SJ Ophthalmology Africa
Vol. 3 No. 2 (2026): April 2026 Issue
https://doi.org/10.51168/9csyte96
Original Article

Assessment of macular parameters and retinal nerve fibre layer thickness in subjects with unilateral amblyopia using Spectral Domain Optical Coherence Tomography: A Cross-Sectional Study.

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Abstract

Background:
Amblyopia is a neurodevelopmental visual disorder characterized by reduced best-corrected visual acuity without an evident structural ocular abnormality. Spectral domain optical coherence tomography (SD-OCT) provides an objective assessment of the retinal nerve fibre layer (RNFL) and macular parameters that could support clinical evaluation.

Objective:
To assess macular parameters and RNFL thickness in subjects with unilateral amblyopia using SD-OCT.

Methods:
This descriptive cross-sectional study included 150 consecutive subjects aged 5-45 years with unilateral amblyopia at the Department of Ophthalmology, Government Institute of Medical Sciences, Greater Noida. BCVA, refractive status, RNFL thickness, and central macular thickness (CMT) were assessed and compared between amblyopic and fellow eyes.

Results:
The mean age was 12.3 ± 3.6 years; 84 (56.0%) subjects were male. Amblyopic eyes had poorer BCVA than fellow eyes (0.61 ± 0.13 vs. 0.08 ± 0.03; $p < 0.001$), higher spherical equivalent (+2.48 ± 1.00 vs. +1.75 ± 0.88; $p = 0.03$), greater mean RNFL thickness (105.2 ± 9.6 µm vs. 100.0 ± 8.5 µm; $p = 0.02$), and higher CMT (265.6 ± 15.1 µm vs. 253.2 ± 14.5 µm; $p = 0.001$). BCVA showed a moderate positive correlation with RNFL thickness ($r = 0.43$; $p = 0.001$).

Conclusion:
Unilateral amblyopia was associated with greater RNFL and central macular thickness in affected eyes, indicating measurable retinal structural alteration alongside visual dysfunction.

Recommendation:
SD-OCT should be considered an objective adjunct for documenting retinal parameters in unilateral amblyopia, and larger longitudinal studies are recommended to clarify prognostic relevance.

Keywords: *Amblyopia; cross-sectional study; macular thickness; retinal nerve fibre layer thickness; spectral domain optical coherence tomography.*

Submitted: *January 17, 2026* ***Accepted:*** *March 15, 2026* ***Published:*** *April 30, 2026*

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Introduction

Amblyopia, commonly called lazy eye, is a developmental disorder of vision in which best-corrected visual acuity remains reduced in one or both eyes despite the absence of a detectable structural abnormality in the eye or visual pathway. It usually arises from abnormal binocular interaction or visual deprivation during the sensitive period of visual maturation. Important etiological contributors include anisometropia, strabismus, ocular media opacity, high uncorrected refractive error, or mixed mechanisms [1]. The global burden of amblyopia remains clinically important because the condition frequently begins in childhood and persists into later life when diagnosis or treatment is delayed. Previous estimates indicate that amblyopia affects approximately 2-5% of individuals, with onset commonly occurring during the early years of retinal-cortical development. Although the primary defect is functional, recent evidence suggests that amblyopia is linked with measurable changes in postnatal retinal maturation, including possible alterations in RNFL and foveal architecture [2].

SD-OCT permits rapid, non-invasive, and reproducible visualization of retinal microstructure. Several OCT-based studies have examined RNFL thickness and macular parameters in amblyopia; however, the findings remain inconsistent. Some investigations have reported increased RNFL or macular thickness, whereas others have observed thinning or no meaningful difference compared with fellow normal eyes. These variations indicate the need for further clinical data from different populations and settings [3].

Assessment of macular parameters and RNFL thickness in unilateral amblyopia is clinically relevant because comparison with the fellow eye reduces inter-individual anatomical variation. Structural retinal evaluation provides an opportunity to examine whether amblyopia is associated only with altered cortical processing or also with retinal-level changes. Improved understanding of these parameters could support objective documentation, risk stratification, and future monitoring strategies [4].

