



Research Article

Correlation Of Macular Ganglion Cell-Inner Plexiform Layer Thickness And Retinal Nerve Fiber Layer Thickness With Visual Field Defects In Primary Open Angle Glaucoma: A Cross-Sectional Study

Dr Soumya M Malkhed¹, Dr Chaitra S², Dr Shivani B H³

¹Senior Resident, Department of Ophthalmology, Raichur institute of medical sciences

²Assistant Professor, Dept Of Ophthalmology, Sri Chamundeshwari Medical College and research Institute

³Assistant professor, Department of ophthalmology, Subbaiah institute of medical sciences and research centre, shivamogga

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Corresponding Author:

Dr Soumya M Malkhed

Senior Resident, Department of
Ophthalmology, Raichur institute
of medical sciences

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ABSTRACT

Background: Primary open angle glaucoma (POAG) is characterized by progressive retinal ganglion cell loss and corresponding visual field defects. Optical coherence tomography (OCT) measurements of ganglion cell-inner plexiform layer (GCIPL) and retinal nerve fiber layer (RNFL) thickness provide objective structural assessment. This study aimed to evaluate the correlation between GCIPL thickness, RNFL thickness, and visual field parameters in POAG patients.

Methods: A cross-sectional observational study was conducted on 50 patients with confirmed POAG. All participants underwent comprehensive ophthalmological examination including spectral-domain OCT for GCIPL and RNFL thickness measurements and standard automated perimetry for visual field assessment. Pearson correlation coefficients were calculated to determine relationships between structural and functional parameters. Multiple regression analysis was performed to identify predictive factors for visual field mean deviation.

Results: Mean RNFL thickness was $72.4 \pm 12.8 \mu\text{m}$ and mean GCIPL thickness was $68.3 \pm 10.2 \mu\text{m}$. Strong positive correlations were found between average GCIPL thickness and visual field mean deviation ($r=0.74$, $p<0.001$) and between average RNFL thickness and mean deviation ($r=0.68$, $p<0.001$). Sectoral analysis revealed strongest correlations in inferior quadrants. Multiple regression analysis showed GCIPL thickness was the strongest predictor of visual field mean deviation ($\beta=0.52$, $p<0.001$).

Conclusion: Both GCIPL and RNFL thickness measurements demonstrate strong correlations with visual field defects in POAG. GCIPL thickness shows marginally stronger correlation with functional loss, suggesting its potential value in glaucoma assessment and monitoring.

Keywords: Primary open angle glaucoma, ganglion cell-inner plexiform layer, retinal nerve fiber layer, optical coherence tomography, visual fields.

INTRODUCTION

Primary open angle glaucoma (POAG) represents the most prevalent form of glaucoma worldwide and constitutes a leading cause of irreversible blindness, affecting approximately 57.5 million individuals globally with projections suggesting an increase to 65.5 million by 2030 (1). The disease is characterized by progressive optic neuropathy with distinctive structural changes to the optic nerve head and retinal nerve fiber layer (RNFL), accompanied by corresponding visual field defects that typically manifest in characteristic patterns. The pathophysiology involves selective loss of retinal ganglion cells (RGCs) through apoptosis, with subsequent degeneration of their axons that comprise the RNFL, ultimately leading to excavation of the optic disc and progressive visual field deterioration (2).

The clinical assessment of glaucoma has evolved substantially with the advent of optical coherence tomography (OCT) technology, which enables precise quantification of retinal structural parameters with unprecedented resolution. Spectral-domain OCT (SD-OCT), in particular, has revolutionized glaucoma diagnosis and monitoring by providing high-

resolution cross-sectional images of retinal structures, allowing for reproducible measurements of RNFL thickness with axial resolution of 5-7 micrometers (3). The RNFL thickness measurement has become established as a fundamental structural biomarker in glaucoma assessment, demonstrating significant thinning that correlates with disease severity and progression. Studies have consistently shown that RNFL thickness decreases progressively with advancing glaucoma severity, with average RNFL thickness demonstrating strong correlations with visual field mean deviation values ranging from $r=0.48$ to $r=0.71$ across different populations (4).

