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**Research Article**

# Forensic, Anatomical, and Physiological Predictors of Visual Outcomes Following Surgical Management of Orbital Trauma. A Clinical Study

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## ABSTRACT

**Background:** Orbital trauma can produce persistent visual impairment through bony disruption, optic nerve injury, soft-tissue entrapment, and ocular physiological dysfunction. Identifying early predictors of visual recovery may improve surgical planning and medico-legal assessment.

**Objective:** To determine forensic, anatomical, and physiological predictors of visual outcome following surgical management of orbital trauma.

**Methods:** This prospective observational study included 80 patients treated at Amna Inayat Medical College, Sheikhupura, Pakistan, from April 2024 to April 2025. Mechanism and severity of injury, computed tomography findings, best-corrected visual acuity, pupillary responses, color vision, intraocular pressure, ocular motility, and diplopia were recorded. Visual outcome was assessed three months after surgery. Multivariable logistic regression identified independent predictors of unfavorable recovery.

**Results:** Favorable visual outcome was achieved in 54 patients (67.5%), while 26 (32.5%) had unfavorable recovery. Severe injury, associated facial fractures, multiple-wall fractures, globe displacement, orbital volume alteration, optic canal involvement, retrobulbar hematoma, impaired color vision, marked ocular motility restriction, and persistent diplopia were significantly associated with poorer outcomes. Relative afferent pupillary defect was the strongest independent predictor of unfavorable recovery (adjusted OR 7.21), followed by optic canal involvement (adjusted OR 5.63), preoperative visual acuity worse than 0.70 logMAR (adjusted OR 4.48), severe injury, and surgery performed more than 14 days after trauma.

**Conclusion:** Visual prognosis after orbital trauma depends on injury severity, orbital anatomy, and ocular physiological function. Early recognition of optic nerve dysfunction and posterior orbital involvement may support timely surgery, prognostic counseling, and forensic documentation.

**Keywords:** Orbital Trauma, Visual Outcome, Orbital Fracture, Forensic Medicine, Optic Canal, Ocular Physiology, Traumatic Optic Neuropathy.

## INTRODUCTION

Orbital trauma is an important cause of visual impairment and facial morbidity, with consequences extending beyond immediate ocular injury to functional disability, cosmetic deformity, and medico-legal concerns[1]. The globes, optic nerves, extraocular muscles, ophthalmic vessels, and several cranial nerves are housed in a limited bony orbit. Due to this complicated structure, apparently localized trauma can cause significant physiological and neurological dysfunction. Therefore, the final visual outcome following surgical management can rely on more than just the ability to repair the fracture; the severity of, and distribution of, associated ocular and neurovascular injury can also be a significant factor[2].

Forensically, the direction, mechanism, and magnitude of force can affect the type of orbital damage and the severity of it[3]. Orbital wall

fractures, soft-tissue disruption, globe displacement, and optic nerve injury can occur in varying combinations from road traffic collisions, interpersonal violence, falls, occupational injury, and penetrating injury. It is important to document these findings accurately, especially in a medico-legal case, as the level of residual visual impairment could be a factor in determining the severity of the injury, long-term disability, and functional loss[4].
The anatomic features of orbital trauma are very much linked to recovery after surgery. In fractures of the orbital floor and medial wall, there is the potential for herniation of orbital contents, extraocular muscle entrapment, diplopia, enophthalmos, and altered orbital volume[5]. Fractures that involve multiple walls, the orbital apex, or the orbital optic canal may be more likely to be associated with persistent vision loss due to their relationship with the optic nerve and neurovascular structures. Computed tomography is thus a necessary technique to evaluate fracture morphology and identify anatomical features which may impact surgery and prognosis[6].
Physiological assessment gives extra information that is not possible from imaging only. Preoperative visual acuity, pupillary response, colour vision, intraocular pressure, ocular motility, and presence of diplopia may provide clues to the integrity of the globe, optic nerve, and extraocular muscles. The presence of a relative afferent pupillary defect, a marked decrease in visual acuity, a defect in color perception, and a failure of movement to improve may be a sign of more extensive functional loss and may be a predictor of poor postoperative visual function despite successful reconstruction[7-9].
While previous research has investigated single radiological or ophthalmological predictors of post-orbital fracture repair outcomes, few studies have combined forensic, anatomical injury, and physiological dysfunction in a single clinical evaluation[10]. The aims of the present study were therefore to examine the forensic, anatomical, and physiological factors that might help to predict the visual outcome after orbital trauma surgery, and to identify clinically relevant factors which are associated with good or poor postoperative visual outcome.

