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Research Article

Forensic and Clinical Evaluation of Orbital Morphometry, Ocular Physiological Dysfunction, and Injury Severity as Predictors of Visual Outcomes Following Orbital Fracture Reconstruction

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ABSTRACT

Background: Orbital fractures may cause persistent visual dysfunction despite successful anatomical reconstruction. Combining radiological morphometry with ocular physiological assessment and injury severity may improve prediction of postoperative visual recovery.

Objective: To evaluate orbital morphometric parameters, ocular physiological dysfunction, and injury severity as predictors of visual outcomes following orbital fracture reconstruction.

Methods: This prospective observational study included 100 adults with unilateral traumatic orbital fractures treated at Amna Inayat Medical College, Sheikhupura, Pakistan, from January 2024 to December 2025. Preoperative computed tomography was used to assess fracture defect area, orbital volume difference, herniated tissue volume, and fracture displacement. Ophthalmic evaluation included best-corrected visual acuity, pupillary responses, color vision, diplopia, intraocular pressure, and extraocular movements. Patients were followed for three months—multivariable logistic regression identified independent predictors of unfavorable visual outcome.

Results: Seventy-six patients achieved favorable visual recovery, whereas 24 had unfavorable outcomes. Poor outcomes were associated with larger fracture defects, greater orbital volume difference, increased tissue herniation, impaired preoperative visual acuity, relative afferent pupillary defect, and marked extraocular movement restriction. Independent predictors included relative afferent pupillary defect, orbital volume difference ≥15%, moderate-to-marked motility restriction, high injury severity, preoperative BCVA >0.50 logMAR, and reconstruction after 14 days. The combined model showed good discrimination and supported the complementary prognostic value of structural and functional parameters in postoperative visual assessment.

Conclusion: Integrated assessment of orbital structure, ocular physiology, and injury severity may improve prognostic stratification, surgical decision-making, patient counseling, and surveillance after orbital fracture reconstruction.

Keywords: Orbital Fracture, Orbital Morphometry, Visual Outcome, Ocular Dysfunction, Computed Tomography, Injury Severity, Forensic Medicine, Orbital Reconstruction.

INTRODUCTION

Orbital fractures are clinically important craniofacial injuries because even apparently localized disruption of the orbital walls may produce persistent impairment of vision, ocular alignment, and globe position[1]. These fractures are often sustained as a result of road traffic accidents, interpersonal violence, falls, work-related accidents, and sporting injuries, and are often in the orbital floor and medial wall. Surgical reconstruction is performed to restore the orbital anatomy and decompress entrapped soft tissues, but the recovery of visual function is not the same in all cases. Even with technically satisfactory reconstruction, some patients recover satisfactory ocular function, while others suffer from decreased visual acuity, diplopia, limited extraocular movements, enophthalmos, and/or other functional problems[2].

Computed tomography has been the mainstay of determining the location, size of the orbital defect, displacement, herniation of soft tissue, and change in orbital volume in the evaluation of orbital trauma[3]. Quantitative Orbital morphometry could give more prognostic information than conventional descriptive radiology. Various parameters like fracture defect area, relative orbital volume expansion, amount of wall displacement, and volume of herniated orbital contents are measures of the structural severity of the injury and may affect postoperative globe position and functional results. Although anatomical measurements might be a good indicator of the degree of damage to the eye or neuro-ophthalmic system at the time of the injury, however[4].

It is therefore essential to assess the physiology of the eye. Abnormal visual acuity, pupillary responses, color vision, intraocular pressure, ocular motility, or diplopia suggest possible functional impairment of the globe, extraocular muscles, optic nerve, or the orbital tissues[5]. However, RAPD, severe limitation of ocular movement, and significant preoperative visual loss may identify patients who are more likely to have a persistent postoperative defect. Combining these physiological data with radiological morphometry might lead to a more complete prediction of visual outcome than either technique alone[6].

Orbital trauma also has great forensic significance as the mechanism, direction, and force of impact can affect fractural configuration and associated ocular trauma[7]. Documentation of injury pattern, fracture severity, associated facial trauma, and resultant functional impairment is important and should be objectively documented both for clinical decision-making and medicolegal assessment. Although these factors are important, few studies have investigated the orbital morphometry, physiological dysfunction of the eye and injury characteristics from a forensic perspective in a unified prognostic framework[8,9]. The present study was thus aimed at investigating these parameters as potential predictors of the visual outcome after orbital fracture reconstruction and to determine clinically meaningful factors that were associated with poor visual outcome after orbital fracture reconstruction.

