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Original Research Article

DIAGNOSTIC EFFICACY OF SLIT-LAMP BIOMICROSCOPY IN THE DETECTION AND CHARACTERIZATION OF ANTERIOR SEGMENT INJURIES AMONG OCULAR TRAUMA PATIENTS: A COMPARATIVE CROSS-SECTIONAL STUDY

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ABSTRACT

Background: Ocular injuries constitute a significant cause of vision impairment globally and demand prompt, accurate diagnosis for optimal clinical management. Slit-lamp biomicroscopy has traditionally served as the primary diagnostic instrument for anterior segment evaluation, though evolving technologies now complement conventional clinical assessment. The objective is to systematically evaluate the diagnostic efficacy and clinical utility of slit-lamp biomicroscopy in identifying, characterizing, and assessing anterior segment injuries among ocular trauma patients, with particular emphasis on injury depth, extent, and anatomical localization.

Materials and Methods: A cross-sectional comparative study was conducted across 55 enrolled patients presenting with documented ocular trauma to the ophthalmology department at a tertiary care institution. Comprehensive clinical history, visual acuity measurement, and systematic anterior segment examination utilizing slit-lamp biomicroscopy were performed for all participants. Demographic variables, injury characteristics, and diagnostic examination findings were systematically recorded and analyzed using descriptive statistical methods. Sensitivity and specificity calculations were performed to evaluate slit-lamp diagnostic performance across various injury categories.

Results: The study cohort demonstrated male predominance (72.7%) with peak incidence in the 31–40-year age group (43.6%, mean 41.6 ± 3.44 years). Penetrating injuries represented the most common mechanism (50.9%), with corneal foreign bodies comprising the largest specific injury category (34.5%). Slit-lamp biomicroscopy demonstrated high sensitivity (0.86) and specificity (0.97) for corneal tear detection. Rusting manifestations predominated among corneal foreign body cases (63.1%), with temporal corneal quadrant involvement most frequently documented (44.1%).

Conclusion: Slit-lamp biomicroscopy remains a reliable, accessible diagnostic modality for anterior segment trauma evaluation, demonstrating excellent diagnostic accuracy for corneal tear and foreign body identification. Integration with complementary imaging techniques enhances diagnostic yield for complex injury scenarios.

Keywords: Anterior segment trauma, Slit-lamp biomicroscopy, Corneal foreign body, Ocular injury diagnosis, Diagnostic imaging modalities.

INTRODUCTION

Eye injuries represent a significant public health challenge, serving as the predominant etiology for acute interventions in ophthalmology worldwide and representing the second most frequent cause of acquired visual disability globally.[1,2] The typical patient profile encompasses young adult males aged 30–35 years.[3,4] The clinical presentation of traumatized patients is often complicated by pain, photophobia, psychological distress, and patient cooperation difficulties, which frequently hinder comprehensive and accurate clinical evaluation. Early and precise diagnosis is fundamental for guiding subsequent clinical management and determining the prognosis of vision recovery.[5] Consequently, accurate categorization of ocular trauma is vital for determining injury severity and selecting appropriate therapeutic interventions. According to the Kuhn classification established in 1996, ocular injuries are stratified into two major categories: non-penetrating injuries without full-thickness disruption and penetrating injuries with tissue discontinuity. Non-penetrating injuries include contusions and superficial lacerations, while penetrating injuries encompass globe rupture and those with foreign body involvement.[6] Anterior segment injuries encompass a diverse spectrum of pathology including corneal epithelial loss, corneal lacerations, hyphema, iris injury, lens dislocation, and thermal or chemical burns.[7] Multiple diagnostic modalities are currently available for evaluating ocular trauma, including computed tomography, magnetic resonance imaging, ultrasonography, ultrasonic biomicroscopy, and optical coherence tomography. Computed tomography, magnetic resonance imaging, and ultrasonography demonstrate utility in identifying intraocular and orbital foreign bodies, whereas ultrasonic biomicroscopy and optical coherence tomography provide superior detailed imaging of anterior segment structures.[8,9] Slit-lamp biomicroscopy has traditionally remained the primary diagnostic instrument for anterior segment evaluation. Although anterior segment optical coherence tomography has emerged as an increasingly valuable diagnostic modality in recent years, slit-lamp biomicroscopy persists as the foundational clinical tool for trauma assessment.[10,11] Anterior segment optical coherence tomography delivers high-resolution imaging of corneal, iris, and anterior chamber architecture, facilitating identification and characterization of anterior segment injuries that may not be apparent during conventional examination alone.

