



Original Article

Association Between Cup-To-Disc Ratio and Structural and Functional Damage Parameters in Glaucoma: A Multiparametric Analysis

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ABSTRACT

Background: Glaucoma is a progressive optic neuropathy characterized by structural damage to the optic nerve head and corresponding visual field loss. It is one of the leading causes of irreversible blindness worldwide. The cup-to-disc ratio (CDR) is widely used in clinical practice to assess optic nerve head damage; however, its relationship with quantitative structural and functional parameters requires further investigation. Advances in imaging techniques such as optical coherence tomography (OCT) and automated perimetry allow objective assessment of retinal nerve fiber layer (RNFL) thickness and visual field indices. Understanding the association between CDR and these parameters may improve the assessment of glaucomatous damage.

Methods: A hospital-based analytical cross-sectional study was conducted in the Department of Ophthalmology at a tertiary care hospital in Udaipur, Rajasthan, between July 2025 and December 2025. A total of 78 patients diagnosed with glaucoma were included using consecutive sampling. All participants underwent comprehensive ophthalmic examination including slit-lamp evaluation, measurement of intraocular pressure, fundoscopic assessment of cup-to-disc ratio, OCT-based measurement of RNFL thickness, and automated perimetry for evaluation of visual field parameters such as mean deviation (MD), pattern standard deviation (PSD), and visual field index (VFI). Data were analyzed using SPSS version 25. Pearson correlation analysis was used to assess associations between CDR and structural as well as functional parameters, while multiple linear regression analysis was performed to identify independent predictors of CDR.

Results: The mean age of the participants was 61.4 ± 10.2 years, with the majority belonging to the 60–69 year age group. The mean cup-to-disc ratio was 0.69 ± 0.11 . The mean average RNFL thickness was $78.6 \pm 12.4 \mu\text{m}$, and the mean mean deviation was $-7.8 \pm 4.3 \text{ dB}$. A significant negative correlation was observed between CDR and average RNFL thickness ($r = -0.62$, $p < 0.001$) as well as between CDR and visual field index ($r = -0.61$, $p < 0.001$). Additionally, a significant negative correlation was found between CDR and mean deviation ($r = -0.59$, $p < 0.001$). The multiparametric regression model demonstrated that average RNFL thickness and VFI were the strongest independent predictors of CDR, explaining 54% of the variance in optic disc cupping ($R^2 = 0.54$, $p < 0.001$).

Conclusion: The study demonstrates a strong association between cup-to-disc ratio, retinal nerve fiber layer thickness, and visual field parameters in glaucoma patients. A multiparametric approach integrating structural and functional assessments provides a more comprehensive evaluation of glaucomatous damage and may improve clinical decision-making in glaucoma management.

Keywords: Glaucoma; Cup-to-disc ratio; Retinal nerve fiber layer; Optical coherence tomography; Visual field analysis; Structural–functional relationship; Multiparametric modeling.

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INTRODUCTION

Glaucoma is a chronic, progressive optic neuropathy characterized by structural damage to the optic nerve head and corresponding visual field defects. It is one of the leading causes of irreversible blindness worldwide and represents a major public health challenge. Recent global estimates suggest that more than 76 million individuals were affected by glaucoma in 2020, and the number is projected to increase to over 110 million by 2040 due to aging populations and increased life expectancy [1,2]. The disease often progresses silently in its early stages, and many patients remain asymptomatic until substantial and irreversible visual field loss occurs. Consequently, early detection and timely intervention are critical to preventing permanent vision impairment and reducing the global burden of glaucoma.

The pathophysiology of glaucoma involves progressive degeneration of retinal ganglion cells and their axons, leading to characteristic structural changes in the optic nerve head and retinal nerve fiber layer (RNFL). Elevated intraocular pressure (IOP) is the most important modifiable risk factor associated with the development and progression of glaucoma. However, the disease may also occur in individuals with normal intraocular pressure, suggesting that other factors such as vascular dysregulation, genetic predisposition, and impaired ocular blood flow contribute to the disease process [3]. The progressive loss of neural tissue ultimately results in structural changes in the optic disc and functional impairment in the form of visual field defects.

One of the most commonly used clinical indicators for evaluating glaucomatous optic nerve damage is the cup-to-disc ratio (CDR). The optic disc contains a central depression known as the cup, and enlargement of this cup relative to the disc is considered a hallmark of glaucomatous damage. Clinically, an increased CDR or asymmetry between the two eyes is often regarded as a suspicious sign for glaucoma. Progressive enlargement of the optic cup occurs due to loss of neuroretinal rim tissue and remodeling of the lamina cribrosa. Measurement of CDR during fundoscopic examination is a simple and widely used method for screening and assessing glaucoma severity. However, interpretation of CDR may sometimes be limited by physiological variations in optic disc size and inter-observer variability [4,5].

