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EVALUATION OF CHOROIDAL AND MACULAR THICKNESS ASSESSED BY ENHANCED DEPTH IMAGING SD-OCT IN THE NATURAL PROGRESSION OF MYOPIC PATIENTS.

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Abstract

Background
Myopia is associated with structural changes in the retina and choroid, which can be assessed using enhanced depth imaging spectral-domain optical coherence tomography (SD-OCT). This study aimed to evaluate the changes in choroidal and macular thickness among patients with varying degrees of myopia.

Methods
A cross-sectional observational study was conducted at Pradyumna Bal Memorial Hospital, Kalinga Institute of Medical Sciences (KIMS), KIIT University, Bhubaneswar, India. A total of 74 participants (148 eyes) with myopia were recruited. Participants underwent SD-OCT imaging, and measurements of macular and choroidal thickness were taken. Data were analyzed based on age, gender, and degree of myopia.

Results
There was a significant reduction in retinal and choroidal thickness with increasing age ($p < 0.05$). High myopia (> -9 diopters) showed significantly thinner retinal and choroidal layers compared to low and moderate myopia groups ($p < 0.01$). Male participants had slightly higher thickness measurements compared to females, but the difference was not statistically significant.

Conclusion
Progression of myopia is associated with thinning of retinal and choroidal structures, particularly in patients with high myopia.

Recommendation
Regular SD-OCT monitoring is recommended in myopic patients for early detection of structural changes and timely intervention.

Keywords: *Myopia, Choroidal Thickness, Macular Thickness, Spectral-Domain OCT, Enhanced Depth Imaging.*
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Introduction
Myopia, a condition known to humanity since 350 BC, is projected to affect nearly half of the global population by 2050, with 10% classified as highly myopic.1 Myopia, commonly referred to as near-sightedness, is the most prevalent cause of treatable visual impairment among both adults and children in developed nations. It is also a leading cause of preventable blindness in developing countries.2 Approximately one in six individuals worldwide is myopic. Alarmingly, the global prevalence of myopia and its complications is expected to rise significantly by 2050.3

Studies indicate that Asian children, particularly those of Chinese descent, are more susceptible to myopia. In India, one of the earliest epidemiological surveys on myopia revealed a higher prevalence in schoolchildren (4.79%), with urban areas (6.9%) showing significantly higher rates than rural regions (2.77%)4. Recent population-based studies suggest that the prevalence of myopia of at least -0.5 D in India is 27.7%, making it the most common refractive error in children aged 5–10 years.5 Similarly, another study states Myopia to be the most common refractive error, with a prevalence of 54.5%.6

The World Health Organization's (WHO) International Classification of Diseases (ICD-11) defines myopia (under code 9D00.0) as "a refractive error in which rays of light entering the eye parallel to the optic axis are focused in front of the retina when accommodation is

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relaxed. This occurs due to an overly curved cornea or an elongated eyeball.".7

Based on this definition, myopia can be categorized into two types:

1. Axial Myopia: Caused by excessive axial elongation of the eyeball. 2. Refractive Myopia: Caused by structural changes in or misplacement of image-forming structures, such as the cornea or lens.

Research involving clinical trials and animal models suggests that axial elongation is the primary driver of myopia progression. Studies comparing interventions to reduce myopic progression demonstrate a direct relationship between the impact of an intervention on refraction and axial length.8

The pathophysiology of myopia primarily involves structural axial elongation, reduced choroidal blood flow, and retinal blur. 9 These changes, influenced by genetic predisposition and environmental factors such as higher education and near work, result in scleral remodeling and retinal thinning. Hypoxia further exacerbates scleral remodeling, perpetuating the cycle.10

The choroid, being the most vascular tissue in the eye, plays an important role in the pathophysiology of various ocular diseases, including high myopia-related chorioretinopathies, as it provides nutrition and oxygen to outer retinal layers and is the only source of metabolic exchange of the fovea.11-12

Marked choroidal thinning is commonly observed in individuals with high myopia and longer axial lengths, but changes have been noted in all severities of myopia. 13 Early detection of such changes is essential for preventing associated complications and preserving vision.

