

Research Article

Quantitative Evaluation of Corneal Ulcer Morphology Using Anterior Segment Optical Coherence Tomography: Implications for Management and Prognosis

Dr Sachin Agrawal¹, Dr Anjali Rahane², Dr Pallak Kusumgar^{3*}

¹Associate Professor, Indira Gandhi Government Medical College and Hospital, Nagpur, Maharashtra, India.

²Junior Resident, Indira Gandhi Government Medical College and Hospital, Nagpur, Maharashtra, India.

^{3*}Consultant ARIHANT Netralaya Nagpur, Maharashtra, India.

Corresponding Author: Dr Pallak Kusumgar

Consultant ARIHANT Netralaya Nagpur, Maharashtra, India.

Email: Pallak3004@gmail.com

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ABSTRACT

Background: Corneal ulceration is a severe, sight-threatening condition conventionally evaluated using slit-lamp biomicroscopy. However, clinical examination is highly subjective and limited by optical scattering from dense infiltrates and edema, which frequently obscures deep stromal necrosis and impending perforations. Anterior Segment Optical Coherence Tomography (AS-OCT) provides a non-invasive, high-resolution solution to objectively map corneal microanatomy, though standardized quantitative thresholds for guiding surgical management remain inadequately established.

Aim: To evaluate the microstructural features of infectious and non-infectious corneal ulcers using Anterior Segment Optical Coherence Tomography (AS-OCT) and assess its role in improving clinical management, predicting prognosis, and guiding surgical interventions.

Materials and Methods: This prospective longitudinal study was conducted at a Department of Ophthalmology at Indira Gandhi Government Medical College, Nagpur over an 18-month duration. A total of 92 patients with clinically and microbiologically diagnosed corneal ulcers (both infectious and non-infectious) were recruited. The study included patients aged 18 years and older. Patients with perforated trauma or prior corneal grafts were excluded. Main investigations included slit-lamp biomicroscopy, microbiological testing, and AS-OCT imaging at baseline, Day 3, Day 7, Day 14, and Month 1. Data were analyzed utilizing Shapiro-Wilk, Student's t-test, Chi-square tests, repeated measures ANOVA, and logistic regression analysis.

Results: The mean age of the cohort was 37.4 ± 13.8 years, with a male preponderance (63.04%, $p=0.012$). Ocular trauma was the primary predisposing factor (60.87%). The etiological spectrum was predominantly bacterial (52.17%) and fungal (38.04%). AS-OCT identified a dense infiltrate pattern in 30.43% of cases and a spongiform pattern in 26.09%. AS-OCT detected a significantly larger mean infiltrate diameter (4.65 ± 1.82 mm) compared to slit-lamp evaluation (3.82 ± 1.54 mm, $p<0.001$). A baseline AS-OCT Residual Corneal Thickness (RCT) < 250 μ m was identified in 30.43% of patients, offering a 75.0% diagnostic gain for impending perforation over slit-lamp examination. Baseline RCT < 250 μ m was an independent predictor for surgical intervention (aOR 11.20, $p<0.001$).

Conclusion: AS-OCT is an objective, high-resolution imaging modality that surpasses subjective slit-lamp biomicroscopy in the structural evaluation of corneal ulcers. Tomographic parameters, specifically an RCT < 250 μ m and spongiform necrosis, serve as highly predictive biomarkers for medical failure, enabling timely therapeutic escalation and surgical intervention.

Keywords: Anterior Segment Optical Coherence Tomography, Corneal Ulcer, Microbial Keratitis, Diagnostic Imaging, Prognosis, Therapeutic Keratoplasty.

INTRODUCTION

Corneal ulceration, encompassing both infectious microbial keratitis and non-infectious inflammatory melts, represents a profound challenge in global ophthalmic public health, contributing significantly to global ocular

morbidity and blindness.^{1,2} Early identification of ulcer depth, size, and location is crucial for preventing devastating complications such as corneal perforation, permanent structural scarring, and intraocular extension.³

Traditionally, clinical slit-lamp biomicroscopy and laboratory microbiological analyses have served as the fundamental mainstays for evaluating corneal ulcers.⁴ However, conventional slit-lamp examination presents substantial diagnostic limitations. It relies inherently on subjective interpretation, resulting in inter-observer variability. Furthermore, optical scattering caused by dense anterior stromal infiltrates, intense edema, and overlying fibrinous slough completely obscures the visualization of deeper corneal stroma and Descemet's membrane.⁵ Consequently, clinicians cannot objectively quantify the exact depth of stromal infiltrates or accurately assess the true anatomical risk of impending perforation.