Recent technological advances have enabled the accurate segmentation and measurement of the macular ganglion cell-inner plexiform layer (GCIPL) complex, representing a paradigm shift in glaucoma assessment. The macula contains approximately 50% of all retinal ganglion cells within its central 4.5 mm diameter region, with RGC bodies comprising multiple layers in this area, making it particularly suitable for detecting glaucomatous damage (5). The ganglion cell layer contains the cell bodies of RGCs, while the inner plexiform layer consists of synaptic connections between RGC dendrites and bipolar and amacrine cells. The combined measurement of these layers as the GCIPL complex has emerged as a sensitive indicator of glaucomatous damage, as RGC loss directly manifests as thinning of this complex. Several studies have demonstrated that GCIPL thickness measurements show comparable or superior diagnostic performance to RNFL measurements for glaucoma detection, with areas under the receiver operating characteristic curves ranging from 0.85 to 0.96 for distinguishing glaucomatous from healthy eyes (6).

The relationship between structural damage and functional loss in glaucoma has been a subject of extensive investigation, with considerable debate regarding the temporal sequence and quantitative relationship between these changes. The structure-function relationship in glaucoma is complex and influenced by multiple factors including measurement variability, the logarithmic scale of perimetric measurements, and the non-uniform distribution of RGCs across the retina. Hood and Kardon proposed a linear model relating RGC loss to visual field sensitivity when both are expressed on appropriate scales, demonstrating that approximately 50% of RGCs may be lost before statistically significant visual field defects become apparent on standard automated perimetry (7). This substantial functional reserve underscores the importance of structural measurements for early disease detection, as morphological changes often precede detectable functional loss by several years.

Visual field testing through standard automated perimetry remains the gold standard for functional assessment in glaucoma, providing quantitative evaluation of differential light sensitivity across the visual field. The 24-2 or 30-2 test patterns employed in clinical practice sample the central visual field at predetermined locations, generating global indices including mean deviation (MD) and pattern standard deviation (PSD) that quantify overall depression and localized loss respectively. However, perimetry has inherent limitations including subjective response requirements, learning effects, and considerable test-retest variability, particularly in areas of moderate damage. The coefficient of variation for threshold sensitivity measurements can exceed 30% in damaged areas, complicating the detection of progression and correlation with structural parameters (8).

The integration of structural and functional assessments has become increasingly recognized as essential for comprehensive glaucoma management. The concept of structure-function correlation in glaucoma extends beyond simple linear relationships, encompassing spatial correspondence between regional structural damage and corresponding visual field defects. Studies utilizing region-specific analysis have demonstrated that inferior RNFL thickness correlates most strongly with superior visual field sensitivity, reflecting the anatomical course of retinal nerve fibers. Similarly, temporal GCIPL thickness shows strong associations with central visual field sensitivity, as the papillomacular bundle serves the central visual field. These regional correlations provide insights into the patterns of glaucomatous damage and may enhance our ability to predict functional loss from structural measurements (9).

Several factors influence the strength of structure-function correlations in glaucoma, including disease severity, measurement floor effects, and individual variability in optic disc anatomy. In early glaucoma, structural measurements may show abnormalities while visual fields remain within normal limits, reflecting the functional reserve capacity of the visual system. Conversely, in advanced disease, structural measurements may reach measurement floors while functional deterioration continues, leading to weakened correlations. The stage of disease significantly impacts correlation coefficients, with moderate glaucoma typically demonstrating the strongest structure-function relationships. Additionally, individual variations in optic disc size, axial length, and RGC distribution patterns contribute to inter-individual differences in structure-function relationships (10).

The comparative evaluation of GCIPL and RNFL measurements for correlation with visual field parameters remains an area of active investigation. While both parameters reflect RGC loss, they may provide complementary information about glaucomatous damage. GCIPL measurements directly assess RGC soma integrity, potentially providing earlier detection of glaucomatous damage as cell body loss may precede axonal degeneration. Conversely, RNFL measurements encompass the entire course of RGC axons from the optic disc, potentially capturing more diffuse damage patterns. Understanding the relative strengths and limitations of these measurements for predicting functional status has important implications for clinical decision-making and monitoring strategies.

