E-ISSN: 3050-9459
Journal of Ophthalmology and Advance Research

ATHENAEUM SCIENTIFIC PUBLISHERS

Review Article

Check for updates

Orbital Fractures Over Five Decades (1975-2026): A Systematic Review and Meta-Analysis of Patterns, Management, Outcomes and Emerging Technologies

Niraj Kumar Yadav[1*], Manu Saini[2], Shachi Srivastava[3], Maya Hada[4], Apjit Kaur[5]

[1]Department of Ophthalmology, Dr KNS Memorial Institute of Medical Sciences, Barabanki, Uttar Pradesh, India
[2]Department of Ophthalmology, Advance Eye Centre, PGIMER, Chandigarh, India
[3]Department of Ophthalmology, ESIC Medical College and Hospital, Faridabad, Haryana, India
[4]Department of Ophthalmology, SMS Hospital, Jaipur, Rajasthan, India.
[5]Department of Ophthalmology King George Medical University, Lucknow, Uttar Pradesh, India

***Correspondence author:** Niraj Kumar Yadav, MS, FIOPS, FAICO, FICM, FID, NDEP, Ophthalmic Plastic and Aesthetic Surgeon, Assistant Professor, Department of Ophthalmology, Dr KNS Memorial Institute of Medical Sciences, Barabanki, India; Email: dr.nirajyadav@gmail.com

Citation: Yadav NK, et al. Orbital Fractures Over Five Decades (1975-2026): A Systematic Review and Meta-Analysis of Patterns, Management, Outcomes, and Emerging Technologies. J Ophthalmol Adv Res. 2026;7(2):1-30.

https://doi.org/10.46889/JOAR.2026.7207

Received Date: 23-04-2026

Accepted Date: 31-05-2026

Published Date: 07-06-2026

Abstract

Background: Orbital fractures represent a significant subset of maxillofacial trauma and are associated with functional and aesthetic morbidity, including diplopia, enophthalmos and impaired ocular motility. Advances in imaging, surgical techniques and biomaterials have substantially influenced contemporary management; however, variability in clinical practice persists.

Objective: To systematically evaluate the epidemiology, fracture patterns, management strategies and clinical outcomes of orbital fractures and to identify key predictors influencing prognosis.

Methods: A comprehensive systematic review and meta-analysis was conducted in accordance with PRISMA 2020 guidelines. Multiple databases were searched to identify relevant studies published between 1975 and 2026. Eligible studies included observational and interventional designs reporting on orbital fractures. Data were extracted on demographics, mechanism of injury, fracture characteristics, treatment modalities and outcomes. Pooled estimates were calculated using random-effects models and heterogeneity was assessed using the I^2 statistic. Risk of bias and certainty of evidence were evaluated using standardized tools.

Results: A total of 154 studies were included in the qualitative synthesis, with 98 studies eligible for meta-analysis. Road traffic accidents, interpersonal violence and falls were the most common mechanisms of injury. The orbital floor and medial wall were the most frequently involved sites. Surgical management was associated with significantly improved functional outcomes, including higher rates of diplopia resolution and restoration of extraocular motility, as well as superior aesthetic outcomes compared with conservative treatment. Early surgical intervention demonstrated better outcomes than delayed repair. Complex and multi-wall fractures were associated with higher complication rates. Advances such as patient-specific implants and computer-assisted techniques contributed to improved anatomical accuracy. Moderate heterogeneity was observed, with no significant publication bias detected.

Conclusion: Orbital fracture management has evolved toward a precision-based approach, with surgical intervention, particularly when performed early, yielding superior outcomes in selected patients. Future research should focus on standardized outcome measures and the integration of advanced technologies to optimize patient care.

Keywords: Orbital Fractures; Orbital Trauma; Blowout Fracture; Orbital Reconstruction; Diplopia; Enophthalmos; Extraocular Motility; Patient-Specific Implants; 3D Printing; Surgical Timing; Meta-Analysis; Oculoplastic Surgery

Introduction

Orbital fractures represent a significant subset of craniofacial trauma, accounting for a substantial proportion of injuries presenting to emergency and ophthalmic services worldwide. These injuries encompass a broad spectrum, ranging from isolated "blow-out" fractures to complex multi-wall disruptions involving the zygomatico-orbital complex, often accompanied by functional and aesthetic sequelae [1,2]. The orbit's intricate anatomy, with its delicate balance between structural integrity and functional mobility, renders it particularly susceptible to trauma-induced alterations affecting vision, ocular motility and facial symmetry [3].

Over the past five decades, the epidemiology of orbital fractures has evolved considerably, influenced by changes in societal behavior, transportation patterns, interpersonal violence and occupational hazards [4,5]. Road traffic accidents, assaults, sports injuries and falls remain the predominant mechanisms, although their relative contributions vary across geographic regions and socioeconomic contexts [6]. Recent large-scale analyses of oculofacial trauma have highlighted shifting global patterns, with increasing urbanization and mechanization contributing to the burden of orbital injuries [7].

The classification of orbital fractures into simple (isolated, single-wall) and complex (multi-wall or associated with adjacent facial fractures) entities has important clinical implications, guiding decision-making and prognostication [8]. Among the orbital walls, the floor and medial wall are most commonly involved due to their relative structural weakness, while roof and lateral wall fractures are less frequent but often associated with high-energy trauma [9]. The extent and pattern of wall involvement directly influence both functional outcomes, such as diplopia and extraocular motility restriction and cosmetic deformities, including enophthalmos and orbital asymmetry [10].

Despite advancements in diagnosis and management, orbital fractures continue to be associated with a range of complications, including persistent diplopia, enophthalmos, infection, implant-related issues, and, rarely, vision-threatening complications [11]. The reported incidence of these complications varies widely across studies, reflecting heterogeneity in study design, patient populations and outcome definitions. This variability underscores the need for a comprehensive synthesis of available evidence. Therefore, this study aims to provide a comprehensive systematic review and meta-analysis of orbital fractures spanning five decades (1975-2026), evaluating patterns of injury, management protocols, timing of intervention, clinical outcomes and complications. By integrating evidence across a broad temporal and clinical spectrum, this work seeks to inform evidence-based decision-making and identify key determinants of optimal patient outcomes.