MATERIALS AND METHODS

Study Design and Setting

A prospective observational study was conducted at Amna Inayat Medical College, Sheikhupura, Pakistan, from January 2024 to December 2025. A total of 100 patients with traumatic orbital fractures who underwent orbital fracture reconstruction during the study period were enrolled using consecutive sampling. This study aimed at assessing if eye morphological features, physiological impairment of ocular function, and severity of injury could predict the postoperative visual outcome.

Patient Selection

Inclusion criteria involved patients over 18 years of age with confirmed unilateral orbital fracture on CT which required surgical reconstruction. Surgical indications were persistent double vision despite radiological proof of soft-tissue entrapment, significant restriction of eye movements, obvious enophthalmos, significant displacement of the globe, or large orbital wall defects or herniation of orbital contents. Patients with bilateral orbital fracture, previous orbital or craniofacial surgery, severe visual impairment preoperatively, congenital orbital deformities, orbital tumors, penetrating globe injuries necessitating primary globe repair, or incomplete clinical and/or radiological data were excluded.

Forensic and Injury Assessment

A structured data-collection form was used to record the demographic characteristics, mechanism of trauma, circumstances of trauma, anatomical site of fracture, associated facial injuries, and interval between trauma and reconstruction. Mechanisms of injury could be classified as either road traffic collision, interpersonal assault, fall, occupational injury, or sports-related trauma. The severity of the injury was determined based on the number of orbital walls fractured, displacement of the fracture, the presence of comminution, herniation of the soft tissue, and the presence of midfacial fractures. From the findings, injuries were classified as mild, moderate, or severe for comparison.

Orbital Morphometric Assessment

Thin-section computed tomography scans of the orbit were reviewed in a three-dimensional manner preoperatively (axial, coronal, and sagittal planes). The other orbit (contralateral) was used as an internal anatomical landmark. Morphometric parameters were the area of the orbital fracture defect, the volume of the injured orbit, contralateral orbit volume, relative volume difference of the orbits, the largest fragment orbital displacement, number of orbital walls fractured, and volume of orbital tissue herniated. The relative difference in orbital volume was determined as a percentage difference between the injured and unaffected orbital volumes. To minimize the variability in measurements, all the radiological measurements were done using standardized multiplanar CT images.

Ocular Physiological Evaluation

A thorough ophthalmological examination was undertaken before surgery. Best-corrected VA was obtained by calculating the VA using a standard visual acuity chart and converted to logMAR for statistical analysis. Pupillary size and pupillary light reflexes, relative afferent pupillary defect, color vision, intraocular pressure, ocular alignment, diplopia, and extraocular movements were assessed. Restriction of extraocular movement was classified as none, mild, moderate, or marked. Diplopia was recorded independently in primary and eccentric gaze positions. The globe position and the presence of clinically obvious enophthalmos were also noted.

Surgical Reconstruction

Depending on the site and size of the fracture, orbital reconstruction was carried out. Surgical exposure was achieved using an appropriate transconjunctival, subtarsal, or combined approach. The entrapped orbital tissues were carefully dissected free, the margins of the fracture were identified, and then reconstruction of the orbital defect was accomplished using the appropriate implant based on the defect size and surgeon choice. Intraoperatively, before wound closure, restoration of orbital contour and unrestricted movement of the globe were assessed.

Postoperative Follow-up and Outcome Assessment

Patients were assessed postoperatively in the early recovery phase and at around 30 days and 90 days post-reconstruction. Postoperative complications, enophthalmos, globe position, diplopia, pupillary response, ocular motility, and best-corrected visual acuity were assessed at follow-up. Visual status at 3 months was the primary outcome. A poor visual outcome was considered final BCVA worse than 0.30 logMAR and/or more than 2 lines reduction of visual acuity from the baseline or from the appropriate reference eye. Diplopia and clinically significant enophthalmos were assessed as secondary functional outcomes.

Statistical Analysis

The data were analyzed using IBM SPSS Statistics. Categorical data were presented as frequencies and percentages, and continuous data were expressed as either mean ± standard deviation or median with interquartile range depending on data distribution. Patients were split into a favorable and an unfavorable visual-outcome group. Independent-samples t-test or Mann–Whitney U test was used to compare continuous variables, and chi-square test or Fisher's exact test was used to compare categorical variables, as appropriate. All variables that were clinically relevant or that showed significant univariable association with visual outcome were included in the multivariable logistic regression analysis to determine independent predictors of poor visual recovery. Adjusted odds ratios (ORs) and 95% confidence intervals (CIs) were reported. Receiver operating characteristic analysis was used to assess the discriminatory performance of the final predictive model. A p-value <0.05 was considered statistically significant.

