OPTICAL COHERENCE TOMOGRAPHY AS A TOOL FOR DETECTING RETINAL NERVE FIBER LAYER DEFECTS IN GLAUCOMA PATIENTS: A CROSS-SECTIONAL STUDY

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Abstract

Introduction: Optical Coherence Tomography (OCT) has emerged as a valuable tool in glaucoma diagnosis, particularly for assessing retinal nerve fiber layer (RNFL) thickness changes. It enables precise evaluation of glaucomatous optic neuropathy and provides critical insights into the association between RNFL thickness and disease progression. Additionally, OCT supports diagnosis, assessment, prediction, and research in glaucoma.

Materials and Methods: This cross-sectional study involved patients diagnosed with glaucoma. OCT scans were performed to measure RNFL thickness, and data on demographics, intraocular pressure (IOP), and cup-to-disc (CD) ratio were collected via questionnaires. The aim was to identify correlations between RNFL defects and clinical parameters.

Results: Glaucoma patients exhibited significantly thinner RNFL compared to healthy controls. A notable correlation was observed between elevated IOP and the severity of RNFL defects. These findings underscore OCT's efficacy in enhancing glaucoma diagnosis and facilitating early intervention. The study was conducted at an eye surgery clinic using the NIDEK RS 3000 OCT device for RNFL analysis. Measurements across four quadrants (superior, inferior, nasal, temporal) were obtained from 45 patients with primary open-angle glaucoma. RNFL thickness changes were detected in 39 patients (86.7%), with marked thinning in the nasal quadrant (80%), temporal quadrant (66.7%), superior quadrant (71.1%), and inferior quadrant (60%).

Conclusion: OCT serves as an effective indicator for detecting RNFL defects in glaucoma patients. This study highlights its clinical utility for early detection and intervention, aiding in vision preservation for at-risk individuals.

Keywords: Optical Coherence Tomography, Retinal Nerve Fiber Layer, Glaucoma, Intraocular Pressure, Cup-to-Disc Ratio, Optic Neuropathy

ОПТИЧЕСКАЯ КОГЕРЕНТНАЯ ТОМОГРАФИЯ КАК ИНСТРУМЕНТ ДЛЯ ВЫЯВЛЕНИЯ ДЕФЕКТОВ СЛОЯ НЕРВНЫХ ВОЛОКОН СЕТЧАТКИ У ПАЦИЕНТОВ С ГЛАУКОМОЙ: ПОПЕРЕЧНОЕ ИССЛЕДОВАНИЕ

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Аннотация

Введение: Оптическая когерентная томография (ОКТ) стала ценным инструментом в диагностике глаукомы, особенно для оценки изменений толщины слоя нервных волокон сетчатки (СНС). Она позволяет точно оценить глаукоматозную оптическую

нейропатию и предоставляет важную информацию о связи между толщиной СНС и прогрессированием заболевания. Кроме того, ОКТ поддерживает диагностику, оценку, прогнозирование и исследования глаукомы.

Материалы и методы: В этом поперечном исследовании приняли участие пациенты с диагнозом глаукома. Для измерения толщины слоя нервных волокон сетчатки (RNFL) были проведены ОКТ-сканирования, а данные о демографических характеристиках, внутриглазном давлении (ВГД) и соотношении экскавации диска зрительного нерва (CD) были собраны с помощью анкет. Целью исследования было выявление корреляций между дефектами RNFL и клиническими параметрами.

Результаты: У пациентов с глаукомой наблюдалась значительно меньшая толщина RNFL по сравнению со здоровыми контрольными группами. Была отмечена значительная корреляция между повышенным ВГД и тяжестью дефектов RNFL. Эти результаты подчеркивают эффективность ОКТ в улучшении диагностики глаукомы и содействии раннему вмешательству. Исследование проводилось в офтальмологической хирургической клинике с использованием ОКТ-аппарата NIDEK RS 3000 для анализа RNFL. Измерения в четырех квадрантах (верхний, нижний, носовой, височный) были получены от 45 пациентов с первичной открытоугольной глаукомой. Изменения толщины слоя нервных волокон сетчатки (RNFL) были выявлены у 39 пациентов (86,7%), с выраженным истончением в носовом квадранте (80%), височном квадранте (66,7%), верхнем квадранте (71,1%) и нижнем квадранте (60%).