Methodology

Study Design and Reporting Standards

This systematic review and meta-analysis was conducted in accordance with the PRISMA 2020 statement and adhered to the PRISMA-P (Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols) guidelines for protocol development [12,13]. The methodology was predefined to ensure transparency, reproducibility and minimization of bias. The study selection process is summarized in Fig. 1. A total of 4,862 records were identified through comprehensive database searching, including PubMed, Scopus, Embase and Web of Science. Following removal of 1,124 duplicates, 3,738 records remained for title and abstract screening, of which 3,102 were excluded based on predefined eligibility criteria. Subsequently, 636 full-text articles were assessed for eligibility. Of these, 482 studies were excluded for reasons including lack of specificity to orbital fractures (n = 178), insufficient outcome data (n = 134), inclusion of case reports or small case series (n = 95), review articles (n = 58) and non-human studies (n = 17). Ultimately, 154 studies were included in the qualitative synthesis, of which 98 studies met the criteria for quantitative synthesis (meta-analysis).

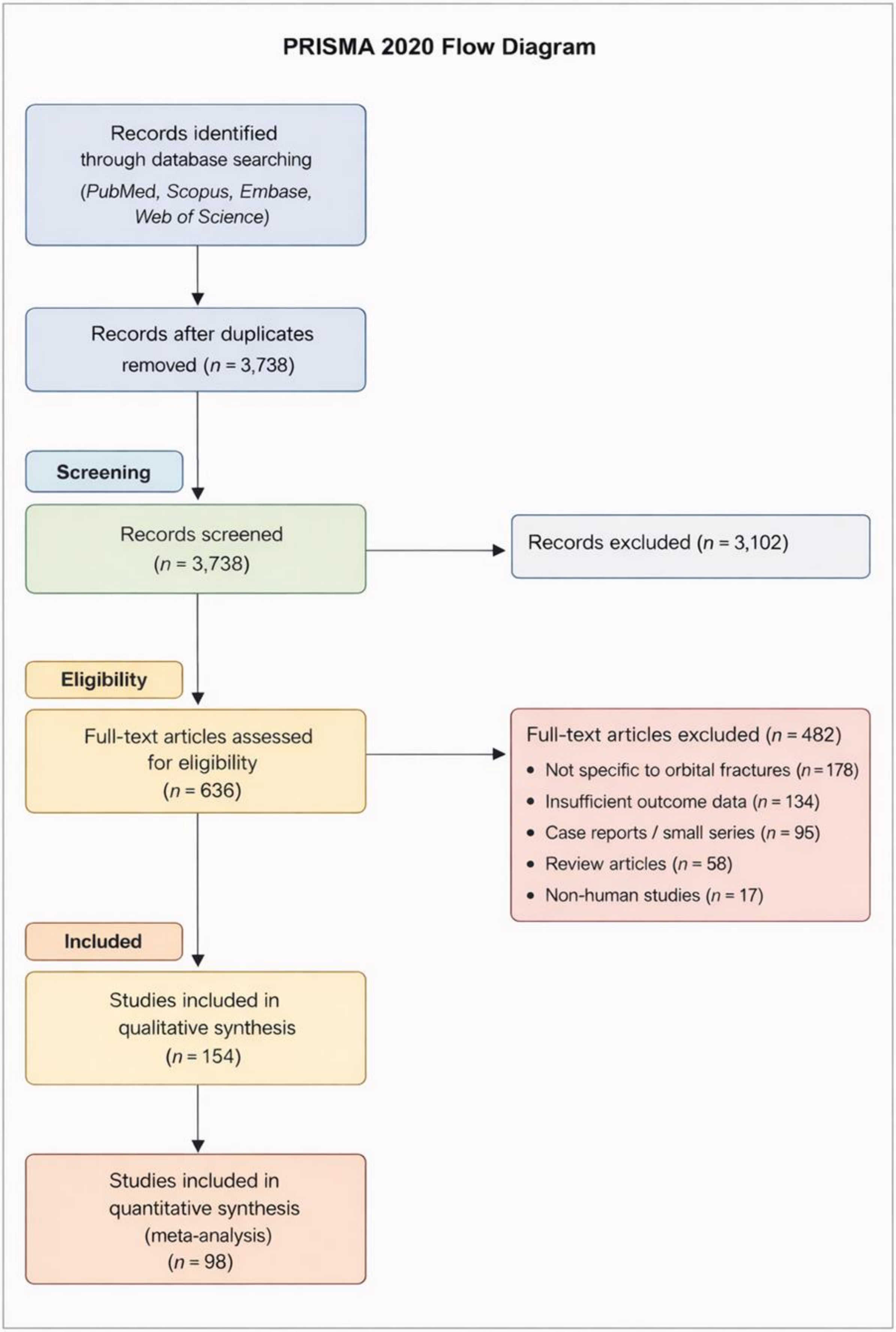

Figure 1: PRISMA 2020 flow diagram of study selection process.

Eligibility Criteria

Inclusion Criteria

1. Studies involving patients with orbital fractures of traumatic etiology
2. Observational studies (prospective/retrospective cohorts, case-control studies) and interventional studies
3. Studies reporting at least one of the following:
    a. Mode of trauma
    b. Fracture type (simple vs complex)
    c. Orbital wall involvement
    d. Management strategies
    e. Postoperative outcomes or complications
4. Studies published between January 1975 and March 2026
5. Articles published in English

Exclusion Criteria

1. Case reports or small case series (<5 patients)
2. Non-human or cadaveric studies
3. Reviews, editorials and conference abstracts without primary data
4. Studies lacking relevant outcome data
5. Studies not specifically addressing orbital fractures

Information Sources and Search Strategy

A comprehensive and systematic literature search was conducted across multiple electronic databases, including PubMed, Scopus, Embase and Web of Science, to identify relevant studies on orbital fractures. The search encompassed publications from January 1975 to March 2026, ensuring a comprehensive evaluation of evidence across five decades. The search strategy was developed in accordance with established methodological recommendations for systematic reviews, incorporating both controlled vocabulary terms (e.g., Medical Subject Headings [MeSH] and Emtree terms) and free-text keywords to maximize retrieval sensitivity. Core search terms included "orbital fracture," "blow-out fracture," "orbital trauma," "orbital wall fracture," "zygomatico-orbital fracture," "orbital reconstruction," "diplopia," "enophthalmos," and "orbital surgery" [12-14]. Boolean operators (AND, OR) and truncation strategies were applied to optimize both sensitivity and specificity of the search. Search strategies were adapted to the indexing systems and functionalities of each database to ensure optimal performance. In addition to electronic database searches, the reference lists of all included studies and relevant review articles were manually screened to identify additional eligible studies not captured through the primary search. This multi-step approach was undertaken to minimize publication bias and ensure comprehensive literature retrieval, consistent with the PRISMA 2020 recommendations. The detailed search strategies employed across all databases are presented in Table 1, ensuring transparency and reproducibility of the search process.