Therefore, this study aims to systematically evaluate the diagnostic efficacy and clinical utility of slit-lamp biomicroscopy in detecting, characterizing, and managing anterior segment injuries in trauma patients.

MATERIALS AND METHODS

This cross-sectional comparative investigation was conducted at the Department of Ophthalmology, at a tertiary care hospital in Indore, Madhya Pradesh. Indore is the largest and most populous urban center in Madhya Pradesh and has been recognized as the cleanest city in India. The study employed a cross-sectional design with prospective enrollment of consecutive patients.

The study was conducted over 12 months following approval from the institutional ethics committee. Written informed consent was obtained from all enrolled participants prior to enrollment. The purpose, objectives, and procedures of the investigation were explained to all participants in their local language to ensure understanding and voluntary participation.

Patients presenting to the Ophthalmology outpatient department or emergency services at the hospital with confirmed clinical signs and history of ocular trauma, with or without intraocular foreign bodies, were eligible for enrollment. Using Cochran's formula (N=4PQ/d^2) with a reported prevalence of anterior segment ocular trauma in India of 2.05%, a prevalence (P) of 2.05%, and a margin of error (d) of 4% at 95% confidence interval, the calculated minimum sample size was 50 patients. The final enrolled sample comprised 55 patients with complete data documentation.

Patients were excluded if they: declined written informed consent; had a history of antecedent ocular pathology that compromised best-corrected visual acuity; presented in poor general medical condition unsuitable for examination; had undergone recent ocular surgery; were less than 10 years of age; or were unable to cooperate with examination procedures.

Following informed consent, a comprehensive clinical history was obtained from each participant, including the mode and mechanism of ocular trauma, the nature of the object causing injury, and the time interval from injury to presentation. Additional relevant information included past ocular and systemic history, current medication use, occupational details, and socioeconomic status.

Standardized visual acuity assessment was performed using Snellen's chart, Tumbling E chart, or Landolt C chart, with best-corrected vision recorded for each eye independently. Gross external examination of the periocular region and anterior eyelid structures was performed using handheld penlight illumination. Anterior segment evaluation was subsequently conducted using slit-lamp biomicroscopy, employing standardized technique and magnification levels. Advanced imaging was performed using anterior segment optical coherence tomography. Radiological investigations including orbital radiography, computed tomography, and magnetic resonance imaging were reserved for

clinically indicated cases based on findings from clinical examination and non-contact imaging.

Operational Definitions

Slit-Lamp Biomicroscopy: Slit-lamp biomicroscopy is a contact optical examination technique that provides binocular, magnified illumination of the anterior ocular segment, enabling direct visualization and assessment of eyelid structures, conjunctival tissues, corneal layers, anterior chamber, iris, and lens. The technique allows qualitative assessment of anterior segment pathology and is considered the gold standard for clinical anterior segment evaluation.[11]

Corneal Tear (Corneal Laceration): A corneal tear represents a partial or full-thickness disruption of corneal tissue architecture resulting from mechanical trauma. Full-thickness lacerations involve disruption of all corneal layers including the epithelium, stroma, and endothelium, potentially with prolapse of intraocular contents. Partial-thickness lacerations involve disruption limited to superficial corneal strata without involving Descemet's membrane or endothelial layer. The Seidel test, utilizing fluorescein staining and observation for aqueous humor leakage, provides evidence of full-thickness involvement.[12]

