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Correlation of Retinal Nerve Fibre Layer Thickness with Visual Field Changes in Primary Open-Angle Glaucoma: A Cross-Sectional Study

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ABSTRACT

Background: Primary open-angle glaucoma (POAG) causes progressive retinal ganglion cell loss expressed structurally as retinal nerve fibre layer (RNFL) thinning and functionally as visual field (VF) loss. Quantifying the structure–function relationship supports diagnosis and staging. Objectives: To correlate optical coherence tomography (OCT)–measured RNFL thickness with VF indices in POAG, and to examine RNFL thickness across VF severity strata. Methods: A cross-sectional study of 150 eyes of 150 patients with POAG assessed average and sectoral peripapillary RNFL thickness by OCT and VF mean deviation (MD), visual field index (VFI) and pattern standard deviation (PSD) by automated perimetry. Associations used Pearson and Spearman correlation; RNFL thickness across VF severity (mild/moderate/severe) was compared by one-way ANOVA. Results: Patients had a mean age of 60.4 ± 10.0 years; mean IOP was 16.8 ± 2.6 mmHg and mean cup-to-disc ratio 0.7 ± 0.1. Mean average RNFL was 72.2 ± 12.3 µm and mean VF MD −8.6 ± 6.4 dB. Average RNFL correlated strongly with VF MD ($r = 0.94$, $p < 0.001$) and VFI ($r = 0.92$, $p < 0.001$), and inversely with PSD ($r = −0.86$) and cup-to-disc ratio ($r = −0.84$); the Spearman coefficient for RNFL–MD was 0.91. RNFL thickness decreased stepwise across VF severity (mild 82.4, moderate 71.7, severe 54.7 µm; ANOVA $p < 0.001$). All four sectoral RNFL measurements correlated significantly with VF MD ($r = 0.87$–0.90). Conclusion: OCT-measured RNFL thickness was strongly and consistently correlated with visual field loss across the severity spectrum of POAG, supporting the complementary use of structural and functional testing in glaucoma assessment and staging..

Keywords: primary open-angle glaucoma; retinal nerve fibre layer; optical coherence tomography; visual field; structure–function; mean deviation..

INTRODUCTION

Primary open-angle glaucoma (POAG) is a chronic progressive optic neuropathy characterised by the loss of retinal ganglion cells and their axons, producing structural thinning of the retinal nerve fibre layer (RNFL) and neuroretinal rim and corresponding functional loss detectable on the visual field (VF) [7]. Because ganglion cell loss is irreversible, early detection and reliable staging are central to preserving vision, and both structural and functional testing are integral to clinical management. Optical coherence tomography (OCT) has become the principal tool for objective, reproducible quantification of peripapillary RNFL thickness, with successive generations of time-domain and spectral-domain instruments improving resolution and measurement reproducibility [3,6]. Standard automated perimetry, summarised by indices such as mean deviation (MD), the visual field index (VFI) and pattern standard deviation (PSD), quantifies the functional consequence of ganglion-cell loss. A large body of work has examined how these structural and functional measures relate — the "structure–function" relationship of glaucoma — because understanding it informs which test is most sensitive at a given disease stage and how the two can be combined [2,4,5]. The relationship is not simply linear across the disease continuum. Studies relating RNFL thickness to VF sensitivity have shown that the association is weak in normal and pre-perimetric eyes but becomes strong once perimetric glaucoma is established, and that it is best described by curvilinear or logarithmic models when sensitivity is expressed in decibels [4,5]. A theoretical and empirical synthesis linking ganglion-..

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cell density to perimetric sensitivity has provided a framework reconciling the decibel and linear scales [2]. Importantly, several studies have identified a "tipping point": substantial RNFL loss — on the order of 17% below normative values, or an average thickness in the region of 75–89 µm — appears necessary before VF defects become reliably detectable, implying that OCT may reveal structural loss before conventional perimetry [9,10]. OCT-derived RNFL and optic-nerve-head parameters also discriminate glaucomatous from healthy eyes with high accuracy, with average and inferior RNFL thickness among the strongest single parameters [3,6,8,11]. Despite extensive international data, continued documentation of the RNFL–VF relationship in defined POAG populations remains useful for local validation and for illustrating disease staging. The present cross-sectional study therefore correlated OCT-measured RNFL thickness with VF indices in patients with POAG and examined how RNFL thickness varies across VF severity strata. The objectives were to quantify the association between average and sectoral RNFL thickness and VF MD, VFI and PSD, and to characterise the stepwise structural difference between mild, moderate and severe functional disease.

