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ASSESSMENT OF MACULAR VOLUME AND RETINAL NERVE FIBER LAYER THICKNESS IN DIFFERENT DEGREES OF MYOPIA

Original Research

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ABSTRACT

Background: Myopia is an increasingly prevalent refractive error and a growing global public health concern, with projections indicating that nearly half of the world's population may be affected by 2050. Progressive myopia, particularly at higher degrees, is associated with structural retinal alterations that increase susceptibility to glaucomatous damage and myopic maculopathy. Among these changes, variations in retinal nerve fiber layer thickness and macular volume are clinically important, as they reflect retinal integrity and may serve as early indicators of disease-related complications.

Objective: To evaluate and compare macular volume and retinal nerve fiber layer thickness across different degrees of myopia.

Methods: A comparative cross-sectional study was conducted at The University of Lahore Teaching Hospital from November 2024 to February 2025. A total of 51 myopic eyes from participants aged 18–45 years were included. Based on refractive error, eyes were categorized into mild, moderate, and high myopia groups, with 17 eyes in each category. Comprehensive ophthalmic evaluation was performed, and retinal nerve fiber layer thickness and macular volume were measured using spectral-domain optical coherence tomography. Data were analyzed using SPSS version 25. One-way analysis of variance was applied to compare group means, followed by Tukey's HSD post hoc test for pairwise comparisons, with statistical significance set at $p < 0.05$.

Results: Mean retinal nerve fiber layer thickness was 95.58 ± 12.19 µm in mild myopia, increased to 100.09 ± 9.61 µm in moderate myopia, and decreased markedly to 77.25 ± 2.75 µm in high myopia, with overall differences reaching statistical significance ($p < 0.001$). Macular volume demonstrated a similar pattern, measuring 8.36 ± 1.55 mm^3 in mild myopia, 8.62 ± 1.55 mm^3 in moderate myopia, and declining significantly to 6.39 ± 0.27 mm^3 in high myopia ($p < 0.05$). The most pronounced reductions in both parameters were observed in the high myopia group.

Conclusion: High myopia was associated with significant thinning of the retinal nerve fiber layer and reduction in macular volume, highlighting the importance of early screening and regular retinal monitoring in myopic individuals to support timely detection of structural vulnerability and prevention of long-term visual impairment.

Keywords: Macular Volume, Myopia, Optical Coherence Tomography, Retinal Nerve Fiber Layer, Retinal Structure, Visual Impairment, Vision Screening.