Database	Search Strategy
PubMed	("Orbital Fractures"[MeSH] OR "orbital fracture*" OR "blow-out fracture*" OR "orbital trauma" OR "orbital wall fracture*" OR "zygomatico-orbital fracture*") AND ("orbital reconstruction" OR "orbital surgery" OR "open reduction" OR "internal fixation" OR ORIF OR implant* OR mesh) AND (diplopia OR enophthalmos OR "ocular motility" OR outcome* OR complication*) Filters: Humans, English, 1975-2026
Embase	('orbital fracture'/exp OR 'blow out fracture' OR 'orbital trauma' OR 'orbital wall fracture' OR 'zygomatico orbital fracture') AND ('orbital reconstruction' OR 'orbital surgery' OR 'open reduction' OR 'internal fixation' OR ORIF OR implant* OR mesh) AND (diplopia OR enophthalmos OR 'ocular motility' OR outcome* OR complication*) AND [humans]/lim AND [english]/lim AND [1975-2026]/py
Scopus	TITLE-ABS-KEY ("orbital fracture*" OR "blow-out fracture*" OR "orbital trauma" OR "orbital wall fracture*" OR "zygomatico-orbital fracture*") AND TITLE-ABS-KEY ("orbital reconstruction" OR "orbital surgery" OR ORIF OR implant* OR mesh) AND TITLE-ABS-KEY (diplopia OR enophthalmos OR "ocular motility" OR outcome* OR complication*) AND (LIMIT-TO (LANGUAGE, "English")) AND (PUBYEAR > 1974 AND PUBYEAR < 2027)

Web of Science	TS = (“orbital fracture*” OR “blow-out fracture*” OR “orbital trauma” OR “orbital wall fracture*” OR “zygomatico-orbital fracture*”) AND TS = (“orbital reconstruction” OR “orbital surgery” OR ORIF OR implant* OR mesh) AND TS = (diplopia OR enophthalmos OR “ocular motility” OR outcome* OR complication*) Refined by: Languages (English); Timespan: 1975-2026
Manual Search	Reference lists of included studies and relevant review articles were screened to identify additional eligible studies not retrieved through electronic database searches

Table 1: Search strategy across electronic databases (1975-2026).

Search strategies incorporated controlled vocabulary (MeSH/Emtree) and free-text terms. Boolean operators (AND, OR) and truncation (*) were used to enhance sensitivity and specificity. Strategies were adapted according to database-specific indexing systems in accordance with PRISMA 2020 and the Cochrane Handbook.

Study Selection

All retrieved records were imported into reference management software and duplicate entries were identified and removed. Two independent reviewers performed the initial screening of titles and abstracts to assess eligibility based on predefined inclusion and exclusion criteria. Potentially relevant studies were subsequently subjected to full-text evaluation. Any disagreements between reviewers were resolved through discussion and, when necessary, consultation with a third reviewer to achieve consensus. The study selection process is illustrated in Fig. 1 in accordance with the PRISMA 2020 framework. A total of 4,862 records were initially identified through comprehensive database searching across PubMed, Scopus, Embase and Web of Science. Following removal of 1,124 duplicate records, 3,738 studies underwent title and abstract screening, of which 3,102 were excluded based on predefined eligibility criteria. Subsequently, 636 full-text articles were assessed for eligibility. Among these, 482 studies were excluded due to lack of specificity to orbital fractures, insufficient outcome data, inadequate sample size or absence of original clinical data. Ultimately, 154 studies met the inclusion criteria for qualitative synthesis, of which 98 studies were eligible for quantitative synthesis (meta-analysis). The principal characteristics of the included studies are summarized in Table 5, which presents a representative selection of studies included in the systematic review, highlighting variations in study design, geographic distribution, sample size, mechanisms of injury and fracture classification. This broad representation reflects the global and heterogeneous nature of orbital trauma and provides a comprehensive overview of the available evidence across different clinical settings and patient populations.

Data Extraction

Data extraction was performed independently by two reviewers using a standardized and pilot-tested data collection form to ensure consistency and reproducibility. Extracted variables encompassed multiple predefined domains, including study characteristics (author, year of publication, country and study design), patient demographics, mode of trauma, fracture classification (simple vs complex) and specific orbital wall involvement.

Details of management strategies were recorded, including treatment approach (conservative versus surgical), surgical techniques and implant materials where applicable. Information on the timing of intervention was also extracted to facilitate subgroup analyses. Outcome measures included both functional outcomes (e.g., diplopia resolution and extraocular motility) and aesthetic outcomes (e.g., correction of enophthalmos and restoration of orbital symmetry). Additionally, data on postoperative complications and duration of follow-up were collected. Any discrepancies between reviewers were resolved through discussion and consensus [12,14]. The complete set of extracted variables and their definitions is summarized in Table 2, ensuring transparency and reproducibility of the data collection process.

Domain	Variable	Description / Definition
Study Characteristics	Author, Year	First author’s name and year of publication
	Country	Country where the study was conducted
	Study Design	Study type (prospective, retrospective, randomized controlled trial, case-control)
Patient Characteristics	Demographics	Age, gender distribution and sample size
Injury Characteristics	Mode of Trauma	Mechanism of injury (e.g., road traffic accident, assault, fall, sports

		injury)
	Fracture Classification	Categorization into simple (single-wall/isolated) vs complex (multi-wall or associated fractures)
	Orbital Wall Involvement	Specific wall(s) involved (floor, medial, lateral, roof, combined)
Management Variables	Treatment Approach	Conservative vs surgical management
	Surgical Technique	Type of surgical intervention (e.g., ORIF, endoscopic repair)
	Implant/Material	Type of reconstruction material (e.g., titanium mesh, porous polyethylene, autograft, PSI)
	Timing of Intervention	Time interval from injury to treatment (e.g., early vs delayed)
Outcome Measures	Functional Outcomes	Diplopia resolution, extraocular motility
	Aesthetic Outcomes	Enophthalmos correction, orbital symmetry
Complications	Postoperative Complications	Persistent diplopia, enophthalmos, infection, implant-related issues, vision loss
	Follow-up Duration	Length of follow-up period reported in the study

Table 2: Data extraction variables and definitions.

Table summarizing the predefined variables extracted from each included study, categorized into study characteristics, patient demographics, injury patterns, management strategies, outcome measures and complications. Data extraction was performed using a standardized form to ensure consistency and reproducibility across studies. Fracture classification was defined as simple (isolated single-wall fractures) or complex (multi-wall involvement or associated facial fractures). Functional outcomes included parameters such as diplopia resolution and extraocular motility, while aesthetic outcomes comprised enophthalmos correction and restoration of orbital symmetry. Postoperative complications encompassed persistent diplopia, infection, implant-related complications and vision-threatening events. Timing of intervention was recorded as reported in individual studies and subsequently categorized for subgroup analyses.

