

Original Research Article

CORRELATION OF RETINAL NERVE FIBRE LAYER THICKNESS WITH PERIMETRIC SEVERITY IN PRIMARY OPEN-ANGLE GLAUCOMA: A CROSS-SECTIONAL STUDY

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ABSTRACT

Background: Primary open-angle glaucoma is characterised by progressive retinal ganglion-cell and retinal nerve fibre loss with corresponding visual-field impairment. Optical coherence tomography provides objective structural measurements, while standard automated perimetry evaluates functional damage. **Aim:** To determine the correlation between retinal nerve fibre layer thickness and perimetric severity in patients with primary open-angle glaucoma. **Materials and Methods:** This hospital-based cross-sectional study included 82 eyes of 46 patients with POAG. Participants underwent comprehensive ophthalmic examination, spectral-domain optical coherence tomography and standard automated perimetry. Average and quadrant-wise peripapillary RNFL thickness and macular GCL+IPL thickness were recorded. Glaucoma was classified as mild, moderate or severe using the Hodapp-Parrish-Anderson criteria. Continuous measurements were compared using one-way ANOVA, and correlations were assessed using Pearson's correlation coefficient. A p value <0.05 was considered statistically significant.

Results: Of the 82 eyes, 22 (26.8%) had mild, 18 (22.0%) had moderate and 42 (51.2%) had severe glaucoma. Average RNFL thickness decreased from 86.55 (11.50) μ m in mild glaucoma to 64.67 (12.05) μ m in moderate glaucoma and 61.12 (16.44) μ m in severe glaucoma ($F=23.497$, $p<0.001$). Superior, inferior and temporal RNFL thicknesses also decreased significantly with increasing severity (all $p<0.001$), while nasal RNFL thickness showed a smaller difference ($p=0.017$). Average and minimum GCL+IPL thickness declined significantly across stages (both $p<0.001$). Mean deviation worsened from -3.54 (1.20) dB to -23.07 (6.27) dB, while visual field index decreased from 93.59% (4.16) to 39.71% (27.27) (both $p<0.001$). Average RNFL thickness showed a moderate inverse correlation with perimetric stage ($r=-0.573$; 95% CI: -0.703 to -0.407; $p<0.001$).

Conclusion: Average and quadrant-wise RNFL thickness decreased significantly with increasing perimetric severity of POAG. The strongest structural relationships were observed in the inferior, temporal and superior quadrants. SD-OCT-derived RNFL and ganglion-cell measurements complemented visual-field indices and may facilitate objective staging and monitoring of POAG.

Keywords: Primary open-angle glaucoma; retinal nerve fibre layer; optical coherence tomography.

INTRODUCTION

Primary open-angle glaucoma (POAG) is a chronic, progressive optic neuropathy characterised by degeneration of retinal ganglion cells, thinning of the retinal nerve fibre layer (RNFL), characteristic optic-disc changes and corresponding visual-field defects. It is an important cause of irreversible blindness worldwide and frequently remains undetected until substantial structural and functional damage has occurred because the early stages are usually asymptomatic.^[1] The diagnosis and monitoring of POAG therefore require a combined assessment of intraocular pressure, anterior chamber angle, optic nerve head, RNFL and visual function. Standard automated perimetry is the conventional method for evaluating functional loss and determining glaucoma severity. However, perimetric examination is subjective, depends on patient attention and response reliability, and may fail to identify early glaucomatous damage. Current clinical guidelines consequently recommend complementary structural assessment using optical coherence tomography (OCT).^[2]

Spectral-domain optical coherence tomography (SD-OCT) provides rapid, non-invasive and reproducible quantitative measurements of the peripapillary RNFL, optic nerve head and macular ganglion cell-inner plexiform layer. Structural injury to retinal ganglion-cell axons may precede detectable visual-field loss; therefore, OCT can facilitate the early recognition of glaucomatous damage. Progressive RNFL thinning has also been associated with an increased risk of subsequent visual-field deterioration, supporting its role in monitoring disease progression.^[3] Nevertheless, the relationship between structural and functional damage is complex and may vary according to the stage and anatomical location of glaucomatous injury.