The objective of the present cross-sectional study was to assess macular parameters and retinal nerve fibre layer thickness in subjects with unilateral amblyopia using spectral domain optical coherence tomography and to compare these findings between amblyopic eyes and normal fellow eyes.

Materials and Methods

Study design

The study was designed as a descriptive cross-sectional study and was conducted from August 2025 to December 2025. Each participant was evaluated once during the study period. Macular parameters, retinal nerve fiber layer [RNFL] thickness, refractive status, and best-corrected visual acuity [BCVA] were assessed and compared between the amblyopic eye and the normal fellow eye. The cross-sectional design was selected because the primary aim was to describe structural ocular parameters at a defined point in clinical assessment, rather than to evaluate treatment response or temporal changes over time.

Study setting

The study was conducted in the Department of Ophthalmology, Government Institute of Medical Sciences (GIMS), Greater Noida, Uttar Pradesh, India. GIMS is a government medical teaching institution providing patient care, medical education, and research services. The Ophthalmology department provides ocular health services through clinical evaluation, diagnostic assessment, refraction services, fundus evaluation, and specialty-based eye care.

Participants

Participants were selected by consecutive sampling from subjects presenting to the Ophthalmology department with unilateral amblyopia during the study period. Consecutive selection was used to reduce investigator-driven selection and to include all eligible cases available within the clinical setting. The study included subjects aged 5-45 years with amblyopia in one eye and a normal fellow eye. Inclusion criteria were known unilateral amblyopia, intraocular pressure below 21 mmHg, and age between 5 and 45 years. Exclusion criteria were previous retinal surgery, ocular trauma, congenital optic atrophy, neurological disorders causing RNFL damage, bilateral amblyopia, optic atrophy from other causes, fundus degenerative changes, and advanced glaucomatous changes.

Study size

The final study size was 150 subjects. This number represented the complete set of eligible unilateral amblyopia cases available during the defined recruitment period who met the selection criteria and had complete clinical and SD-OCT data. The sample was considered practically adequate for a single-centre cross-sectional comparison of paired ocular measurements because each subject contributed an amblyopic eye and an internal fellow-eye comparator.

Bias

Potential sources of bias were addressed through predefined inclusion and exclusion criteria, consecutive recruitment of eligible subjects, comparison of each amblyopic eye with the fellow normal eye, and use of the same SD-OCT platform for all measurements. Conditions known to influence RNFL thickness, such as glaucoma, optic atrophy, fundus degenerative changes, neurological disorders, ocular trauma, and previous retinal surgery, were excluded. Measurement bias was reduced by using standard ocular examination procedures and complete-case analysis. Residual referral bias and single-centre bias were considered unavoidable limitations of the study setting.

Data collection

Clinical data were collected from all subjects diagnosed with unilateral amblyopia. Demographic details included age and sex. Relevant clinical history was obtained with attention to ocular surgery within the previous six months, anti-glaucoma medication use, trauma history, and systemic or neurological disorders capable of affecting RNFL thickness. A general physical examination and comprehensive ocular examination were performed for each participant. The recorded ophthalmic assessments included torchlight examination for pupillary reactions, neutral

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density filter testing to support diagnosis of amblyopia, cycloplegic refraction, Snellen visual acuity testing with conversion to logarithm of minimum angle of resolution (LogMAR) for statistical analysis, non-contact tonometry, slit-lamp anterior segment examination, fundus examination using direct and indirect ophthalmoscopy, slit-lamp biomicroscopy with 78D and 90D lenses, and SD-OCT evaluation of RNFL and macular parameters. Data were entered into a structured proforma before statistical analysis.

Statistical analysis

Data were analysed using SPSS software version 24.0 (IBM Corp., Armonk, NY, USA). Continuous variables were summarized as mean ± standard deviation. Categorical variables were summarized as frequency and percentage. Paired eye-wise comparisons between amblyopic and fellow eyes were assessed using the paired t-test when data were normally distributed; non-parametric comparison was planned using the Mann-Whitney U test when distributional assumptions were not met. Categorical variables were assessed using the chi-square test. Correlation between BCVA and RNFL thickness was evaluated using the Pearson correlation coefficient. A p-value below 0.05 was considered statistically significant.