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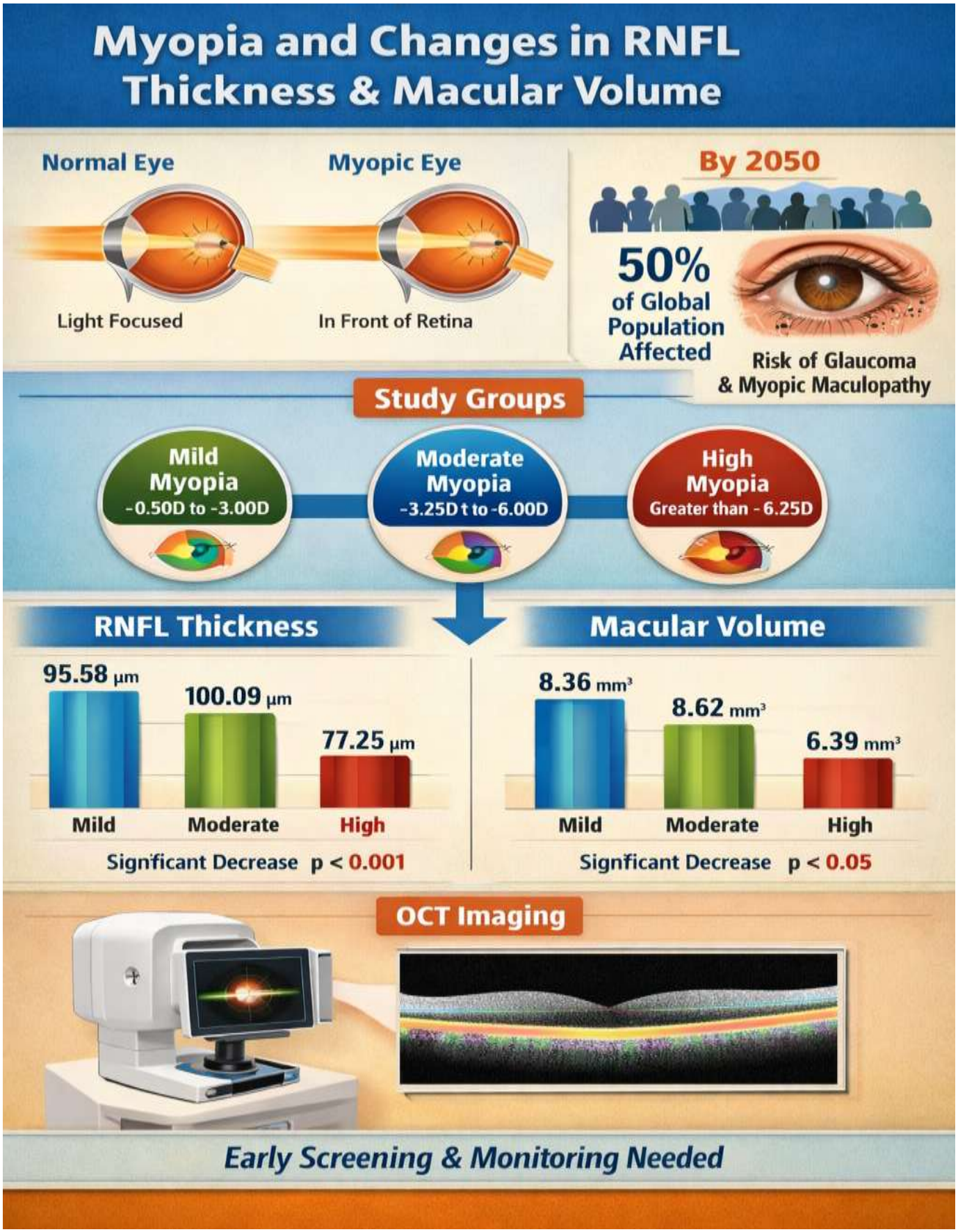

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INTRODUCTION

Myopia, commonly referred to as near-sightedness, is one of the most prevalent refractive errors worldwide and has emerged as a major public health concern due to its rapidly increasing incidence, particularly among children and young adults. Characterized by the focusing of incoming light in front of the retina, myopia results in blurred distance vision and can significantly impair visual function and quality of life. Over recent decades, environmental and lifestyle factors—most notably prolonged educational demands, increased near work, and reduced outdoor exposure—have been strongly implicated in the rising global burden of myopia (1). Anatomically, myopia primarily develops due to excessive axial elongation of the eyeball or alterations in the curvature of the cornea and crystalline lens, leading to structural and functional changes within the eye (2). Of particular clinical importance is pathological myopia, a severe and vision-threatening form of the condition that represents a leading cause of irreversible visual impairment worldwide. Unlike high myopia, pathological myopia is defined by characteristic fundus changes, including posterior staphyloma, myopic maculopathy, chorioretinal atrophy, and choroidal neovascularization, which collectively reflect progressive degeneration of ocular tissues (3,4). These changes are driven by marked thinning of the sclera, atrophy of the choroid, and stretching of the neurosensory retina, resulting in retinal expansion and heightened vulnerability to sight-threatening complications. The distinction between high myopia and pathological myopia is therefore clinically critical, as the latter carries a substantially greater risk of permanent vision loss (5). The global prevalence of myopia continues to rise at an alarming rate, with projections suggesting that nearly half of the world's population may be affected by 2050 (6). This epidemiological shift is accompanied by an earlier age of onset, which in turn increases the lifetime risk of developing high or pathological myopia. As a result, myopia has transitioned from a simple refractive condition to a complex, chronic disease with significant public health implications. Within this context, there is growing interest in identifying reliable biomarkers that can improve early detection, risk stratification, and monitoring of disease progression. Given that the retina is the primary site of structural and functional damage in myopia, retinal imaging has become a central focus of contemporary research (7).