Ethical Considerations

The study was carried out in compliance with the ethical principles of the Declaration of Helsinki. Approval was obtained from the relevant institutional ethical review committee of Amna Inayat Medical College, Sheikhupura, Pakistan, before commencement of the study. All participants provided written informed consent, and patient confidentiality was respected during data collection, analysis, and reporting.

RESULTS

A total of 100 patients with unilateral traumatic orbital fractures who underwent surgical reconstruction were included in the analysis. The age of the study population had a mean of 35.2 ± 12.1 years. Among the participants, 73 (73.0%) were male, and 27 (27.0%) were female. The 76 patients (76.0%) had a favourable outcome at 3-month follow-up, while there were 24 patients (24.0%) with an unfavourable outcome. Road traffic collisions were the commonest mechanism of injury, accounting for 40.0% of cases, followed by interpersonal assault (30.0%), falls (20.0%), and occupational or sports-related injuries (10.0%). There was no significant relationship between age and sex and visual outcome. However, complex fracture patterns, midfacial fractures, high anatomical injury severity, and reconstruction over 14 days after trauma were significantly more common in patients with less favorable visual recovery (Table 1).

Table 1. Demographic, Forensic, and Injury Characteristics According to Visual Outcome

Variable	Total (n=100)	Favorable outcome (n=76)	Unfavorable outcome (n=24)	p-value
Age, years	35.2 ± 12.1	34.4 ± 11.7	37.8 ± 13.1	0.229
Sex				0.802
Male	73 (73.0%)	55 (72.4%)	18 (75.0%)	—
Female	27 (27.0%)	21 (27.6%)	6 (25.0%)	—
Mechanism of injury				0.318
Road traffic collision	40 (40.0%)	28 (36.8%)	12 (50.0%)	—
Interpersonal assault	30 (30.0%)	22 (28.9%)	8 (33.3%)	—
Fall	20 (20.0%)	17 (22.4%)	3 (12.5%)	—
Occupational/sports injury	10 (10.0%)	9 (11.8%)	1 (4.2%)	—
Fracture pattern				0.018
Isolated orbital floor fracture	40 (40.0%)	36 (47.4%)	4 (16.7%)	—
Floor + medial-wall fracture	32 (32.0%)	21 (27.6%)	11 (45.8%)	—
Other/complex orbital fracture	28 (28.0%)	19 (25.0%)	9 (37.5%)	—
Associated midfacial fracture	36 (36.0%)	23 (30.3%)	13 (54.2%)	0.031
High anatomical injury severity	25 (25.0%)	12 (15.8%)	13 (54.2%)	<0.001
Reconstruction >14 days after trauma	27 (27.0%)	16 (21.1%)	11 (45.8%)	0.017

Unfavorable visual outcomes had significantly higher structural orbital disruption on the pre-operative CT. The mean fracture defect area in the unfavorable group was significantly larger (2.74 ± 0.81 cm²) than that in the favorable group (1.86 ± 0.62 cm², $p<0.001$). ROVD was also significantly greater in patients with unfavorable outcomes (18.2 ± 5.8% vs. 10.1 ± 4.3%, $p<0.001$), and the volume of herniated tissue and the maximum fracture displacement were also significantly different. The unfavorable group showed more abnormalities in the ocular physiology. The mean preop BCVA in the patients with favourable recovery was 0.29 ± 0.21 logMAR, whereas in the remaining patients it was 0.68 ± 0.34 logMAR. Relative afferent pupillary defect, abnormal color vision, moderate-to-marked extraocular movement restriction, and primary-gaze diplopia were all significantly associated with unfavorable postoperative vision, whereas elevated intraocular pressure was not significantly different between the groups (Table 2).