The present study was designed to comprehensively evaluate and compare the correlations between GCIPL thickness, RNFL thickness, and visual field parameters in a cohort of POAG patients, addressing the need for better understanding of structure-function relationships in glaucoma management. By examining both global and sectoral correlations, this investigation aims to elucidate which structural parameters most strongly predict functional status and to identify patterns that may enhance clinical assessment strategies. The findings may contribute to optimizing the integration of structural and functional assessments in glaucoma management, potentially improving early detection, monitoring protocols, and treatment decisions.

AIMS AND OBJECTIVES

The primary aim of this study was to evaluate and compare the correlation between macular ganglion cell-inner plexiform layer thickness and retinal nerve fiber layer thickness with visual field parameters in patients diagnosed with primary open angle glaucoma. The investigation sought to determine which structural parameter demonstrated stronger association with functional visual field deficits, thereby providing evidence for optimal structural assessment strategies in glaucoma management. The study aimed to establish quantitative relationships between OCT-derived structural measurements and perimetric indices, contributing to the understanding of structure-function relationships in glaucomatous optic neuropathy.

The specific objectives included assessment of global and sectoral GCIPL thickness measurements and their correlation with visual field mean deviation and pattern standard deviation values. The study evaluated average and quadrant-specific RNFL thickness parameters and their relationships with corresponding visual field sectors. Comparative analysis was performed to determine the relative strength of correlations between GCIPL versus RNFL measurements with functional parameters. The investigation examined the influence of glaucoma severity on structure-function correlations, analyzing whether correlation strengths varied across different stages of disease. Additionally, the study sought to identify the structural parameters that served as the strongest predictors of visual field mean deviation through multiple regression analysis, potentially informing clinical decision-making regarding optimal monitoring strategies.

MATERIALS AND METHODS

Study Design and Setting

This cross-sectional observational study was conducted at the ophthalmology department of a tertiary care center between January 2023 and December 2023. The study protocol received approval from the institutional ethics committee and adhered to the tenets of the Declaration of Helsinki. Written informed consent was obtained from all participants prior to enrollment.

Study Population and Sample Size

A total of 50 patients with confirmed diagnosis of primary open angle glaucoma were recruited through consecutive sampling from the glaucoma clinic. The sample size was calculated based on previous studies reporting correlation coefficients between structural and functional parameters, with alpha error of 0.05 and power of 80%.

Inclusion Criteria

Patients aged 40-75 years with established diagnosis of POAG were included. The diagnosis was based on characteristic optic disc changes including increased cup-disc ratio greater than 0.6, neuroretinal rim thinning, or localized notching, along with corresponding visual field defects on at least two reliable tests. Open angles were confirmed on gonioscopy with Shaffer grade 3 or 4 in all quadrants. Best corrected visual acuity of 20/40 or better was required to ensure reliable testing. Refractive error was limited to within ± 6.0 diopters sphere and ± 3.0 diopters cylinder. Clear ocular media allowing good quality OCT imaging with signal strength greater than 7/10 was mandatory.

Exclusion Criteria

Patients with any form of secondary glaucoma including pseudoexfoliative, pigmentary, neovascular, or uveitic glaucoma were excluded. Those with history of intraocular surgery except uncomplicated cataract extraction performed more than 6 months prior were excluded. Coexisting retinal pathology including diabetic retinopathy, age-related macular degeneration, or retinal vascular occlusions was exclusionary. Neurological conditions affecting the visual pathway and unreliable visual field tests defined by fixation losses greater than 20% or false positive/negative rates exceeding 33% led to exclusion. Media opacities preventing adequate OCT image quality were also exclusionary.

Clinical Examination Protocol

All participants underwent comprehensive ophthalmological examination by a single experienced glaucoma specialist. Visual acuity was assessed using Snellen charts and converted to LogMAR notation for analysis. Slit-lamp biomicroscopy evaluated anterior segment structures and lens clarity. Intraocular pressure was measured using Goldmann applanation tonometry with three readings averaged. Gonioscopy was performed using a Goldmann three-mirror lens to confirm open angles. Dilated funduscopy assessed optic disc morphology, with vertical cup-disc ratio documented. Central corneal thickness was measured using ultrasonic pachymetry, with five readings averaged.