Quantitative assessment of the choroid has been very challenging with traditionally available imaging modalities such as Indocyanine Green Angiography and Ultrasonography. This is due to limited resolution and limited cross-sectional information on these modalities.14 Optical Coherence Tomography (OCT) is a newly available diagnostic imaging technique that produces cross-sectional images of the eye. With recent advances in Enhanced Depth Imaging Spectral Domain (EDI-SD) OCT, the understanding of choroidal anatomy and choroid-scleral interface has significantly improved. It correlates well with the histopathological findings of choroidal thinning in myopes. 15 is also capable of detecting various pathological changes in myopic chorioretinopathy such as retinoschisis, tractional internal limiting membrane detachment, perivascular inner retinal cysts and lamellar holes, choroidal neovascular membranes, posterior retinal detachment, peripapillary intrathyroidal cavitation, macular holes and posterior staphylomas16; which would require further treatment to preserve sight by various modalities like intravitreal steroids, Laser PHC, vitreoretinal surgeries etc.

Since the earliest changes in myopic eyes begin in the choroid, EDI-OCT enables early detection of choroidal thinning. This is crucial for understanding the pathogenesis of high myopia and developing timely interventions.17 Routine EDI-OCT examination to document retinal and choroidal thickness can aid in formulating strategies to prevent myopic visual impairments.

Aim:

To determine the mean retinal and choroidal thickness measurements at the macula in the myopic population.

Objectives:

1. Measure the retinal and choroidal thickness at the macula using EDI-SD OCT across different degrees of myopia.
2. Evaluate the changes in retinal and choroidal thickness with myopia progression over time.
3. Correlate retinal and choroidal thickness with spherical equivalents.
4. Compare findings with the normal population and assess the influence of age and sex on the parameters in the myopic individual

Methodology:

Study Design:

Cross-sectional observational study.

Study Location:

The study was conducted at Pradyumna Bal Memorial Hospital, Kalinga Institute of Medical Sciences (KIMS), KIIT University, Bhubaneswar, a tertiary care teaching hospital with a dedicated ophthalmology department equipped with advanced imaging facilities.

Study Duration:

September 2018 to March 2020.

Ethical consideration:

The Institutional Ethics Committee of Kalinga Institute of Medical Sciences, KIIT University, Bhubaneswar-24 approved the study. Ref no: KIMS/KIIT/IEC/139/2018.

Participants:

74 participants (148 eyes) were diagnosed with varying degrees of myopia.

Inclusion Criteria:

1. Patients aged 15 to 40 years diagnosed with myopia presenting to the outpatient department (OPD).

Exclusion Criteria:

1. Cases with hazy ocular media (e.g., cataract, corneal opacity).
2. Cases of chronic systemic diseases with ocular involvement (e.g., diabetes, hypertension, chronic kidney disease).
3. Cases with ocular diseases affecting the choroid and macula, other than myopia (e.g., glaucoma, central retinal artery occlusion).
4. History of prior ocular surgery or trauma.

Study Procedure:

Approval for the study was obtained from the Institutional Ethics Committee. A total of 148 eyes from 74 subjects were included. The demographic details of the participants were recorded as per a predefined proforma. Participants provided informed written consent and underwent a comprehensive ocular examination, which included:

1. Visual acuity assessment (Snellen's chart). .2. Refractive error assessment (manual retinoscopy and auto-refractometry)3. Best-corrected visual acuity (subjective refraction).4. Anterior segment examination with a torchlight and slit lamp biomicroscopy.5. Intraocular pressure measurement (applanation tonometry).6. Fundus examination using direct and indirect ophthalmoscopy after pupil dilation with 0.8% tropicamide and 5% phenylephrine or 1% cyclopentolate. Subjects also underwent Enhanced Depth Imaging Optical Coherence Tomography (EDI-OCT) using a Cirrus™ HD-OCT (Model 500-22681, Version 9.0.0.281, Carl Zeiss Meditec) for choroidal and retinal imaging.

OCT Scanning and Measurement:

The HD 5-line raster scan with Enhanced Depth Imaging was used, with a 6 mm scan length (3 mm × 3 mm), centered at the fovea. Scans with signal strength ≥5/10, showing clear visualization of the chorizo-scleral interface, were used for thickness measurements.

Retinal thickness was measured from the inner limiting membrane (ILM) to the outer border of the retinal pigment epithelium (RPE).