Myopic maculopathy represents one of the most devastating complications of myopia and is a leading cause of legal blindness in both Asian and Western populations (8,9). Progressive axial elongation in myopic eyes leads to mechanical stretching of the retina, a highly specialized, multilayered tissue responsible for visual signal transduction. During myopia development, the retinal pigment epithelium undergoes adaptive yet ultimately maladaptive physiological changes, resulting in cellular dysfunction, impaired metabolic support, and progressive visual decline (10). These retinal alterations underscore the need for detailed structural assessment to better understand disease mechanisms and outcomes. In high and pathological myopia, changes in the retinal microvasculature provide valuable insight into the underlying pathophysiology. Reductions in retinal vessel density, perfusion, and choroidal blood flow have been consistently reported, particularly in eyes with increased axial length, where mechanical stretching compromises vascular integrity (11). Longitudinal assessment of these microvascular changes offers the potential to detect early retinal compromise before irreversible damage occurs. The retinal microvasculature plays a vital role in delivering oxygen and nutrients to retinal cells, and disruptions in this system have been directly linked to declines in visual acuity. Notably, reduced macular flow density has been shown to correlate with poorer visual outcomes, with significant decreases in vessel length density and perfusion density observed in eyes with longer axial lengths, especially in parafoveal and inferior regions (12). Structural changes in macular thickness further reflect the complex biomechanical effects of axial elongation. While central macular thickness may increase due to scleral traction and centripetal forces exerted by the internal limiting membrane and posterior vitreous, peripheral macular regions tend to thin as axial length increases (13). In early stages of myopia, this imbalance may contribute to vitreomacular traction, whereas progressive disease is associated with thinning of the ganglion cell layer and inner plexiform layer, alongside reductions in retinal perfusion that impose metabolic stress on retinal tissue (14,15). Importantly, increasing axial length and refractive error have been strongly associated with higher risks of retinal detachment and myopic macular degeneration, which occurs far more frequently in myopic individuals than in those with emmetropic eyes and often results in irreversible vision loss (8).

Myopic maculopathy encompasses a spectrum of pathological entities, including myopic atrophic maculopathy, chorioretinal atrophy, myopic choroidal neovascularization, and dome-shaped macula. Although dome-shaped macula is considered a hallmark of pathological myopia, inconsistencies remain in the literature regarding macular thickness changes and their relationship with visual acuity, highlighting ongoing uncertainty in disease characterization (9,10). Advances in imaging modalities, particularly spectral-domain optical coherence tomography, have enabled more precise evaluation of subtle macular changes in myopic eyes. However, measurement variability related to refractive error and axial length persists, as increasing axial length is associated with reductions in macular volume and average thickness alongside paradoxical increases in central foveal thickness (11,12). Concurrently, choroidal thinning—most pronounced at the posterior pole—has been closely linked to axial elongation, reinforcing the importance of comprehensive posterior