METHODS

Participants

One hundred and fifty patients with established POAG were included, one eye per patient. Eligible eyes had a clinical diagnosis of POAG with an open angle, glaucomatous optic-nerve-head changes and reliable OCT and VF testing.

Measurements

A single study eye per patient underwent measurement of best-corrected visual acuity (logMAR), intraocular pressure (IOP), central corneal thickness, axial length and vertical cup-to-disc ratio. Peripapillary RNFL thickness (average and superior, inferior, nasal and temporal sectors) was measured by OCT with adequate signal strength. Automated perimetry provided VF MD, VFI and PSD; only reliable fields were analysed. VF severity was categorised as mild, moderate or severe.

Statistical analysis

Continuous variables are summarised as mean ± SD and categorical variables as counts and percentages. The associations between RNFL thickness and VF indices (MD, VFI, PSD) and other structural measures were assessed with Pearson correlation, with the Spearman coefficient reported for the primary RNFL–MD relationship. RNFL thickness across the three VF severity strata was compared with one-way analysis of variance (ANOVA). Two-sided $p < 0.05$ was considered significant. Analyses used Python (pandas, SciPy).

RESULTS

Participant characteristics

The 150 patients had a mean age of 60.4 ± 10.0 years; 79 (52.7%) were male. A family history of glaucoma was present in 29 (19.3%), diabetes in 27 (18.0%) and hypertension in 57 (38.0%). Mean disease duration was 3.9 ± 2.7 years, with a mean of 1.9 ± 0.9 topical glaucoma medications. Mean IOP was 16.8 ± 2.6 mmHg, mean central corneal thickness 534 ± 30 µm, mean axial length 23.6 ± 1.0 mm and mean vertical cup-to-disc ratio 0.7 ± 0.1 (Table 1).

Structural and functional measures

Mean average RNFL thickness was 72.2 ± 12.3 µm (superior 92.0 ± 16.7, inferior 94.2 ± 16.9 µm). Mean VF MD was −8.6 ± 6.4 dB, mean VFI 76.3 ± 17.4% and mean PSD 7.0 ± 3.6 dB. VF severity was mild in 63, moderate in 52 and severe in 35 eyes; by RNFL band, 46 eyes were classified as preserved, 79 as thin and 25 as markedly thin (Table 2).

Correlation of RNFL thickness with visual field indices

Average RNFL thickness was strongly and positively correlated with VF MD (Pearson $r = 0.94$, $p < 0.001$) and with VFI ($r = 0.92$, $p < 0.001$), and negatively correlated with PSD ($r = −0.86$, $p < 0.001$), vertical cup-to-disc ratio ($r = −0.84$, $p < 0.001$) and disease duration ($r = −0.65$, $p < 0.001$); the correlation with IOP was weaker ($r = −0.25$, $p = 0.002$). The nonparametric Spearman coefficient for RNFL–MD was 0.91 ($p < 0.001$) (Figure 1; Table 3). The strength of these associations is consistent with the strong structure–function relationship reported once perimetric glaucoma is established [4,5].

Sectoral correlations

All four sectoral RNFL measurements correlated significantly with VF MD: superior $r = 0.90$, temporal $r = 0.88$, inferior $r = 0.87$ and nasal $r = 0.87$ (all $p < 0.001$). The broadly comparable sectoral correlations indicate diffuse structural–functional concordance across the peripapillary region in this cohort.

RNFL thickness across visual field severity

Mean average RNFL thickness decreased stepwise across VF severity strata: 82.4 ± 5.0 µm in mild, 71.7 ± 5.6 µm in moderate and 54.7 ± 7.8 µm in severe disease (one-way ANOVA $F = 242.7$, $p < 0.001$), with corresponding mean VF MD of −3.1, −8.8 and −18.4 dB (Figure 2; Table 4). This ordered structural gradient across functional stages reflects the

progressive nature of ganglion-cell loss and supports the use of RNFL thickness as a staging complement to perimetry [2,9,10].