In recent years, advancements in ocular imaging technologies have significantly enhanced the evaluation of structural changes associated with glaucoma. Optical coherence tomography (OCT) is a non-invasive imaging modality that provides high-resolution cross-sectional images of retinal structures, allowing quantitative measurement of RNFL thickness and other optic nerve head parameters. Thinning of the RNFL is considered one of the earliest indicators of glaucomatous damage and may occur even before detectable visual field abnormalities develop. OCT-derived parameters such as average RNFL thickness, quadrant-specific RNFL measurements, and ganglion cell complex thickness are therefore widely used in the diagnosis and monitoring of glaucoma [6,7].

In addition to structural alterations, glaucoma leads to progressive functional impairment, which is commonly assessed using automated perimetry. Visual field testing provides important indices such as mean deviation (MD), pattern standard deviation (PSD), and visual field index (VFI), which help quantify the severity and pattern of visual field loss. The relationship between structural damage and functional impairment in glaucoma is complex and varies depending on the stage of the disease. In early glaucoma, structural changes in the optic nerve and RNFL may precede measurable functional loss, whereas in advanced stages, visual field defects become more evident and progressive. Understanding the correlation between structural and functional parameters is therefore crucial for accurate diagnosis and disease monitoring [8].

Several studies have attempted to evaluate the relationship between optic nerve head parameters, RNFL thickness, and visual field indices in glaucoma patients. However, many traditional diagnostic approaches rely on individual parameters rather than integrating multiple structural and functional indicators simultaneously. A multiparametric approach, which combines clinical, structural, and functional measurements, may provide a more comprehensive understanding of glaucomatous damage. Such models can improve diagnostic accuracy, enhance early detection of disease progression, and aid clinicians in making more informed management decisions [9,10].

Despite the availability of advanced diagnostic tools, variability still exists in the relationship between clinical indicators such as cup-to-disc ratio and quantitative structural and functional parameters. Furthermore, regional clinical data evaluating these associations remain limited, particularly in tertiary care settings in developing countries. Investigating the association between CDR and other indicators of glaucoma severity may therefore help clarify the clinical relevance of optic disc morphology in relation to structural and functional damage.

Therefore, the present study was conducted at a tertiary care hospital in Udaipur between July 2025 and December 2025 to evaluate the association between cup-to-disc ratio and structural as well as functional damage parameters in patients with glaucoma. By applying a multiparametric analytical approach, this study aims to provide insights into the relationship between optic disc morphology, retinal nerve fiber layer thickness, and visual field indices, thereby contributing to improved clinical assessment and monitoring of glaucoma.

MATERIALS AND METHODS

Study Design: The present study was a hospital-based analytical cross-sectional study conducted to evaluate the association between cup-to-disc ratio and structural as well as functional damage parameters in glaucoma.

Study Setting: The study was conducted in the Department of Ophthalmology at a tertiary care teaching hospital in Udaipur, Rajasthan, India.

Study Duration: The study was carried out over a period of six months from July 2025 to December 2025.

Study Population: The study population comprised patients diagnosed with glaucoma who attended the ophthalmology outpatient department during the study period and fulfilled the eligibility criteria.

Sample Size: A total of 78 patients diagnosed with glaucoma were included in the study. Eligible patients presenting during the study period were recruited consecutively until the desired sample size was achieved.

Inclusion Criteria

Patients fulfilling the following criteria were included in the study:

1. Patients aged 40 years and above.
2. Patients diagnosed with primary open-angle glaucoma or other types of glaucoma based on clinical examination.
3. Patients willing to participate and provide informed consent.

Exclusion Criteria

The following patients were excluded from the study:

1. Patients with history of ocular trauma or previous intraocular surgery affecting optic nerve evaluation.
2. Patients with retinal diseases or neurological disorders that could influence visual field testing.
3. Patients with media opacities such as dense cataract interfering with fundus examination or imaging.
4. Patients with unreliable visual field test results.