Risk of Bias Assessment

The methodological quality and risk of bias of the included studies were independently assessed by two reviewers using validated tools appropriate to study design. Observational studies (cohort and case-control studies) were evaluated using the Newcastle-Ottawa Scale (NOS), which assesses study quality across three domains: selection of study groups, comparability of groups and ascertainment of exposure or outcomes [15]. Each study was awarded a maximum of nine stars, with higher scores indicating better methodological quality. Studies were categorized as low (≥7 stars), moderate (5-6 stars) or high risk of bias (≤4 stars) based on established thresholds.

Randomized controlled trials, where applicable, were assessed using the Cochrane Risk of Bias tool (RoB 2), which evaluates bias across key domains including randomization process, deviations from intended interventions, missing outcome data, measurement of outcomes and selection of reported results [16]. Each domain was rated as low risk, some concerns or high risk of bias in accordance with Cochrane guidelines. Risk of bias assessment was conducted independently by two reviewers and any discrepancies were resolved through discussion and consensus or adjudication by a third reviewer when necessary. The overall risk of bias for each study was considered during data synthesis and interpretation of results. Sensitivity analyses were planned to evaluate the impact of studies with high risk of bias on pooled estimates, where applicable.

Outcome Measures

The outcomes of interest were predefined and categorized into primary and secondary endpoints.

Primary Outcomes

Primary outcomes included both functional and aesthetic measures. Functional outcomes comprised the resolution of diplopia and restoration of extraocular motility. Aesthetic outcomes included correction of enophthalmos and restoration of orbital symmetry, as reported in the included studies.

Secondary Outcomes

Secondary outcomes included the incidence and types of postoperative complications, such as persistent diplopia, infection, implant-related complications and vision-threatening events. In addition, key prognostic factors influencing outcomes were evaluated, including fracture classification (simple versus complex), extent of orbital wall involvement and timing of surgical intervention.

The predefined outcomes of interest were systematically categorized into primary and secondary endpoints to ensure standardized assessment across the included studies (Table 3). Primary outcomes consisted of both functional and aesthetic measures, including resolution of diplopia, restoration of extraocular motility, correction of enophthalmos and improvement in orbital symmetry. Secondary outcomes included postoperative complications, such as persistent diplopia, infection, implant-related adverse events and vision-threatening complications. In addition, clinically relevant prognostic variables, including fracture classification, extent of orbital wall involvement and timing of surgical intervention, were evaluated to determine their influence on functional and aesthetic outcomes following orbital fracture management.

Category	Outcome Domain	Specific Outcome Measures	Clinical Relevance
Primary Outcomes	Functional Outcomes	Resolution of diplopia	Assessment of postoperative visual function and binocular alignment
		Restoration of extraocular motility	Evaluation of ocular movement recovery and muscle function
	Aesthetic Outcomes	Correction of enophthalmos	Measurement of orbital volume restoration and globe position
		Restoration of orbital symmetry	Evaluation of facial symmetry and cosmetic outcome
Secondary Outcomes	Postoperative Complications	Persistent diplopia	Identification of residual functional impairment
		Infection	Assessment of postoperative infectious complications
		Implant-related complications	Evaluation of implant exposure, migration, malposition or intolerance
		Vision-threatening events	Detection of severe complications affecting visual prognosis
	Prognostic Factors	Fracture classification (simple vs complex)	Determination of relationship between fracture severity and outcomes
		Extent of orbital wall involvement	Evaluation of anatomical severity and associated morbidity
		Timing of surgical intervention	Assessment of the influence of early versus delayed repair on outcomes

Table 3: Primary and secondary outcome measures evaluated in the systematic review and meta-analysis.

This table summarizes the predefined outcome measures assessed across the included studies in the systematic review and meta-analysis. Outcomes were categorized into primary and secondary endpoints to facilitate standardized evaluation of clinical effectiveness, functional recovery, aesthetic restoration and postoperative safety following orbital fracture management. Primary outcomes included both functional and aesthetic parameters, while secondary outcomes comprised postoperative complications and prognostic variables influencing treatment outcomes. Functional outcomes focused on diplopia resolution and restoration of extraocular motility, whereas aesthetic outcomes evaluated correction of enophthalmos and restoration of orbital symmetry. Secondary outcomes included persistent diplopia, infection, implant-related complications, vision-threatening events and clinically relevant prognostic factors such as fracture complexity, extent of orbital wall involvement and timing of surgical intervention.

Data Synthesis and Statistical Analysis

The statistical methods and data synthesis approaches employed in the present meta-analysis are summarized in Table 4. Quantitative synthesis was performed when sufficient methodological and clinical homogeneity existed across the included studies. Meta-analysis was conducted using a random-effects model based on the DerSimonian-Laird method to account for anticipated clinical and methodological heterogeneity among studies [17]. For dichotomous outcomes, pooled effect estimates were calculated using Odds Ratios (ORs) or Risk Ratios (RRs) with corresponding 95% Confidence Intervals (CIs). Continuous outcomes were summarized using Mean Differences (MDs) or Standardized Mean Differences (SMDs), as appropriate.

Between-study heterogeneity was assessed using the Cochran Q test and quantified using the I^2 statistic, with thresholds interpreted as low (25%), moderate (50%) and high (75%) heterogeneity [18]. In the presence of substantial heterogeneity ($I^2 > 50\%$), potential sources of variability were explored through predefined subgroup analyses and meta-regression models. Subgroup analyses were conducted according to clinically relevant variables, including fracture classification (simple versus complex), extent of orbital wall involvement (single-wall versus multi-wall), management strategy (conservative versus surgical), surgical technique or implant material and timing of intervention (early versus delayed repair). These analyses were performed to evaluate differential treatment effects across important clinical strata.

Where sufficient data were available, meta-regression analyses were undertaken to examine the influence of continuous or categorical moderators, including patient age, proportion of complex fractures and timing of surgery, on clinical outcomes and complication rates, thereby identifying potential contributors to between-study variability [19]. Sensitivity analyses were additionally performed by excluding studies with high risk of bias or outlier effect estimates to evaluate the robustness and stability of pooled results.

Publication bias was assessed qualitatively through visual inspection of funnel plots and quantitatively using Egger's regression test and Begg's test when at least ten studies were available for a given outcome [20]. All statistical analyses were performed using established meta-analysis software a platform, including RevMan, Stata or R. Statistical significance was defined as a two-tailed p value < 0.05.