Anterior Segment Optical Coherence Tomography (AS-OCT) has emerged as an invaluable non-invasive imaging technique that provides high-resolution, cross-sectional tomograms of the anterior segment.^{6,7} Utilizing long-wavelength infrared light (e.g., 1310 nm), AS-OCT minimizes tissue scattering, allowing the optical beam to penetrate opaque purulent exudates.⁸ This enables the direct visualization of the exact depth of stromal necrosis, precise measurement of the residual stromal bed, and identification of retrocorneal inflammatory plaques.^{9,10} Despite these transformative capabilities, significant gaps persist in the literature regarding the standardized clinical application of AS-OCT. Specifically, validated quantitative thresholds for metrics such as minimal residual stromal thickness, which dictate the escalation from medical therapy to tectonic surgery, remain inadequately defined in varied clinical populations.^{11,12}

Aim of the Study: To evaluate the features of corneal ulcers using AS-OCT and assess its role in improving the management and prognosis of the disease.

Objectives of the Study

- To analyze the structural features of corneal ulcers using AS-OCT, including stromal involvement, epithelial integrity, and corneal thickness.
- To compare the efficacy of AS-OCT in assessing corneal ulcers with traditional clinical methods such as slit-lamp biomicroscopy.
- To determine the impact of AS-OCT-guided treatment on the clinical outcomes of corneal ulcers.

- To evaluate the prognostic value of AS-OCT in predicting complications such as corneal scarring, thinning, or perforation.

Materials and Methods

Study Design: This was a prospective longitudinal study. **Study Setting:** The study was conducted at the Department of Ophthalmology at Indira Gandhi Government Medical College, Nagpur. **Study Duration:** The study duration was 18 months (August 2023 to January 2025). **Study Population:** Patients presenting with active corneal ulceration. **Sample Size:** 92 patients with diagnosed corneal ulcers, determined via a structured sample size formula utilizing a 90% confidence level and 12% margin of error.

Inclusion Criteria

- Patients aged 18 years and older diagnosed with corneal ulcers based on clinical and microbiological evaluations.
- Both male and female patients.
- Patients willing to provide informed consent.
- Patients with both infectious and non-infectious corneal ulcers.

Exclusion Criteria

- Patients younger than 18 years.
- Patients with corneal ulcers secondary to trauma with perforation.
- Patients with prior corneal grafts.
- Patients unwilling to participate or provide consent.
- Pregnant and lactating women.

Methodology: All patients underwent a complete baseline ophthalmological examination, including best-corrected visual acuity (BCVA) testing and detailed slit-lamp biomicroscopy. Ulcer size, depth, and the presence of hypopyon were clinically graded. Corneal swabs and scrapings were collected from the active leading edge and deep base of the ulcers for Gram staining, 10% Potassium Hydroxide (KOH) wet mount, and standard culture and sensitivity testing.

High-resolution cross-sectional imaging was performed using an AS-OCT system. Key evaluated parameters included complete epithelial defect diameter, infiltrate thickness, maximum infiltrate depth, Total Corneal Thickness (TCT), Residual Corneal Thickness (RCT), and Descemet's membrane/endothelial complex integrity. Follow-up clinical and AS-OCT examinations were performed at Day 1, Day 3, Day 7, Day 14, and Month 1 to monitor

treatment response, resolution of stromal edema, and impending complications.

Patients with mild to moderate ulcers received targeted topical antimicrobials. Cases with severe thinning or impending perforation identified via AS-OCT underwent surgical interventions such as Amniotic Membrane Transplantation (AMT) or Therapeutic Penetrating Keratoplasty (TPK).

Ethical Considerations: Ethical approval was obtained from the Institutional Review Board (IRB) prior to initiation. Informed consent was obtained from all participants.

Statistical Analysis

Data were analyzed using biostatistical software. Normality was assessed via the Shapiro-Wilk test. Continuous variables were reported as mean $\pm$ SD or median (IQR), and categorical variables as frequencies and percentages. Comparisons utilized Student's t-test, Mann-Whitney U, Chi-square, or Fisher's exact tests. Longitudinal data were evaluated with repeated measures ANOVA and Wilcoxon signed-rank tests. Inter-modality agreement

was quantified by Cohen's Kappa. Univariate and multivariable logistic regression identified predictors of prognosis and surgery, reporting adjusted Odds Ratios (aOR) and 95% Confidence Intervals (CI). Significance was set at $p < 0.05$.