Optical Coherence Tomography Imaging

Spectral-domain OCT imaging was performed using the Cirrus HD-OCT 5000 (Carl Zeiss Meditec, Dublin, CA) after pupillary dilation. The macular cube 512×128 protocol was utilized for GCIPL thickness measurements, covering a 6×6 mm area centered on the fovea. The ganglion cell analysis algorithm automatically segmented and measured GCIPL thickness in six wedge-shaped sectors and calculated average thickness. The optic disc cube 200×200 protocol assessed RNFL thickness, with measurements obtained in a 3.46 mm diameter circle centered on the optic disc. Average RNFL thickness and quadrant values (superior, inferior, temporal, nasal) were recorded. All scans were reviewed for quality, with signal strength ≥ 7 , absence of motion artifacts, and proper centration required for inclusion. Three scans were obtained and averaged for each parameter.

Visual Field Testing

Standard automated perimetry was performed using the Humphrey Field Analyzer 3 (Carl Zeiss Meditec) with the 24-2 Swedish Interactive Threshold Algorithm (SITA) Standard protocol. Testing was conducted in a dark room after appropriate refractive correction based on age and testing distance. Reliability criteria included fixation losses $< 20\%$, false positives $< 33\%$, and false negatives $< 33\%$. Visual field parameters analyzed included mean deviation (MD) indicating overall field depression, pattern standard deviation (PSD) representing localized loss, and visual field index (VFI) providing a percentage of remaining visual function. Glaucoma hemifield test (GHT) results were recorded as within normal limits, borderline, or outside normal limits. For patients with multiple reliable tests, the most recent examination was utilized for analysis.

Glaucoma Severity Classification

Disease severity was classified based on visual field mean deviation values according to the Hodapp-Parrish-Anderson criteria. Early glaucoma was defined as MD better than -6 dB, moderate glaucoma as MD between -6 and -12 dB, and severe glaucoma as MD worse than -12 dB. This classification enabled subgroup analysis of structure-function correlations across disease stages.

Statistical Analysis

Statistical analysis was performed using SPSS version 26.0 (IBM Corp., Armonk, NY). Descriptive statistics were calculated for all variables, with continuous data expressed as mean $\pm$ standard deviation and categorical data as frequencies and percentages. Normality of distribution was assessed using the Shapiro-Wilk test. Pearson correlation coefficients were calculated to evaluate relationships between structural (GCIPL and RNFL thickness) and functional (visual field) parameters. Correlation strengths were classified as weak ($r < 0.3$), moderate ($r = 0.3-0.7$), or strong ($r > 0.7$). Partial correlation analysis controlled for potential confounding factors including age, intraocular pressure, and central corneal thickness. Multiple linear regression analysis identified independent predictors of visual field mean deviation, with structural parameters entered as predictor variables. Comparison of correlation coefficients between GCIPL and RNFL was performed using Fisher's z-transformation. Subgroup analysis examined correlations stratified by glaucoma severity. Statistical significance was set at $p < 0.05$ for all analyses.

RESULTS

Demographic and Clinical Characteristics

The study cohort comprised 50 patients with primary open angle glaucoma with a mean age of 62.4 ± 8.7 years (range 42-75 years). Gender distribution showed 28 males (56%) and 22 females (44%). The mean duration of diagnosed glaucoma was 4.8 ± 3.2 years. Mean best corrected visual acuity was 0.12 ± 0.14 LogMAR units, corresponding to approximately 20/25 Snellen equivalent. Average intraocular pressure at the time of examination was 16.8 ± 3.4 mmHg, with 88% of patients on topical antiglaucoma medications. Mean central corneal thickness measured 542.6 ± 35.8 micrometers. The vertical cup-disc ratio averaged 0.74 ± 0.12 , indicating moderate to advanced structural damage.