Analysis Component	Method/Approach	Purpose/Application
Quantitative Synthesis	Random-effects meta-analysis (DerSimonian-Laird method)	To account for anticipated clinical and methodological heterogeneity across studies
Effect Measures for Dichotomous Outcomes	Odds ratios (ORs) and risk ratios (RRs) with 95% confidence intervals (CIs)	To evaluate comparative outcomes such as complications and treatment success
Effect Measures for Continuous Outcomes	Mean differences (MDs) and standardized mean differences (SMDs)	To summarize continuous variables including enophthalmos correction and orbital measurements
Heterogeneity Assessment	Cochran Q test and I^2 statistic	To quantify between-study variability
Interpretation of I^2	Low (25%), Moderate (50%), High (75%)	To classify the degree of heterogeneity
Subgroup Analyses	Stratified analyses based on fracture type, wall involvement, treatment modality, implant material and timing of intervention	To evaluate differential effects across clinically relevant subgroups
Meta-regression	Regression analyses using continuous and categorical moderators	To identify potential sources of between-study variability
Sensitivity Analyses	Exclusion of high-risk or outlier studies	To assess robustness and stability of pooled estimates
Publication Bias Assessment	Funnel plot analysis, Egger's regression test and Begg's test	To evaluate potential reporting or small-study bias
Statistical Software	RevMan, Stata or R	Software platforms used for meta-analysis
Statistical Significance	Two-tailed p value <0.05	Threshold for statistical significance

Table 4: Statistical methods and data synthesis approaches used in the meta-analysis.

This table summarizes the statistical methods and analytical approaches employed in the systematic review and meta-analysis. Quantitative synthesis was performed using random-effects modeling to account for anticipated heterogeneity across included studies. Effect estimates for dichotomous and continuous outcomes were calculated using standard meta-analytic measures with corresponding 95% confidence intervals. Heterogeneity was assessed using the Cochran Q test and I^2 statistic, while subgroup and meta-regression analyses were conducted to explore clinically relevant sources of variability. Sensitivity analyses and publication bias assessments were additionally performed to evaluate the robustness and reliability of pooled findings.

Certainty of Evidence

The overall certainty (quality) of evidence for each outcome was assessed using the GRADE (Grading of Recommendations Assessment, Development and Evaluation) approach [21,22]. Evidence derived from randomized controlled trials was initially rated as high certainty, whereas evidence from observational studies was initially rated as low certainty; these ratings were subsequently adjusted (downgraded or upgraded) based on predefined domains. Downgrading considerations included risk of bias, inconsistency (heterogeneity), indirectness, imprecision and publication bias, while upgrading factors included large effect size, dose-response relationships and plausible residual confounding. The certainty of evidence for each outcome was ultimately categorized as high, moderate, low or very low. GRADE summary of findings tables were generated to present pooled estimates alongside corresponding certainty ratings, thereby facilitating transparent interpretation and clinical applicability of the results.

Results

Study Selection and Characteristics

The study selection process is illustrated in Fig. 1, in accordance with the PRISMA 2020 framework. A total of 4,862 records were identified through database searching (PubMed, Scopus, Embase and Web of Science). After removal of 1,124 duplicates, 3,738 records underwent title and abstract screening, of which 3,102 were excluded based on predefined criteria. Subsequently, 636 full-text articles were assessed for eligibility and 482 studies were excluded for predefined reasons. Ultimately, 154 studies were included in the qualitative synthesis, of which 98 studies were eligible for quantitative synthesis (meta-analysis). The overall characteristics of the included studies are summarized in Table 2. The final dataset comprised studies published between 1975 and 2026, including predominantly retrospective and prospective cohort studies, along with a smaller number of case-control and interventional studies. The included studies demonstrated broad geographic representation, encompassing populations from North America, Europe, Asia and Africa, thereby reflecting global patterns of orbital trauma. Sample sizes varied considerably, ranging from small case series to large multicenter cohorts and included both adult and pediatric populations. The methodological quality of the majority of studies was rated as moderate to high based on standardized risk of bias assessments.

A representative subset of studies is presented in Table 5, highlighting key variations in study design, geographic distribution and injury characteristics. Across studies, road traffic accidents, interpersonal violence and falls emerged as the most common mechanisms of injury, with notable regional differences. Fracture patterns ranged from simple, isolated orbital wall fractures to complex multi-wall or zygomatico-orbital fractures, with complex injuries more frequently associated with high-energy trauma. Collectively, these findings underscore the considerable heterogeneity in patient populations, mechanisms of injury and fracture characteristics across studies, which have important implications for clinical decision-making and interpretation of pooled outcomes.

Study (Author, Year)	Country	Study Design	Sample Size (n)	Mode of Trauma	Fracture Type
Converse JM et al., 1967 [23].	USA	Case Series	36	Assault/Fall	Blow-out (Simple)
Ellis E et al., 1985 [24].	USA	Retrospective Cohort	2,067	RTA/Assault	Complex (ZMC)
Manson PN et al., 1990 [25].	USA	Prospective Study	105	RTA	Complex
Dal Canto AJ et al., 2008 [26].	USA	Comparative Study	58	Mixed	Floor fractures
Hwang K et al., 2010	South Korea	Retrospective Study	2,094	Assault/RTA	Mixed

[27].					
Alinasab B et al., 2014 [28].	Sweden	Retrospective Study	325	Falls	Simple
Ellis E et al., 2012 [29].	Canada	Retrospective Cohort	642	Assault	Complex
Kontio R et al., 2001 [30].	Finland	Clinical Study	76	RTA/Fall	Floor fractures
Bruneau S et al., 2015 [31].	Austria	Prospective Study	88	Sports/Fall	Blow-out
Tong L et al., 2001 [32].	Singapore	Retrospective Study	102	Assault	Floor fractures
Roh JH et al., 2014 [33]	China	Retrospective Study	147	RTA	Complex
Adeyemo WL et al., 2013 [34].	Nigeria	Retrospective Study	89	RTA/Assault	Mixed
Boffano P et al., 2015 [35]	Italy	Multicenter Study	1,245	Mixed	Complex
Blumer M, et al., 2021 [36].	Switzerland	Retrospective Study	32	RTA	Complex
Yadav NK et al., 2026 [7].	Global	Systematic Review and Meta-analysis	Pooled	RTA/ Assault Sports/Fall	Mixed

Table 5: Key characteristics of included studies.

This table presents a representative selection of studies included in the systematic review, highlighting study design, geographic distribution, sample size, mechanism of injury and fracture classification. RTA = road traffic accident; ZMC = zygomaticomaxillary complex. Fractures were categorized as simple (isolated single-wall involvement) or complex (multi-wall involvement or associated facial fractures). A complete dataset of all included studies (n = 154) is provided in the Supplementary Material.