Заключение: ОКТ является эффективным индикатором для выявления дефектов RNFL у пациентов с глаукомой. Данное исследование подчеркивает его клиническую ценность для ранней диагностики и вмешательства, способствуя сохранению зрения у лиц из группы риска.

Ключевые слова: Оптическая когерентная томография, слой нервных волокон сетчатки, глаукома, внутриглазное давление, соотношение экскавации диска зрительного нерва к его диаметру, оптическая нейропатия.

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Introduction

The human eye is a complex organ responsible for vision. Its anatomy includes the cornea, iris, lens, vitreous humor, retina, and optic nerve. The retina contains photoreceptors (rods and cones) that convert light into neural signals transmitted via the optic nerve to the brain. The retinal nerve fiber layer (RNFL) consists of axons from retinal ganglion cells, which converge at the optic disc to form the optic nerve. [1] Physiologically, the eye maintains intraocular pressure (IOP) through aqueous humor production and drainage. Disruptions in this balance can lead to conditions like glaucoma.[2] Glaucoma is a group of eye diseases characterized by progressive optic nerve damage, often due to elevated IOP, leading to vision loss. It is a leading cause of irreversible blindness worldwide. Primary open-angle glaucoma (POAG), the most common form, involves gradual blockage of the trabecular meshwork, increasing IOP and damaging the RNFL.[3]RNFL defects manifest as thinning or loss of nerve fibers, detectable before visual field loss. Early detection is crucial for preventing progression.[4] OCT is a non-invasive imaging technique using low-coherence interferometry to produce

high-resolution cross-sectional images of retinal structures.[5] OCT operates on the principle of light interference. A broadband light source is split into reference and sample arms; backscattered light from the tissue interferes with the reference beam to generate detailed images with micrometer resolution [6]. Following are types of OCT Scans :

- *Retinal Thickness Map:* Displays macular thickness variations.
- *RNFL Scan:* Measures peripapillary RNFL thickness in quadrants.
- *3D Disc Scan:* Provides volumetric analysis of the optic disc.
- *TSNIT Map:* Plots RNFL thickness in temporal-superior-nasal-inferior-temporal sequence for deviation analysis.

Rationale of the Study

Despite OCT's established role, limited data exist on its application in Pakistani populations with POAG. This study addresses this gap by evaluating OCT's efficacy in detecting RNFL defects and correlating them with clinical parameters.

Objectives

- To assess RNFL thickness in glaucoma patients using OCT.
- To correlate RNFL defects with IOP and CD ratio.
- To evaluate OCT's diagnostic utility in early glaucoma detection.
- To determine the effectiveness of OCT in identifying RNFL defects for improved glaucoma management.

Methodology

Study Population

Participants included 45 patients diagnosed with POAG, aged 40-70 years, from the eye surgery clinic at Rawalpindi Medical University & Allied Hospitals.

Study Place

The study was conducted at Prof. Niazi's Eye Surgery Clinic, Rawalpindi, Pakistan.

Study Design

Cross-sectional observational design among the patient diagnosed with POAG.

Study Sample

Convenience sampling was used to recruit eligible patients.

Study Methods

OCT scans (NIDEK RS 3000) were performed to measure RNFL thickness in superior, inferior, nasal, and temporal quadrants. IOP was measured using Goldmann applanation tonometry, and CD ratio via slit-lamp biomicroscopy. Demographic data were collected via structured questionnaires.

Sample Size

Sample of 45 patients diagnosed with POAG took and, calculated based on expected RNFL thinning prevalence.

Duration of Study

From January 15,2025 to July 15,2025 .

Ethical Consideration:

This study was conducted after approval from the ethical committee board. Data was collected from doctors and optometrists working in Professor Niazi's Eye Surgery. Informed consent was obtained. Clinical examinations and OCT scans were conducted, with data recorded anonymously.