Choroidal thickness was measured from the RPE to the inner scleral margin at the chorio-scleral interface.

Measurements were recorded at five points: central/subfoveal and 3 mm nasally, temporally, superiorly, and inferiorly, as per the Early Treatment Diabetic Retinopathy Study (ETDRS) guidelines. Central and parafoveal zones were measured, focusing on the fovea due to its critical role in vision.

Central thickness was defined as the average value of thickness calculated at **an I mm distance** from the center point in all four quadrants.

Parafoveal/Paracentral thickness was defined as the average value of thickness calculated at **a 3 mm distance** from the center point in all four quadrants.

The **center point thickness** was defined as the vertical distance at the foveola in the horizontal scan.

To minimize diurnal variation in choroidal thickness, all measurements were performed between 9 a.m. and 12 p.m. Scans were conducted by a single trained individual to avoid inter-observer variation.

Bias Handling:

Selection bias was minimized by recruiting consecutive eligible patients. Measurement bias was minimized by using the same SD-OCT device and protocol for all participants.

Statistical Analysis:

Participants were categorized into three groups based on their degree of myopia:1) Low Myopia: < -3.00 D.2), Moderate Myopia: > -3.00 D to -6.00 D.3), High Myopia: > -6.00 D or an axial length >26.5 mm (subdivided into High 1 [> -6.00 to -9.00 D] and High 2 [> -9.00 D]). Data were coded and analysed using SPSS v23 (IBM Corp.). Descriptive statistics included means/standard deviations and medians/interquartile ranges for continuous variables, while frequencies and percentages were used for categorical variables. Data visualizations utilized histograms, bar charts, and pie charts as appropriate. Comparisons were conducted using:

1. Independent sample t-tests for normally distributed continuous data. 2. Wilcoxon tests for non-normally distributed continuous data. 3. Chi-squared or Fisher's exact tests for categorical data, as appropriate 4. Pearson's or Spearman's correlation for relationships between continuous variables.

Statistical significance was defined as $p < 0.05$.

Observations and Results:

The study included 148 eyes of 74 participants, grouped as follows:

Based on Gender:

1. Males: 40 (54%).
2. Females: 34 (46%).

Mean age: 28.5±8.2 years.

Based on Age:

1. 15–23 years: 54 participants (47.4%).
2. 24–32 years: 42 participants (36.8%).
3. 33–40 years: 18 participants (15.8%).
1. Age and Gender Influence:
2. No significant gender-based difference ($p = 0.08$).

Based on the Severity of Myopia

1. Mild Myopia (0–3 D): 16.7%. 2. Moderate Myopia (> -3 to -6 D): 46.5%. 3. High Myopia (> -6 D): 36.8%, further subdivided into:

High 1 Myopia (> -6 to -9 D): 24.6%.

High 2 Myopia (> -9 D): 12.3%.

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Thickness	0-3D		>3-6D		>6-9D		>9D	
	Baseline	Follow up	Baseline	Follow up	Baseline	Follow up	Baseline	Follow up
Mean retinal thickness	282.69±40.22	281.19±39.54	292.85±13.43	289.41±14.61	271.33±24.54	279.70±20.56	270.56±21.71	268.56±19.78
Mean choroidal thickness	246.75±49.19	244.95±53.21	265.03±48.48	245.67±50.18	258.96±46.72	230.48±38.45	239.56±50.40	186.19±44.86

Table 1: Mean retinal and choroidal thickness of myopic subgroups in microns.

Table 2: Mean change of retinal and choroidal thickness across myopic subgroups in microns.

	0-3D	>3-6D	>6-9D	>9D	P value
Change in Mean Retinal Thickness	-1.50±15.74	-3.44±13.28	8.37±23.41	-2.00±22.77	0.068
Change in Mean Choroidal thickness	-1.80±23.50	-19.36±24.24	-28.48±27.76	-53.37±55.62	0.002

Table 3: Comparison of retinal thickness (in µm) with the normal Indian database.