RESULTS

The study included 92 eyes of 92 patients with a mean age of 37.4 ± 13.8 years (range 16–80 years). A statistically significant male preponderance was observed (63.04%, $p=0.012$). Occupationally, the majority of patients were engaged in agriculture/farming (39.13%) and industrial/construction work (26.09%) (Table 1).

The median duration of symptoms prior to presentation was 6.5 days. Ocular trauma emerged as the single most critical predisposing factor (60.87%), predominantly driven by vegetative trauma (32.61%). Mean baseline BCVA was 1.38 ± 0.52 LogMAR. The central cornea was affected in 45.65% of cases. Hypopyon was present in 38.04% of eyes.

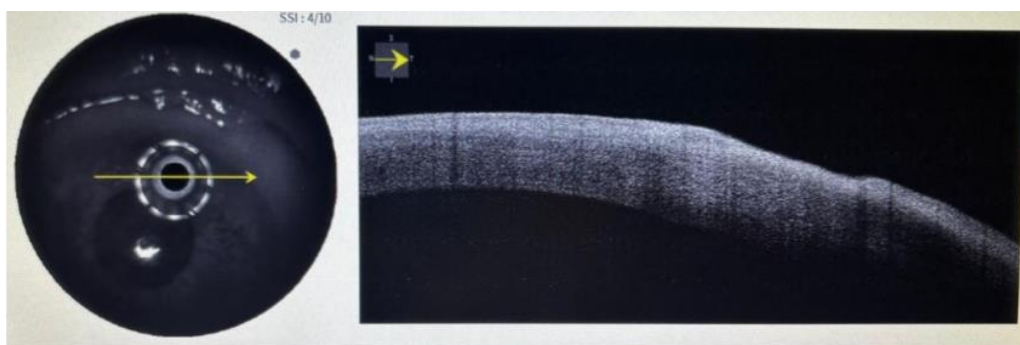


Figure 1: Localized Anterior Stromal Thinning Is Seen in the Paracentral Cornea

There is loss of normal smooth anterior corneal contour at the site of the lesion, corresponding to the ulcer crater.

The underlying stroma shows increased hyperreflectivity, suggestive of inflammatory infiltrate

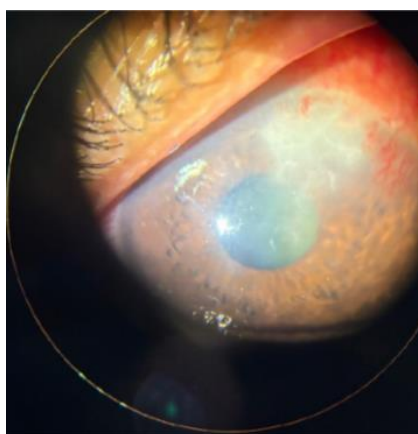


Figure 2: Slit Lamp Image of the Same Ulcer

Table 1: Baseline Demographic and Clinical Characteristics of the Study Cohort (N=92)

Characteristic	Frequency (n)	Percentage (%)
Age Group (Years)		
< 30	34	36.96
31 – 50	43	46.74
> 50	15	16.30
Gender		
Male	58	63.04
Female	34	36.96
Primary Predisposing Factor		
Vegetative Trauma	30	32.61
Dust / Particulate Trauma	26	28.26
Idiopathic / No Trauma	20	21.74
Definitive Etiology		
Bacterial	48	52.17
Fungal	35	38.04
Others / Viral	9	9.78

KOH smear identified fungal filaments in 30.43% of cases. Overall culture positivity was 76.09%. The definitive etiological spectrum revealed 52.17% bacterial and 38.04% fungal infections. Fungal etiology was significantly associated with a severe clinical presentation ($p=0.003$).

AS-OCT confirmed complete epithelial defects spanning the infiltrate in 58.70% of eyes. The mean baseline RCT was $302.4 \pm 108.6 \mu\text{m}$, with 30.43% of the cohort presenting with an RCT < $250 \mu\text{m}$ (high-risk thinning). AS-OCT identified

Descemet's membrane bulging/descemetocoele in 33.70% and retrocorneal endothelial plaques in 34.78% of cases.