Table 1: Demographic and Clinical Characteristics of Study Population (n=50)

Parameter	Mean $\pm$ SD	Range
Age (years)	62.4 ± 8.7	42-75
Gender (M:F)	28:22	-
Disease duration (years)	4.8 ± 3.2	1-12
Visual acuity (LogMAR)	0.12 ± 0.14	-0.1 to 0.4
IOP (mmHg)	16.8 ± 3.4	10-24
CCT (μm)	542.6 ± 35.8	478-612
Vertical CDR	0.74 ± 0.12	0.6-0.95
Number on medication (%)	44 (88%)	-

Structural Parameters

Analysis of OCT structural parameters revealed mean average RNFL thickness of 72.4 ± 12.8 micrometers, representing significant thinning compared to normative databases. Quadrant analysis demonstrated greatest thinning in the inferior sector ($68.2 \pm 18.4 \mu\text{m}$), followed by superior ($74.8 \pm 16.2 \mu\text{m}$), temporal ($56.3 \pm 10.8 \mu\text{m}$), and nasal ($82.1 \pm 14.6 \mu\text{m}$) quadrants. Mean average GCIPL thickness measured 68.3 ± 10.2 micrometers. Sectoral GCIPL analysis showed most

pronounced thinning in the inferior-temporal sector ($64.8 \pm 12.4 \mu\text{m}$) and superior-temporal sector ($66.2 \pm 11.8 \mu\text{m}$), with relative preservation in nasal sectors. Signal strength for OCT imaging averaged 8.4 ± 0.8 , indicating good image quality across the cohort.

Table 2: Optical Coherence Tomography Structural Parameters

OCT Parameter	Mean $\pm$ SD (μm)	Range (μm)
RNFL Thickness		
Average	72.4 ± 12.8	48-95
Superior	74.8 ± 16.2	45-108
Inferior	68.2 ± 18.4	38-102
Temporal	56.3 ± 10.8	38-78
Nasal	82.1 ± 14.6	52-112
GCIPL Thickness		
Average	68.3 ± 10.2	48-85
Superior-temporal	66.2 ± 11.8	44-84
Superior	69.4 ± 10.6	48-86
Superior-nasal	72.8 ± 11.2	50-90
Inferior-nasal	71.6 ± 10.8	49-88
Inferior	67.8 ± 12.2	45-85
Inferior-temporal	64.8 ± 12.4	42-82

Visual Field Parameters

Visual field analysis demonstrated mean deviation of -8.42 ± 6.28 dB, indicating moderate functional loss on average. Pattern standard deviation averaged 6.84 ± 3.42 dB, reflecting significant localized defects. Visual field index showed mean preservation of $74.6 \pm 18.2\%$ of visual function. Based on MD values, 14 patients (28%) were classified as early glaucoma, 22 patients (44%) as moderate glaucoma, and 14 patients (28%) as severe glaucoma. Glaucoma hemifield test was outside normal limits in 39 patients (78%), borderline in 7 patients (14%), and within normal limits in 4 patients (8%). Superior hemifield showed greater mean sensitivity loss (-10.2 ± 7.4 dB) compared to inferior hemifield (-6.8 ± 5.2 dB), consistent with inferior RNFL thinning patterns.

Table 3: Visual Field Parameters and Glaucoma Severity Distribution

Visual Field Parameter	Mean $\pm$ SD	Range
Mean Deviation (dB)	-8.42 ± 6.28	-22.4 to -0.8
Pattern Standard Deviation (dB)	6.84 ± 3.42	1.8 to 14.2
Visual Field Index (%)	74.6 ± 18.2	35 to 98
Glaucoma Severity	n (%)	
Early (MD > -6 dB)	14 (28%)	
Moderate (MD -6 to -12 dB)	22 (44%)	
Severe (MD < -12 dB)	14 (28%)	
GHT Classification	n (%)	
Within normal limits	4 (8%)	
Borderline	7 (14%)	
Outside normal limits	39 (78%)	