Study Tools

Statistical analysis used SPSS software. Descriptive statistics summarized demographics and measurements. One-sample t-tests compared RNFL thickness to normative values. Pearson correlation assessed relationships between variables.

Inclusion Criteria: Confirmed POAG, age >40 and <70 years old, no prior surgery.

Exclusion Criteria: Other ocular pathologies, unreliable scans and POAG patient age less than 40 years old and greater than 70 years old.

Limitations of Study

Small sample size, single-center, cross-sectional nature limiting causality inference.

Data Collection Tools

OCT device, tonometry, biomicroscope, questionnaires.

Results:

This study was conducted in Eye surgery clinic where OCT (NIDEK RS 3000) was used to conduct RNFL analysis. The RNFL thickness measurements of four quadrants (superior, inferior, nasal, and temporal) of a total of 45 patients suffering from primary open-angle glaucoma were conducted. From the analysis, changes in RNFL thickness were noted in 39 of them (86.7%), with considerably marked thinning of about 80% in the RNFL of the nasal quadrant. Followed by this was the observation of mid-thinning of the temporal quadrant in 66.7% of the patients and then, the superior quadrant creeping up to 71.1%. The inferior quadrant was around 60% resistant to thinning, making it the most resistant quadrant.

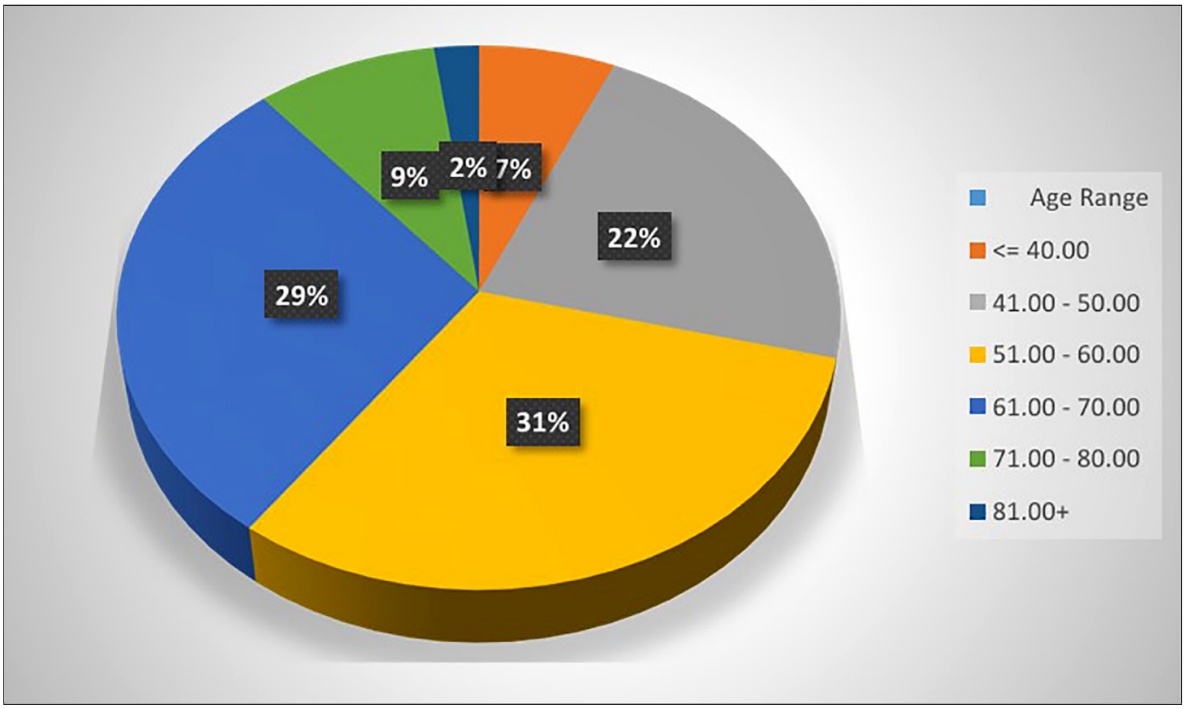
In Age wise distribution graph, we get to know that the prevalence of glaucoma is most seen in the age range of 51-60, with a significant proportion (28.9%) in 61-70 years range. Prevalence of Glaucoma correlates with age-related degeneration of retinal ganglion cells and optic nerve fibers.