Corneal Foreign Body: An intraocular foreign body represents any external material embedded within the corneal substance, typically resulting from high-velocity penetrating trauma. Foreign bodies may be classified by composition (metallic versus non-metallic), location (epithelial, stromal, or deeper involvement), size, and orientation. Metallic foreign bodies typically develop a characteristic rust ring within adjacent corneal stroma within several hours. Non-metallic foreign bodies (wooden, organic materials) present different biological responses and removal considerations.[13-15]

Hyphema: Hyphema is defined as the presence of blood or blood-derived elements within the anterior chamber. Quantification traditionally employs the anterior chamber height classification system (grade 1: blood layer <1 mm; grade 2: blood level 1–3 mm; grade 3: blood level >3 mm but less than total chamber; grade 4: total anterior chamber hyphema or "8-ball hyphema"). Hyphema results from disruption of iris or ciliary body vasculature following blunt ocular trauma.[16]

Traumatic Cataract: Traumatic cataract represents lens opacity developing secondary to mechanical ocular trauma. Opacity may develop immediately at the moment of trauma or may progress over days to weeks following injury. Presentations include localized subcapsular opacity at the site of impact, or generalized lens clouding resulting from disruption of lens fiber architecture and protein denaturation.[16,17]

Ocular Chemical Injury: Chemical burns of the ocular surface result from exposure to either acidic or alkaline substances. The severity of chemical injury depends upon the hydrogen ion concentration (pH) of the offending substance, duration of exposure, penetrability of the chemical, and volume of material. Alkali burns generally produce more severe and progressive injury compared to acid burns due to lipophilic and hydrophilic degeneration of cellular membranes through saponification. Initial presentation includes conjunctival erythema, eyelid edema, tear production, and blepharospasm.[18-20]

Corneal Epithelial Defect: Corneal epithelial defect represents disruption of the corneal epithelial layer, exposed on slit-lamp examination as a punctate or confluent area of epithelial loss that stains with fluorescein dye, appearing bright green under cobalt blue illumination.[21,22]

Stromal Edema: Stromal edema is manifested as corneal haziness or opacity resulting from disruption of corneal hydration regulation and accumulation of fluid within the corneal stroma. On slit-lamp examination, this appears as diffuse or localized clouding of the normally transparent stroma.[22,23]

Statistical Analysis: Data were systematically recorded in Microsoft Excel spreadsheets and analyzed using Open Epi software and SPSS statistical package. Continuous variables were described using mean values and standard deviations. Categorical variables were expressed as frequencies and percentages. Associations between categorical variables were evaluated using chi-square test. Independent samples t-testing was employed for comparison of continuous variables between groups. Statistical significance was established at $p < 0.05$ for all analyses.

RESULTS

Table 1: Baseline Socio-demographic and Clinical Characteristics (n=55)

Characteristic	Category	Number (n)	Percentage (%)
Age (years)	10–20	3	5.5
	21–30	9	16.4
	31–40	24	43.6
	41–50	5	9.1
	51–60	6	10.9
	61–70	8	14.5
	Mean ± SD	41.6 ± 3.44 years	—
Gender	Male	40	72.7
	Female	15	27.3
Eye Involved	Left	38	69.0
	Right	17	30.9

Type of Injury	Penetrating	28	50.9
	Blunt trauma	13	23.6
	Chemical injury	9	16.3
	Other	5	9.0
Anterior Segment Structure Involved	Cornea	37	67.2
	Cornea-sclera	6	10.9
	Conjunctiva	5	9.1
	Hyphema	4	7.3
	Lens	3	5.4
Total		55	100

[Table 1] depicts the baseline sociodemographic and clinical characteristics of the 55 enrolled study participants. The predominance of ocular injuries was observed in the 31–40-year age group (43.6%), with a mean age of 41.6 ± 3.44 years. A marked male predominance was evident, comprising 72.7% of the study population. The left eye was affected more frequently (69.0%) compared to the right eye (30.9%), and penetrating injuries represented the most common mechanism of injury (50.9%).