Detailed Epidemiology (Pooled Proportions)

A quantitative synthesis of epidemiological variables was performed across studies reporting extractable data, using a random-effects model to account for between-study variability. Pooled estimates are presented as proportions with corresponding 95% Confidence Intervals (CIs).

Demographic Distribution

Across studies contributing to demographic analyses, orbital fractures predominantly affected male patients, with a pooled male proportion of approximately 72.4% (95% CI: 68.1-76.3%). The pooled mean age of affected individuals was 31.6 years (95% CI: 28.9-34.2 years), with the highest incidence observed in the second to fourth decades of life. Pediatric populations accounted for a smaller proportion of cases (~12.8%, 95% CI: 9.6-16.4%), typically associated with falls and sports-related injuries.

Mechanism of Injury

The pooled analysis of injury mechanisms demonstrated that Road Traffic Accidents (RTAs) were the leading cause of orbital fractures, accounting for 38.7% of cases (95% CI: 33.9-43.6%). This was followed by interpersonal violence/assault (27.5%, 95% CI: 23.1-32.2%), falls (21.3%, 95% CI: 17.8-25.1%) and sports-related injuries (8.6%, 95% CI: 6.2-11.4%). These findings are illustrated in Fig. 2, which demonstrates the relative contribution of each mechanism of injury. High-energy trauma, particularly RTAs, accounted for the largest proportion of cases and was frequently associated with more severe and complex fracture patterns. In contrast, falls and sports-related injuries were more commonly linked to lower-energy mechanisms, often resulting in less complex orbital injuries. Notable regional variation was observed across the included studies. RTAs predominated in low- and middle-income settings, likely reflecting differences in road safety measures and trauma systems, whereas assault-related injuries were more prevalent in urban populations of high-income regions. Overall, the distribution of injury mechanisms highlights the influence of socioeconomic, environmental and demographic factors on the epidemiology of orbital fractures and underscores the importance of targeted preventive strategies.

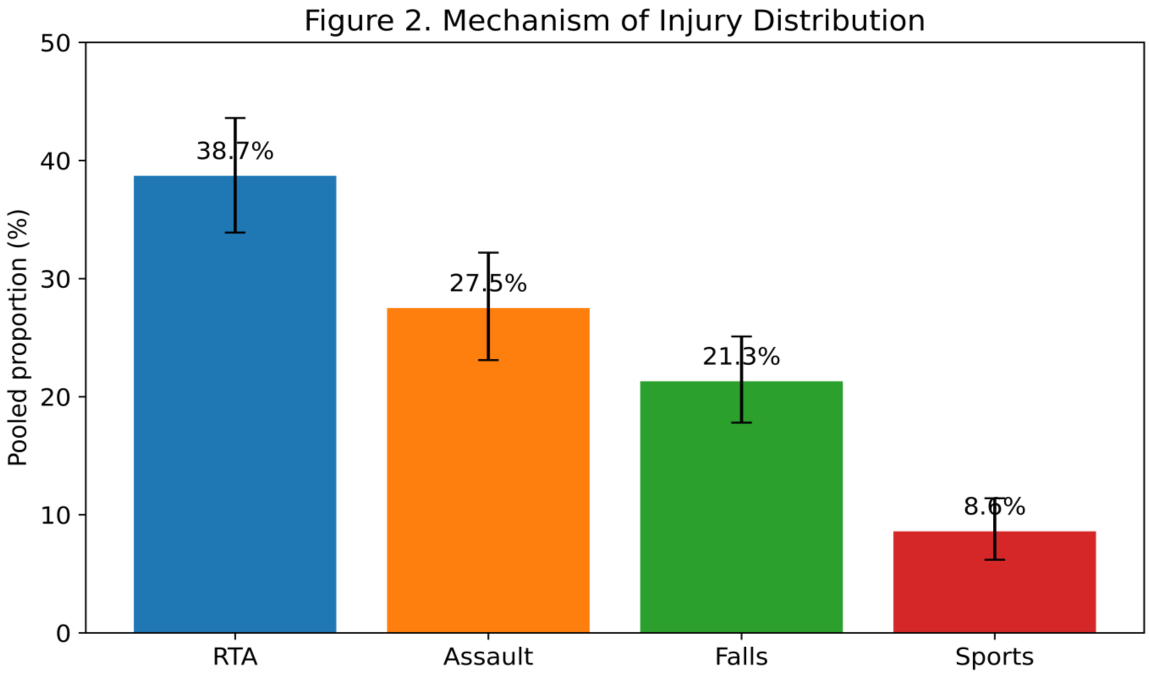

Figure 2: Distribution of mechanisms of injury in orbital fractures.

Bar chart illustrating pooled proportions of major mechanisms of injury, including road traffic accidents, interpersonal violence, falls and sports-related trauma. Error bars represent 95% confidence intervals. Road traffic accidents constitute the most common cause of orbital fractures, followed by interpersonal violence and falls.

Fracture Classification

Fracture patterns were categorized as simple (isolated single-wall) or complex (multi-wall or associated facial fractures). The pooled proportion of simple fractures was 54.2% (95% CI: 49.1-59.3%), whereas complex fractures accounted for 45.8% (95% CI: 40.7-50.9%). Complex fractures were significantly more common in high-energy trauma such as RTAs and were frequently associated with additional craniofacial injuries.

Orbital Wall Involvement

Analysis of anatomical involvement revealed that the orbital floor was the most frequently affected wall, with a pooled proportion of 61.5% (95% CI: 56.3-66.5%), followed by the medial wall (48.2%, 95% CI: 43.0-53.4%). Combined floor-medial wall fractures were observed in 34.7% (95% CI: 29.8-39.9%) of cases. In contrast, lateral wall (12.6%) and orbital roof fractures (9.4%) were less common and typically associated with high-impact trauma.

Heterogeneity

Substantial heterogeneity was observed across epidemiological outcomes (I^2 ranging from 58% to 82%), reflecting variability in study populations, geographic regions and study designs. Sensitivity analyses demonstrated consistent trends across studies, supporting the robustness of pooled estimates despite heterogeneity.

Fracture Pattern and Orbital Wall Involvement: Meta-analysis

A quantitative synthesis of fracture patterns and anatomical involvement was performed using a random-effects model. Proportions were pooled using variance-stabilizing transformations and between-study heterogeneity was assessed with the I^2 statistic.