Previous studies have demonstrated significant correlations between peripapillary RNFL thickness and visual-field indices such as mean deviation, pattern standard deviation and visual field index.^[4] Average and sectoral RNFL thickness generally decrease as perimetric severity increases. The superior and inferior RNFL quadrants are particularly vulnerable because they contain dense bundles of retinal ganglion-cell axons corresponding to the arcuate regions commonly affected in glaucoma. However, OCT measurements may demonstrate a “floor effect” in advanced disease, whereas visual-field testing may be less sensitive during the early stages. Consequently, structural and functional assessments provide complementary information across different stages of glaucoma.^[5]

AIM: To determine the correlation between retinal nerve fibre layer thickness and perimetric severity in patients with primary open-angle glaucoma.

Objectives:

1. To measure the average and quadrant-wise peripapillary RNFL thickness using spectral-

domain optical coherence tomography in patients with POAG.

2. To classify POAG into mild, moderate and severe stages using standard automated perimetry according to the Hodapp-Parrish-Anderson criteria.
3. To correlate average and quadrant-wise RNFL thickness with perimetric stage and visual-field indices, including mean deviation, pattern standard deviation and visual field index.

MATERIALS AND METHODS

Source of Data: The study population consisted of patients diagnosed with primary open-angle glaucoma who attended the Ophthalmology Outpatient Department of Shri Dharmasthala Manjunatheshwara College of Medical Sciences and Hospital, Sattur, Dharwad, during the study period. Patients who fulfilled the eligibility criteria and provided written informed consent were enrolled consecutively.

Study Design: This was a hospital-based cross-sectional observational study.

Study Location: The study was conducted in the Department of Ophthalmology, Shri Dharmasthala Manjunatheshwara College of Medical Sciences and Hospital, Sattur, Dharwad, Karnataka, India.

Study Duration: The study was conducted over two years, from July 2022 to July 2024.

Sample Size: The sample size was calculated for detecting a significant correlation between RNFL thickness and perimetric severity using Fisher's z transformation:

$$n = \left[\frac{Z_{(1-\alpha/2)} + Z_{(1-\beta)}}{0.5 \ln \left(\frac{(1+r)}{(1-r)} \right)} \right]^2 + 3$$

Where:

n = required number of participants

$Z_{(1-\alpha/2)} = 1.96$ at a 5% two-sided significance level

$Z_{(1-\beta)} = 0.84$ for 80% statistical power

$r = 0.404$, the anticipated correlation between RNFL thickness and perimetric severity

$$n = \left[\frac{(1.96 + 0.84)}{0.5 \ln \left(\frac{(1 + 0.404)}{(1 - 0.404)} \right)} \right]^2 + 3$$

$$n = (2.80 / 0.428)^2 + 3 = 45.8 \approx 46$$

Thus, the required sample size was 46 patients. A total of 46 patients contributing 82 eligible eyes were included in the final analysis.

Sampling Method

Consecutive sampling was used. All eligible patients presenting during the study period were invited to participate until the required sample size was achieved.

Inclusion Criteria

- Patients diagnosed with primary open-angle glaucoma.
- Patients attending the Ophthalmology Outpatient Department during the study period.
- Patients with open anterior chamber angles on gonioscopy.

- Patients with glaucomatous optic nerve head or RNFL changes, with or without corresponding visual-field defects.
- Patients who could undergo reliable OCT and standard automated perimetry.
- Patients who provided written informed consent.

Exclusion Criteria

- Refractive error greater than -6.00 dioptres.
- Axial length greater than 24 mm.
- Significant media opacity interfering with fundus examination, OCT imaging or perimetry.
- Retinal diseases capable of affecting RNFL thickness or the visual field.
- Secondary glaucoma or angle-closure glaucoma.
- Non-glaucomatous optic neuropathy.
- Neurological or other diseases affecting the visual pathway.
- Previous ocular trauma.
- Previous intraocular surgery, except uncomplicated cataract surgery or trabeculectomy performed in a confirmed POAG patient.
- Unreliable visual-field examination or poor-quality OCT scans.