Table 2: Slit-Lamp Biomicroscopy Findings in Corneal Foreign Body Cases

Slit-Lamp Findings	Number of Cases (n = 19)	Percentage (%)
Rusting	12	63.1
Pigmentation	4	21.0
Vascularization	3	15.8

[Table 2] demonstrates the distribution of slit-lamp biomicroscopy findings in 19 cases of corneal foreign bodies. Rusting was the predominant finding (63.1%), indicating the high prevalence of metallic foreign bodies and the typical corneal tissue response to metallic oxidation. Pigmentation (21.0%) and vascularization (15.8%) were observed in fewer cases, suggesting longer-standing or chronic inflammatory responses. [Table 2]

Table 3: Depth of Corneal Involvement Detected by Slit-Lamp Biomicroscopy

Depth of Corneal Involvement	Corneal Foreign Body (n = 19)	Corneal Tear (n = 7)
Epithelium	13 (68.4)	0 (0.0)
Bowman's Layer	1 (5.2)	0 (0.0)
Stroma	5 (26.3)	2 (28.6)
Descemet's Membrane	0 (0.0)	0 (0.0)
Endothelium	0 (0.0)	5 (71.4)
Total	19 (100)	7 (100)

[Table 3] presents the depth-wise distribution of anterior segment involvement as detected by slit-lamp biomicroscopy in corneal foreign bodies and corneal tears. In corneal foreign body cases, 68.4% were localized to the epithelial layer, while 26.3% extended into the stromal layer. In contrast, corneal tears demonstrated a distinctly different pattern, with 71.4% affecting the endothelium and 28.6% involving the stroma, reflecting deeper penetration of traumatic lacerations compared to superficial foreign bodies. [Table 3]

Table 4: Comparison of Slit-Lamp Biomicroscopy Performance in Detecting Anterior Segment Injuries

Injury Type	Slit-Lamp Sensitivity	Slit-Lamp Specificity
Penetrating Injuries		
Corneal tear	0.86	0.97
Corneal foreign body	0.84	0.95
Blunt Trauma		
Hyphema	0.70	0.92
Traumatic cataract	0.60	0.91
Chemical Injuries		
Corneal endothelitis	0.55	0.88
Stromal edema	0.40	0.80
Corneal neovascularization	0.50	0.89

[Table 4] presents the diagnostic performance metrics of slit-lamp biomicroscopy across various types of anterior segment injuries. Slit-lamp examination demonstrated the highest sensitivity (0.86) and specificity (0.97) for detecting corneal tears, indicating excellent diagnostic capability for this injury type. Sensitivity for corneal foreign body detection was also high (0.84), with outstanding specificity (0.95). For blunt trauma findings, hyphema detection showed good sensitivity (0.70) and specificity (0.92), whereas traumatic cataract exhibited lower sensitivity (0.60). In chemical injuries, stromal edema demonstrated the lowest sensitivity (0.40), suggesting that subtle edematous changes may evade clinical detection on slit-lamp

examination in the presence of corneal opacity. [Table 4]

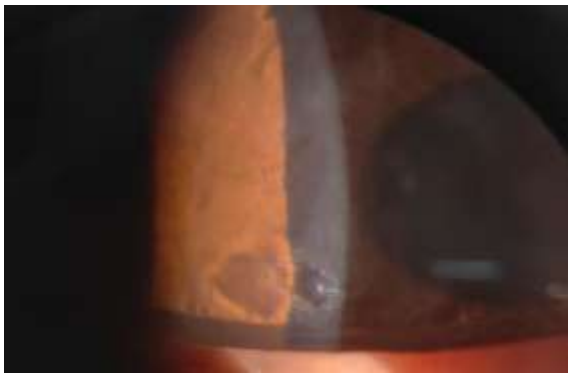

Figure 1: Slit-Lamp Biomicroscopy of an Occupational Corneal Injury

[Figure 1] illustrates a discrete, opaque foreign body embedded within the corneal surface of a factory worker with a history of trauma during aluminium cutting. A distinct epithelial defect is visible surrounding the object, accompanied by localized stromal haze, which indicates an acute inflammatory response and peri-lesional edema.