A highly significant correlation was identified between AS-OCT microstructural patterns and microbial etiologies (Table 2). Spongiform patterns, dense endothelial plaques, and feathery stromal patterns heavily favored fungal keratitis, whereas diffuse edema and homogeneous hyperreflectivity predominated in bacterial infections ($p<0.001$).

Table 2: AS-OCT Morphological Patterns and Pathogen Correlation

AS-OCT Pattern	Total (n=92)	Bacterial (n=48)	Fungal (n=35)	p-value
Dense Homogeneous Infiltrate	28 (30.4%)	18 (37.5%)	8 (22.9%)	<0.001*
Spongiform (Cystic Spaces)	24 (26.1%)	14 (29.2%)	10 (28.6%)	
Diffuse Edema	15 (16.3%)	10 (20.8%)	3 (8.6%)	
Patchy Hyperreflective	13 (14.1%)	6 (12.5%)	3 (8.6%)	
Dense Endothelial Plaque	9 (9.8%)	0 (0.0%)	8 (22.9%)	
Feathery Stromal Pattern	3 (3.3%)	0 (0.0%)	3 (8.6%)	
<i>(Fisher's Exact Test).</i>				

AS-OCT generated significantly larger linear infiltrate measurements than clinical slit-lamp estimation ($4.65 \pm 1.82 \text{ mm}$ vs. $3.82 \pm 1.54 \text{ mm}$, $p<0.001$). Clinical subjective evaluation underestimated depth; AS-OCT reclassified 14

cases into the deep category, yielding only fair diagnostic agreement ($\kappa = 0.38$) (Table 3). AS-OCT demonstrated a 75.0% diagnostic gain in identifying severe structural thinning.

Table 3: Diagnostic Agreement: Slit-Lamp Biomicroscopy vs. AS-OCT

Diagnostic Parameter	Slit-Lamp Estimation	AS-OCT Measurement	p-value / Agreement
Mean Infiltrate Diameter	$3.82 \pm 1.54 \text{ mm}$	$4.65 \pm 1.82 \text{ mm}$	$p < 0.001^*$
Depth Categorization			
Superficial (< 30%)	14 cases	9 cases	$\kappa = 0.38$ (Fair)
Moderate (30–70%)	48 cases	39 cases	
Deep (> 70%)	30 cases	44 cases	

Detection of Severe Thinning	16 cases	28 cases	+75.0% Diagnostic Gain
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Significant diametric contraction (15.0%) became statistically evident by Day 7 ($p=0.045$), culminating in a robust 54.8% reduction by Month 1. Functional visual recovery lagged behind structural resolution; statistically significant improvement in BCVA occurred by Day 14 (1.15 ± 0.60 LogMAR, $p=0.045$). Complete re-epithelialization was achieved in 81.69% of the medically managed cohort by Month 1.

Structural deterioration (descemetocoele/impending melt) occurred in 19.57% of cases, and spontaneous perforation complicated 9.78% of cases. Eyes demonstrating baseline AS-OCT 'Spongiform' patterns accounted for the vast majority of these structural failures.

The objective tomographic evidence from AS-OCT compelled a modification in the

management plan in 36.96% of cases. A favorable anatomical outcome was secured in 86.96% of cases (healed either medically or via successful surgery). Surgical stabilization via TPK was mandated in 22.83% of the population.

Delayed healing (>40 days) correlated significantly with a baseline diameter > 5.0 mm and deep stromal involvement $> 70\%$ ($p<0.001$). A poor final visual outcome was independently predicted by an initial infiltrate depth $> 500 \mu\text{m}$ ($p<0.001$). In multivariable modeling, adjusting for all covariates, a baseline AS-OCT RCT $< 250 \mu\text{m}$ was the strongest independent prognosticator for requiring surgical intervention (aOR 11.20, $p<0.001$) (Table 4).

Table 4: Multivariable Logistic Regression for Risk of Requiring Surgical Intervention (TPK)

Predictor Variable	Adjusted Odds Ratio (aOR)	95% Confidence Interval	p-value
Baseline Slit-lamp Size $> 5\text{mm}$	1.95	0.65 – 5.85	0.230
Fungal Etiology	2.10	0.78 – 5.65	0.142
AS-OCT Spongiform/Plaque Pattern	3.45	1.15 – 10.35	0.027*
Baseline AS-OCT RCT $< 250 \mu\text{m}$	11.20	3.55 – 35.30	$<0.001^*$
<i>(Model Fit: Hosmer-Lemeshow test $p = 0.68$. Nagelkerke $R^2 = 0.54$).</i>			

