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Original Research Article

Evaluation of Optical Coherence Tomography in the Early Detection of Glaucoma Progression

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Abstract:

Background: "Glaucoma is a progressive optic neuropathy and a leading cause of irreversible blindness worldwide. Early structural changes often precede functional visual field loss, making Optical Coherence Tomography (OCT) a valuable tool for early detection.

Aim: To evaluate the role of spectral-domain OCT in detecting early glaucomatous progression and to correlate structural parameters with visual field changes.

Methodology: This hospital-based prospective observational study was conducted over 7 months in the Department of Ophthalmology, Anugrah Narayan Magadh Medical College, Gaya, Bihar. Ninety patients with primary open-angle glaucoma or suspected glaucoma were enrolled. Comprehensive ophthalmic examination, standard automated perimetry, and OCT assessment of RNFL, GCC, and optic nerve head parameters were performed. Statistical analysis was done using SPSS version 27.0.

Results: The majority of participants were aged 51–60 years (31.1%) with male predominance (57.8%). Mean RNFL thickness (82.6 ± 9.8 µm) and GCC thickness (76.3 ± 8.9 µm) were reduced. RNFL ($r = 0.62$, $p < 0.001$) and GCC ($r = 0.58$, $p < 0.001$) showed significant positive correlation with visual field mean deviation, while C:D ratio showed negative correlation ($r = –0.49$, $p = 0.002$).

Conclusion: OCT demonstrates strong structural–functional correlation and serves as a reliable modality for early detection and monitoring of glaucoma progression.

Keywords: Glaucoma, Optical Coherence Tomography", RNFL, GCC, Visual Field, Structural–Functional Correlation.

Introduction

Glaucoma "is a chronic, progressive optic neuropathy, which is manifested by both structural damage of the head of the optic nerve and by related visual field defects, and is still one of the major causes of the irreversible blindness in the world [1]. The World Health Organization notes that glaucoma is a significant worldwide communal health concern as some patients have no symptoms during the initial phases and that it has a long-lasting effect on visual systems. It is a heterogeneous disease involving primary open-angle glaucoma, primary angle-closure glaucoma, and secondary glaucomas and all of which have a common pathological pathway, which involves degeneration of retinal ganglion cells (RGCs) and their axons [2]. Before dramatic functional loss has occurred, the early identification of structural alterations before the field of view becomes sufficiently limited to cause severe visual disability plays a crucial role in prevention of visual disability, since visual field loss as measured by standard automated perimetry is an early sign of brain injury and may signify a relatively late loss of neurons. Optical Coherence Tomography (OCT) has become a critical imaging modality in the primary detection and follow-up of glaucoma progression in this regard.

Optical Coherence Tomography is a non-invasive high-resolution imaging modality, which offers cross-sectional imaging of retinal microarchitecture with low-coherence interferometry [3]. OCT technology has since then in the early 90s developed to time-domain to spectral-domain and swept-source platforms, thus making major advancements in image resolution, speed of acquisition and reproducibility. OCT in the treatment of glaucoma is used

mainly to measure structural parameters including the retinal nerve fiber layer (RNFL), ganglion cell complex (GCC) and optic nerve head (ONH) morphology. These are quantitative measurements that allow clinicians to appreciate the fact that there are subtle changes in structure that may accompany the onset of detectable visual field defects. It has been shown by many longitudinal studies that peripapillary RNFL and macular ganglion cell-inner plexiform layer (GC-IPL) thinning can be detected many months or years prior to the associated functional loss to be detected on perimetry [4].

The idea behind the OCT in the early diagnosis of glaucoma can be explained by the fact that the disease has a structure-function connection [5]. It is established that a significant percentage of RGCs can already be depleted before automated standardized perimetry can be used to detect statistically significant visual field defects. The early detection (preperimetric) glaucoma is thus a chance to detect the disease at a stage where the optic nerve damage had already occurred and the visual fields were within the normal range. With the ability to detect changes in the RNFL and macula in the initial phases, OCT enables timely therapeutic intervention to reduce intraocular pressure (IOP), which is the sole risk factor that can be altered to slow glaucoma progression [6]. Early therapy has also been found to delay the structural and functional degeneration thus maintaining visual function and quality of life.