Data Collection Procedure: After obtaining informed consent, detailed demographic and clinical information was recorded using a predesigned data collection form. All participants underwent a comprehensive ophthalmic evaluation which included visual acuity assessment, slit-lamp examination, measurement of intraocular pressure using applanation tonometry, and dilated fundus examination. The cup-to-disc ratio (CDR) was assessed through stereoscopic evaluation of the optic disc during fundoscopic examination. Structural assessment of the optic nerve was performed using optical coherence tomography (OCT) to measure parameters such as average retinal nerve fiber layer (RNFL) thickness and quadrant-specific RNFL measurements. Functional assessment was carried out using standard automated perimetry, and visual field indices including mean deviation (MD), pattern standard deviation (PSD), and visual field index (VFI) were recorded. All examinations were performed using standardized procedures to ensure consistency and reliability of measurements.

Study Variables: The primary independent variable in the study was the cup-to-disc ratio (CDR). Structural parameters included average RNFL thickness and quadrant RNFL thickness measured by OCT, while functional parameters included visual field indices such as mean deviation (MD), pattern standard deviation (PSD), and visual field index (VFI) obtained from automated perimetry.

Statistical Analysis: The collected data were entered into Microsoft Excel and analyzed using Statistical Package for Social Sciences (SPSS) software version 25. Continuous variables were expressed as mean \pm standard deviation, while categorical variables were presented as frequencies and percentages. The association between cup-to-disc ratio and structural as well as functional parameters was assessed using Pearson's correlation coefficient. Multiple linear regression analysis was performed to evaluate the relationship between cup-to-disc ratio and selected structural and functional variables while controlling for potential confounding factors. A p-value of less than 0.05 was considered statistically significant.

Ethical Considerations: All procedures performed in the study adhered to the ethical principles outlined in the Declaration of Helsinki. Written informed consent was obtained from all participants after explaining the purpose and procedures of the study. Confidentiality and anonymity of the participants were strictly maintained, and the collected data were used solely for research purposes. Participation in the study was entirely voluntary, and participants were free to withdraw from the study at any stage without any effect on their clinical care.

RESULTS

A total of 78 patients diagnosed with glaucoma were included in the study conducted at a tertiary care hospital in Udaipur between July 2025 and December 2025. The analysis evaluated the association between cup-to-disc ratio (CDR) and

various structural parameters (RNFL thickness) as well as functional parameters (visual field indices). Table 1 summarizes the socio-demographic profile of the participants. The mean age of the study population was 61.4 ±10.2 years, with the highest proportion in the 60–69 year age group (32.1%). Males constituted 57.7% of the participants. Primary open-angle glaucoma was the most common type (71.8%), consistent with patterns reported in hospital-based glaucoma studies.

Table 1: Socio-demographic and Clinical Characteristics of Study Participants (n = 78)

Variable	Category	n (%)
Age group (years)	40–49	14 (17.9)
	50–59	21 (26.9)
	60–69	25 (32.1)
	≥70	18 (23.1)
Gender	Male	45 (57.7)
	Female	33 (42.3)
Residence	Urban	41 (52.6)
	Rural	37 (47.4)
Type of glaucoma	Primary open-angle glaucoma	56 (71.8)
	Normal tension glaucoma	12 (15.4)
	Angle closure glaucoma	10 (12.8)
Mean age (years)	—	61.4 ± 10.2

Table 2 shows the distribution of cup-to-disc ratio among glaucoma patients. The majority of patients had moderate optic disc cupping (0.61–0.7). A markedly enlarged cup (CDR >0.8) was observed in 20.5% of patients, indicating advanced glaucomatous optic neuropathy.

Table 2: Distribution of Cup-to-Disc Ratio among Study Participants (n = 78)

Cup-to-Disc Ratio	n (%)
0.50–0.60	18 (23.1)
0.61–0.70	24 (30.8)
0.71–0.80	20 (25.6)
>0.80	16 (20.5)
Mean CDR	0.69 ± 0.11

Table 3 presents the mean values of structural and functional parameters. The average RNFL thickness was 78.6 ±12.4 μm, indicating structural thinning consistent with glaucomatous damage. The mean MD of –7.8 dB reflects moderate functional visual field loss in the study population.

Table 3: Structural (OCT) and Functional (Visual Field) Parameters among Study Participants

Parameter	Mean ± SD	
Structural Parameters (OCT)	Average RNFL thickness (μm)	78.6 ± 12.4
	Superior RNFL thickness (μm)	92.1 ± 15.3
	Inferior RNFL thickness (μm)	89.7 ± 14.6
	Nasal RNFL thickness (μm)	63.4 ± 11.2
	Temporal RNFL thickness (μm)	58.9 ± 9.8
Functional Parameters (Perimetry)	Mean Deviation (MD) (dB)	–7.8 ± 4.3
	Pattern Standard Deviation (PSD) (dB)	6.2 ± 2.1
	Visual Field Index (VFI) (%)	82.4 ± 10.7

Table 4 demonstrates the correlation between cup-to-disc ratio and structural as well as functional parameters. A significant negative correlation was observed between CDR and RNFL thickness, indicating progressive RNFL thinning with

increasing optic disc cupping. Functional parameters also showed significant associations, with higher CDR associated with worse MD and lower VFI.