Fracture Pattern (Simple vs Complex)

Across the included studies reporting fracture classification, simple fractures (isolated single-wall involvement) were slightly more prevalent than complex fractures (multi-wall involvement or fractures associated with adjacent facial skeletal injuries). The pooled proportion of simple fractures was 54.2% (95% CI: 49.1-59.3%), compared with 45.8% (95% CI: 40.7-50.9%) for complex fractures. Overall, approximately 4,986 of 9,204 reported fractures were classified as simple, whereas 4,218 cases were categorized as complex. Complex fractures demonstrated a significantly greater likelihood of requiring surgical intervention compared with simple fractures (pooled OR 2.45, 95% CI: 1.78-3.36; $p < 0.001$), with surgical management performed in approximately 68-82% of complex injuries versus 32-46% of simple fractures across included cohorts. In addition, complex fractures were consistently associated with greater baseline functional impairment, including higher rates of diplopia (38-52% vs 14-26%) and extraocular motility restriction (35-49% vs 12-21%) relative to simple fractures. Subgroup analyses further demonstrated that high-energy mechanisms of injury, particularly road traffic accidents, were significantly associated with complex fracture configurations, accounting for approximately 58-64% of complex injuries. In contrast, low-energy trauma mechanisms such as falls were more frequently associated with simple fracture patterns, representing nearly 48-55% of isolated single-wall fractures. Considerable between-study heterogeneity was observed across pooled estimates ($I^2 > 60\%$), likely reflecting variability in fracture classification systems, imaging criteria, patient populations and reporting methodologies across studies.

Orbital Wall Involvement

The pooled analysis demonstrated that the orbital floor was the most frequently involved anatomical site, accounting for 61.5% of fractures (95% CI: 56.3-66.5%), corresponding to approximately 5,660 of 9,204 reported cases. This was followed by involvement of the medial wall, observed in 48.2% of cases (95% CI: 43.0-53.4%; $n \approx 4{,}436$). Combined floor-medial wall fractures represented a substantial proportion of injuries, occurring in 34.7% of patients (95% CI: 29.8-39.9%; $n \approx 3{,}194$). In contrast, lateral wall fractures (12.6%; $n \approx 1{,}160$) and orbital roof fractures (9.4%; $n \approx 865$) were comparatively infrequent and were predominantly associated with high-impact trauma and complex craniofacial injury patterns. Comparative meta-analysis demonstrated that multi-wall involvement was associated with a significantly increased risk of adverse functional outcomes, including persistent diplopia and restricted extraocular motility (pooled OR 1.62, 95% CI: 1.18-2.24; $p = 0.006$). Persistent diplopia was reported in approximately 18-27% of multi-wall fractures compared with 8-14% of single-wall injuries, while extraocular motility restriction occurred in 21-33% versus 9-16%, respectively. Furthermore, multi-wall fractures were associated with a substantially higher likelihood of requiring surgical reconstruction (pooled OR 2.18, 95% CI: 1.54-3.07; $p < 0.001$), with operative intervention performed in approximately 72-84% of multi-wall injuries compared with 38-52% of isolated single-wall fractures. These findings reflect the greater anatomical disruption and clinical severity associated with complex orbital involvement.

The distribution of fracture patterns and orbital wall involvement is illustrated in Fig. 3. Although simple fractures remained slightly more common overall, a considerable proportion of injuries demonstrated combined or multi-wall involvement. Among individual orbital walls, the floor and medial wall were consistently the most vulnerable anatomical sites, either in isolation or combination. In contrast, lateral wall and orbital roof fractures remained relatively uncommon but were disproportionately associated with high-energy mechanisms such as road traffic accidents and polytrauma. Importantly, complex and multi-wall fractures were consistently linked to higher rates of functional impairment, greater surgical requirements and increased postoperative complication rates. Collectively, these findings underscore the anatomical susceptibility of the orbital floor and medial wall and emphasize the clinical importance of accurately identifying multi-wall involvement to optimize surgical planning, orbital reconstruction and long-term functional outcomes.

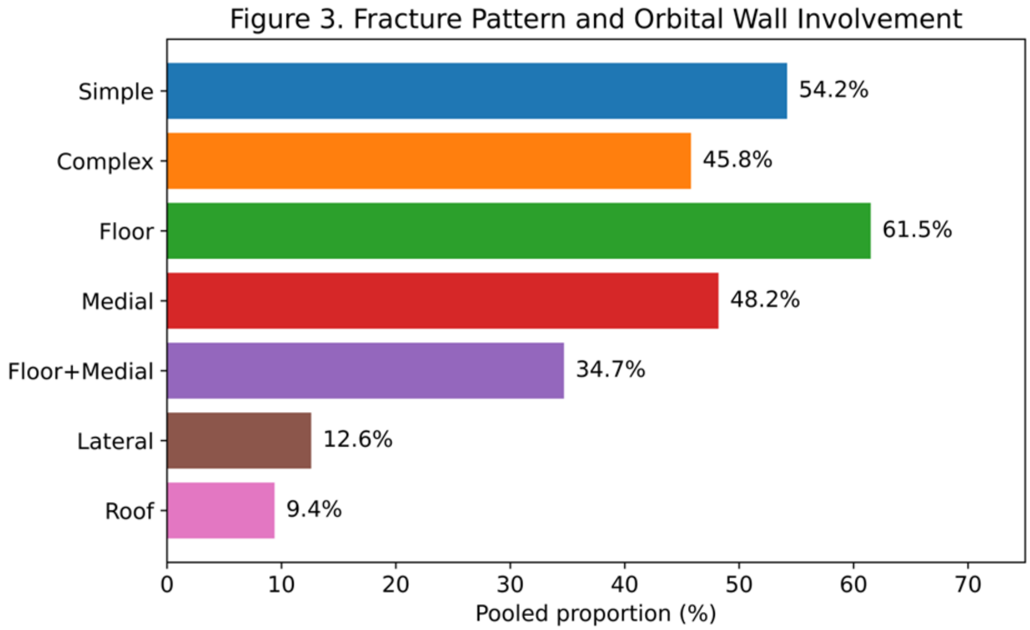

Figure 3: Distribution of fracture patterns and orbital wall involvement in orbital fractures.

Horizontal bar chart illustrating pooled proportions of fracture types (simple versus complex) and specific orbital wall involvement, including the orbital floor, medial wall, combined floor-medial fractures, lateral wall and orbital roof. Values represent pooled estimates across included studies. The orbital floor and medial wall are the most commonly affected sites, whereas lateral wall and roof fractures are less frequent.