## Materials and Methods

### Study Design and Setting

It was a prospective observational clinical study and was conducted at Amna Inayat Medical College, Sheikhupura, Pakistan, from April 2024 to April 2025. Forensic, anatomical, and physiological factors related to the postoperative visual outcome in patients with traumatic orbital injuries were assessed.

### Study Population

A total of 80 patients with clinically and radiologically confirmed orbital trauma requiring surgical intervention were enrolled using consecutive sampling. Patients were eligible if they had complete ophthalmological and radiological evaluations before surgery and unilateral or bilateral traumatic orbital fractures, aged 18 years and over. Patients with pre-existing severe visual impairment, previous orbital surgery, chronic optic nerve or retinal disease, pathological fractures, penetrating globe injuries that required primary globe repair, and incomplete follow-up were excluded.

### Forensic and injury assessment

The circumstances of the injury were obtained in detail from the patient, attendants, Emergency documents, and Medico-legal documents when available. Mechanism of trauma was classified as RTA, interpersonal assault, fall, occupational injury, and other accidental trauma. Injuries were also differentiated by the mechanism of injury, blunt or penetrating. Facial injuries, soft tissue wounds, fracture complexity, and time from trauma to presentation to hospital were documented. The severity of the overall injury was classified as mild, moderate, or severe based on the combined clinical and radiological evaluation.

### Anatomical and Radiological Evaluation

A computed tomography was performed for all patients of the orbit and facial skeleton in axial, coronal, and sagittal planes. Orbital fractures were classified based on the wall involved – floor fracture, medial wall fracture, lateral wall fracture, roof fracture, or multiple-wall fracture. Fracture displacement, herniation of orbital contents, extraocular muscle entrapment, orbital volume alteration, globe displacement, retrobulbar hematoma, and extension to the orbital apex/optic canal were evaluated radiographically. The optic canal involvement was recorded if the fracture line involved or was immediately adjacent to the optic canal.

### Physiological and Ophthalmological Evaluation

A full eye exam was done before surgery. BCVA was measured with a standard visual acuity chart and converted to Log MAR values for statistical purposes. Pupillary responses were tested to look for the presence of a relative afferent pupillary defect. The visual acuity, intraocular pressure, eye movements, presence of diplopia, globe position, anterior segment findings, fundus examination, and optic disc appearance were recorded. Ocular motility was classified as normal, mildly restricted, or markedly restricted based on the restriction noted in cardinal positions of gaze.

**Surgical Management**

Surgical indications included the presence of clinically significant diplopia with radiological entrapment, persistent ocular movement restriction, substantial orbital wall defect, globe displacement, enophthalmos, or complex orbital fracture requiring anatomical reconstruction. Surgery included release of entrapped orbital tissues, restoration of orbital contents, and reconstruction of the fractured orbital wall with an appropriate implant based on fracture features and surgeon preference. The time from injury to definitive surgery was also noted for prognostic analysis.

**Pre- and Post-op Evaluation & Visual Outcomes**

Patients were assessed postoperatively and for up to three months after surgery. Postoperative complications, intraocular pressure, globe position, pupillary response, color vision, and ocular motility were assessed at follow-up visits along with the best corrected visual acuity. The primary outcome was postoperative visual recovery. Good outcomes were considered as significant improvement in visual acuity or reaching a functional visual acuity of 0.30 logMAR or better at last visit. Patients who did not reach this level or those who had a clinically significant visual impairment were considered to have an unfavorable visual outcome.

**Statistical Analysis**

IBM SPSS Statistics software version 26 was used for data analysis. Categorical variables were reported as frequencies and percentages, and continuous variables were reported as mean ± standard deviation or median (interquartile range). Categorical variables were compared between the favorable and the unfavorable group of visual outcome using the chi-square test or Fisher's exact test. Independent-samples t-test or Mann-Whitney U test was used to compare continuous variables as appropriate. Variables that were clinically relevant or statistically significantly associated on univariable analysis were selected for inclusion in the multivariable binary logistic regression to determine independent variables associated with an unfavourable visual outcome. The odds ratios and 95% confidence intervals were adjusted, and a p-value < 0.05 was regarded as statistically significant.

**Ethical Considerations**

The study was carried out in line with the principles of the Declaration of Helsinki. This study was approved by the relevant Institutional Review Board/Ethical Review Committee of Amna Inayat Medical College, Sheikhupura, Pakistan, and written informed consent was obtained from all the participants prior to involvement in the study.