Table 1. Participant characteristics (N=150).

Characteristic	Value
Age, years (mean ± SD)	60.4 ± 10.0
Male sex, n (%)	79 (52.7)
Family history of glaucoma, n (%)	29 (19.3)
Diabetes, n (%)	27 (18.0)
Hypertension, n (%)	57 (38.0)
Disease duration, years	3.9 ± 2.7
Number of glaucoma medications	1.9 ± 0.9
IOP, mmHg	16.8 ± 2.6
Central corneal thickness, µm	534 ± 30
Axial length, mm	23.6 ± 1.0
Vertical cup-to-disc ratio	0.7 ± 0.1

Table 2. Structural and functional measures (N=150).

Measure	Value
Average RNFL, µm	72.2 ± 12.3
Superior RNFL, µm	92.0 ± 16.7
Inferior RNFL, µm	94.2 ± 16.9
VF mean deviation, dB	−8.6 ± 6.4
Visual field index, %	76.3 ± 17.4
Pattern standard deviation, dB	7.0 ± 3.6
VF severity: mild / moderate / severe	63 / 52 / 35
RNFL band: preserved / thin / markedly thin	46 / 79 / 25

Table 3. Correlation of average RNFL thickness with structural and functional parameters (Pearson).

Parameter	r	*p* value
VF mean deviation	+0.94	<0.001
Visual field index	+0.92	<0.001
Pattern standard deviation	−0.86	<0.001
Vertical cup-to-disc ratio	−0.84	<0.001
Disease duration	−0.65	<0.001
IOP	−0.25	0.002

RNFL–MD (Spearman ρ)	+0.91	<0.001

Table 4. Average RNFL thickness and VF mean deviation by visual field severity.

VF severity	n	RNFL (µm, mean ± SD)	VF MD (dB, mean)
Mild	63	82.4 ± 5.0	−3.1
Moderate	52	71.7 ± 5.6	−8.8
Severe	35	54.7 ± 7.8	−18.4
ANOVA	—	F = 242.7, $p < 0.001$	—

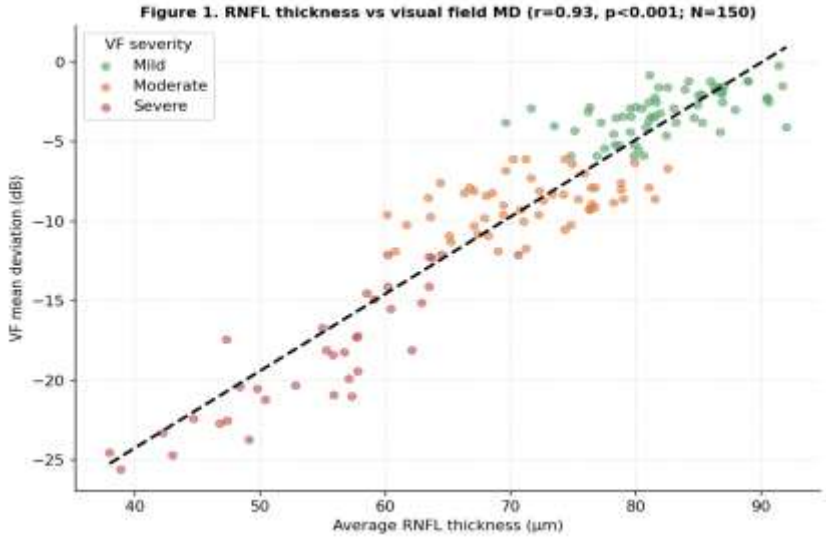

Figure 1. Average RNFL thickness versus visual field mean deviation, coloured by VF severity, with fitted regression line (r = 0.94, $p < 0.001$; N=150).