Correlation Analysis

Pearson correlation analysis revealed strong positive correlation between average GCIPL thickness and visual field mean deviation ($r = 0.74$, $p < 0.001$), indicating better preserved GCIPL thickness associated with less negative MD values. Average RNFL thickness also demonstrated strong positive correlation with MD ($r = 0.68$, $p < 0.001$). The correlation between average GCIPL thickness and pattern standard deviation was moderately negative ($r = -0.52$, $p < 0.001$), while RNFL showed similar negative correlation with PSD ($r = -0.48$, $p < 0.001$). Visual field index correlated strongly with both average GCIPL thickness ($r = 0.71$, $p < 0.001$) and average RNFL thickness ($r = 0.65$, $p < 0.001$). Comparison of correlation coefficients using Fisher's z-transformation showed marginally stronger correlation for GCIPL versus RNFL with MD ($z = 1.82$, $p = 0.068$), though this difference did not reach statistical significance.

Table 4: Correlation Between Structural and Functional Parameters

Structural Parameter	VF Mean Deviation	Pattern Standard Deviation	Visual Field Index
	r (p-value)	r (p-value)	r (p-value)
GCIPL Thickness			
Average	0.74 (<0.001)	-0.52 (<0.001)	0.71 (<0.001)
Superior-temporal	0.68 (<0.001)	-0.48 (<0.001)	0.65 (<0.001)
Inferior-temporal	0.72 (<0.001)	-0.54 (<0.001)	0.69 (<0.001)
RNFL Thickness			

Average	0.68 (<0.001)	-0.48 (<0.001)	0.65 (<0.001)
Superior	0.62 (<0.001)	-0.44 (0.002)	0.58 (<0.001)
Inferior	0.70 (<0.001)	-0.51 (<0.001)	0.67 (<0.001)
Temporal	0.54 (<0.001)	-0.38 (0.008)	0.52 (<0.001)
Nasal	0.42 (0.003)	-0.28 (0.048)	0.40 (0.004)

Sectoral Structure-Function Correlations

Regional analysis demonstrated strongest correlations between inferior RNFL thickness and superior visual field sensitivity ($r = 0.72$, $p < 0.001$), reflecting the anatomical correspondence of nerve fiber distribution. Superior RNFL thickness correlated strongly with inferior visual field sensitivity ($r = 0.64$, $p < 0.001$). Inferior-temporal GCIPL thickness showed the strongest correlation with central visual field points ($r = 0.76$, $p < 0.001$), while superior-temporal GCIPL correlated with inferior paracentral sensitivity ($r = 0.68$, $p < 0.001$). Temporal RNFL and nasal RNFL showed weaker correlations with corresponding visual field regions, consistent with the distribution of arcuate fiber bundles primarily affecting superior and inferior quadrants.

Multiple Regression Analysis

Multiple linear regression analysis was performed with visual field mean deviation as the dependent variable and structural parameters as predictors. The final model explained 62.8% of variance in MD (adjusted $R^2 = 0.628$, $F = 18.42$, $p < 0.001$). Average GCIPL thickness emerged as the strongest predictor ($\beta = 0.52$, $p < 0.001$), followed by inferior RNFL thickness ($\beta = 0.28$, $p = 0.018$). Age ($\beta = -0.15$, $p = 0.124$) and intraocular pressure ($\beta = -0.08$, $p = 0.386$) did not significantly contribute to the model. The regression equation was: $MD = -28.64 + 0.24(\text{GCIPL}) + 0.08(\text{Inferior RNFL})$, indicating that each micrometer increase in GCIPL thickness corresponded to 0.24 dB improvement in MD.

Table 5: Multiple Regression Analysis for Predictors of Visual Field Mean Deviation

Predictor Variable	β Coefficient	Standard Error	Standardized β	t-value	p-value
Constant	-28.64	4.82	-	-5.94	<0.001
Average GCIPL (μm)	0.24	0.06	0.52	4.12	<0.001
Inferior RNFL (μm)	0.08	0.03	0.28	2.45	0.018
Superior RNFL (μm)	0.06	0.04	0.18	1.58	0.121
Age (years)	-0.09	0.06	-0.15	-1.56	0.124
IOP (mmHg)	-0.11	0.13	-0.08	-0.87	0.386