Data Collection

Data were collected using a predesigned and pretested study proforma. Information recorded included age, sex, presenting complaints, duration of glaucoma, treatment history, personal history, previous ophthalmic history and family history of glaucoma. Information regarding recognised risk factors, including myopia, diabetes mellitus, hypertension and positive family history, was also documented.

A general physical examination was performed, and pulse rate and blood pressure were recorded. Relevant medical and ophthalmic records were reviewed whenever available. Data obtained from clinical examination, OCT and perimetry were entered into the proforma on the same day.

Procedure and Methodology: Institutional Ethics Committee approval was obtained before beginning the study. Eligible patients were informed about the purpose, procedures, potential benefits and possible discomfort associated with the study. Written informed consent was obtained before enrolment. Each participant underwent a detailed bilateral ophthalmic examination. Best-corrected visual acuity was recorded using a standard visual-acuity chart. The eyelids, conjunctiva, cornea, anterior chamber, iris, pupil and crystalline lens were evaluated using slit-lamp biomicroscopy. Intraocular pressure was measured using Goldmann applanation tonometry. Central corneal thickness was assessed by pachymetry, and the anterior chamber angle was examined by gonioscopy.

The optic disc, neuroretinal rim, cup-disc ratio, retinal blood vessels, macula and posterior pole were evaluated by slit-lamp biomicroscopy using a +78 D lens and by indirect ophthalmoscopy. Evidence of glaucomatous optic neuropathy, including increased

vertical cup-disc ratio, focal or diffuse neuroretinal-rim thinning, notching and RNFL defects, was documented.

Peripapillary RNFL thickness was measured using SD-OCT. A circular scan centred on the optic nerve head was obtained, and average RNFL thickness and thickness in the superior, inferior, nasal and temporal quadrants were recorded in micrometres. Macular ganglion cell-inner plexiform layer parameters, including average and minimum GCL-IPL thickness, were also documented when available. Images with poor signal strength, segmentation errors, motion artefacts or improper centration were repeated.

Visual-field assessment was performed using a Humphrey Field Analyzer with the Swedish Interactive Threshold Algorithm standard 24-2 programme. The 10-2 programme was used when clinically required, particularly in advanced glaucoma or when central-field assessment was necessary. Mean deviation, pattern standard deviation and visual field index were recorded.

Visual fields were checked for reliability. Tests showing excessive fixation losses or unacceptable false-positive or false-negative responses were repeated. Based on the visual-field findings, eyes were classified as having mild, moderate or severe glaucoma according to the Hodapp-Parrish-Anderson criteria.

Perimetric Staging

- Mild glaucoma: Mean deviation of -6.00 dB or better, with relatively limited glaucomatous field loss.
- Moderate glaucoma: Mean deviation worse than -6.00 dB but better than -12.00 dB, with field loss not meeting the criteria for severe glaucoma.
- Severe glaucoma: Mean deviation of -12.00 dB or worse, or advanced field loss involving both hemifields and/or points within the central 5°.

Sample Processing

No biological specimen was collected or processed because the study involved clinical ophthalmic examination and instrument-based measurements. OCT scans and perimetry reports constituted the study records. Each report was assigned a unique study identification number and was reviewed for image quality, segmentation accuracy and perimetric reliability before being included in the analysis.

Outcome Measures: The primary outcome measure was the correlation between average RNFL thickness and perimetric glaucoma severity.

Secondary outcome measures included:

- Correlation of superior, inferior, nasal and temporal RNFL thickness with glaucoma severity.
- Differences in average RNFL thickness across mild, moderate and severe glaucoma.
- Correlation of RNFL thickness with mean deviation, pattern standard deviation and visual field index.
- Differences in average and minimum GCL-IPL thickness across glaucoma stages.

Statistical Methods: Data were entered into a spreadsheet, checked for completeness and analysed using Jamovi software, version 2.5.7. Categorical variables were summarised as frequencies and percentages. Continuous variables were expressed as mean and standard deviation; median and interquartile range were used where distributions were markedly non-normal.

The chi-square test or Fisher's exact test was used to examine associations between categorical variables. Mean RNFL and GCL-IPL thicknesses across mild, moderate and severe glaucoma groups were compared using one-way analysis of variance. When the overall ANOVA was significant, suitable post-hoc pairwise comparisons were performed.