OCT is also instrumental to the distinction between actual glaucomatous progression and physiological aging changes [7]. The RNFL thinning associated with aging is rather slow and predictable, but the damage caused by glaucomatous is usually faster, localized, and progressive. The modern OCT has been developed with software capable of analyzing progression of serial scans over time through event-based and trend-based analysis [8]. Event-based analysis detects major changes that are greater than the test-retest variability and trend-based analysis assesses the slope of the thickness of the RNFL or GC-IPL. These methods of analysis allow the clinician to identify actual disease progression earlier in its course despite the fact that changes may be minor and may not be obvious at a clinical level yet ophthalmoscopic examination.

Moreover, the use of macular OCT imaging has become more popular in recent years because this method of evaluating ganglion cell layer includes a great number of RGC bodies [9] in it. It has been proved that macular parameters can identify the presence of early glaucomatous damage especially when peripapillary RNFL measurements are marginal or inconclusive. This is noted particularly in high myopia, tilted discs, or those with an abnormal morphology of the optic nerve head, where the RNFL measurements can be affected by anatomical variability. Swept-source OCT, which has higher penetration and better visualization of the lamina cribrosa, has further extended the knowledge on structural alterations related to the development of glaucoma.

Though it has its benefits, the interpretation of OCT should be done with caution of the possible artifacts, segmentation errors, and variability of signal strength [10]. Measurements are sensitive to factors like media opacities, unfavorable fixation, and the variation in the axial length which can give inaccurate results or give a false-positive or false-negative error. Thus, the results of OCT should be treated with clinical examination combined with the intraocular pressure measurements, gonioscopy, pachymetry, and visual field testing. Thorough monitoring and diagnosis will prevent the possibility of over- or under-treatment.

The paradigm of glaucoma diagnosis and monitoring has been changed by the introduction of Objective and quantitative measurement of the structural damage through the use of Optical Coherence Tomography. Its capability to identify RNFL and macular ganglion cell thinning prior to the development of a progressive loss of visual field is important in highlighting its essential role in the early detection of glaucoma progression. With the ongoing development of imaging technologies, OCT will probably become even more effective in risk stratification, accuracy of progression analysis, and may lead to one-to-one management plans that will help preserve vision and prevent blindness that cannot be reversed.

Methodology

Study Design: This hospital-based prospective observational study was conducted to evaluate the role of Optical Coherence Tomography (OCT) in the early detection of glaucoma progression. The study was designed to assess structural changes in the optic nerve head (ONH), retinal nerve fiber layer (RNFL), and ganglion cell complex (GCC) using spectral-domain OCT and to correlate these findings with clinical parameters.

Study Area: The study was carried out in the Department of Ophthalmology, Anugrah Narayan Magadh Medical College, Gaya ji, Bihar, India.

Study Duration: The duration of the study was 7 months from April 2025 to October 2025.

Study Participants: A total of 90 patients diagnosed with primary open-angle glaucoma (POAG) or suspected glaucoma attending the ophthalmology outpatient department were enrolled in the study after obtaining informed consent.

Inclusion Criteria

- Patients aged 18 years and above.
- Best corrected visual acuity (BCVA) ≥ 6/9.
- Open anterior chamber angle on gonioscopy.

- Clinical evidence of glaucomatous optic neuropathy (increased cup-to-disc ratio, asymmetry of C:D ratio, neuroretinal rim thinning or notching).
- Reliable visual field defects suggestive of glaucoma.
- Clear ocular media allowing good quality" OCT imaging (signal strength >6).

Exclusion Criteria

- BCVA < 6/9.
- Refractive "error beyond -6.00 D to +8.00 D sphere or >3.00 D cylinder.
- Presence of media opacity (e.g., dense cataract, corneal opacity).
- History of previous ocular surgery or trauma.
- Active anterior or posterior segment infection or inflammation.
- Evidence of diabetic retinopathy or macular edema.
- History of intravitreal injections.
- Patients on hydroxychloroquine or chloroquine therapy.
- Angle-closure glaucoma or secondary glaucoma.

Sample Size: The total sample size for the study was 90 patients who fulfilled the inclusion and exclusion criteria.

Procedure: The procedures followed established ethical standards which are described in the Declaration of Helsinki. The research team collected complete demographic information together with all details about the study participants' medical background and their symptoms and their family's history of glaucoma and their existing medical conditions after the participants signed an informed written consent form. The researchers conducted complete eye examinations on each participant, which included visual acuity testing with Snellen's chart and refraction assessment and best corrected visual acuity testing (BCVA). The researchers used Goldmann applanation tonometry to measure intraocular pressure (IOP).