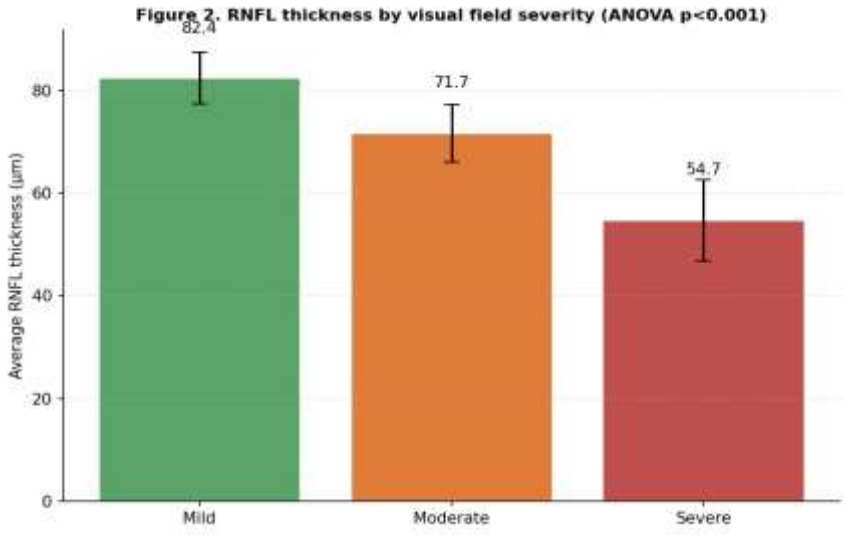

Figure 2. Average RNFL thickness across visual field severity strata (one-way ANOVA $p < 0.001$); error bars are standard deviations.

DISCUSSION

In this cross-sectional study of 150 eyes with POAG, OCT-measured RNFL thickness showed a strong and consistent correlation with visual field loss: average RNFL correlated with VF MD at r = 0.94 and with VFI at r = 0.92, correlated inversely with PSD and cup-to-disc ratio, and decreased stepwise across mild, moderate and severe functional disease. These results reproduce, in a defined POAG population, the robust structure–function relationship documented across the international literature once perimetric glaucoma is established [4,5]. The strength of the association here is characteristic of eyes with established, rather than pre-perimetric, disease. Studies relating RNFL thickness to VF sensitivity have repeatedly shown that the correlation is weak or absent in normal and pre-perimetric eyes and becomes strong and curvilinear in POAG, particularly once average RNFL falls below roughly 70 µm — close to the mean observed in the present cohort [4,5]. The concept of a structural "tipping point," at which further RNFL loss becomes tightly coupled to measurable VF decline, has been demonstrated with spectral-domain OCT: substantial RNFL loss (on the order of 17%, or an average thickness of about 75–89 µm) appears necessary before VF defects are reliably detected [9,10]. The stepwise decline in RNFL across severity strata observed here, from 82 µm in mild to 55 µm in severe disease, is consistent with this graded structure–function coupling and with the theoretical framework linking ganglion-cell density to perimetric sensitivity [2]. The comparable correlations across all four RNFL sectors indicate diffuse concordance in this cohort. In clinical practice, superior and inferior RNFL thinning typically corresponds to inferior and superior arcuate field loss respectively, and average and inferior RNFL are among the most discriminating single OCT parameters for glaucoma detection [3,6,8,11]. The stronger relationship of RNFL with MD, VFI and cup-to-disc ratio than with IOP is expected: RNFL thickness reflects accumulated structural damage, whereas a single IOP reading is a weaker cross-sectional correlate of established damage. The inverse correlation with disease duration is likewise consistent with progressive axonal loss over time. Clinically, these findings reinforce the complementary value of structural and functional testing. OCT provides objective, reproducible quantification of RNFL that correlates closely with field loss and can reveal structural change, particularly in earlier disease where perimetry is less sensitive; perimetry remains essential for quantifying functional impairment and guiding treatment intensity, especially in advanced disease where RNFL measurements approach a measurement floor [2,3,9]. Combining both, and interpreting RNFL against normative and severity-stratified expectations, supports more reliable diagnosis and staging [6,8,11].

CONCLUSION

In POAG cohort, OCT-measured RNFL thickness was strongly and consistently correlated with visual field loss — with VF MD, VFI, PSD and cup-to-disc ratio — and declined stepwise across mild, moderate and severe functional disease. These findings support the complementary use of structural OCT and functional perimetry for the diagnosis and staging of primary open-angle glaucoma....

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