n = 534)	0.55	0.11	<0.0001

Tukey post hoc multiple-comparison test revealed significant differences between all pairs. Discs with no cupping were not included. * One-way ANOVA.

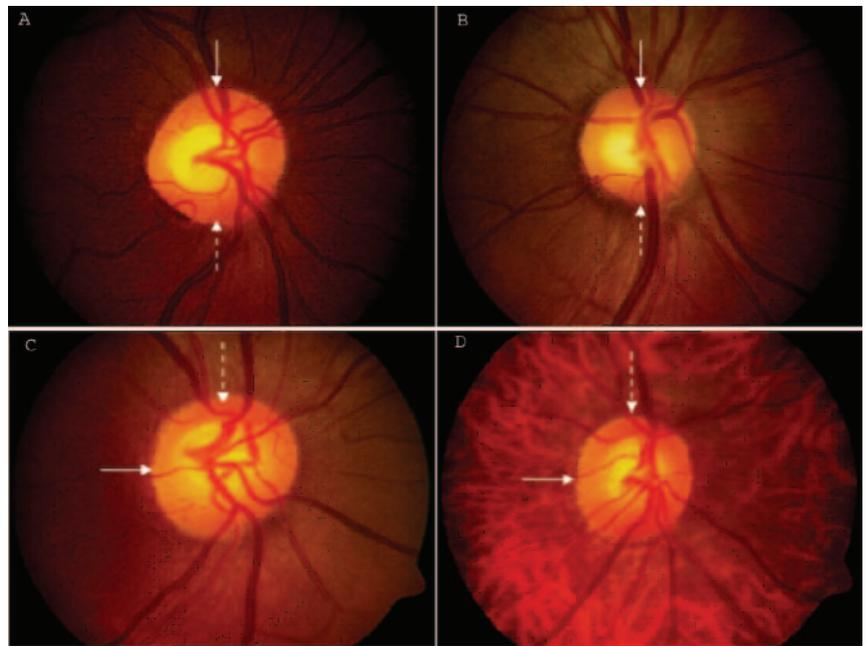


FIGURE 6. Deviations from ISNT rule. (A, B) Examples of discs with thinner inferior (dotted arrows) than superior (solid line arrows) rims. The difference is more pronounced in (B) than in (A). (C, D) Examples of discs where the temporal rim is not the thinnest. In both images, the superior rim (dotted arrows) is thinner than the temporal (solid line arrows).

another physiological variable—the morphologic type of cupping. However, the most important findings of this report are the deviations from the ISNT rule (inferior rim thicker than superior rim, thicker than nasal rim, thicker than temporal rim) in a significant minority of healthy subjects and the associations of these deviations with easily identifiable clinical parameters.

Neural Rim Area

Mean neural rim area in this study was higher than that reported by Jonas et al.⁴ among white subjects ($1.97 \pm 0.5 \text{ mm}^2$). Two other studies of smaller groups of normal persons reported rim areas among South Indians to be $1.6 \pm 0.37 \text{ mm}^2$, in a planimetric study of 70 participants of the Vellore Eye survey,⁶ and $2.8 \pm 0.53 \text{ mm}^2$, in a study of 153 participants of the Andhra Pradesh Eye Diseases Study (APEDS).¹⁵ Our estimate falls between these two reported measures. Differences

in marking the cup border (which in the present study, were marked according to the OHTS protocol), and/or inclusion of a larger range of sizes in the present study due to a much larger sample size may be responsible for the differences. Magnification differences in the software programs used by the different studies may have contributed to the differences, as acknowledged by Jonas et al.⁶ The software used in the present study was validated against a widely available fundus camera (model FF450 and VISUPAC digital image archiving system; Carl Zeiss Meditec), and care was taken to exclude all possible causes of alteration in magnification including any cataract, aphakia, and pseudophakia.