Table 4: Correlation between Cup-to-Disc Ratio and Structural and Functional Parameters

Parameter	Pearson r	p-value
Average RNFL thickness	-0.62	<0.001
Superior RNFL thickness	-0.55	<0.001
Inferior RNFL thickness	-0.58	<0.001
Nasal RNFL thickness	-0.41	0.002
Temporal RNFL thickness	-0.39	0.004
Mean Deviation (MD)	-0.59	<0.001
Pattern Standard Deviation (PSD)	0.47	<0.001
Visual Field Index (VFI)	-0.61	<0.001

Statistical test: Pearson correlation

Table 5 shows the relationship between structural damage (RNFL thinning) and functional impairment (visual field parameters). A strong positive correlation was observed between RNFL thickness and both MD and VFI, indicating that structural loss of retinal nerve fibers corresponds closely with functional visual field deterioration.

Table 5: Structural-Functional Relationship in Glaucoma

Structural Parameter	Functional Parameter	Correlation (r)	p-value
Average RNFL thickness	Mean Deviation (MD)	0.64	<0.001
Average RNFL thickness	Visual Field Index (VFI)	0.66	<0.001
Average RNFL thickness	Pattern Standard Deviation (PSD)	-0.51	<0.001

Statistical test: Pearson correlation

Table 6 presents the multiparametric linear regression model evaluating predictors of cup-to-disc ratio. Average RNFL thickness and visual field index emerged as the strongest independent predictors of CDR. The model explained 54% of the variance in cup-to-disc ratio, indicating a substantial relationship between optic disc morphology and combined structural and functional glaucoma parameters.

Table 6: Multiparametric Linear Regression Model Predicting Cup-to-Disc Ratio

Predictor Variable	β coefficient	Standard Error	p-value
Average RNFL thickness	-0.43	0.08	<0.001
Visual Field Index (VFI)	-0.37	0.09	<0.001
Mean Deviation (MD)	-0.21	0.07	0.012
Pattern Standard Deviation (PSD)	0.18	0.06	0.021

Model statistics: $R^2 = 0.54$, Adjusted $R^2 = 0.51$, $F = 21.7$, $p < 0.001$

DISCUSSION

The present study evaluated the association between cup-to-disc ratio (CDR) and both structural and functional parameters of glaucomatous damage in patients attending a tertiary care hospital in Udaipur. The findings demonstrated significant correlations between CDR, retinal nerve fiber layer (RNFL) thickness, and visual field indices, highlighting the importance of integrating structural and functional assessments in glaucoma evaluation.

Glaucoma is characterized by progressive optic nerve damage and visual field loss, making early detection and monitoring crucial for preventing irreversible blindness. Previous studies have reported that optic nerve head changes, particularly increased CDR, are among the earliest clinical indicators of glaucomatous damage [4,5]. In the present study, the mean

CDR was 0.69 ± 0.11 , and approximately one-fifth of patients exhibited a CDR greater than 0.8, indicating advanced optic disc cupping. These findings are consistent with earlier reports that progressive enlargement of the optic cup occurs as a result of neuroretinal rim loss and structural remodeling of the optic nerve head in glaucoma [3].

The study population had a mean age of 61.4 ± 10.2 years, with the highest proportion of patients in the 60–69 year age group, which aligns with the well-established observation that glaucoma prevalence increases with age [1,2]. Age-related susceptibility to glaucomatous optic neuropathy may be attributed to degenerative changes in retinal ganglion cells, vascular alterations, and reduced neuronal resilience. Furthermore, the predominance of primary open-angle glaucoma observed in this study is comparable with findings reported in hospital-based studies worldwide, where it remains the most common form of glaucoma [3].

Structural assessment using optical coherence tomography (OCT) revealed a mean average RNFL thickness of 78.6 ± 12.4 μm , indicating significant thinning compared with normal populations. RNFL thinning has been widely recognized as a sensitive structural marker of glaucomatous damage. Previous studies have demonstrated that RNFL thickness measured using OCT can detect structural changes even before visual field abnormalities become clinically evident [6,7]. In the present study, the strongest negative correlation was observed between CDR and average RNFL thickness ($r = -0.62$, $p < 0.001$). This finding indicates that larger optic disc cupping is associated with greater loss of retinal nerve fibers, which is consistent with the fundamental pathological mechanism of glaucoma.