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segment assessment (13). Beyond the macula, myopia induces notable changes in the optic nerve head and peripapillary region, including disc tilt, ovalization, and expansion of peripapillary atrophy, which complicate structural assessment and may obscure early glaucomatous damage. Emerging imaging techniques such as swept-source OCT and OCT angiography have demonstrated improved sensitivity in detecting these alterations, revealing reduced macular vascular density without significant changes in the foveal avascular zone or outer retinal layers (12,16). Progressive thinning of the retinal nerve fiber layer, which correlates with axial length and refractive error, further complicates the differentiation between myopic and glaucomatous damage, particularly given the accelerated RNFL loss observed in myopic eyes (8,9,12). OCT angiography has shown promise in overcoming some of these limitations by enabling noninvasive, high-resolution assessment of retinal blood flow, even in eyes with marked axial elongation (15). Despite substantial advances in imaging and epidemiological understanding, important gaps remain in fully elucidating the relationship between axial elongation, retinal microvascular alterations, and structural retinal changes across the spectrum of myopia. Clarifying these associations is essential for improving early diagnosis, distinguishing pathological changes from benign myopic variations, and guiding timely intervention. Therefore, the objective of the present study is to systematically evaluate retinal structural and microvascular changes in myopic eyes, with particular emphasis on their relationship to axial length and disease severity, in order to enhance understanding of myopia progression and support strategies for early detection and vision preservation.

METHODS

This cross-sectional comparative study was conducted at The University of Lahore Teaching Hospital, Lahore, over a three-month period from November 2024 to January 2025. The study was designed to evaluate variations in macular volume and retinal nerve fiber layer (RNFL) thickness across different degrees of myopia. A total of 51 participants were enrolled, with the sample size calculated using OpenEpi software based on a 95% confidence level and predefined statistical assumptions to ensure adequate precision and feasibility for exploratory analysis. Participants were recruited using non-probability convenience sampling. Eligible individuals included adults aged 18 to 45 years of either gender who were clinically diagnosed with myopia, categorized as mild, moderate, or high based on refractive error. All participants were required to provide written informed consent prior to inclusion. Exclusion criteria were applied to minimize confounding and included emmetropic and hyperopic individuals, astigmatism greater than 0.50 diopters sphere, presence of any ocular pathology, history of ocular surgery, known systemic diseases with potential ocular involvement, and inability or unwillingness to cooperate during examinations. These criteria were implemented to maintain a relatively homogeneous sample focused on uncomplicated myopia. Comprehensive ophthalmic evaluation was performed using standardized instruments and protocols. Visual acuity was assessed using a Snellen chart, followed by objective refraction with an auto-refractometer and subjective refinement using a trial lens set to determine the degree of myopia. Anterior and posterior segment examinations were carried out using a slit lamp biomicroscope and ophthalmoscope, respectively. Pupillary dilation was achieved with topical Tropicamide and Phenylephrine (1%) to allow detailed retinal assessment. Optical coherence tomography was performed using the Optopol FC REVO OCT system to obtain high-resolution measurements of macular volume and RNFL thickness. All OCT scans were acquired by trained personnel following manufacturer-recommended acquisition protocols to reduce operator-related variability.

Demographic information and clinical findings were recorded on a self-designed proforma developed specifically for this study. Ethical approval was obtained from the institutional ethical review committee of The University of Lahore Teaching Hospital prior to data collection. The study procedures, objectives, and potential risks were clearly explained to all participants, and written informed consent was obtained in accordance with the principles of the Declaration of Helsinki. Collected data were entered into Microsoft Excel and cross-checked for completeness and accuracy before analysis. Descriptive statistics were planned to summarize demographic and clinical variables, while comparative analyses were intended to explore differences in macular volume and RNFL thickness across myopia severity groups using appropriate statistical tests, with significance set at a conventional threshold. Overall, the methodology was structured to generate reliable and clinically relevant data on structural retinal changes associated with myopia, while adhering to ethical standards and standardized ophthalmic assessment practices.