## RESULTS

A total of 80 patients undergoing surgical management for orbital trauma were included in the final analysis. The mean age was 34.3 ± 11.6 years. There were 64 males (80.0%) and 16 females (20.0%). At the three-month follow-up, 54 patients (67.5%) achieved a favorable visual outcome, while 26 (32.5%) had an unfavorable outcome. Of those males, 42 (65.6%) had a favorable outcome and 22 (34.4%) had an unfavorable outcome, while of the females, 12 (75.0%) had a favorable outcome and 4 (25.0%) had an unfavorable outcome. There was no statistically significant difference between genders and visual outcome at the end of the study (p=0.562). The most common mechanism of trauma was road traffic accidents (39, 48.8%), interpersonal assault (20, 25.0%), falls (13, 16.3%), and occupational or accident (8, 10.0%). Final visual outcome was not significantly different with respect to the mechanism of injury. Conversely, patients with poor outcome had severe injury in 61.5% vs 20.4% of patients with good outcome (p<0.001). An associated facial fracture and surgery carried out >14 days after trauma were also significantly correlated with an unfavorable visual outcome (Table 1).

Table 1. Forensic and Clinical Characteristics According to Visual Outcome

| Variable | Total (n=80) | Favorable (n=54) | Unfavorable (n=26) | p-value |
|---|---|---|---|---|
| Age, years, mean ± SD | 34.3 ± 11.6 | 33.2 ± 10.9 | 36.7 ± 12.7 | 0.205 |

| | | | | |
|---|---|---|---|---|
| **Gender** | | | | **0.562** |
| Male | 64 (80.0%) | 42 (77.8%) | 22 (84.6%) | |
| Female | 16 (20.0%) | 12 (22.2%) | 4 (15.4%) | |
| **Mechanism of injury** | | | | **0.469** |
| Road traffic accident | 39 (48.8%) | 23 (42.6%) | 16 (61.5%) | |
| Interpersonal assault | 20 (25.0%) | 15 (27.8%) | 5 (19.2%) | |
| Fall | 13 (16.3%) | 10 (18.5%) | 3 (11.5%) | |
| Occupational/other accident | 8 (10.0%) | 6 (11.1%) | 2 (7.7%) | |
| **Injury severity** | | | | **<0.001** |
| Mild | 18 (22.5%) | 16 (29.6%) | 2 (7.7%) | |
| Moderate | 35 (43.8%) | 27 (50.0%) | 8 (30.8%) | |
| Severe | 27 (33.8%) | 11 (20.4%) | 16 (61.5%) | |
| Associated facial fracture | 32 (40.0%) | 17 (31.5%) | 15 (57.7%) | 0.025 |
| Surgery >14 days after trauma | 10 (12.5%) | 3 (5.6%) | 7 (26.9%) | 0.011 |

Orbital floor fracture alone was the most frequently found anatomical fracture and occurred in 34 patients (42.5%). Multiple-wall fractures were noted in 22 (27.5%) patients and were significantly more common in the patients who had unfavorable postoperative vision (46.2% vs. 18.5%, p=0.015). There was also a statistically significant globe displacement (p=0.007) and a marked orbital volume alteration in 53.8% of the patients with poor and 22.2% with favorable outcomes (p=0.010). Anatomical involvement of the optic canal was seen in 10 (12.5%) patients, 8 (30.8%) in the unfavorable group, and only 2 (3.7%) patients in the favorable group, and had the highest association with poor visual recovery (p=0.001). Retrobulbar hematoma also occurred significantly more often in patients with poor outcome (Table 2).

Table 2. Anatomical Characteristics of Orbital Trauma According to Visual Outcome

| Anatomical Finding | Total (n=80) | Favorable (n=54) | Unfavorable (n=26) | p-value |
|---|---|---|---|---|
| Isolated orbital floor fracture | 34 (42.5%) | 26 (48.1%) | 8 (30.8%) | 0.157 |
| Isolated medial wall fracture | 16 (20.0%) | 12 (22.2%) | 4 (15.4%) | 0.562 |
| Lateral wall/orbital roof fracture | 8 (10.0%) | 6 (11.1%) | 2 (7.7%) | 1.000 |
| Multiple-wall fracture | 22 (27.5%) | 10 (18.5%) | 12 (46.2%) | 0.015 |
| Extraocular muscle entrapment | 25 (31.3%) | 14 (25.9%) | 11 (42.3%) | 0.198 |
| Significant globe displacement | 21 (26.3%) | 9 (16.7%) | 12 (46.2%) | 0.007 |
| Marked orbital volume alteration | 26 (32.5%) | 12 (22.2%) | 14 (53.8%) | 0.010 |
| Optic canal involvement | 10 (12.5%) | 2 (3.7%) | 8 (30.8%) | 0.001 |
| Retrobulbar hematoma | 11 (13.8%) | 4 (7.4%) | 7 (26.9%) | 0.033 |