Pearson's correlation coefficient was used to assess relationships between normally distributed continuous OCT and visual-field parameters. Spearman's rank correlation coefficient was used for ordinal glaucoma severity or non-normally distributed variables. Correlation coefficients were reported with 95% confidence intervals. All statistical tests were two-sided, and a p value <0.05 was considered statistically significant.

Because some patients contributed both eyes, the statistical interpretation considered possible within-patient correlation. Where supported by the analysis software, generalised estimating equations or mixed-effects models with patient identification as a clustering variable were used for eye-level comparisons.

RESULTS

Table 1. Hypothetical demographic profile of patients with POAG (N = 46)

Characteristic	Hypothetical value
Age, years, mean (SD)	61.3 (9.8)
Male, n (%)	27 (58.7)
Female, n (%)	19 (41.3)
Total	46 (100.0)

In this hypothetical demographic profile, the mean age of the 46 patients was 61.3 years (SD 9.8). Males constituted 58.7% (27/46) and females 41.3% (19/46). These age and sex values are illustrative and should be replaced with the actual study data.

Table 2. Distribution of study eyes by perimetric severity (N = 82 eyes)

Glaucoma severity	Eyes, n (%)	95% CI
Mild	22 (26.8)	18.4%–37.3%
Moderate	18 (22.0)	14.4%–32.1%
Severe	42 (51.2)	40.6%–61.7%
Total	82 (100.0)	

Of the 82 study eyes, severe glaucoma was the most frequent stage, affecting 42 eyes (51.2%; 95% CI: 40.6%–61.7%). Mild glaucoma was observed in 22 eyes (26.8%), while 18 eyes (22.0%) had moderate glaucoma. These counts refer to eyes, not individual patients.

Table 3: Association of average RNFL and ganglion-cell thickness with perimetric severity of POAG (N=82 eyes)

OCT parameter	Mild (n=22), mean (SD); 95% CI	Moderate (n=18), mean (SD); 95% CI	Severe (n=42), mean (SD); 95% CI	ANOVA F (df=2,79)	p value
Average RNFL thickness, μm	86.55 (11.50); 81.45–91.65	64.67 (12.05); 58.68–70.66	61.12 (16.44); 56.00–66.24	23.497	<0.001
Average GCL+IPL thickness, μm	75.86 (14.73); 69.33–82.39	66.72 (8.64); 62.43–71.01	60.52 (12.78); 56.54–64.50	10.754	<0.001
Minimum GCL+IPL thickness, μm	68.00 (14.80); 61.44–74.56	57.22 (12.18); 51.17–63.27	51.02 (14.84); 46.39–55.65	10.178	<0.001

Table 3 demonstrates a progressive reduction in RNFL and ganglion-cell thickness with increasing perimetric severity of POAG. The mean average RNFL thickness decreased from 86.55 (11.50) μm in mild glaucoma to 64.67 (12.05) μm in moderate glaucoma and 61.12 (16.44) μm in severe glaucoma. This difference was statistically significant ($F=23.497$, $p<0.001$). Similarly, average GCL+IPL

thickness declined from 75.86 (14.73) μm in mild disease to 66.72 (8.64) μm in moderate disease and 60.52 (12.78) μm in severe disease ($F=10.754$, $p<0.001$). Minimum GCL+IPL thickness also decreased significantly from 68.00 (14.80) μm to 57.22 (12.18) μm and 51.02 (14.84) μm across the mild, moderate and severe stages, respectively ($F=10.178$, $p<0.001$).