In agreement with previous studies among Indians and white Caucasians, rim area showed a significant positive correlation with disc area. In addition, rim area was significantly influenced by the physiological type of cupping. As suggested

TABLE 4. Univariate and Multivariate Associations with Thicker Superior Than Inferior Rims

	IR > SR	SR > IR	P (Univariate)	P* (Multivariate) (OR, 95% CI)
N (%)	496 (92.88)	38 (7.12)	—	—
Age (mean \pm SD) (y)	48.24 \pm 6.87	48.36 \pm 7.11	0.92†	0.59
Sex (M:F)	196:300	23:15	0.02‡	0.04 (2.2, 1.1–4.43) for men
Disc area (mean \pm SD)	2.90 \pm 0.51	2.7 \pm 2.79	0.18†	0.2
VDD/HDD (mean \pm SD)§	1.08 \pm 0.08	1.05 \pm 0.09	0.03†	0.42
Disc torsion (ratio of torted to nontorted)	26:470	8:30	0.001‡	0.002 (4.8, 2–11.43) for torted discs
Disc tilt (ratio of tilted to non-tilted)	12:484	1:37	1.00‡	0.59
Type of cupping (ratio of steep to partial slope to fully sloping)	291:69:136	26:2:10	0.28‡	0.28
IOP (mean \pm SD) (mm Hg)	16.11 \pm 3.86	15.26 \pm 3.45	0.19†	0.23
CCT (mean \pm SD) (μm)	519.6 \pm 31.39	525.76 \pm 28.41	0.24†	0.11
Refraction (mean \pm SD) (D)	0.45 \pm 1.15	0.28 \pm 1.5	0.39†	0.7
Astigmatism (mean \pm SD) (D)	–0.35 \pm 0.47	–0.46 \pm 0.45	0.15†	0.16

Data in bold represent significant differences in multivariate analyses. IR, inferior rim width; SR, superior rim width; OR, odds ratio; VDD, vertical disc diameter; HDD: horizontal disc diameter; IOP, intraocular pressure; CCT, central corneal thickness.

* Calculated by logistic regression.

† Calculated by *t*-test.

‡ Calculated by χ^2 test.

§ As a measure of disc shape.

TABLE 5. Univariate and Multivariate Associations with Relative Temporal Rim Width*

	Temporal Rim Not Thinnest	Temporal Rim Thinnest	P (Univariate)	P (Multivariate)†
N (%)	65 (12.2%)	469 (87.8%)	—	—
Age (mean ± SD) (y)	50.11 ± 7	48 ± 6.84	0.02‡	0.78
Sex (M:F)	33:32	186:283	0.1§	0.7
Disc area (mean ± SD)	2.97 ± 0.53	2.88 ± 0.51	0.19‡	0.3
VDD/HDD (mean ± SD)	1.02 ± 0.08	1.08 ± 0.08	<0.0001‡	<0.0001
Disc torsion (ratio of tormented to nontorted)	8:57	26:443	0.042§	0.85
Disc tilt (ratio of tilted to nontilted)	2:63	11:458	0.6§	0.87
Type of cupping (ratio of steep to partial slope to fully sloping)	27:13:25	290:58:121	0.007§	0.006
IOP (mean ± SD) (mm Hg)	15.26 ± 3.59	16.16 ± 3.9	0.08‡	0.09
CCT (mean ± SD) (μm)	515.52 ± 29.88	520.67 ± 31.36	0.22‡	0.30
Refraction (mean ± SD) (D)	0.44 ± 1.6	0.44 ± 1.12	0.99‡	0.33
Astigmatism (mean ± SD) (D)	-0.54 ± 0.63	-0.33 ± 0.44	<0.001‡	0.001

Data in bold represent significant differences in multivariate analyses. VDD, vertical disc diameter; HDD, horizontal disc diameter; CCT, central corneal thickness.

* Excluding nasal rims.

† Calculated by logistic regression.

‡ Calculated by *t*-test.