Functional impairment in glaucoma is typically assessed using automated perimetry. In the present study, the mean mean deviation (MD) was -7.8 ± 4.3 dB, indicating moderate visual field loss among the participants. Similarly, the mean visual field index (VFI) was $82.4 \pm 10.7\%$, suggesting varying degrees of functional impairment. These results are comparable to findings reported in earlier studies examining the structural–functional relationship in glaucoma [8,10]. The study demonstrated a significant negative correlation between CDR and MD ($r = -0.59$, $p < 0.001$), indicating worsening visual field damage with increasing optic disc cupping.

One of the key findings of this study was the strong relationship between structural damage and functional impairment. Average RNFL thickness showed significant correlations with both mean deviation and visual field index, suggesting that structural loss of retinal nerve fibers corresponds closely with functional deterioration in glaucoma. These findings support the framework proposed by Hood and Kardon, which describes the relationship between structural and functional measures of glaucomatous damage [8]. Similar correlations between OCT-derived structural parameters and visual field indices have also been reported in several studies evaluating glaucoma progression [10].

An important aspect of the present study was the application of a multiparametric regression model to evaluate predictors of cup-to-disc ratio. The regression analysis demonstrated that average RNFL thickness and visual field index were the strongest independent predictors of CDR, explaining a substantial proportion of the variance in optic disc cupping. This finding highlights the importance of integrating multiple diagnostic parameters when assessing glaucoma severity. Previous studies have emphasized that combined indices incorporating structural and functional measures may improve diagnostic accuracy and staging of glaucoma compared with isolated parameters [9].

Recent studies have further emphasized the value of multimodal assessment in glaucoma. Rao HL et al. reported that combining OCT-derived RNFL measurements with visual field indices significantly improved the detection of glaucomatous damage compared with individual diagnostic parameters [13]. Similarly, Lisboa et al. demonstrated that integrated structure–function indices provide better discrimination between early glaucoma and normal eyes [9]. Another study by Pradhan ZS et al. highlighted the potential of multiparametric models to predict disease progression and guide clinical decision-making [14].

The findings of the present study therefore reinforce the concept that glaucoma evaluation should not rely solely on a single parameter such as cup-to-disc ratio. While CDR remains a valuable clinical indicator during fundoscopic examination, its interpretation can be influenced by physiological variations in optic disc size. Integration of structural imaging techniques such as OCT and functional assessments through automated perimetry provides a more comprehensive evaluation of disease severity.

The present study has certain limitations. Being a single-center study with a relatively modest sample size, the findings may not be fully generalizable to the broader population. Additionally, the cross-sectional design limits the ability to assess longitudinal progression of glaucoma. Future studies with larger sample sizes and longitudinal follow-up would be valuable in further clarifying the relationship between structural and functional parameters in glaucoma progression.

Despite these limitations, the present study provides valuable insights into the relationship between optic disc morphology, retinal nerve fiber layer thickness, and visual field parameters in glaucoma patients. The findings support the use of a

multiparametric approach combining clinical examination, structural imaging, and functional testing for comprehensive evaluation and monitoring of glaucoma.

CONCLUSION

The present study demonstrated a significant association between cup-to-disc ratio (CDR) and both structural and functional indicators of glaucomatous damage. Increasing optic disc cupping was strongly correlated with retinal nerve fiber layer (RNFL) thinning and worsening visual field parameters, including mean deviation and visual field index. These findings support the concept that structural changes of the optic nerve head are closely linked with functional deterioration in glaucoma. The multiparametric regression analysis further revealed that average RNFL thickness and visual field index were the strongest predictors of cup-to-disc ratio, highlighting the value of integrating multiple diagnostic indicators in glaucoma evaluation. While CDR remains an important clinical marker during fundoscopic examination, reliance on a single parameter may not fully capture disease severity. Therefore, combining optic disc assessment, optical coherence tomography, and automated perimetry provides a more comprehensive evaluation of glaucomatous damage. Adoption of such multiparametric approaches may enhance early detection, improve disease monitoring, and support better clinical decision-making in glaucoma management.

DECLARATIONS

Consent for Publication: Written informed consent for publication of anonymized data was obtained from all participants.
Availability of Data and Materials: The datasets used and analyzed during the study are available from the corresponding author on reasonable request.

Competing Interests: The authors declare that they have no competing interests.

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