Age (Years)

Age Range	Frequency	Percent	Valid Percent	Cumulative Percent
<= 40.00	3	6.7	6.7	6.7
41.00- 50.00	10	22.2	22.2	28.9

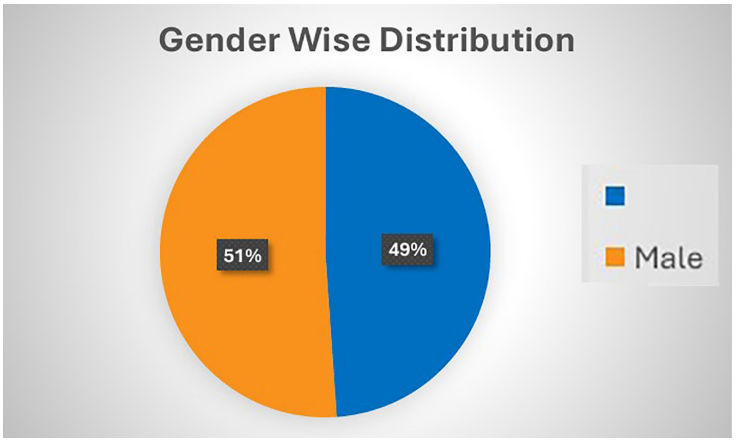
51.00- 60.00	14	31.1	31.1	60.0
61.00- 70.00	13	28.9	28.9	88.9
71.00- 80.00	4	8.9	8.9	97.8
81.00+	1	2.2	2.2	100.0
Total	45	100.0	100.0	

• *Table.3.1.1 Pie-Chart Representation of Age Wise Distribution of Patients With Glaucoma*



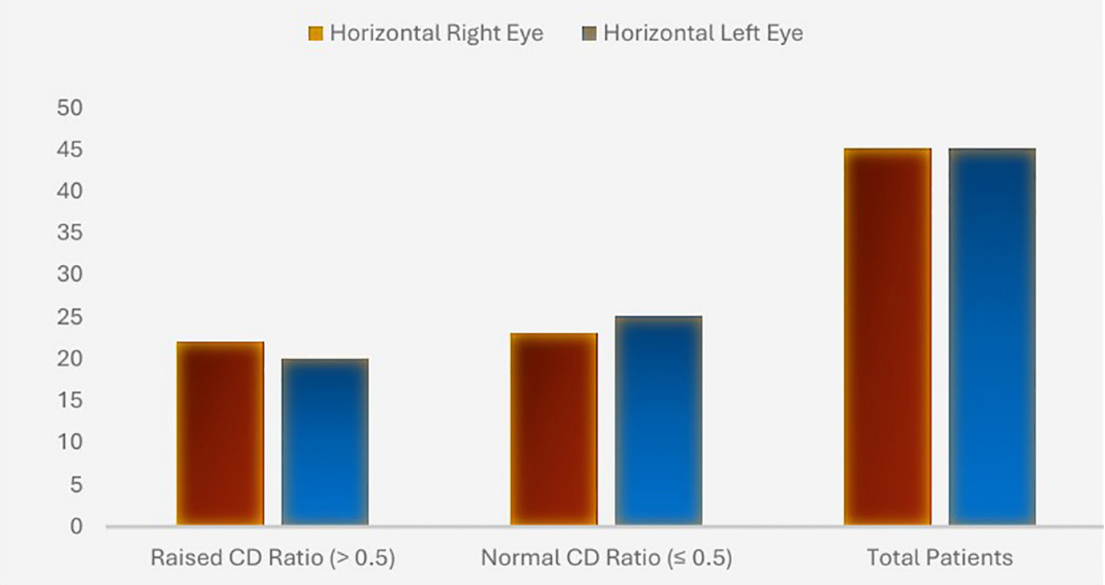
The study included equal proportions of males (48.9%) and females (51.1%), indicating no significant gender predisposition in the prevalence of glaucoma within the sample.