Table 4: Average and quadrant-wise peripapillary RNFL thickness according to POAG severity (N=82 eyes)

RNFL parameter	Overall mean (SD); 95% CI	Mild (n=22), mean (SD)	Moderate (n=18), mean (SD)	Severe (n=42), mean (SD)	ANOVA F (df=2,79)	p value
Average RNFL, μm	68.72 (17.93); 64.78–72.66	86.55 (11.50)	64.67 (12.05)	61.12 (16.44)	23.497	<0.001
Superior RNFL, μm	81.66 (27.20); 75.68–87.64	105.50 (17.16)	78.56 (28.22)	70.50 (23.33)	16.831	<0.001

Inferior RNFL, μm	80.22 (27.74); 74.13-86.31	107.23 (19.22)	74.17 (20.06)	68.67 (24.90)	22.028	<0.001
Nasal RNFL, μm	63.74 (13.23); 60.83-66.65	70.45 (12.64)	60.06 (7.87)	61.81 (14.30)	4.300	0.017
Temporal RNFL, μm	52.51 (11.28); 50.03-54.99	62.41 (11.32)	47.50 (8.60)	46.48 (9.06)	16.165	<0.001

Table 4 presents the average and quadrant-wise peripapillary RNFL measurements according to POAG severity. The overall average RNFL thickness was 68.72 (17.93) μm , with a 95% CI of 64.78-72.66 μm . It declined significantly from 86.55 (11.50) μm in mild glaucoma to 61.12 (16.44) μm in severe glaucoma ($F=23.497$, $p<0.001$). Superior RNFL thickness decreased from 105.50 (17.16) μm in mild disease to 78.56 (28.22) μm in moderate disease and 70.50 (23.33) μm in severe disease ($F=16.831$,

$p<0.001$). A similar marked reduction was observed in the inferior quadrant, from 107.23 (19.22) μm to 74.17 (20.06) μm and 68.67 (24.90) μm , respectively ($F=22.028$, $p<0.001$). Temporal RNFL thickness also decreased significantly from 62.41 (11.32) μm in mild glaucoma to 46.48 (9.06) μm in severe glaucoma ($F=16.165$, $p<0.001$). The nasal quadrant showed a smaller and less consistent reduction, although the overall difference remained statistically significant ($F=4.300$, $p=0.017$).

Table 5: Perimetric classification and visual-field indices according to Hodapp-Parrish-Anderson criteria (N=82 eyes)

Perimetric finding	Mild (n=22)	Moderate (n=18)	Severe (n=42)	Test statistic	p value
Distribution, n (%)	22 (26.8)	18 (22.0)	42 (51.2)	$\chi^2=11.22$, $df=2$	0.004
95% CI for proportion	18.4%-37.3%	14.4%-32.1%	40.6%-61.7%		
Mean deviation, dB, mean (SD)	-3.54 (1.20)	-8.29 (2.51)	-23.07 (6.27)	$F=145.204$	<0.001
95% CI for mean deviation	-4.07 to -3.01	-9.54 to -7.04	-25.03 to -21.12		
Pattern standard deviation, dB, mean (SD)	3.76 (2.08)	7.35 (3.30)	8.22 (4.12)	$F=15.724$	<0.001
95% CI for pattern standard deviation	2.84-4.69	5.71-9.00	6.94-9.51		
Visual field index, %, mean (SD)	93.59 (4.16)	79.56 (11.67)	39.71 (27.27)	$F=57.531$	<0.001
95% CI for visual field index	91.75-95.43	73.76-85.36	31.21-48.21		

Table 5 shows the distribution of perimetric severity and corresponding visual-field indices. Of the 82 eyes, 22 (26.8%; 95% CI: 18.4%-37.3%) had mild glaucoma, 18 (22.0%; 95% CI: 14.4%-32.1%) had moderate glaucoma and 42 (51.2%; 95% CI: 40.6%-61.7%) had severe glaucoma. The distribution differed significantly across the three stages ($\chi^2=11.22$, $df=2$, $p=0.004$), with severe glaucoma being the most frequent category. Mean deviation became progressively more negative, declining from

-3.54 (1.20) dB in mild disease to -8.29 (2.51) dB in moderate disease and -23.07 (6.27) dB in severe disease ($F=145.204$, $p<0.001$). Pattern standard deviation increased from 3.76 (2.08) dB to 7.35 (3.30) dB and 8.22 (4.12) dB, respectively ($F=15.724$, $p<0.001$). In contrast, the visual field index decreased markedly from 93.59% (4.16) in mild glaucoma to 79.56% (11.67) in moderate glaucoma and 39.71% (27.27) in severe glaucoma ($F=57.531$, $p<0.001$).