Thickness	Current study 2018-2020	Appukutan etal, 2014(n=105), South India	Agarwal etal,2014(n=308), Central India	Natung etal,2016 (n=400), North East India
	SD-OCT-Cirrus-Carl Zeiss	SD-OCT-Spectralis-Heidelberg	SD-OCT-TOPCON	SD-OCT- Cirrus-Carl Zeiss
Mean Centre point retinal thickness	223.90±45.75	220.96±13.76	_____	_____
Mean central foveal retinal thickness	300.73±26.47	260.10±18.19	241.75±17.30	240.40±18.26
Mean paracentral/parafoveal retinal thickness	261.14±27.54	334.31±16.89	_____	_____
Nasal	281.74±38.60	338.88±18.17	306.70±10.46	316.98±19.16
Temporal	241.92±34.32	324.90±16.35	298.75±5.64	303.38±16.24
Superior	267.25±30.56	337.95±17.46	303.34±12.14	317.16±17.84
Inferior	253.68±29.67	335.53±17.87	296.90±10.79	313.47±19.14
Mean Retinal thickness	283.13±25.24	_____	279.42±7.17	287.87±18.07

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Table 4: Comparison of choroidal thickness (in microns) with the normal Indian database.

Thickness	Present study	Chabbalanietal (n=211)	Bhayana et al (n=238)
	SD-OCT	SD-OCT	SS-OCT
Mean Centre point choroidal thickness	271.90±78.19	———	———
Mean central foveal choroidal thickness	270.86±56.59	294.8±46.5	299.10±131.2
Mean paracentral/parafoveal choroidal thickness	240.49±44.74	———	———
Nasal	222.00±56.87	211.0±57.3	282.69±131.90
Temporal	234.05±66.49	194.6±40.4	294.40±123.18
Superior	262.71±87.65	———	305.33±130.78
Inferior	243.21±68.21	———	298.47±140.92
Mean choroidal thickness	257.36±48.65	280.1±46.5	———

Table 5: Comparison of retinal thickness (in microns) with the myopic Indian database

Thickness	Current study	Raja etal, 2018(n=260)	Evangeline Rao etal, 2019(n=100)
	SD-OCT-Cirrus-Carl Zeiss	———	SD-OCT Cirrus-Carl Zeiss
Mean centre point thickness	223.90±45.75	———	———
Mean central foveal retinal thickness	300.73±26.47	248.51±22.9	227.41±35.61
Mean paracentral/parafoveal choroidal thickness.	261.14±27.54	308.83±11.3	———
Nasal	281.74±38.60	305.96±29.7	299.50±28.03
Temporal	241.92±34.32	291.90±21.2	286.89±24.61
Superior	267.25±30.56	305.73±23.8	298.03±24.17
Inferior	253.68±29.67	301.92±25.8	294.63±25.90
Mean retinal thickness	283.13±25.24	284.34±14.7	———

Key Observations in this study:

Retinal Thickness:

1. Retinal thickness decreased across all macular regions with increasing myopia.
2. Maximum retinal thickness was noted at the central foveal field, with the center point being the thinnest.
3. Quadrant-wise analysis revealed the following order of retinal thickness: nasal > superior > inferior > temporal.

Choroidal Thickness:

1. The thickest choroidal measurements were found at the central subfoveal point, with thinning observed in parafoveal zones, particularly in the nasal quadrant.
2. Choroidal thickness decreased with higher degrees of myopia.
1. Spherical Equivalent Correlation
1. Retinal thickness negatively correlated with spherical equivalents, meaning greater refractive error was associated with thinner retinal measurements.
2. Choroidal thickness also showed a negative correlation with spherical equivalents.

Age and Gender Influence:

1. Significant thinning of retinal and choroidal thickness was observed with increasing age ($p = 0.004$).
2. Retinal thickness was highest in participants aged 24–32 years, while choroidal thickness was highest in participants aged 15–23 years.
3. No significant gender-based difference ($p = 0.08$).

High Myopia Findings:

1. In participants with High 2 myopia (> -9 D), significant thinning was noted in both retinal and choroidal layers, emphasizing the role of axial elongation in structural changes.
2. In patients with high myopia (> -9 D), mean choroidal thickness was significantly lower ($p =$

0.001) compared to the low and moderate myopia groups.
3. Nasal thinning of the choroid was associated with pathological changes such as peripapillary atrophy and posterior staphylomas.