• *Table.3.1.2 Pie-Chart Representation of Gender Wise Distribution of Patients With Glaucoma*

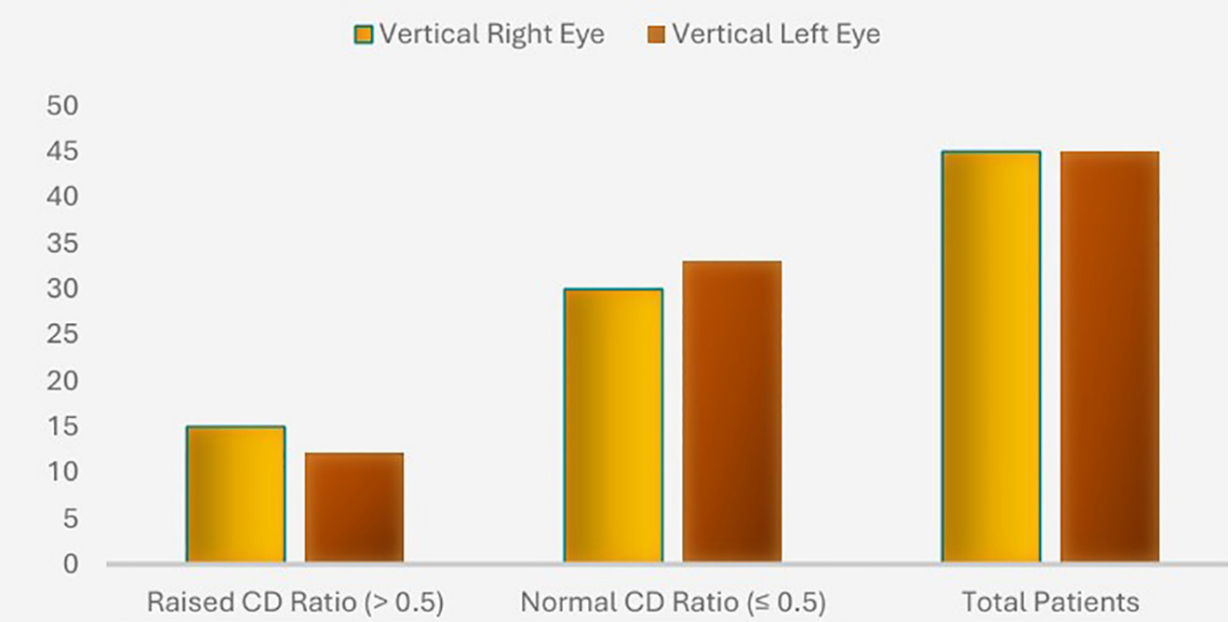


Cup-to-Disc (CD) ratios were also analyzed for both horizontal and vertical measurements. Raised horizontal CD ratios (>0.5) were observed in 48.9% of patients in the right eye and 44.4% in the left eye. The Vertical CD Ratios which were less prevalent and seen in 33.3% of right eyes and 26.7% of left eye.

• *Table 3.1.3 Graphical Representation of Horizontal CD Ratio of Patients with Glaucoma*