Table 6: Correlation of RNFL thickness and visual-field indices with perimetric stage (N=82 eyes)

Parameter	Correlation with increasing perimetric stage, r	95% CI for r	Test statistic, t (df=80)	p value	Interpretation
Average RNFL thickness	-0.573	-0.703 to -0.407	-6.253	<0.001	Moderate inverse correlation
Superior RNFL thickness	-0.528	-0.668 to -0.351	-5.561	<0.001	Moderate inverse correlation
Inferior RNFL thickness	-0.562	-0.695 to -0.393	-6.077	<0.001	Moderate inverse correlation
Nasal RNFL thickness	-0.250	-0.443 to -0.035	-2.309	0.024	Weak inverse correlation
Temporal RNFL thickness	-0.540	-0.677 to -0.366	-5.739	<0.001	Moderate inverse correlation
Mean deviation	-0.862	-0.909 to -0.794	-15.210	<0.001	Strong inverse correlation
Pattern standard deviation	0.460	0.270-0.616	4.634	<0.001	Moderate positive correlation
Visual field index	-0.752	-0.833 to -0.639	-10.204	<0.001	Strong inverse correlation

Table 6 demonstrates significant correlations between OCT-derived RNFL measurements, visual-field indices and increasing perimetric stage. Average RNFL thickness showed a moderate inverse correlation with glaucoma severity ($r=-0.573$; 95% CI: -0.703 to -0.407; $t=-6.253$; $p<0.001$). Significant moderate inverse correlations were also observed for

superior ($r=-0.528$), inferior ($r=-0.562$) and temporal RNFL thickness ($r=-0.540$), with all $p<0.001$. Nasal RNFL thickness demonstrated a comparatively weak inverse correlation ($r=-0.250$; 95% CI: -0.443 to -0.035; $p=0.024$). Among the visual-field indices, mean deviation had the strongest inverse correlation with perimetric stage ($r=-0.862$; 95% CI: -0.909 to -

0.794; $p < 0.001$), followed by the visual field index ($r = -0.752$; 95% CI: -0.833 to -0.639; $p < 0.001$). Pattern standard deviation showed a moderate positive correlation with increasing disease severity ($r = 0.460$; 95% CI: 0.270-0.616; $p < 0.001$).

DISCUSSION

The present hospital-based cross-sectional study evaluated the relationship between structural retinal damage measured by spectral-domain optical coherence tomography and functional visual-field loss in 82 eyes with primary open-angle glaucoma. Average and quadrant-wise RNFL thickness, average GCL+IPL thickness and minimum GCL+IPL thickness progressively declined with increasing perimetric severity. These findings established a significant structure-function relationship in POAG and supported the complementary use of OCT and standard automated perimetry for disease assessment. The mean average RNFL thickness decreased from 86.55 μm in mild glaucoma to 64.67 μm in moderate glaucoma and 61.12 μm in severe glaucoma ($F = 23.497$, $p < 0.001$). Bhat et al. (2022).^[1] Similarly reported progressive thinning of the average RNFL with increasing perimetric severity and observed a mean overall RNFL thickness comparable to the 68.72 μm recorded in the present study. Gupta et al. (2021).^[2] also reported lower RNFL measurements in more advanced POAG, although the difference in average RNFL thickness across stages was less marked in their study. Differences in sample composition, proportion of advanced cases, OCT instrument, scan protocol, refractive status and segmentation algorithm may explain this variation. Abd El-Naby et al. (2018).^[3] demonstrated a significant association between RNFL thickness and perimetric changes, supporting the use of RNFL measurements as structural indicators of functional damage.

Kang et al. (2015).^[4] reported a moderate relationship between peripapillary RNFL thickness and visual-field severity indices. Their findings supported the present observation that RNFL thickness does not decline independently of functional loss but shows a measurable relationship with worsening perimetric stage. Monsalve et al. (2015).^[5] also demonstrated significant topographical relationships between RNFL thickness and corresponding visual-field regions, with particularly strong correlations in the superior and inferior arcuate regions.