Ethical consideration

The study protocol was reviewed and approved by the Institutional Ethics Committee, Government Institute of Medical Sciences, Greater Noida, Uttar Pradesh, India.

Informed consent

Written informed consent was obtained before participation. For participants below 18 years of age, consent was obtained from a parent or legally authorized guardian, with age-appropriate assent wherever applicable. Participant confidentiality was maintained, and the study data were handled in anonymized form during analysis and reporting.

Results

Participant flow

A total of 150 consecutive subjects with unilateral amblyopia were identified in the Ophthalmology department during the study period. All 150 subjects were examined for eligibility, confirmed eligible, included in the cross-sectional assessment, completed clinical and SD-OCT evaluation at the index visit, and were included in the final analysis. No exclusion or non-participation was documented in the submitted source data. Follow-up completion was not applicable because the study used a cross-sectional design.

Table 1: *Participant flow through the study.*

Study stage	Number of subjects	Reason or status
Potentially eligible subjects identified in the Ophthalmology OPD	150	Consecutive unilateral amblyopia cases during the study period
Examined for eligibility	150	Screened using predefined inclusion and exclusion criteria
Excluded before enrolment	0	No exclusion or non-participation documented
Confirmed eligible	150	Met the eligibility criteria
Included in the study	150	Underwent clinical and SD-OCT evaluation
Completed index visit assessment	150	Cross-sectional assessment completed; follow-up not applicable
Included in final analysis	150	Complete analysable data available

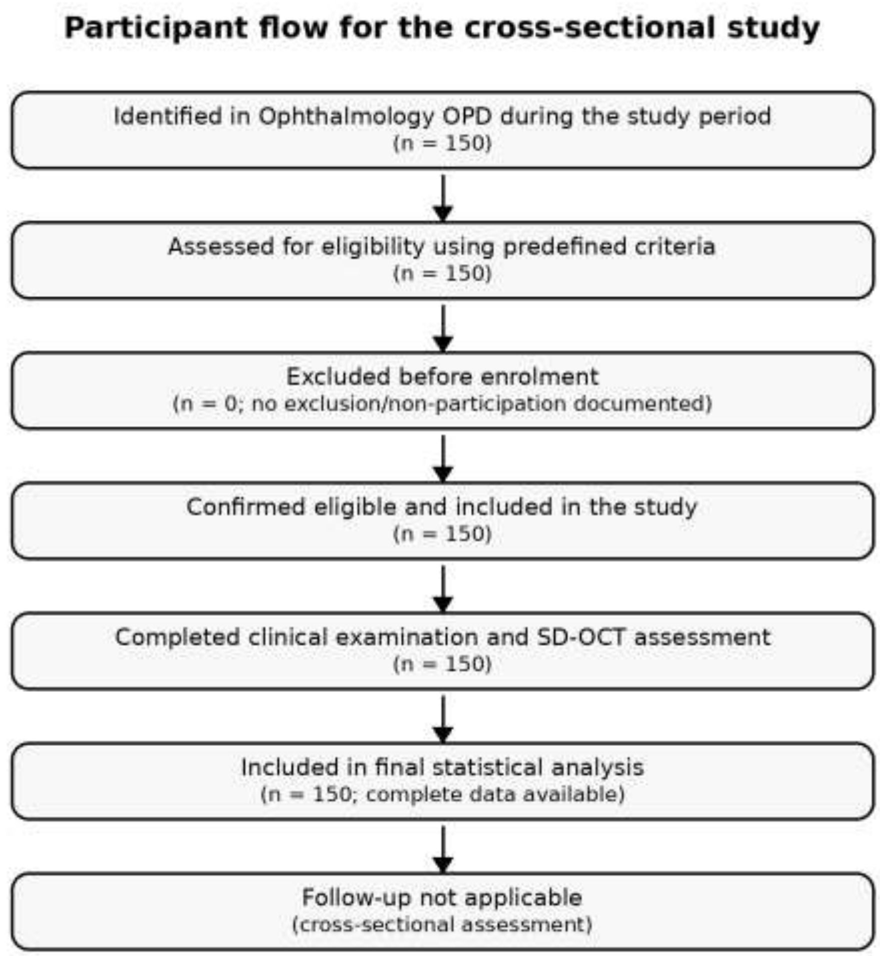

Figure 1. Participant flow diagram for the cross-sectional study.