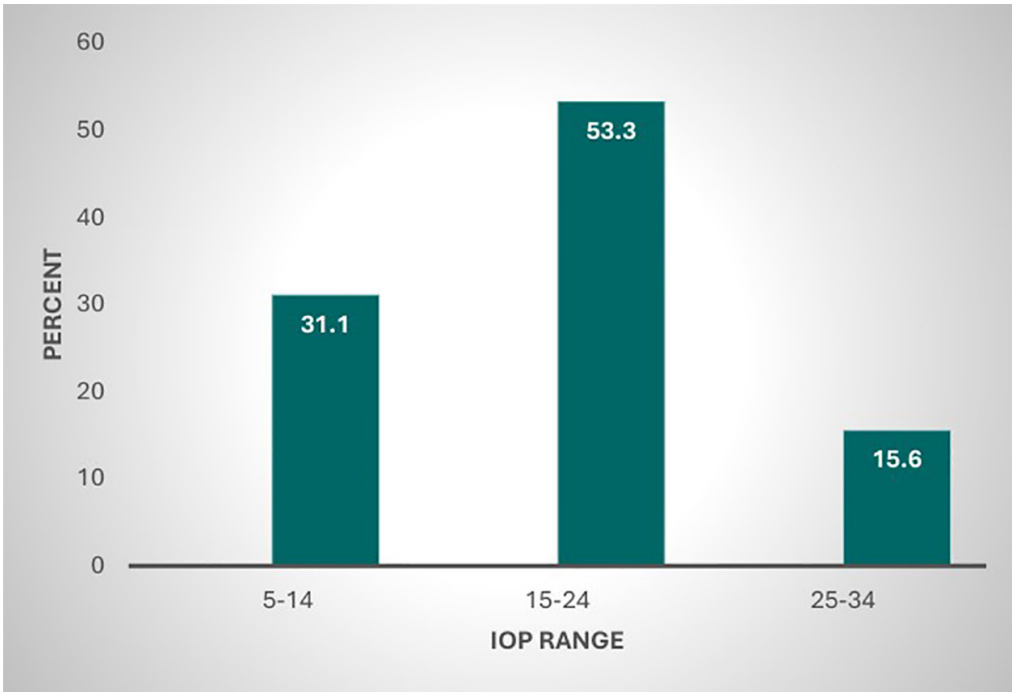


• *Table 3.1.4 Graphical Representation of Vertical CD Ratio of Patients With Glaucoma*

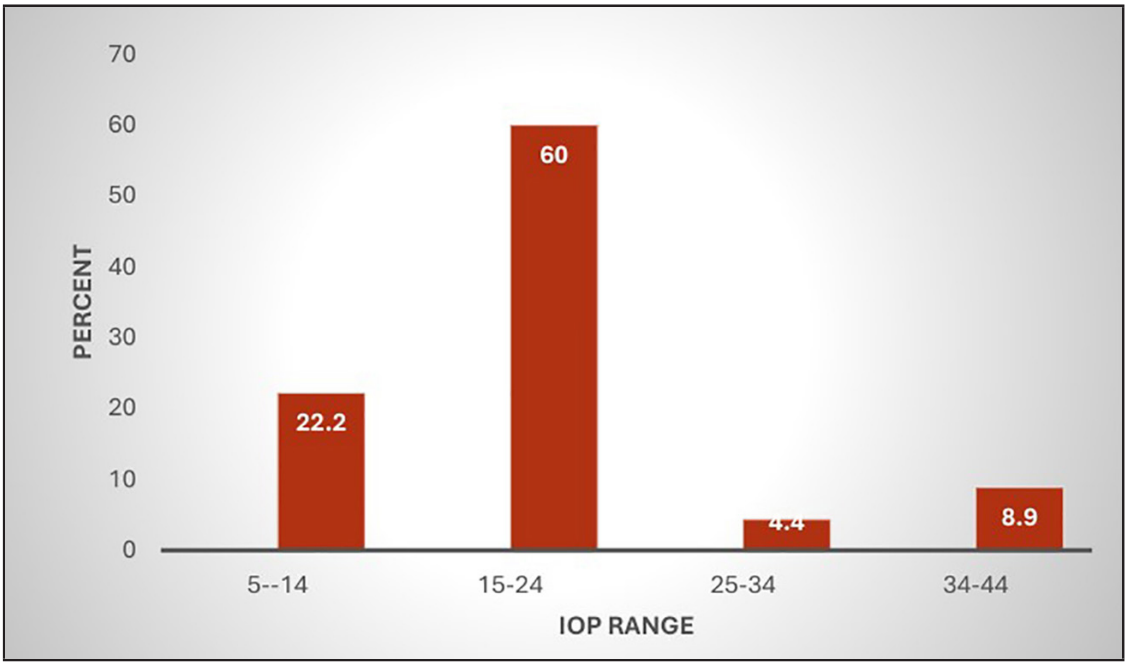


IOP measurements revealed the different distributions across eyes, majority of patients had IOP in the range of 15-24 mmHg. Elevated IOP levels are a critical risk factor for optic nerve damage, which emphasize the role of tonometry in glaucoma management. Elevated IOP levels are seen in the range of 15-24 in the left eye as well.