The average GCL+IPL thickness decreased from 75.86 μm in mild glaucoma to 60.52 μm in severe glaucoma, while minimum GCL+IPL thickness declined from 68.00 to 51.02 μm . Both reductions were statistically significant ($p < 0.001$). Bambo et al. (2017).^[6] similarly demonstrated progressive thinning of both circumpapillary RNFL and macular GCIPL across early, moderate and severe glaucoma and reported significant correlations with visual-field indices. Zivkovic et al. (2018).^[7] found that GCIPL

thickness differed significantly across glaucoma stages and was closely associated with overall visual-field sensitivity. These observations are clinically important because macular GCIPL represents the cell bodies and dendrites of retinal ganglion cells and may provide additional information when peripapillary RNFL measurements approach their lower measurement limit.

Hu et al. (2021).^[8] observed significant relationships between macular GCIPL thickness and 24-2 and 10-2 visual-field sensitivity in advanced glaucoma. They found that macular GCIPL measurements reflected functional damage better than circumpapillary RNFL measurements in advanced cases. This supports the significant GCL+IPL reduction found in the present study, particularly because 51.2% of the examined eyes had severe glaucoma. Hence, macular ganglion-cell analysis may remain clinically valuable when average RNFL thickness demonstrates limited additional decline.

Quadrant-wise analysis revealed that RNFL thinning was most prominent in the inferior and superior quadrants. Inferior RNFL thickness decreased from 107.23 μm in mild disease to 68.67 μm in severe disease, while superior RNFL thickness decreased from 105.50 to 70.50 μm . Temporal RNFL thickness also declined significantly from 62.41 to 46.48 μm . These findings agreed with Bhat et al. (2022).^[1] and Abd El-Naby et al. (2018).^[3] who reported substantial superior and inferior RNFL loss with increasing glaucoma severity. The preferential involvement of these quadrants is anatomically consistent with the vulnerability of the superior and inferior arcuate nerve-fibre bundles.

Nasal RNFL thickness demonstrated only a weak inverse relationship with disease stage ($r = -0.250$, $p = 0.024$), and its stage-wise pattern was less consistent than those of the other quadrants. The nasal thickness decreased from 70.45 μm in mild glaucoma to 60.06 μm in moderate glaucoma but was slightly higher at 61.81 μm in severe glaucoma. The small difference between moderate and severe groups may represent biological variability, scan-position variation or the reduced sensitivity of the nasal quadrant for distinguishing advanced stages. Abd El-Naby et al. (2018).^[3] reported significant RNFL loss in all quadrants, whereas Bhat et al. (2022).^[1] found stronger relationships in superior, inferior and temporal measurements. This indicates that average, inferior and superior RNFL measurements may be more dependable for clinical staging than isolated nasal measurements.

More than half of the eyes in the present study had severe POAG, whereas 26.8% had mild and 22.0% had moderate disease. This high proportion of advanced disease may reflect delayed presentation because POAG remains asymptomatic until considerable visual-field loss has occurred. The distribution also indicates that the study was conducted in a tertiary-care setting where patients with advanced or treatment-resistant disease are more likely to be referred.

Mean deviation became progressively more negative, from -3.54 dB in mild glaucoma to -8.29 dB in moderate glaucoma and -23.07 dB in severe glaucoma ($F=145.204$, $p<0.001$). Pattern standard deviation increased from 3.76 to 8.22 dB ($F=15.724$, $p<0.001$), while the visual field index decreased from 93.59% to 39.71% ($F=57.531$, $p<0.001$). Iutaka et al. (2017)[11] reported that VFI was strongly correlated with MD and PSD and significantly correlated with RNFL thickness, supporting its use as an indicator of functional impairment.^[11] Their reported correlation between VFI and RNFL thickness was statistically significant but weaker than the correlations among functional indices themselves.

In the present study, average RNFL thickness demonstrated a moderate inverse correlation with increasing perimetric stage ($r=-0.573$, $p<0.001$). Inferior, temporal and superior RNFL measurements also showed moderate inverse correlations, whereas the nasal quadrant showed a weak inverse correlation. The stronger relationship involving the inferior and superior sectors was consistent with Monsalve et al. (2015),^[5] who identified strong regional structure-function associations involving corresponding arcuate visual-field regions.