Figure 2: Clinical Presentation of a Self-Sealed Corneal Laceration with Traumatic Cataract.

[Figure 2] demonstrates Slit-lamp examination of a 46-year-old agricultural worker reveals a corneal laceration situated in the superior quadrant. The wound demonstrated a negative Seidel test upon evaluation, indicating no active aqueous leakage. Additionally, dense lenticular opacification is evident through the pupil, confirming the diagnosis of a concurrent traumatic cataract.

Figure 3: AS-OCT picture of corneal foreign body-2.

[Figure 3] demonstrates the AS-OCT picture of the same foreign body embedded at epithelial level, showing hyperreflectivity with posterior shadowing. Also note that epithelial layer is missing in the area in close vicinity of foreign body, suggestive of epithelial defect around foreign body.

Figure 4: AS-OCT of the same case of corneal tear.

[Figure 4] depicts full-thickness involvement of cornea, hyperreflectivity can be seen across the whole depth of tear and seidel's test was negative, arising suspicion of impacted foreign body in the tear. Also, hyperreflectivity can be noted in the deeper layers (posterior stroma and endothelium), suggestive of edema.

Quantitative Assessment of Corneal Injury Depth

Among the 19 patients with corneal foreign bodies evaluated in this study, AS-OCT provided quantitative measurements demonstrating a mean depth of foreign body penetration of 200.6 ± 212.92 micrometers (μm), with statistical significance ($p = 0.001$). In the 7 cases of corneal tears, AS-OCT measurements revealed a mean depth of 448.6 ± 182.93 μm, also achieving statistical significance ($p = 0.001$). These quantitative measurements underscore the clinical relevance of objective assessment in guiding surgical decision-making and prognosis determination for anterior segment trauma management.

DISCUSSION

Among the 55 enrolled ocular trauma patients, the 31–40-year age cohort demonstrated the highest

disease burden (43.6%), with a mean age of 41.6 ± 3.44 years. This temporal distribution parallels epidemiological patterns documented in anterior segment injury literature. Wylegala et al. (2009) documented a comparable mean patient age of 33.8 years in anterior segment injury cohorts, while Sukrati et al. (2015) emphasized that anterior segment trauma predominantly affects younger individuals engaged in high-risk occupational activities.[1,24] Murlidhar et al. (2013) similarly demonstrated peak incidence in 30–50-year-old males, attributable to increased environmental hazard exposure in industrial and construction sectors.[25] However, Dalal et al. (2018) reported a higher mean age of 48.3 ± 13.9 years in a non-trauma population, highlighting the distinction between trauma and non-trauma cohorts.[26] Ryan et al. (2013) documented variable age distribution in combat-related trauma, reflecting heterogeneous military personnel demographics.[27]

A pronounced male predominance emerged in this analysis, with males comprising 72.7% of cases compared to females at 27.3%. This gender disparity corroborates findings from Ryan et al. (2013), who attributed elevated male trauma susceptibility to exposure in military and occupational high-risk environments.[27] Wylegala et al. (2009) similarly documented male preponderance, attributing this to increased participation in high-risk recreational and occupational pursuits.[1] Sukrati et al. (2015) emphasized behavioral and societal factors predisposing males to manual labor, industrial tasks, and physically demanding employment.[24] Dinc et al. (2015) corroborated this trend in slit-lamp optical coherence tomography trauma evaluation studies, demonstrating consistent male predominance across diverse trauma-related ophthalmic investigations.[10]

Penetrating injuries constituted the dominant trauma mechanism (50.9%), followed by blunt trauma (23.6%) and chemical injuries (16.3%). Sukrati et al. (2015) emphasized the prevalence and severity of open globe injuries with penetrating lacerations, frequently resulting in significant visual morbidity through corneal and scleral involvement.[24] Ryan et al. (2013) highlighted penetrating injury predominance in combat scenarios, particularly from high-velocity projectiles and explosive fragments.[27] Wylegala et al. (2009) similarly documented anterior segment trauma predominantly resulting from penetrating mechanisms involving sharp objects and shrapnel, emphasizing the deeper corneal involvement characterizing such injuries.[1]