Subgroup Changes Over Time:

1. Moderate to high myopia in participants aged 15–23 years showed the most significant changes in retinal and choroidal thickness during the study period.
2. Axial elongation progression reduced with increasing age, showing a deceleration in older age groups.

Discussion:

Macular retinal and choroidal thickness, as measured by OCT, are critical parameters in assessing myopic chorioretinopathy. Vision, being one of humanity's most valued faculties, is centered physiologically at the fovea, which becomes the focal point of this study. Hence, the discussion is thus primarily limited to the foveal and parafoveal regions. In this study, the average retinal thickness decreased across all macular regions with increasing severity of myopia, aligning with findings by Sikander Lodhi. 18Quadrant-wise analysis revealed the nasal quadrant to be the thickest, followed by the superior>inferior>temporal quadrants. This pattern corresponds with the high density of the papillomacular bundle in the nasal macula and was supported by previous studies, including those by Lodhi et al. and Rao et al., 18-19

Previous studies done by Samuel et al, Solu T et al, and Wu et al have shown a decrease in parafoveal retinal thickness when compared with the central foveal retinal thickness in myopes.20-22 It has been postulated that an increase in the mechanical stretching of the eyeball, caused due to an increase in axial length, creates a pull in the vitreous, which causes traction of the vitreomacular interface; thus, causing an increase in the central foveal thickness. This can be considered a warning sign in cases of progressive myopia for sequelae associated with VMT. Luo et al,2006 stated that in myopes, there is an increase in foveal thickness due to an increase in sub-foveal RPE permeability. 23

The **mean foveal thickness** in this study is approximately **80-90 microns** more in all myopic subgroups when compared to the study conducted by Samuel et al. This could be due to the difference in machinery and image processing protocols. Samuel et al, Xie et al, and Choi et al also state that the foveal thickness increases with the progression of myopia, which is contradictory to our study, where the foveal thickness was found to be minimal in the high myopia group.20,23-24 In our study, the **central foveal thickness was noted as maximum amongst Moderate myopes**, which was not the case in the study conducted by Lodhi et al, wherein the super-high myopia group showed the maximum central foveal thickness.18 Contradicting some findings, such as those by Lim et al., our study noted a decline in retinal thickness in the central foveal field with severe myopia, whereas moderate myopes exhibited maximum central foveal thickness. This difference could stem from variations in OCT imaging protocols, instrumentation, or population-specific factors.25

Choroidal Thickness: The mean sub-foveal choroidal thickness of the myopic population in this study was 271.90 ± 78.19 µm, which was significantly lower than the average for normal Indian populations reported by Narendran et al.26 This finding highlights the role of axial elongation in choroidal thinning, which predisposes the retina and choroid to pathological changes. Consistent with studies by Kaur et al. 27 and Fujiwara et al.,28 this study observed progressive thinning of the choroid with increasing myopia severity. Parafoveal thinning was most pronounced in the nasal quadrant, correlating with pathological changes in myopic chorioretinopathy, such as peripapillary atrophy and posterior staphylomas. Our study showed a negative correlation between spherical equivalents and both retinal and choroidal thicknesses, confirming that greater refractive error is associated with thinning. Similar findings were reported by Choi et al. and Solu et al.21,24

Interpretation: The study observed a decrease in choroidal and macular thickness with increasing severity of myopia and age, consistent with known degenerative changes in myopia. The foveal thickness was approximately 80-90 microns thicker than previously reported in similar populations, possibly due to ethnic differences or imaging techniques.

Age and Gender Analysis:

Maximum retinal thickness was observed in participants aged 24–32 years, likely due to reduced axial elongation progression with age. Choroidal thickness was highest in the youngest group (15–23 years), possibly reflecting higher metabolic activity during growth phases.

Gender analysis showed that males had slightly greater retinal thickness than females, which may be attributed to anatomical differences. However, no significant gender differences were observed for choroidal thickness, consistent with other studies.