Table 2. Orbital Morphometric and Preoperative Ocular Physiological Findings

Variable	Favorable outcome (n=76)	Unfavorable outcome (n=24)	p-value
Fracture defect area, cm²	1.86 ± 0.62	2.74 ± 0.81	<0.001
Relative orbital volume difference, %	10.1 ± 4.3	18.2 ± 5.8	<0.001
Herniated orbital tissue volume, mL	1.32 ± 0.58	2.27 ± 0.75	<0.001
Maximum fracture displacement, mm	4.0 ± 1.5	5.9 ± 1.9	<0.001
Preoperative BCVA, logMAR	0.29 ± 0.21	0.68 ± 0.34	<0.001
Relative afferent pupillary defect	5 (6.6%)	9 (37.5%)	<0.001
Abnormal color vision	8 (10.5%)	9 (37.5%)	0.002
Moderate/marked EOM restriction	19 (25.0%)	14 (58.3%)	0.003
Primary-gaze diplopia	15 (19.7%)	10 (41.7%)	0.029
Intraocular pressure >21 mmHg	7 (9.2%)	3 (12.5%)	0.698

BCVA: best-corrected visual acuity; **EOM:** extraocular movement.

Orbital fracture reconstruction resulted in progressive improvement in both visual acuity and ocular function during follow-up. Mean BCVA improved from 0.38 ± 0.31 logMAR preoperatively to 0.23 ± 0.25 logMAR at one month and 0.17 ± 0.20 logMAR at three months (p<0.001). Any diplopia was reported in 44.0% of patients before surgery, 25.0% after 1 month, and 14.0% after 3 months. Primary-gaze diplopia decreased from 25.0% to 7.0%, and moderate to marked restriction of extraocular movement decreased from 33.0% to 10.0%. In a similar fashion, the incidence of clinically significant enophthalmos (2 mm or more) was reduced from 24.0% before surgery to 7.0% at three months. Overall, 76.0% of patients achieved a favorable visual outcome at final follow-up, while 24.0% continued to demonstrate unfavorable visual recovery (Table 3).

Table 3. Visual and Functional Outcomes Following Orbital Fracture Reconstruction

Outcome	Preoperative	1 month	3 months	p-value
BCVA, logMAR	0.38 ± 0.31	0.23 ± 0.25	0.17 ± 0.20	<0.001
Any diplopia	44 (44.0%)	25 (25.0%)	14 (14.0%)	<0.001
Primary-gaze diplopia	25 (25.0%)	13 (13.0%)	7 (7.0%)	<0.001
Moderate/marked EOM restriction	33 (33.0%)	18 (18.0%)	10 (10.0%)	<0.001
Enophthalmos ≥2 mm	24 (24.0%)	10 (10.0%)	7 (7.0%)	<0.001
Favorable visual outcome	—	—	76 (76.0%)	—
Unfavorable visual outcome	—	—	24 (24.0%)	—

Multivariable logistic regression found a number of independent predictive factors of poor visual outcome at three months. The strongest physiologic predictor was relative afferent papillary defect, and this was associated with a 5.5-fold increase in the adjusted odds of poor visual recovery. A relative orbital volume difference of ≥15% resulted in a greater than fourfold increase in the adjusted odds. The presence of moderate to marked EOM restriction and high anatomical injury severity was associated with nearly three times the odds of poor outcome. Other factors independently associated with poor visual recovery were poor BCVA at presentation (>0.50 logMAR) and reconstruction performed more than 14 days after the trauma. The combined predictive model had good discriminatory ability and had an area under the receiving operating characteristic curve of 0.86 (95% CI: 0.78–0.93) (Table 4).

Table 4. Multivariable Logistic Regression Analysis of Predictors of Unfavorable Visual Outcome

Predictor	Adjusted OR	95% CI	p-value
Relative afferent pupillary defect	5.48	1.58–18.96	0.007

Relative orbital volume difference ≥15%	4.21	1.49–11.90	0.007
Moderate/marked EOM restriction	3.36	1.22–9.27	0.019
High anatomical injury severity	3.12	1.08–9.01	0.035
Preoperative BCVA >0.50 logMAR	2.94	1.05–8.22	0.040
Reconstruction >14 days after trauma	2.71	1.00–7.34	0.049

OR: odds ratio; **CI:** confidence interval; **BCVA:** best-corrected visual acuity; **EOM:** extraocular movement.

DISCUSSION

The present study evaluated orbital morphometry, ocular physiological dysfunction, and injury severity as predictors of visual recovery following orbital fracture reconstruction[1]. The main conclusion was that poor postoperative visual outcome correlated with high structural orbital disruption, as well as worse visual function preoperatively. The independent factors associated with poor recovery were determined to be relative afferent papillary defect, relative orbital volume difference ≥15%, moderate-to-marked extraocular movement restriction, high anatomical injury severity, poor preoperative visual acuity, and reconstruction performed beyond 14 days of trauma. These data argue for a multimodal radiological/physiological method for prognosis, not based on fracture morphology alone[2,3].