RESULTS

A total of 51 myopic eyes from 51 participants were evaluated, including 26 males and 25 females, to assess variations in macular volume and retinal nerve fiber layer (RNFL) thickness across different degrees of myopia. The study population was evenly distributed across mild, moderate, and high myopia categories, with 17 eyes in each group. The findings demonstrated measurable and statistically

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significant structural retinal changes with increasing myopia severity. RNFL thickness showed a non-linear pattern across myopia categories. In mild myopia (−0.50 Ds to −3.00 Ds), the mean RNFL thickness was 95.58 µm with a standard deviation of ± 12.19. A slight increase was observed in moderate myopia (−3.00 Ds to −6.00 Ds), where the mean RNFL thickness reached 100.09 µm ± 9.61. In contrast, a pronounced reduction was noted in high myopia (> −6.00 Ds), with a mean RNFL thickness of 77.25 µm ± 2.75. When all participants were considered collectively, the overall mean RNFL thickness was 95.64 µm ± 12.24. Post hoc comparisons using Tukey's HSD test demonstrated that RNFL thickness in high myopia was significantly lower than in mild myopia, with a mean difference of −18.33 µm ($p = 0.008$), and significantly lower than in moderate myopia, with a mean difference of −22.84 µm ($p = 0.001$). No statistically significant difference was observed between mild and moderate myopia ($p = 0.375$). Macular volume also varied significantly with the degree of myopia. Eyes with mild myopia demonstrated a mean macular volume of 8.36 mm^3 ± 1.55, while those with moderate myopia showed a slightly higher mean value of 8.62 mm^3 ± 1.22. In high myopia, macular volume declined markedly to a mean of 6.39 mm^3 ± 0.266. The combined mean macular volume for all participants was 8.29 mm^3 ± 1.48. Tukey's HSD post hoc analysis revealed that macular volume in high myopia was significantly lower than in mild myopia, with a mean difference of −2.12 mm^3 ($p = 0.021$), and significantly lower than in moderate myopia, with a mean difference of −2.34 mm^3 ($p = 0.015$). No significant difference was detected between mild and moderate myopia ($p = 0.532$), indicating that substantial macular volume reduction primarily occurred at higher levels of myopia. Overall, the results demonstrated a clear association between increasing myopia severity and reductions in both RNFL thickness and macular volume, with the most pronounced structural changes observed in high myopia.

Table 1: Descriptive Statistics of Rnfl Thickness in Different Degrees of Myopia Using One-Way Anova Test

Degree Of Myopia	Number OF Eyes	Mean	Std. Deviation
Mild Degree of Myopia (-0.50Ds to -3.00Ds)	17	95.58µm	± 12.19
Moderate Degree of Myopia (-3.00Ds TO -6.00Ds)	17	100.09µm	± 9.61
High Degree of Myopia (Greater than -6.00Ds)	17	77.25µm	± 2.75
Total	51	95.64µm	± 12.24

Table 2: Multiple Comparison of Rnfl Thickness in Different Degree of Myopia Using Tukey Hsd Test

Degree Of Myopia	Comparison with other Degrees of Myopia	Mean Difference	Level of Sig.
Mild Degree of Myopia (-0.50Ds to -3.00Ds)	Moderate Myopia	-4.512451µm	.375
	High Myopia	-18.331667*µm	.008
Moderate Degree of Myopia (-3.00Ds TO -6.00Ds)	Mild Myopia	4.512451µm	.375
	High Myopia	-22.844118*µm	.001
High Degree of Myopia (Greater than -6.00Ds)	Mild Myopia	-18.331667*µm	.008
	Moderate Myopia	-22.844118*µm	.001

* Indicating the mean difference is significant at the 0.05 level.

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Table 3: Descriptive Statistics of Macular Volume in Different Degree of Myopia

Degree Of Myopia	Number of Eyes	Mean	Std. Deviation
Mild Degree of Myopia (-0.50Ds to -3.00Ds)	17	8.36 mm3	± 1.55
Moderate Degree of Myopia (-3.00Ds TO -6.00Ds)	17	8.62 mm3	± 1.22
High Degree of Myopia (Greater than -6.00Ds)	17	6.39 mm3	± 0.266
Total	51	8.29 mm3	± 1.48

Table 4: Multiple Comparison of Macular Volume in Different Degree of Myopia Using Tucky Hsd Test