Overall, the mean best-corrected visual acuity was 0.57 ± 0.41 logMAR at baseline and 0.28 ± 0.29 logMAR at 3 months after surgery (p<0.001). Baseline VA was significantly poorer in patients with unfavorable outcomes, with a mean BCVA of 0.39 ± 0.25 logMAR compared to 0.94 ± 0.41 logMAR (p<0.001). A relative afferent pupillary defect was documented in 12 (15.0%) patients and was markedly more common in the unfavorable group, occurring in 10 (38.5%) patients compared with 2 (3.7%) patients in the favorable group (p<0.001). Significant association with unfavourable visual recovery was also found with impaired colour vision and marked ocular motility restriction. Preoperative diplopia was seen in both groups and was not statistically significantly related, but persistent postoperative diplopia was significantly more common in the patients with unfavourable visual outcome (34.6% vs 9.3%, p=0.010), as shown in Table 3.

Table 3. Physiological and Functional Findings According to Visual Outcome

| Physiological Variable | Favorable (n=54) | Unfavorable (n=26) | p-value |
|---|---|---|---|
| Preoperative BCVA, logMAR, mean ± SD | 0.39 ± 0.25 | 0.94 ± 0.41 | <0.001 |
| Postoperative BCVA, logMAR, mean ± SD | 0.14 ± 0.09 | 0.58 ± 0.28 | <0.001 |
| Relative afferent pupillary defect | 2 (3.7%) | 10 (38.5%) | <0.001 |
| Impaired color vision | 4 (7.4%) | 9 (34.6%) | 0.004 |
| Abnormal intraocular pressure | 7 (13.0%) | 8 (30.8%) | 0.071 |
| Marked ocular motility restriction | 10 (18.5%) | 11 (42.3%) | 0.031 |
| Preoperative diplopia | 25 (46.3%) | 16 (61.5%) | 0.238 |
| Persistent postoperative diplopia | 5 (9.3%) | 9 (34.6%) | 0.010 |

Multivariable binary logistic regression was performed with variables showing clinically important or statistically significant relationships with an unfavorable recovery. On adjusted models, the only independent factor associated with worse visual outcomes was the presence of a relative afferent papillary defect, which was associated with an odds ratio of about seven (aOR 7.21; 95% CI 1.75–29.72; p=0.006). Preoperative BCVA poorer than 0.70 logMAR showed an approximately 4.5-fold increase in the odds of poor visual recovery (p=0.003), and optic canal involvement showed a 5.63-fold increase in the odds (p=0.022). Surgical treatment more than 14 days after the trauma and the severe injury category were also independently associated with poor postoperative vision. These results indicate that physiological evidence of optic nerve dysfunction, posterior orbital anatomical injury, greater overall trauma severity, and delayed definitive management were the principal predictors of poor visual recovery (Table 4).

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

| Predictor | Adjusted Odds Ratio | 95% Confidence Interval | p-value |
|---|---|---|---|
| Relative afferent pupillary defect | 7.21 | 1.75–29.72 | 0.006 |
| Optic canal involvement | 5.63 | 1.28–24.73 | 0.022 |
| Preoperative BCVA >0.70 logMAR | 4.48 | 1.65–12.14 | 0.003 |
| Severe injury category | 3.51 | 1.25–9.86 | 0.017 |
| Surgery >14 days after trauma | 3.46 | 1.01–11.88 | 0.048 |

Surgical reconstruction was generally successful for approximately two-thirds of patients in terms of visual recovery. The findings suggest that relative afferent pupillary defect, optic canal involvement, severe initial visual impairment, greater forensic injury severity, and delayed surgical intervention were the most important predictors of unfavorable postoperative visual outcomes following orbital trauma.

## DISCUSSION

The present study compared several variables, including forensic, anatomical, and physiological factors, regarding the visual recovery after surgical treatment of orbital trauma[1]. At three months, favorable visual outcome was achieved in about two-thirds of patients, with almost a third of patients showing persistent visual impairment. The results suggest that the postoperative vision not only depends on the anatomical range of fracture but also on the severity of the primary traumatic insult and the functional integrity of the optic pathway[2].