Demographic characteristics

The study included 150 subjects. The mean age was 12.3 ± 3.6 years, with an age range of 5-45 years. Male subjects constituted 56.0% of the sample, while female subjects constituted 44.0%. The demographic profile is shown in Table 2.

Table 2: *Demographic characteristics of the study subjects*

Parameter	Value
Mean age, years	12.3 ± 3.6
Age range, years	5-45
Total subjects, n	150
Male, n (%)	84 (56.0)
Female, n (%)	66 (44.0)

Comparison of ocular parameters

Amblyopic eyes had significantly poorer BCVA than normal fellow eyes. The spherical equivalent was also significantly higher in amblyopic eyes. Mean RNFL thickness was greater in amblyopic eyes than in fellow eyes, and the difference was statistically significant (Table 3).

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Table 3: *Comparison of ocular parameters between amblyopic and fellow normal eyes*

Parameter	Amblyopic eye	Normal fellow eye	p-value
BCVA (LogMAR)	0.61 ± 0.13	0.08 ± 0.03	<0.001
Spherical equivalent	+2.48 ± 1.00	+1.75 ± 0.88	0.03
Mean RNFL thickness, µm	105.2 ± 9.6	100.0 ± 8.5	0.02

Quadrant-wise analysis showed consistently higher RNFL thickness in amblyopic eyes across temporal, nasal, inferior, and superior quadrants compared with fellow normal eyes. The highest absolute values were observed in the inferior and superior quadrants (Table 4).

Table 4: *Quadrant-wise RNFL thickness in amblyopic and fellow normal eyes*

Quadrant	Amblyopic eye (µm)	Fellow eye (µm)
Temporal	60 ± 5	56 ± 4
Nasal	70 ± 6	66 ± 5
Inferior	133 ± 11	128 ± 10
Superior	128 ± 10	123 ± 9

Central macular thickness was significantly higher in amblyopic eyes than in fellow normal eyes. This finding supports the presence of measurable macular structural variation in unilateral amblyopia (Table 5).

Table 5: *Central macular thickness in amblyopic and fellow normal eyes*

Parameter	Amblyopic eye (µm)	Fellow eye (µm)	p-value
Central macular thickness	265.6 ± 15.1	253.2 ± 14.5	0.001

Correlation and chi-square results

RNFL thickness demonstrated a moderate positive correlation with poorer BCVA, indicating that higher RNFL thickness was associated with worse visual acuity in amblyopic subjects. The chi-square test for sex distribution did not show a statistically significant deviation from an equal male-female distribution (Table 6).

Table 6: *Correlation and chi-square analysis*

Analysis	Statistic	p-value	Interpretation
BCVA vs. RNFL thickness	r = 0.43	0.001	Moderate positive correlation
Sex distribution	$\chi^2(1) = 2.16$	0.142	Not statistically significant

Discussion

This cross-sectional study demonstrated that amblyopic eyes had significantly poorer visual acuity, higher spherical equivalent, greater mean RNFL thickness, and higher central macular thickness compared with fellow normal eyes. The findings indicate that unilateral amblyopia is associated with detectable structural differences in retinal and macular parameters when examined using SD-OCT. The moderate positive correlation between BCVA and RNFL thickness further suggests that greater RNFL thickness was linked with poorer visual function in the study population.

The higher RNFL thickness observed in amblyopic eyes is consistent with the concept that altered visual stimulation during the sensitive period of development could influence retinal maturation. Delayed or incomplete postnatal retinal refinement has been proposed as one mechanism by which amblyopic eyes retain thicker retinal layers. The increased central macular thickness observed in the affected eyes also supports the presence of macular-level structural variation. These changes do not necessarily indicate a primary retinal disease; rather, they indicate measurable retinal differences accompanying disrupted visual development.