§ Calculated by χ^2 test.

|| As a measure of disc shape.

by Jonas et al.,⁴ sloping rims represent more horizontally or obliquely arranged nerve fibers at the optic nerve head, whereas steep rims represent a more compact arrangement of nerve fibers which bend posteriorly at an almost 90° angle at the optic disc. In their landmark study of 457 normal Caucasian eyes, they demonstrated steeper regression slopes in discs with sloping cups compared with punched-out cups. The rim area/disc area measure examined in this study provides a similar estimate (i.e., rim area per unit of disc area, which was maximum for discs with no cups, lesser for discs with fully sloping rims, and least for cups with partly sloping rims and punched-out cups), indicating progressively more compact arrangement of nerve fibers at the optic disc. The dependence of rim area, in addition to disc area, on morphologic cup type suggests the need to consider both physiological variables in the assessment and interpretation of variations in rim area.

Rim Area Asymmetry

As expected, rim area asymmetry showed a significant correlation with disc area asymmetry. The association of rim area asymmetry with IOP asymmetry in this normal group was somewhat surprising in view of the fact that previous analysis of rim area versus IOP values (not asymmetry) did not yield any significant correlations. However, the magnitude of this association was very small. Inter-eye asymmetry analysis adjusts for interindividual variations of several known and unknown biological influences that may have an effect on optic disc parameters, and this adjustment may have unmasked a weak, although clinically insignificant, association between IOP and rim area in healthy eyes.

Neural Rim Shape

The ISNT rule was suggested by Jonas et al.⁴ based on findings in their study of 457 Caucasian eyes. However, as is true of most parameters in medicine, variability even within normal eyes is not surprising and must be expected. In a subsequent study of 193 normal eyes,¹⁶ they reported violations of this rule—the thickest rim was located outside the inferior rim in 37.8% of eyes and in 24.9%, it was the superior rim. They also reported that the temporal rim was not the thinnest rim in 4.2% eyes. In another study that involved evaluation of masked disc

photographs of 66 normal eyes of black subjects and white subjects, Harizman et al.¹⁷ report violation of the ISNT rule in 21% of eyes. Of the 14 normal eyes that violated the ISNT rule, 7 had an inferior rim that was thinner than the superior rim, 5 had a nasal rim that was thicker than the inferior rim, and 2 had a temporal rim that was thicker than the superior rim.

The nasal rim is usually the last to be affected by glaucomatous cupping, and it is often difficult to identify distinctly the borders of the optic cup in the nasal optic disc sector due to the presence of the large retinal vessels. For these reasons, it has been suggested that the nasal sector should be excluded from morphometric disc analysis.¹⁸ Also, during clinical evaluation of optic discs using biomicroscopic examination, one usually evaluates two factors: First, the relative thickness of the inferior to superior rim, as glaucomatous damage most commonly manifests as thinning of the inferior rim, and second, whether the temporal rim is the thinnest of the three rims, as a thinner superior/inferior than temporal rim is considered highly suspect in regard to glaucoma. In a Heidelberg Retina Tomograph (HRT) study involving 136 normal North Indian eyes, Sihota et al.¹⁹ reported the inferior rim area > superior rim area > temporal rim area in 71% of normal eyes and violation in the remaining 29%.

In the present study, we found that on examination of mean values, the inferior rim was thickest, and temporal rim was thinnest, in accordance with the most important components of the ISNT rule as stated by Jonas et al.⁴ We also found that on average, the inferior rim was approximately 20% thicker than the superior rim. The lower 2.5 percentile of the ratio of inferior to superior rim was 0.9, which indicates that in this ethnic group, an inferior rim that is 90% of the thickness of the superior rim may be considered the lower limit of normal. Multivariate analysis of possible contributors to a thicker superior than inferior rim revealed that torsion of the disc increased the odds of a thicker superior rim by more than four times. Nasal or temporal torsion of the disc would change the relative rim positions measured at the 12 (for superior) and 6 (inferior) o'clock positions and contribute to relatively thinner rim measurement inferiorly than for a nontorted disc. Therefore, in this population, a normal disc need not have a thicker inferior than superior rim. In the absence of other glaucomatous features, an

inferior rim with width at least 90% of the superior rim may be normal, especially if the disc is torped.