Degree Of Myopia	Comparison with other Degrees of Myopia	Mean Difference	Level of Sig.
Mild Degree of Myopia (-0.50Ds to -3.00Ds)	Moderate Myopia	-0.29mm3	0.532
	High Myopia	-0.308*mm3	0.021
Moderate Degree of Myopia (-3.00Ds TO -6.00Ds)	Mild Myopia	0.29mm3	0.532
	High Myopia	+2.43* mm3	0.015
High Degree of Myopia (Greater than -6.00Ds)	Mild Myopia	-2.12* mm3	0.021
	Moderate Myopia	-2.34* mm3	0.015

* Indicating the mean difference is significant at the 0.05 level.

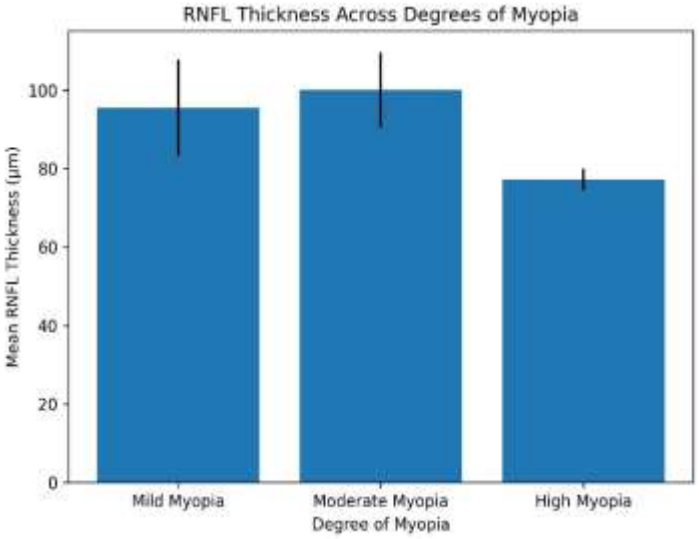

Figure 2 RNFL Thickness Across Degrees of Myopia

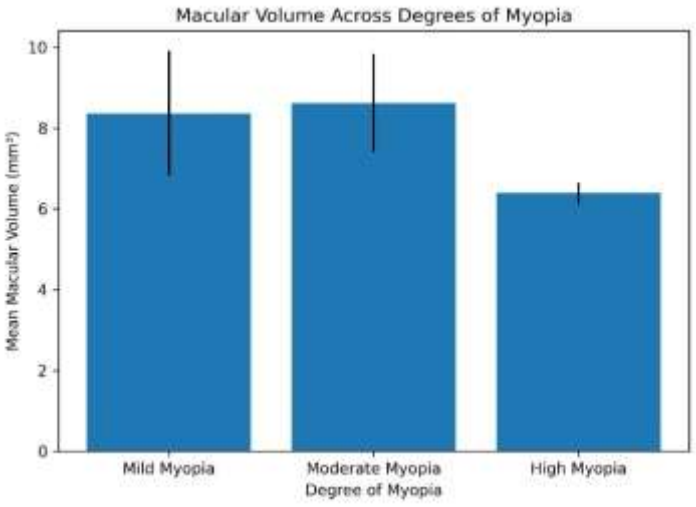

Figure 2 Macular Volume Across Degrees of Myopia

DISCUSSION

The present study demonstrated that increasing severity of myopia was associated with progressive structural changes in the retina, particularly reflected by a marked reduction in retinal nerve fiber layer thickness and macular volume in eyes with high myopia. While mild and moderate myopia showed relatively preserved or slightly fluctuating measurements, a distinct threshold effect was observed at higher degrees of myopia, where both parameters declined substantially. These findings support the concept that high myopia is not