The demographic profile of the study showed a mean age of 12.3 ± 3.6 years and a male predominance. Similar age distributions and sex patterns have been reported in previous amblyopia-related OCT studies [5,6]. The significantly poorer BCVA and higher spherical equivalent in the amblyopic eye are expected clinical findings because amblyopia is frequently associated with refractive imbalance and impaired visual development.

The study findings are broadly comparable with studies that reported increased RNFL or macular thickness in amblyopic eyes [7,11,12]. However, the literature remains heterogeneous, with some reports demonstrating no difference or variable quadrant-specific changes. Differences in age distribution, type of amblyopia, OCT platform, refractive error profile, axial length, disease duration, and statistical approach could explain the inconsistent findings across studies. The present results add to the evidence that SD-OCT can detect retinal structural differences in unilateral amblyopia.

Clinically, these observations support the role of SD-OCT as an adjunctive tool in the assessment of unilateral amblyopia. Visual acuity testing remains central to diagnosis and monitoring, but OCT-derived parameters provide objective structural information that can support documentation and future research. The findings also highlight the need for longitudinal studies to determine whether increased RNFL and macular thickness change with amblyopia treatment and whether these parameters have prognostic utility.

Generalizability

The findings are most generalizable to patients with unilateral amblyopia attending tertiary care ophthalmology services with access to SD-OCT. The use of fellow-eye comparison strengthens internal validity by reducing inter-individual anatomical variation. However, wider generalization to community populations, bilateral amblyopia, different ethnic groups, and primary care settings is limited because the study was conducted at a single government teaching institute and included only subjects meeting specific eligibility criteria.

Conclusion

The study concludes that unilateral amblyopic eyes show significantly higher RNFL thickness and central macular thickness compared with fellow normal eyes. Poorer BCVA was associated with increased RNFL thickness, indicating a relationship between retinal structural parameters and visual dysfunction. SD-OCT provides a useful, objective, and non-invasive adjunct for documenting retinal and macular characteristics in amblyopia. These findings improve understanding of retinal-level changes associated with disrupted visual development and support further longitudinal studies to clarify clinical and prognostic significance.

Limitations

The study was limited by its single-centre cross-sectional design, lack of longitudinal follow-up, absence of axial length adjustment, and lack of subgroup analysis by type and severity of amblyopia.

Recommendations

SD-OCT should be incorporated as an adjunctive assessment tool for documenting RNFL and macular parameters in unilateral amblyopia, where facilities are available. Future studies should use multicentre recruitment, predefined sample size estimation, amblyopia subtype stratification, axial length adjustment, and longitudinal follow-up after treatment. These steps will help determine whether OCT-derived retinal parameters can serve as diagnostic, monitoring, or prognostic biomarkers in amblyopia care.

Acknowledgement

The authors acknowledge the Department of Ophthalmology, Government Institute of Medical Sciences, Greater Noida, Uttar Pradesh, India, for institutional support and for facilitating clinical evaluation of the study participants.

List of Abbreviations

Abbreviation	Full form
BCVA	Best-corrected visual acuity
CMT	Central macular thickness
GIMS	Government Institute of Medical Sciences
LogMAR	Logarithm of the minimum angle of resolution
OCT	Optical coherence tomography
RNFL	Retinal nerve fibre layer
SD-OCT	Spectral domain optical coherence tomography
SPSS	Statistical Package for the Social Sciences

Declarations

Conflict of interest

The authors declared no conflict of interest.

Source of funding

The study received no external funding.

Author contributions

Dr Nandita Chaturvedi contributed to study conception, clinical assessment, data acquisition, manuscript drafting, and final approval. Dr Krishna Kuldeep contributed to study design, supervision, methodology, interpretation of findings, critical review, and final approval. Dr Shailly Raj contributed to data organization, literature review, statistical interpretation, manuscript revision, and final approval. All authors agreed to be accountable for the integrity and accuracy of the work.

Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Author Biography

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