Unfavorable visual recovery was significantly associated with severe injury. This discovery validates the use of the principle that the amount and direction of traumatic force is more relevant than mechanism of injury alone[3]. Road traffic accidents (RTAs) were the most common mechanism of orbital trauma, but were not, alone, associated with postoperative vision. However, patients with more severe facial trauma and a higher degree of orbital disruption had worse outcomes. Forensic highlights the need for documentation of the severity, direction, and consequences of trauma, in addition to the mechanism of the trauma[4].

Optic canal involvement was best correlated with poor visual outcome among the anatomical variables[5]. Within the rigid optic canal, the optic nerve is at special risk of compression or irreversible axonal damage by optic nerve swelling, bleeding, bony displacement, or transferred forces. Other factors associated with poor postoperative vision were multiple wall fractures, large globe displacement, decrease in orbital volume, and retrobulbar hematoma. These results showed that involvement of the posterior orbit and disturbance of the normal orbital geometry can be a negative factor in visual recovery despite the surgery of reconstruction[6].

Physiological data yielded valuable prognostic data. Relative afferent pupillary defect was the best independent predictor of poor postoperative visual outcome[7]. This is relevant clinically because RAPD is a sign of major damage to the afferent pathway of the eye and can be seen with traumatic optic neuropathy and severe retinal damage. Impaired color vision and significant restriction in ocular motility were also more common in patients with poor visual recovery, indicating that functional testing could be helpful in identifying patients at higher risk, despite limited anatomical abnormalities[8-10].

Another independent strong predictor was the preoperative visual acuity. Patients with poor visual loss were significantly less likely to have a good postoperative outcome[11]. Baseline visual acuity is important and is an integrated measure of globe, retinal, optic nerve, and orbital injury, and thus an important component of early prognostic assessment. Postoperative mean visual acuity improvement, however, suggests that when indicated, orbital reconstruction can have a functional impact that can be important[12].

Persistent postoperative diplopia was significantly higher in the group of patients with unfavorable visual outcome. Diplopia can be caused by entrapment of extraocular muscles, nerve damage, fibrosis, edematous damage, or changes in globe position[13]. While surgical release and orbital anatomy restoration resulted in improvement in many patients, persistent diplopia may represent some residual mechanical dysfunction or neuromuscular dysfunction. Diplopia alone was not highly predictive of the preoperative state, and thus, the prognostic significance may be dependent on the persistence of diplopia following anatomical correction[14].

Factors independently associated with poor visual outcome were delayed surgical intervention (after 14 days). Failure to act promptly to reconstruct may permit fibrosis, scar formation, persistent tissue incarceration, and abnormal orbital remodeling to occur, which may make complete anatomical and functional reconstruction less likely. This relationship should, however, be viewed with caution as patients with more severe systemic or craniofacial injuries may have undergone delayed surgery to achieve clinical stability[15,16].

The overall results highlight the importance of a multi-disciplinary approach to orbital trauma. Forensic documentation gives an idea about the severity and mechanism of injury, computed tomography gives information about the anatomical injury, and ophthalmological examination gives information about the physiological injury. The combination of these domains could increase the prioritization of surgery, prognosis counselling, and medico-legal evaluation of permanent visual disability[17,18].

There are a number of limitations in the study. It was carried out in a single institution with a relatively small sample size, so there might be some limits on its generalizability. The follow-up period was limited to 3 months, and more patients may have additional functional recovery after this time. There was also a lack of quantitative measurement of orbital volume and optic nerve function, which are only available in the clinic and on the radiology market. These predictors need further validation in larger multicenter prospective studies using standardized volumetric imaging and objective ON testing with longer follow-up[19,20].

## CONCLUSION

The visual prognosis after orbital trauma surgery depends on the interplay of the extent of the forensic trauma, the anatomical disruption, and the physiological dysfunction. The main independent factors associated with poor postoperative visual function were relative afferent pupillary defect, optic canal involvement, severe visual defects at the time of surgery, high injury severity scores, and delayed surgical procedures. Anatomical reconstruction is often successful, but early recognition of visual nerve dysfunction and posterior orbital involvement is important because these features have a much worse prognosis. Structured evaluation with injury characteristics, computed-tomographic characteristics, and ophthalmological functional evaluation can augment the accuracy of prognosis, facilitate prompt surgical management, and provide objective medico-legal documentation of orbital injuries.

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