The relationship between structural and functional measurements is not expected to remain linear throughout the disease spectrum. Mwanza et al. (2015).^[10] showed that RNFL measurements have a limited dynamic range and eventually reach a residual measurement floor. Bowd et al. (2017).^[9] similarly demonstrated that GCIPL retains more measurable tissue above the OCT floor than several other structural parameters in advanced glaucoma. This floor effect may explain why average RNFL thickness declined considerably between mild and moderate glaucoma but demonstrated a smaller difference between moderate and severe disease in the present study.

Zhang et al. (2017).^[12] reported that OCT could detect progression effectively, particularly during earlier disease, while macular ganglion-cell measurements retained usefulness in advanced stages. Their findings emphasised that the relative performance of OCT and visual-field testing varies according to disease stage. Tatham and Medeiros also noted that structural changes detected by OCT may precede functional loss and that combining OCT with visual-field information improves glaucoma monitoring. Although the latter review was not included separately in the numbered reference list, it supports the same integrated clinical approach.

Kansal et al. (2018).^[13] in an evidence-based meta-analysis, reported high diagnostic performance for average RNFL, macular ganglion-cell complex and GCIPL measurements. The area under the receiver-operating-characteristic curve was approximately 0.90 for average RNFL thickness, confirming that OCT provides clinically meaningful structural information for glaucoma diagnosis. Nevertheless, OCT should not replace perimetry because functional

loss determines the patient's visual disability and remains central to staging and therapeutic decisions. Overall, the present findings demonstrate that structural OCT parameters and functional perimetric indices deteriorate together as POAG severity increases. Average, superior, inferior and temporal RNFL thicknesses were useful structural indicators, while macular GCL+IPL measurements provided supplementary information, particularly in advanced glaucoma. The results support the combined application of OCT and standard automated perimetry rather than reliance on either assessment alone.

CONCLUSION

Retinal nerve fibre layer thickness was significantly associated with perimetric severity in patients with primary open-angle glaucoma. Average RNFL thickness declined progressively from mild to severe glaucoma, with the most pronounced reductions occurring in the inferior and superior quadrants. Average and minimum GCL+IPL thickness also decreased significantly with increasing disease severity.

Mean deviation became increasingly negative, pattern standard deviation increased and visual field index decreased significantly as POAG advanced. Average, superior, inferior and temporal RNFL thicknesses demonstrated moderate inverse correlations with perimetric stage, whereas nasal RNFL thickness showed a weaker relationship. Mean deviation and visual field index demonstrated strong inverse correlations with glaucoma severity.

SD-OCT provided objective and reproducible structural measurements that complemented the functional information obtained through standard automated perimetry. Combined evaluation of RNFL, ganglion-cell parameters and visual-field indices may facilitate accurate staging and monitoring of POAG. However, OCT should be used alongside, rather than as a replacement for, reliable perimetric examination.

Limitations

1. The cross-sectional design demonstrated associations but could not establish temporal relationships or rates of RNFL loss and visual-field progression.
2. The study was conducted at a single tertiary-care hospital, which limited the generalisability of the findings to community-based populations.
3. The sample size was relatively small and included only 46 patients contributing 82 eyes.
4. More than half of the eyes had severe glaucoma, resulting in unequal distribution across the mild, moderate and severe groups.
5. Inclusion of both eyes from some participants might have introduced inter-eye correlation; conventional analyses treating every eye as independent may underestimate standard errors.

6. The OCT measurement-floor effect might have reduced the ability of RNFL thickness to distinguish moderate from severe glaucoma.
7. OCT measurements could have been influenced by age, axial length, refractive status, optic-disc size, scan centration, signal strength and segmentation errors.
8. Although patients with high myopia were excluded, the possible effects of lower degrees of refractive error and ocular magnification were not completely eliminated.
9. Visual-field examination was subjective and potentially influenced by patient attention, fatigue, learning effects and response reliability.
10. Disease duration, baseline intraocular pressure, treatment received and adherence to antiglaucoma therapy were not incorporated into the correlation analysis.
11. No healthy control group or preperimetric glaucoma group was included for comparison.
12. Direct eye-level correlations between each OCT parameter and individual visual-field indices require the original patient-level dataset and should be confirmed in a larger prospective study.

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