Of interest is the finding in the present study that the temporal rim was not the thinnest in 12% of eyes (excluding nasal rims), with disc shape (VDD/HDD), astigmatism, and type of cupping being significant contributors to this outcome. A shorter vertical-to-horizontal disc diameter (i.e., a more horizontally oval disc) increases the relative availability of space for arrangement of nerve fibers at the superior and inferior poles, and decreases the space available nasally and temporally, necessitating that the nerve fibers be bunched thicker at the latter positions. The same reasoning was mentioned by Budde et al.¹⁶ to explain the occurrence of thicker nasal rims in eyes with lower VDD/HDD. However, in their study, very few eyes had thinnest rims outside the temporal zone (4.2%, eight eyes), which may be the reason that this parameter did not show significant correlations with VDD/HDD. A significantly higher percentage of eyes with sloping rims (sectoral or total) than eyes with steep rims had temporal rims that were not the thinnest rims. Oblique arrangement of fibers in the horizontal temporal region in discs with sloping cups may contribute to measurement of wider rim widths temporally, analogous to the earlier discussion of the influence of type of cupping on rim area. Therefore, in the assessment of discs with thinner superior or inferior than temporal rims, in the absence of any other features suggestive of glaucoma, disc shape, astigmatism, and any oblique arrangement of nerve fibers must be considered possible physiological reasons for this finding.

The advantages of our study are its relatively large sample size and population-based design. To the best of our knowledge, this is the largest study of quantitative optic disc dimensions to be undertaken in this part of the world, which is home to approximately one sixth of the world's population. As far as we are aware, ours is also the only study so far to explore in such detail the clinically relevant issues of neuroretinal rim shape and its dependence on other optic disc features in perimetrically normal persons. As recommended by the ISGEO in recognition of racial variations in optic disc parameters, it is best that limits of normal parameters be derived from examination of perimetrically normal persons from the same populations.¹⁰ Our conclusions regarding relative rim thickness would therefore be applicable to South Indians. To the best of our knowledge, this is also the first report of rim area asymmetry among Indians.

Though time consuming, the technique of planimetry of digital photographs has its distinct advantages. First, it presents the optic disc to the examiner as it is and directly permits clinically relevant measurements with direct clinical applicability. The HRT (Heidelberg Engineering) is used more and more today to obtain planimetric data²⁰; however, it does not provide direct linear measures of disc diameters or rim widths, which are what the examiner usually estimates during a routine clinical disc examination. It also does not provide measures of such features as torsion and tilting of the optic disc.

Our custom software, being specifically designed for optic disc planimetry, is more user friendly for this purpose than is the commercially available VISUPAC system (Carl Zeiss Meditec). In addition to several tools and commands that make it easier to use for planimetry, it is portable (it can be used on any PC), marks curved lines between marked points that follow disc and cup outlines better than the straight lines in the VISUPAC system, and automatically saves measurements to a file in the same directory as the pictures without the need to record measurements separately as with the VISUPAC system.

A possible limitation of this study is that the mean age of participants in the planimetric study was significantly lower than the mean age of the larger group of CGS participants from the two selected clusters. However, in the interest of obtaining true dimensions and in an effort to avoid inappropriate influences on ocular magnification, we took care to avoid including any persons with cataract, aphakia, and pseudophakia, and therefore this age difference was unavoidable. The inclusion of only two of five clusters is another possible source of error. The last two clusters were chosen due to logistic reasons—keratometry was performed only for these two clusters. The selection was not in any way based on, or influenced by, the nature of the data or findings. The inclusion of patients with ocular hypertension in the present study introduces the possibility that we may have included some with early (preperimetric) glaucoma.

In conclusion, we report normative neural rim measurements among South Indians. Rim area was significantly influenced by disc area and by morphologic type of cupping. The inferior rim was thickest, and the temporal rim was thinnest. The inferior rim was, on average, approximately 20% thicker than the superior rim. If every other relevant finding is normal, an inferior rim that is 90% of the superior rim thickness may be considered the lower limit of normal for the South Indian population. The occurrence of thicker superior than inferior rims was influenced by torsion of the disc, and, possibly by male sex. Excluding nasal rims, the temporal rim was not thinnest in 12% of eyes. The occurrence of nonthinnest temporal rims was influenced by disc shape, astigmatism, and morphologic type of cupping.

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