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merely a refractive condition but a structural disorder with clinically relevant implications for early glaucomatous damage. Comparable trends have been reported in recent regional and international studies, where RNFL thickness remained relatively stable or mildly increased in moderate myopia but showed a significant reduction in high myopia. In those studies, RNFL thickness values in high myopia closely approximated the measurements observed in the present cohort, reinforcing the consistency of RNFL thinning as myopia progresses. Similarly, macular volume demonstrated a stepwise decline with increasing refractive error, with the most pronounced reduction occurring in high myopia (17). The convergence of findings across different populations and imaging platforms suggests that these structural alterations represent a reproducible biological response to axial elongation rather than measurement variability. The observed non-linear pattern, particularly the relatively higher RNFL thickness in moderate myopia compared with mild myopia, may reflect compensatory or redistribution effects related to ocular magnification, retinal stretching, or scan circle displacement in elongated eyes (18,19). This phenomenon has been highlighted in earlier research emphasizing that axial length and ocular magnification significantly influence OCT-derived measurements. Failure to adjust for these factors may lead to overestimation of RNFL thickness in moderate myopia and underestimation in high myopia, underscoring the need for careful interpretation when screening myopic patients for early primary open-angle glaucoma (20,21).

The reduction in macular volume observed in high myopia is clinically relevant, as macular parameters reflect ganglion cell integrity and may serve as complementary markers for early glaucomatous damage. Previous glaucoma-focused studies have demonstrated that loss of macular tissue parallels RNFL thinning and correlates with functional visual field loss. The present findings align with this concept by showing that eyes with higher myopia, which are already structurally vulnerable, exhibit significant macular volume reduction that may predispose them to earlier or more aggressive glaucomatous changes (22). This reinforces the potential role of macular assessment alongside RNFL evaluation in improving early detection strategies for glaucoma in myopic populations. One of the strengths of this study was the direct comparison of RNFL thickness and macular volume across clearly defined myopia severity groups using standardized OCT measurements. The balanced distribution of participants across myopia categories allowed for meaningful comparative analysis, and the use of post hoc testing strengthened the validity of observed intergroup differences. Additionally, focusing on both RNFL and macular parameters provided a more comprehensive structural assessment than reliance on a single metric. However, several limitations warrant consideration. The cross-sectional design precluded assessment of longitudinal changes, limiting the ability to infer causality or progression over time. The relatively small sample size and single-center setting may restrict generalizability to broader populations. Axial length measurements and ocular magnification correction were not incorporated into the analysis, which may have influenced OCT measurements, particularly in moderate and high myopia. Furthermore, functional assessments such as visual field testing were not included, preventing direct correlation between structural changes and functional outcomes. Future research would benefit from longitudinal, multicenter studies with larger sample sizes and inclusion of axial length-adjusted OCT measurements. Integrating functional parameters, such as standard automated perimetry, alongside structural metrics could further clarify the clinical significance of RNFL and macular changes in myopic eyes (23). Exploration of quadrant-wise RNFL analysis and ganglion cell complex measurements may also enhance early detection of glaucomatous damage in this high-risk group. Collectively, such refinements could improve screening accuracy and guide more individualized monitoring strategies for patients with moderate to high myopia.

CONCLUSION

This study concluded that increasing severity of myopia is associated with progressive structural alterations in the retina, reflected by a consistent reduction in retinal nerve fiber layer thickness and macular volume, with the most pronounced changes observed in high myopia. These findings underscore the importance of considering myopia severity when interpreting retinal imaging, as highly myopic eyes appear to be more vulnerable to structural damage that may predispose them to early glaucomatous changes. From a clinical perspective, routine assessment of RNFL and macular parameters in myopic patients can enhance early risk identification and support timely monitoring strategies, thereby contributing to improved preservation of visual function and more informed clinical decision-making.

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AUTHOR CONTRIBUTIONS

Author	Contribution
Shah Fahad	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Hamna Quddoos Sadiq	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Maryam Hameed	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Faiza Akhtar	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Hafsa Majeed	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Usama Elahi*	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published

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