Model Summary: $R^2 = 0.648$, Adjusted $R^2 = 0.628$, $F = 18.42$, $p < 0.001$

Subgroup Analysis by Disease Severity

Structure-function correlations varied significantly across disease severity stages. In early glaucoma ($n=14$), GCIPL thickness showed moderate correlation with MD ($r = 0.58$, $p = 0.028$), while RNFL correlation was weaker ($r = 0.46$, $p = 0.098$). Moderate glaucoma ($n=22$) demonstrated the strongest correlations, with GCIPL-MD correlation of $r = 0.82$ ($p < 0.001$) and RNFL-MD correlation of $r = 0.74$ ($p < 0.001$). In severe glaucoma ($n=14$), correlations weakened, with GCIPL-MD correlation of $r = 0.52$ ($p = 0.054$) and RNFL-MD correlation of $r = 0.44$ ($p = 0.114$), likely reflecting floor effects in structural measurements.

Table 6: Structure-Function Correlations Stratified by Glaucoma Severity

Disease Stage	n	GCIPL-MD Correlation	RNFL-MD Correlation
		r (p-value)	r (p-value)
Early (MD > -6 dB)	14	0.58 (0.028)	0.46 (0.098)
Moderate (MD -6 to -12 dB)	22	0.82 (<0.001)	0.74 (<0.001)
Severe (MD < -12 dB)	14	0.52 (0.054)	0.44 (0.114)
Overall	50	0.74 (<0.001)	0.68 (<0.001)

DISCUSSION

The present investigation demonstrates robust correlations between both GCIPL and RNFL thickness measurements with visual field parameters in primary open angle glaucoma, with GCIPL thickness showing marginally stronger associations with functional measures. These findings contribute to the growing body of evidence supporting the utility of macular structural assessments in glaucoma evaluation and align with recent studies emphasizing the importance of ganglion cell analysis in disease monitoring.

The strong correlation observed between average GCIPL thickness and visual field mean deviation ($r = 0.74$) in our cohort exceeds that reported by Kim et al., who found a correlation of $r = 0.65$ in 142 glaucoma patients using similar SD-OCT technology (11). This enhanced correlation may reflect our strict inclusion criteria ensuring high-quality imaging and reliable visual fields, as well as the relatively homogeneous disease severity distribution in our sample. The marginally stronger correlation of GCIPL compared to RNFL thickness with visual field parameters supports the hypothesis that direct assessment of ganglion cell integrity provides more precise structure-function relationships. Sung

et al. similarly reported superior correlations for GCIPL measurements in a cohort of 198 POAG patients, with correlation coefficients of 0.71 for GCIPL versus 0.63 for RNFL with mean deviation (12).

The sectoral analysis revealing strongest correlations in inferior quadrants aligns with the typical pattern of glaucomatous damage, which preferentially affects the inferior and superior poles of the optic disc. Our finding of inferior RNFL thickness strongly correlating with superior visual field sensitivity ($r = 0.72$) corresponds closely to the structure-function map described by Garway-Heath et al., confirming the anatomical basis of these relationships (13). The inferior-temporal GCIPL sector showing the highest correlation with central visual field points ($r = 0.76$) is particularly noteworthy, as this region corresponds to the vulnerability zone described by Hood et al., where early glaucomatous damage frequently manifests (14).

The variation in structure-function correlations across disease severity stages observed in our study has important clinical implications. The strongest correlations in moderate glaucoma (GCIPL-MD: $r = 0.82$) compared to early ($r = 0.58$) or severe disease ($r = 0.52$) reflects the complex relationship between structural and functional measurements throughout the disease continuum. This finding corroborates the work of Medeiros et al., who analyzed 397 eyes and demonstrated peak correlations at moderate disease stages, attributing this to the logarithmic nature of visual field scaling and measurement floor effects in advanced disease (15). In early disease, the relative preservation of redundant ganglion cells may maintain visual function despite measurable structural loss, while in advanced disease, both structural and functional measurements approach their measurement floors, weakening correlations.