• *Table 3.1.5 Graphical Representation of Intraocular Pressure of Right Eye of Patients With Glaucoma*



• *Table 3.1.6 Graphical Representation of Intraocular Pressure of Left Eye of Patients With Glaucoma*



RNFL thickness was assessed in four quadrants (superior, inferior, nasal, and temporal). RNFL thinning was detected which was most prominent in the nasal area consistent with glaucomatous degeneration. One sample statistic test was applied and standard deviation of the mean thickness of RNFL values of all four quadrants of both eyes were calculated.

• *Table 3.1.7.1 Table Representation of Retinal Nerve Fiber Layer (RNFL) Thickness of Patients with Glaucoma*

One-Sample Statistics	N	Mean	Std. Deviation	Std. Error Mean
Superior Quadrant	45	88.4111	27.33801	4.07531
Inferior Quadrant	45	84.8000	23.99986	3.57769
Nasal Quadrant	45	56.9889	13.58328	2.02488
Temporal Quadrant	45	78.8667	43.39674	6.46920

The correlation between CD ratio (horizontal and vertical) and RNFL thickness for both eyes was analysed. This research shows that the CD ratio has a negative relationship with the RNFL thickness (Pearson's $r = -0.229$, $p < 0.05$) for both eyes supporting the hypotheses that as the CDR increases, there is a decrease in the RNFL thickness. This is in concordance with glaucomatous progression whereby there is both an increase in optic nerve cupping and thinning of RNFL. Yet, the two parameters were only modestly associated with each other, and no correlation was found between RNFL thickness of the right and the left eye, which suggests that glaucoma affects the eyes asymmetrically. This is shown in the correlation analysis table below:

• *Table 3.1.7.2 Table Representation of Mean Retinal Nerve Fiber Layer (RNFL) Thickness of Patients With Glaucoma*

One-Sample Test. Comparison of Total number of cases in term of quadrants.	Test Value = 45					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Superior Quadrant	10.652	44	.000	43.41111	35.1979	51.6244
Inferior Quadrant	11.125	44	.000	39.80000	32.5896	47.0104
Nasal Quadrant	5.921	44	.000	11.98889	7.9080	16.0698
Temporal Quadrant	5.235	44	.000	33.86667	20.8288	46.9045

Discussion

The findings of this cross-sectional study underscore the utility of optical coherence tomography (OCT) in detecting retinal nerve fiber layer (RNFL) defects in patients with primary open-angle glaucoma (POAG). In our cohort of 45 patients, RNFL thinning was observed in 86.7% of cases, with the nasal quadrant exhibiting the most pronounced thinning (80%), followed by the superior (71.1%), temporal (66.7%), and inferior quadrants (60%). This pattern suggests that early glaucomatous damage may preferentially affect the nasal and superior regions, potentially reflecting the vulnerability of retinal ganglion cell axons in these areas due to mechanical stress or vascular insufficiency. The inferior quadrant's relative resistance to thinning aligns with known anatomical variations in optic nerve head susceptibility, where inferior fibers may be more resilient in early-stage POAG.

Demographic analysis revealed a higher prevalence of glaucoma in the 51-60 age group (predominant), with a notable proportion in the 61-70 range (28.9%), consistent with age-related degeneration of retinal ganglion cells. No significant gender bias was observed (48.9% male, 51.1% female), supporting the notion that POAG risk is not markedly sex-dependent in this population. Clinical parameters further highlighted disease markers: elevated horizontal cup-to-disc (CD) ratios (>0.5) in approximately 45-49% of eyes and vertical ratios in 26-33%, alongside intraocular pressure (IOP) predominantly in the 15-24 mmHg range. These IOP levels, while within a moderate range, emphasize tonometry's role in monitoring, as even controlled pressures can correlate with progressive damage. Statistical evaluation via one-sample t-tests confirmed significant RNFL thinning across quadrants, and Pearson correlation analysis demonstrated a modest negative association between CD ratio and RNFL thickness ($r = -0.229$, $p < 0.05$), indicating that increased optic disc cupping corresponds to RNFL loss. The lack of inter-eye correlation suggests asymmetrical progression, a common feature in POAG that warrants bilateral monitoring.