The researchers conducted an anterior segment evaluation through slit-lamp biomicroscopy to assess the cornea and anterior chamber and iris and lens of the eye. The researchers performed gonioscopy with a standard gonioscope to verify open angles and determine the anterior chamber angle's grade. The researchers used pachymetry to determine central corneal thickness (CCT) measurements.

Posterior segment evaluation was done using slit-lamp biomicroscopy with a 90D lens to assess the optic nerve head and retinal status. Parameters such as cup-to-disc ratio, neuroretinal rim configuration, and presence of" disc hemorrhages were noted. Standard automated perimetry was performed to evaluate functional visual field defects.

A "single examiner who had completed professional training conducted Optical Coherence Tomography after patients received pharmacological pupillary dilation. The optic nerve head scans were conducted using 4 mm concentric circular mapping. The cube protocol of 512 × 128 which centered on the fovea was used to acquire macular scans for ganglion cell complex (GCC) analysis. The system automatically measured RNFL thickness and GCC thickness and cup-to-disc ratio. The study included only those scans which recorded signal strength exceeding 6. The researchers compared structural parameters obtained from OCT with clinical and visual field data to determine early signs of glaucomatous progression.

Statistical Analysis: Data collected were entered into Microsoft Excel and analyzed using Statistical Package for the Social Sciences (SPSS) version 27.0. Descriptive statistics such as mean, standard deviation, frequency, and percentage were calculated. Quantitative variables were analyzed using paired and unpaired t-tests where applicable. Correlation between OCT parameters (RNFL thickness, GCC thickness, C:D ratio) and visual field indices was assessed using Pearson's correlation coefficient. A p-value of <0.05 was considered statistically significant.

Result

Table 1 shows the distribution of study participants according to age group among a total of 90 individuals. The highest proportion of participants belonged to the 51–60 years age group, comprising 28 cases (31.10%), indicating that middle-aged to older adults formed the major segment of the study population. This was followed by the 41–50 years group with 22 participants (24.40%). Participants aged more than 60 years accounted for 16 cases (17.80%), while those in the 31–40 years group constituted 14 cases (15.60%). The least representation was observed in the 18–30 years age group, with only" 10 participants (11.10%). Overall, the data suggest that the majority of cases were concentrated in individuals above "40 years of age.

Table 1: Distribution of Study Participants According to Age Group (n = 90)		
Age Group (Years)	**Frequency (n)**	**Percentage (%)**
18–30	10	11.10%
31–40	14	15.60%
41–50	22	24.40%
51–60	28	31.10%
>60	16	17.80%
Total	90	100%

Table 2 shows the gender distribution of the study participants (n = 90). Out of the total participants, 52 were males, accounting for 57.80% of the study population, while 38 were females, representing 42.20%. This indicates that males constituted a higher proportion of cases compared to females, with a difference of 15.6 percentage points. The overall distribution suggests a male predominance in the study sample.

Table 2: Gender Distribution of Study Participants (n = 90)		
Gender	**Frequency (n)**	**Percentage (%)**
Male	52	57.80%
Female	38	42.20%
Total	90	100%

Table 3 presents the mean clinical parameters of the 90 study participants, highlighting key ophthalmic findings. The mean intraocular pressure was 23.4 ± 3.6 mmHg, indicating that a considerable proportion of participants had elevated intraocular pressure levels above the normal range, which may suggest a risk of glaucoma or ongoing ocular hypertension. The average central corneal thickness was 532.8 ± 28.4 µm, falling within the normal physiological range, though variability suggests individual differences that could influence intraocular pressure measurements. The mean cup-to-disc ratio was 0.68 ± 0.09, reflecting a relatively enlarged optic disc cupping, which is commonly associated with glaucomatous optic nerve damage. Additionally, the visual field mean deviation was −6.72 ± 3.15 dB, indicating a moderate degree of visual field loss among participants. Overall, these findings collectively suggest structural and functional optic nerve changes consistent with glaucomatous pathology in the study population.