There was a strong association of orbital morphometric parameters with outcome. Patients with unfavorable visual recovery had larger fracture defects, more relative orbital volume expansion, more herniation of orbital contents, and more fracture displacement[4]. Previous studies have demonstrated that enlargement of orbital volume after trauma contributes to globe malposition and enophthalmos and that restoration of orbital volume is an important objective of reconstruction.5-8 The present findings extend this concept by suggesting that pronounced orbital volume alteration may also serve as a marker of overall injury severity and may help identify patients at increased risk of persistent visual dysfunction[5].

Of these abnormalities, particularly important were those of the ocular physiology. In the absence of other factors, the most significant independent factor associated with poor visual outcome was relative afferent pupillary defect, which may suggest more severe injury to the eye or optic nerve[6]. Poor BCVA has also been shown to be a significant predictor of outcome in earlier studies, highlighting the importance of formal visual assessment early on in the course of treatment in patients with orbital fractures.11-14 Abnormal pupillary responses were also important predictors of serious ocular injury[7].

The other factors significantly related to poor postoperative recovery were extraocular movement restriction and diplopia. Restriction can be due to muscle capture, edema, contusion, ischemia, fibrosis, or nerve injury[8]. Previous studies have reported that preoperative motility limitation and combined orbital wall fractures increase the risk of persistent postoperative diplopia.9,15 In the present study, moderate-to-marked motility restriction increased the adjusted odds of unfavorable visual outcome by more than threefold, supporting careful functional assessment before surgical intervention[9].

Another independent predictor was high anatomical injury severity. There was an increased risk of unfavorable recovery in patients with complex fractures and concurrent midfacial trauma[10]. The amount of skeletal disruption would seem to correlate with the amount of traumatic force transmitted and the possibility for concomitant soft tissue or neuro-ophthalmic injury. Objective evidence of fracture complexity, facial injury, and physiological impairment may consequently be more useful in a medicolegal context than the mechanism of injury alone, from a forensic point of view[11].

Timing of reconstruction was also clinically important. Reconstruction >14 days post-trauma was correlated with a higher risk of poor outcome[12]. Without prompt treatment, fibrosis of the eye and ongoing entrapment of the tissue by extraocular muscles may occur, decreasing the chance for full functional recovery. However, the timing of surgery should still be individualized since not every orbital fracture needs urgent surgical intervention, and should take into account the status of the vision and eye movements, the position of the globe, the size of the fracture and associated injuries[13].

The mean visual acuity, diplopia, extraocular movement limitation and enophthalmos were all significantly improved after surgery.

However, 24% continued to show unfavourable visual outcome at three months[14,15]. This discovery underscores the fact that a technically successful reconstruction does not necessarily undo the effects of the initial ocular/neuro-ophthalmic trauma. The combined predictive model presented good discrimination, indicating that the combination of morphometric, physiological, and injury-severity data could be beneficial in early risk stratification[16,17].

There are a number of limitations in this study. It was carried out at a single institution, and a moderate sample size was included, with only patients undergoing surgical reconstruction. The results are therefore not necessarily applicable to those treated conservatively[18,19]. Imaging technique and observer variability may also be a factor in orbital volume and fracture-area measurements. Also, a 3-month follow-up period might not adequately reflect long-term changes in diplopia, globe position, and visual function. There is a need for larger multicenter studies with longer follow-up and external validation of the predictive model[20].

CONCLUSION

The visual outcome after orbital fracture reconstruction is dependent upon the combination of structural damage to the orbit and physiological dysfunction of the eye. Independent factors predicting poor visual recovery were relative afferent papillary defect, an orbital volume difference of ≥15%, and marked restriction of extraocular movements, high anatomical injury severity, poor visual acuity at presentation, and delayed reconstruction. Combining quantitative CT-based orbital morphometry with standardized ophthalmic exam and medicolegal injury evaluation may help enhance the accuracy of prognosis, prioritization of surgical procedures, medicolegal documentation, and help identify patients at increased risk for postoperative monitoring.

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

Data Availability: Data are available from the corresponding author upon reasonable request.

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Author Contributions: MAA and SA conceived and designed the study. MYK and AUH contributed to clinical, forensic, and ophthalmological assessment. HH and NS contributed to data collection, analysis, and interpretation. MAA and SA drafted the manuscript. All authors critically reviewed and approved the final manuscript.

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