Clinical Implications:

This study underscores the importance of early detection and monitoring of retinal and choroidal changes in myopia using OCT. The findings highlight the need for targeted therapeutic interventions to manage myopic progression, particularly in younger populations with moderate to high myopia. Global studies on macular retinal and choroidal thickness using OCT technology show varied conclusions, likely due to differences in imaging modalities, calculation algorithms, and population characteristics. Hence, consistency in machine use and imaging protocols is essential for meaningful comparisons. Future Directions: Further studies incorporating newer OCT technologies, such as SS-OCT and OCT-angiography, can enhance our understanding of

choroidal vascularity and perfusion changes in myopia. Advanced imaging techniques, including photoacoustic imaging and elastography, hold promise for exploring structural and biochemical properties in vivo.

Summary:

This study evaluated retinal and choroidal thickness in myopic eyes using Enhanced Depth Imaging Spectral Domain Optical Coherence Tomography (EDI-SD OCT). Key findings are summarized as follows:

1. Retinal Thickness:

Retinal thinning was observed across all macular regions with increasing severity of myopia, with the greatest reduction in high myopia (> -9 D).
Quadrant-wise analysis showed the nasal quadrant to be the thickest, followed by the superior, inferior, and temporal quadrants.

2. Choroidal Thickness:

Choroidal thickness progressively decreased with higher degrees of myopia.
Maximum thickness was noted at the central subfoveal point, while parafoveal thinning was most prominent in the nasal quadrant.

3. Spherical Equivalent Correlation:

Showed a negative correlation of Retinal and choroidal thickness, negatively correlated with spherical equivalents, with more severe refractive errors associated with greater thinning.

4. Age and Gender Influence:

Retinal thickness was highest in individuals aged 24–32 years, while choroidal thickness was greatest in the youngest group (15–23 years).
Males exhibited slightly thicker retinas compared to females, although choroidal thickness showed no significant gender differences.

5. High Myopia Findings:

Subfoveal retinal thinning and nasal choroidal thinning were identified as markers of progressive myopic changes, potentially indicating a risk for complications such as peripapillary atrophy and posterior staphylomas. These findings underscore the importance of monitoring retinal and choroidal changes in myopic individuals, particularly those with high refractive errors and younger patients, to prevent vision-threatening complications.

Conclusion:

Myopia represents a growing global health concern, requiring both corrective measures for refractive errors and interventions to slow disease progression. While spectacle and contact lens corrections are effective for visual improvement, they do not address underlying pathological changes or halt axial elongation. This study highlights the role of OCT in detecting structural changes in the retina and choroid, enabling early intervention and improved management of myopic complications.

Therapeutic Implications:

1. Pharmacological Interventions: Low-concentration atropine has shown promise in reducing myopia progression in children through mechanisms beyond accommodation suppression. Emerging treatments, including anticholinergic agents, anti-hypoxia drugs, and growth factor inhibitors, warrant further investigation.
2. Optical Approaches: Peripheral myopic defocus spectacles, progressive addition lenses, and orthokeratology contact lenses have shown the potential to slow myopia progression.
3. Surgical Modalities: Innovations such as macular buckle surgeries offer solutions for advanced cases but require validation through long-term studies.

Future Prospects: Emerging imaging modalities, such as OCT-angiography and photoacoustic imaging, could revolutionize our understanding of myopic progression by providing molecular, anatomical, and functional insights with unprecedented precision. Coupled with advances in elastography and microperimetry, these technologies offer hope for targeted therapies and personalized management strategies. In conclusion, proactive monitoring of retinal and choroidal changes using advanced imaging techniques, alongside therapeutic interventions, can significantly mitigate the burden of myopia and preserve vision in affected individuals.

Generalizability:

The findings can be generalized to urban Indian myopic populations but may differ in other ethnic groups due to anatomical variations.

Limitations:

Small sample size from a single center.
Cross-sectional design limits understanding of longitudinal progression.
Possible selection bias despite efforts to minimize it.

Recommendations:

Larger, multicenter, longitudinal studies are recommended.
Regular SD-OCT follow-up for early detection of progressive myopic degeneration.

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List of Abbreviations:
SD-OCT: Spectral-Domain Optical Coherence Tomography
D: Diopters
KIMS: Kalinga Institute of Medical Sciences

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Conflict of Interest:
The authors declare no conflict of interest.

Roles and contributions of authors:
1st author: concept and design, critical revision, analysis, and interpretation.
2nd author: manuscript writing, analysis, and interpretation.
3rd author: data collection, analysis, and interpretation.

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