Our multiple regression analysis identifying GCIPL thickness as the strongest predictor of visual field mean deviation ($\beta = 0.52$) provides quantitative support for incorporating macular assessments into glaucoma evaluation protocols. The regression model explaining 62.8% of variance in MD is comparable to that reported by Hirooka et al., who found 59% variance explained in their model combining GCIPL and RNFL parameters in 86 patients (16). The coefficient indicating 0.24 dB improvement in MD per micrometer of GCIPL thickness provides a clinically interpretable relationship that may guide expectations for functional change with structural progression.

Contrasting with our findings, some studies have reported equivalent or superior performance of RNFL measurements. Leung et al. examined 164 glaucoma patients and found no significant difference between GCIPL and RNFL correlations with visual field parameters, with both showing correlation coefficients around 0.60-0.65 (17). These discrepancies may reflect differences in patient populations, disease severity distributions, OCT technologies, or analytical approaches. Additionally, the averaging of multiple OCT scans in our protocol may have reduced measurement variability, strengthening observed correlations.

The clinical implications of our findings extend beyond correlation coefficients to practical applications in glaucoma management. The strong structure-function relationships support the use of OCT parameters for estimating functional status when reliable perimetry is challenging, such as in patients with cognitive impairment or physical limitations. Furthermore, the complementary information provided by GCIPL and RNFL measurements suggests that combined assessment may offer more comprehensive evaluation than either parameter alone. The sectoral correspondence between structural and functional damage patterns may enable more precise monitoring of localized progression and guide targeted treatment intensification.

Several methodological considerations strengthen our study's findings. The use of strict quality criteria for both OCT imaging and visual field testing minimized measurement variability that could weaken correlations. The single-center design with standardized protocols and experienced operators reduced inter-observer variability. The inclusion of partial correlation analysis controlling for potential confounders and the use of Fisher's z-transformation for comparing correlation coefficients provide statistical rigor to our conclusions.

Study limitations warrant consideration when interpreting results. The cross-sectional design precludes assessment of longitudinal structure-function relationships and progression patterns. The relatively small sample size of 50 patients, while adequate for correlation analysis, limits subgroup analyses and generalizability. The predominance of moderate glaucoma in our cohort may have biased toward stronger correlations than would be observed in a more varied population. The exclusion of patients with media opacities or poor-quality imaging may limit applicability to real-world clinical populations where such issues are common. Additionally, the use of 24-2 visual field testing may have missed parafoveal defects better detected by 10-2 testing, potentially underestimating structure-function correlations in the macula.

Future research directions should include longitudinal studies examining whether baseline GCIPL thickness predicts future visual field progression more accurately than RNFL measurements. Investigation of structure-function relationships using newer perimetric strategies such as 10-2 testing or frequency-doubling technology may reveal stronger correlations with macular structural parameters. The development of combined structure-function indices incorporating both GCIPL and RNFL measurements could potentially improve glaucoma detection and monitoring.

Studies examining the impact of various factors such as myopia, disc size, and ethnicity on structure-function relationships would enhance clinical applicability across diverse populations.

CONCLUSION

This study demonstrates strong correlations between both GCIPL and RNFL thickness measurements with visual field parameters in primary open angle glaucoma, with GCIPL thickness showing marginally superior associations. The average GCIPL thickness correlation with mean deviation of 0.74 exceeded that of average RNFL thickness at 0.68, while sectoral analyses confirmed anatomically-predicted structure-function relationships. Multiple regression analysis established GCIPL thickness as the strongest predictor of visual field status, explaining substantial variance in functional measurements.

The findings support the integration of macular ganglion cell analysis into routine glaucoma assessment, particularly given its strong correlation with functional status and potential for early detection of glaucomatous damage. The variation in correlation strength across disease stages emphasizes the importance of considering disease severity when interpreting structure-function relationships. The complementary information provided by GCIPL and RNFL measurements suggests that comprehensive evaluation incorporating both parameters may optimize glaucoma management decisions.

These results have practical implications for clinical practice, supporting the use of OCT structural parameters for estimating functional status and monitoring disease progression. The quantitative relationships established between structural and functional measures provide benchmarks for expected functional correlates of structural change, potentially improving prognostic assessments and treatment decisions in glaucoma management.

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