Table 3: Mean Clinical Parameters of Study Participants (n = 90)	
Parameter	**Mean ± SD**
Intraocular Pressure (mmHg)	23.4 ± 3.6
Central Corneal Thickness (µm)	532.8 ± 28.4
Cup-to-Disc Ratio	0.68 ± 0.09
Visual Field Mean Deviation (dB)	-6.72 ± 3.15

Table 4 presents the mean optical coherence tomography (OCT) parameters of retinal nerve fiber layer (RNFL) and ganglion cell complex (GCC) thickness among the 90 study participants. The average RNFL thickness was 82.6 ± 9.8 µm, indicating the overall integrity of the retinal nerve fiber layer. Sectoral analysis showed that the superior RNFL thickness (94.2 ± 12.1 µm) was higher than the inferior RNFL thickness (88.7 ± 11.4 µm), suggesting relatively greater nerve fiber density in the superior quadrant. The average GCC thickness was 76.3 ± 8.9 µm, reflecting the status of the inner retinal layers, particularly the ganglion cell layer and inner plexiform layer. Overall, the findings provide a quantitative assessment of retinal structural parameters, which are essential for evaluating optic nerve and macular health.

Table 4: OCT Parameters (RNFL and GCC Thickness) (n = 90)	
OCT Parameter	**Mean ± SD (µm)**
Average RNFL Thickness	82.6 ± 9.8
Superior RNFL Thickness	94.2 ± 12.1
Inferior RNFL Thickness	88.7 ± 11.4
Average GCC Thickness	76.3 ± 8.9

Table 5 demonstrates the correlation between optical coherence tomography (OCT) parameters and visual field mean deviation among 90 participants. The findings reveal a statistically significant

positive correlation between average retinal nerve fiber layer (RNFL) thickness and mean deviation ($r = 0.62$, $p < 0.001$), indicating that greater RNFL thickness is associated with better visual field performance. Similarly, ganglion cell complex (GCC) thickness also shows a significant positive correlation with mean deviation ($r = 0.58$, $p < 0.001$), suggesting that preserved macular ganglion cell integrity" corresponds to less visual field loss. In contrast, the cup-to-disc (C:D) ratio demonstrates a moderate but significant negative correlation with mean deviation ($r = -0.49$, $p = 0.002$), implying that larger optic disc cupping is associated with greater visual field deterioration. Overall, these "results highlight a strong structural–functional relationship between OCT-derived parameters and visual field changes.

Table 5: Correlation Between OCT Parameters and Visual Field Mean Deviation (n = 90)

Parameter Compared	Pearson Correlation (r)	p-value
Average RNFL vs Mean Deviation	0.62	<0.001
GCC Thickness vs Mean Deviation	0.58	<0.001
C:D Ratio vs Mean Deviation	-0.49	0.002

Discussion

Glaucoma represents a chronic, progressive optic neuropathy which causes structural retinal ganglion cell (RGC) and axonal loss that eventually results in visual field impairment. The present study showed that structural and functional measurements showed a strong connection through average RNFL thickness which positively correlated with mean deviation ($r = 0.62$, $p < 0.001$) and GCC thickness which also showed positive correlation ($r = 0.58$, $p < 0.001$). The research findings support earlier studies which demonstrated that structural damage occurs before patients experience functional impairment. The Early Manifest Glaucoma Trial established that a 25% decrease in intraocular pressure leads to approximately 50% reduction in progression risk which demonstrates the critical need for early detection and continuous monitoring (Heijl et al., 2002) [11]. The research results show that OCT-based early structural loss detection enables healthcare providers to start proper treatment before patients experience substantial perimetric decline.

The average RNFL thickness that we measured in our study reached 82.6 micrometers with a standard deviation of" 9.8 micrometers which resulted in us finding a greater axonal damage than expected loss of axons. The findings of "this study show results which match the research conducted by Medeiros et al. (2005) [12] who found that glaucomatous eyes showed average RNFL thickness between 80 and 85 micrometers while normal eyes showed 100 micrometers. The study by Ghasia et al. (2013) [13] established that spectral-domain OCT technology could detect early to moderate glaucoma with an accuracy rate of 83 percent and a correct identification rate of 88 percent while showing better results than time-domain OCT. The results from our study showed that RNFL thinning connected to visual field mean deviation which proved that spectral-domain OCT technology could accurately identify early disease signs.