DISCUSSION

The present prospective observational study evaluated the morphological and microstructural characteristics of infectious keratitis utilizing AS-OCT in a cohort of 92 eyes. The primary objective was to elaborate the modality's prognostic significance and its role in dictating the trajectory of clinical management. The present study found that the mean age of patients was 37.4 ± 13.8 years with a male preponderance of 63.04%, primarily engaged in agricultural labor. This finding is comparable to the study by Abdelghany et al.¹¹ who reported a strong male skew (73.9%) and an active workforce demographic in their cohort. Similarly, Soliman et al.¹² observed that vegetative trauma was the predominant inciting factor in analogous geographic cohorts. However, Konstantopoulos et al.¹⁴ reported contrasting findings, identifying a cohort with gender parity driven nearly entirely by contact lens wear. Possible reasons for this difference include geographic and socio-economic disparities; agrarian environments pose a

substantially elevated risk of direct bio-hazardous ocular trauma compared to developed regions where cosmetic lens wear dominates.¹³

Regarding microstructural patterns, the present study found that spongiform disorganization (necrotic cystic spaces) and dense retrocorneal endothelial plaques were predominantly associated with fungal keratitis ($p<0.001$). This finding is comparable to the study by Soliman et al.¹² who described these identical features as early localized and diffuse necrotic stromal cystic spaces highly indicative of fungal etiology. Similarly, Abdelghany et al.¹¹ observed complex posterior plaques in severe trans-stromal fungal presentations. However, Chaturvedi et al.²¹ frequently identified homogeneous hyperreflective patterns in their cohort without heavy emphasis on necrotic cysts. Possible reasons for this difference include varying presentations of virulent vegetative trauma cases, which drive massive enzymatic lamellar separation and subsequent cyst formation uniquely visible on AS-OCT.

A critical finding was that subjective clinical evaluation severely underestimated ulcer depth. The present study found that AS-OCT accurately reclassified 14 cases into the high-risk "Deep" category, reflecting poor diagnostic agreement between the modalities (Kappa=0.38). This finding is comparable to Konstantopoulos et al.¹⁴ who reported that objective AS-OCT depth measurement effectively overrides subjective estimation and prevents the dangerous under-treatment of covert deep infections. This discrepancy exists because visible light cannot penetrate dense fibrinous anterior slough at the slit lamp, whereas the 1310 nm wavelength utilized in AS-OCT effortlessly cuts through this opacity to accurately map the posterior stroma.

Most significantly, the present study found that an objective baseline Residual Corneal Thickness (RCT) < 250 μ m was the most powerful independent predictor for the failure of medical therapy and the necessity of therapeutic penetrating keratoplasty (aOR 11.20). This finding is comparable to the assertions of Abdelghany et al.¹¹ who emphasized that precise quantification of deep structural loss dictates tectonic surgical necessity. Similarly, Chaturvedi et al.²¹ observed that measuring stromal metrics is essential for averting impending perforation. Loss of over half of the structural collagen framework severely compromises intrinsic tensile strength; recognizing this < 250 μ m threshold provides a definitive, data-driven trigger to preempt spontaneous global rupture. Finally, the present study found that functional visual recovery significantly lagged behind structural healing, and an AS-OCT infiltrate depth > 500 μ m guaranteed a poor final visual outcome (LogMAR > 1.0). This is comparable to the study by Chaturvedi et al.²¹ who noted that the clearance of cellular mass and resulting fibroblastic scarring permanently degrades optical transparency. Deep infections destroy the deep keratocyte matrix, triggering irreversible myofibroblastic transformation and opaque scar deposition.^{15,17}

CONCLUSION

Anterior Segment Optical Coherence Tomography (AS-OCT) fundamentally shifts the paradigm of corneal ulcer management from subjective clinical estimation to precise, objective microstructural quantification. AS-OCT significantly surpasses standard slit-lamp biomicroscopy in delineating the true dimensions of infiltrates, detecting covert

Descemet's membrane involvement, and mapping pathogen-specific necrotic morphologies. The strict quantification of Residual Corneal Thickness (RCT) serves as an indispensable prognostic biomarker. Identifying an RCT of < 250 μ m provides a critical, evidence-based threshold that independently predicts the failure of conservative medical management and flags the imminent risk of global perforation. Integrating AS-OCT into routine clinical practice is imperative to optimize targeted therapy, accurately guide surgical timing, and mitigate severe visual morbidity.

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