Slit-lamp biomicroscopy demonstrated excellent diagnostic performance for corneal tears, achieving sensitivity of 0.86 and specificity of 0.97, indicating reliable anterior segment injury detection. Ryan et al. (2013) acknowledged slit-lamp examination as essential for initial evaluation while emphasizing anterior segment optical coherence tomography's superior visualization of tissue depth in complex trauma scenarios, allowing enhanced stromal and endothelial delineation often underappreciated on slit-lamp examination.[27] Wylegala et al. (2009) demonstrated that slit-lamp biomicroscopy may fail detecting microstructural damage including Descemet's membrane rupture or endothelial discontinuity in corneal edema or opacity contexts, while anterior segment optical coherence tomography facilitated accurate layer-by-layer assessment.[1] Bhargava et al. (2022) supported anterior segment optical coherence tomography's enhanced diagnostic capability for intracorneal foreign body identification and localization, emphasizing slit-lamp effectiveness limitations in poor visibility or irregular ocular surface contexts, rendering anterior segment optical coherence tomography a valuable complementary modality.[28]

Corneal foreign bodies represented the most frequent specific injury (34.5%), consistent with findings from Bhargava et al. (2022), who documented corneal foreign bodies among most frequently encountered anterior segment injuries in outpatient ophthalmology settings, emphasizing anterior segment optical coherence tomography utility in detecting precise depth and location for surgical planning.[28] Murlidhar et al. (2013) similarly demonstrated corneal foreign bodies as the largest anterior segment trauma proportion, with chemical injury and corneo-scleral tears following in frequency. Rusting manifestations dominated slit-lamp findings (63.1%), indicating prevalent metallic foreign body involvement. Quantitative anterior segment optical coherence tomography measurements revealed mean corneal tear depth of 448.6 ± 182.93 micrometers and mean foreign body penetration depth of 200.6 ± 212.92 micrometers ($p = 0.001$), demonstrating statistically significant clinical relevance.[25] Bhargava et al. (2022) reported most superficial foreign bodies lodged within 150–250 micrometer depth, consistent with this study's findings, emphasizing depth assessment criticality in determining surgical versus conservative management appropriateness.[28]

CONCLUSION

Slit-lamp biomicroscopy remains a reliable, widely available diagnostic instrument for anterior segment ocular trauma assessment, demonstrating high sensitivity (0.86) and specificity (0.97) for corneal tear detection. Corneal foreign bodies represent the predominant injury type (34.5%), predominantly affecting the temporal corneal quadrant (44.1%). While slit-lamp effectively identifies traumatic pathology, anterior segment optical coherence tomography provides complementary objective, quantitative assessment of injury depth and extent, particularly for complex trauma cases requiring precise preoperative evaluation and prognostication.

Recommendations

Routine slit-lamp biomicroscopy should be incorporated as the primary anterior segment evaluation modality in ocular trauma management;

anterior segment optical coherence tomography should supplement slit-lamp examination for complex injury scenarios requiring precise depth and structural assessment.

Strengths and Limitations

Large sample size (n = 55), systematic data collection across multiple injury types, detailed demographic and clinical characterization, quantitative assessment of diagnostic modality performance metrics.

Single-center design limits generalizability; participant population restricted to individuals ≥10 years old; retrospective injury mechanism characterization subject to recall bias; absence of long-term visual outcome follow-up data; anterior segment optical coherence tomography unavailability in resource-limited settings restricts real-world applicability.

Relevance of Study

Establishes slit-lamp biomicroscopy's diagnostic utility in anterior segment trauma evaluation, guides clinical decision-making regarding imaging modality selection, emphasizes importance of standardized trauma assessment protocols in improving patient outcomes.

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