To contextualize these results, comparisons with existing literature reveal both consistencies and variations. For instance, our quadrant-specific thinning pattern, with nasal predominance, contrasts with findings in a 2024 study on early- and late-stage POAG using the Disc Damage Likelihood Scale and OCT, which reported greater thinning in inferior, superior, and temporal quadrants (35). Their emphasis on inferior vulnerability may reflect more advanced disease stages in their cohort, whereas our mild-to-moderate cases show nasal sensitivity, possibly due to regional differences in Pakistani populations. Similarly, a 2025 investigation evaluating OCT maps for RNFL defect detection found that thickness maps identified defects in 100% of mild glaucoma eyes, with narrow defects (<20°) often missed by deviation or clock-hour maps (36). This aligns with our high detection rate (86.7%) using the NIDEK RS 3000, supporting thickness-based analysis but highlighting potential under-detection of subtle changes in our study.

Further comparison with a 2022 analysis of RNFL thinning rates across glaucomatous optic disc phenotypes demonstrated faster inferior temporal thinning in senile sclerotic phenotypes, with temporal and nasal quadrants least affected overall (38). Our inferior resistance (60% thinning) echoes their nasal sparing but differs in superior involvement, suggesting phenotype-specific variations not stratified in our sample. An earlier 2000 study comparing RNFL thickness in glaucomatous, ocular hypertensive, and normal eyes via OCT reported significant thinning in inferior and nasal quadrants in glaucoma versus controls (39), corroborating our nasal findings but contrasting our lower inferior rates, which may indicate our cohort's earlier disease stage. Finally, a 2019 study on risk factors for progressive RNFL thinning in low-IOP OAG identified disc hemorrhage as a key predictor of faster global loss (40). Although disc hemorrhage was not assessed here, our modest CD-RNFL correlation and asymmetrical progression imply similar non-IOP factors, reinforcing the need for multimodal monitoring beyond pressure control.

These comparisons highlight OCT's sensitivity in early detection, as our results show structural changes preceding severe functional loss. Strengths of this study include its focus on a South Asian population, where glaucoma data are underrepresented, and the use of quadrant-specific analysis for precise defect mapping. However, limitations such as the small sample size (n=45), single-center design, and cross-sectional nature preclude causality inferences or long-term progression tracking. Future research should incorporate longitudinal designs, larger cohorts, and integration with visual field testing to validate these patterns and enhance diagnostic protocols. Overall, our findings affirm OCT as a cornerstone for early POAG intervention, potentially preserving vision through timely management.

Conclusion

This work shows the importance of Optical Coherence Tomography (OCT) in the detection and follow up of primary open-angle glaucoma. OCT that measures the RNFL thickness in all the four quadrants is a non-invasive, reproducible technique that can diagnose early glaucomatous changes. Key findings includes; most common pattern of RNFL thinning was in the nasal region in 80% of the eyes followed by the superior region in 71.1% and the temporal region in 66.7%. The inferior quadrant showed lesser degree of thinning compared to other quadrants; only 60% of the patients in this quadrant showed significant changes. A highly significant negative correlation between the cup-to-disc (CD) ratios and the RNFL thickness was also established, underlining the fact that glaucomatous optic neuropathy is a progressive condition. An important risk factor that was significantly raised among the patients was intraocular pressure (IOP), which was raised in 76% of the patients. In view of these findings, OCT has practical benefit in identifying topographical alterations that are antecedent to conventional visual field loss, thus, is very useful in the early diagnosis, management, and assessment of glaucoma progression.

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