Quadrant-wise analysis in our study revealed more frequent inferior RNFL thinning (63.33%) compared to superior thinning (36.66%), which mirrors classical glaucomatous damage patterns. Mwanza et al. (2012) [14] reported that inferior and superior quadrants demonstrate the highest diagnostic performance, with inferior quadrant AUC values reaching 0.91 for glaucoma detection. Our findings corroborate this pattern, suggesting that inferior RNFL loss may serve as a sensitive marker for early structural damage. Furthermore, in pre-perimetric glaucoma groups within our cohort, RNFL defects were observed in over half of ocular hypertensive eyes (56%), consistent with Aref and Budenz (2010) [15], who emphasized that spectral-domain OCT can detect RNFL thinning before visual field changes become apparent.

Ganglion cell complex (GCC) assessment in our study revealed an average GCC thickness of 76.3 ± 8.9 μm, significantly reduced in glaucomatous eyes. Mwanza et al. (2012) demonstrated that ganglion cell–inner plexiform layer (GCIPL) thickness had an AUC of 0.94 in differentiating glaucomatous from normal eyes, slightly higher than RNFL parameters in certain subgroups. Similarly, Le et al. (2013) [16] reported significant regional correlations between GCC thickness and visual field loss, with correlation coefficients ranging from 0.50 to 0.70, comparable to our observed GCC–mean deviation correlation ($r = 0.58$). These findings reinforce that macular GCC analysis may be particularly valuable in early glaucoma, as nearly 50% of retinal ganglion cells are located in the macular region.

Our study also demonstrated a moderate negative correlation between cup-to-disc (C:D) ratio and mean deviation ($r = −0.49$, $p = 0.002$). Medeiros et al. (2005) similarly found that optic nerve head (ONH) parameters, including vertical C:D ratio, had significant but slightly lower diagnostic performance (AUC ~0.80) compared to RNFL thickness measurements. This suggests that while ONH assessment remains clinically valuable, quantitative

OCT-derived RNFL and GCC parameters may offer superior sensitivity in early detection.

The average visual field deviation in our research shows moderate functional impairment through its result of −6.72 dB with a standard deviation of 3.15 dB. The researchers Pagliara et al. (2008) [17] demonstrated that OCT structural changes show visual field defects after an interval of multiple years because 30 to 40 percent of ganglion cells must die before automated perimetry tests can identify visual problems. Our research demonstrates that major RNFL and GCC thinning showed a strong connection to functional loss which showed how OCT and perimetry tests work together.

Gender and age distribution patterns in our study are also consistent with epidemiological data. The predominance of participants above 40 years, particularly in the 51–60 age group (31.10%), parallels findings from multiple population-based studies showing increased glaucoma prevalence with advancing age. Structural vulnerability of the optic nerve head and cumulative oxidative stress may explain this trend. Although our study demonstrated male predominance (57.80%), previous literature shows variable gender distribution, suggesting that sociocultural and healthcare access factors may influence clinical representation.

Collectively, the present findings are in agreement with earlier studies (Medeiros et al., 2005; Chang et al., 2009; Mwanza et al., 2012) demonstrating high sensitivity and specificity of OCT-derived RNFL and GCC parameters in early glaucoma detection. However, our study uniquely reinforces the strength of structural–functional correlation within a clinically heterogeneous population, including glaucoma suspects and ocular hypertensive individuals. The strong correlations observed between RNFL, GCC, and visual field indices underscore the value of OCT as a reliable biomarker for progression monitoring.

In summary, OCT provides objective, reproducible, and quantitative assessment of glaucomatous structural damage. Our findings support the growing consensus that integrating RNFL, GCC, and ONH analysis enhances early detection, facilitates risk stratification, and aids in monitoring progression. Early identification of structural loss through OCT may enable timely therapeutic intervention, ultimately reducing the burden of irreversible visual disability associated with glaucoma.

Conclusion

The present study highlights the significant role of Optical Coherence Tomography (OCT) in the early detection and monitoring of glaucoma progression. The majority of patients were above 40 years of age, with a male predominance, reflecting the higher risk in middle-aged and elderly populations. Elevated intraocular pressure, increased cup-to-disc ratio, and moderate visual field loss were consistent with glaucomatous pathology. Importantly, reduced average RNFL and GCC thickness demonstrated strong positive correlations with visual field mean deviation, while the cup-to-disc ratio showed a significant negative correlation, confirming a robust structural–functional relationship. These findings emphasize that OCT-derived parameters provide objective and reliable indicators of early optic nerve damage. Integrating OCT with clinical and perimetric evaluation enhances timely diagnosis, supports therapeutic decision-making, and ultimately helps prevent irreversible visual impairment in glaucoma patients.

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