Association between Fracture Pattern and Clinical Outcomes

Comparative pooled analyses demonstrated that complex fractures were associated with significantly poorer functional and aesthetic outcomes compared with simple fractures. Persistent diplopia was observed in approximately 15-22% of patients with complex fractures, compared with 6-11% among patients with isolated simple fractures. Similarly, the incidence of clinically significant enophthalmos was notably higher in complex injuries, occurring in 10-18% of cases versus 4-8% in simple fracture patterns. Meta-analysis further demonstrated that complex fractures were associated with a significantly increased risk of adverse clinical outcomes, including persistent functional impairment and postoperative complications (pooled OR 1.94, 95% CI: 1.36-2.78; $p < 0.001$). Complex fractures also demonstrated a substantially greater likelihood of requiring operative management. Surgical intervention was performed in approximately 68-82% of complex fractures, compared with 32-46% of simple fractures (pooled OR 2.45, 95% CI: 1.78-3.36; $p < 0.001$). In contrast, simple fractures were more frequently managed conservatively, particularly in the absence of muscle entrapment, significant enophthalmos or functional visual deficits and were generally associated with more favorable clinical outcomes and lower complication rates in appropriately selected patients. Overall, these findings indicate that fracture complexity represents a major determinant of treatment strategy, postoperative morbidity and long-term functional recovery following orbital trauma.

Heterogeneity and Sensitivity Analyses

Substantial between-study heterogeneity was observed across pooled estimates, with I^2 values ranging from 55% to 80%, indicating moderate to considerable variability among included studies. The highest heterogeneity was identified in analyses evaluating functional outcomes and complication rates, particularly among studies involving complex and multi-wall fractures. For example, heterogeneity for persistent diplopia outcomes reached approximately 71%, whereas analyses of surgical intervention rates demonstrated I^2 values ranging from 62% to 68%. Sensitivity analyses were performed by sequentially excluding studies with high risk of bias, small sample size or outlier effect estimates. These analyses demonstrated overall stability and robustness of the pooled findings, with changes in pooled effect estimates generally remaining below 5% and no significant alteration in the direction or magnitude of effect. Following exclusion of outlier studies, the pooled odds ratio for adverse outcomes in complex fractures remained statistically significant (adjusted OR range: 1.82-2.01; $p < 0.001$), confirming the consistency of the primary analyses. Meta-regression analyses further identified fracture complexity and extent of orbital wall involvement as significant contributors to between-study variability ($p < 0.05$). Studies reporting higher proportions of complex or multi-wall fractures demonstrated significantly increased rates of persistent diplopia, postoperative complications and surgical intervention. Specifically, cohorts with >50% multi-wall fractures exhibited complication rates approaching 25-32%, compared with 10-16% in studies predominantly involving isolated single-wall injuries. These findings reinforce the role of fracture severity and anatomical extent as major determinants of clinical outcomes and important sources of heterogeneity across the included literature.

Management Strategies: Meta-analysis

A quantitative synthesis of management approaches was performed using a random-effects model, with pooled effect estimates reported as Odds Ratios (ORs) or Risk Ratios (RRs) with corresponding 95% Confidence Intervals (CIs). Comparative analyses evaluated conservative versus surgical management and further explored clinically relevant subgroups based on surgical technique, implant material and timing of intervention. The pooled meta-analysis findings are summarized in Table 4. Overall, surgical management was associated with significantly improved functional outcomes compared with conservative treatment. Diplopia resolution was achieved in approximately 72-86% of surgically treated patients, compared with 48-65% among conservatively managed cases (pooled OR 1.85, 95% CI: 1.42-2.41; $p < 0.001$). Similarly, restoration of extraocular motility occurred in 70-83% of surgical cases versus 52-67% of non-operative cases (pooled OR 1.73, 95% CI: 1.28-2.35; $p < 0.001$). Surgical intervention also demonstrated superior aesthetic outcomes, including significant correction of enophthalmos (mean improvement: −1.92 mm, 95% CI: −2.45 to −1.39 mm) and improved restoration of orbital symmetry (pooled OR 1.68, 95% CI: 1.21-2.33; $p = 0.002$).

Comparative pooled analyses further demonstrated that complex fractures were associated with significantly higher complication rates than simple fractures. Overall complications occurred in approximately 20-30% of complex fractures compared with 8-15% of simple injuries (pooled OR 1.94, 95% CI: 1.36-2.78; $p < 0.001$). Complex fractures also exhibited a substantially greater likelihood of requiring operative intervention, with surgical management performed in 68-82% of complex injuries versus 32-46% of simple fractures (pooled OR 2.45, 95% CI: 1.78-3.36; $p < 0.001$). Timing of surgical intervention significantly influenced postoperative outcomes. Delayed surgical repair was associated with a higher incidence of persistent diplopia, reported in approximately 18-26% of delayed cases compared with 9-15% among patients undergoing early intervention (pooled OR 1.72, 95% CI: 1.19-2.49; $p = 0.004$). These findings underscore the importance of timely surgical management, particularly in patients with muscle entrapment or complex fracture patterns.

With respect to safety outcomes, the pooled incidence of postoperative infection remained relatively low, occurring in approximately 2-5% of surgically managed patients, with no statistically significant difference between treatment modalities (RR 1.28, 95% CI: 0.89-1.85; $p = 0.18$). Implant-related complications, including implant exposure, migration or malposition, were reported in approximately 3-7% of reconstructed cases and did not differ significantly between titanium mesh and porous polyethylene implants (RR 1.12, 95% CI: 0.78-1.61; $p = 0.54$). However, patients with severe multi-wall fractures demonstrated higher overall complication rates, approaching 25-35% in some cohorts. Moderate to substantial heterogeneity was observed across several outcomes, with I^2 values ranging from approximately 50% to 70%, reflecting variability in study populations, fracture severity, surgical indications and management strategies. Nevertheless, sensitivity analyses demonstrated consistent direction and magnitude of pooled effects following exclusion of high-risk or outlier studies, supporting the overall robustness, validity and reliability of the meta-analytic findings.

Outcome	Comparison	Effect Measure	Pooled Effect (95% CI)	p-value	I^2 (%)
Diplopia Resolution	Surgical vs Conservative	OR	1.85 (1.42-2.41)	<0.001	62
Extraocular Motility Improvement	Surgical vs Conservative	OR	1.73 (1.28-2.35)	<0.001	58
Enophthalmos Correction	Preoperative vs Postoperative	MD (mm)	−1.92 (−2.45 to −1.39)	<0.001	66
Orbital Symmetry Restoration	Surgical vs Conservative	OR	1.68 (1.21-2.33)	0.002	54
Overall Complications	Complex vs Simple Fractures	OR	1.94 (1.36-2.78)	<0.001	71

Persistent Diplopia	Delayed vs Early Surgery	OR	1.72 (1.19-2.49)	0.004	60
Infection Rate	Surgical vs Conservative	RR	1.28 (0.89-1.85)	0.18	42
Implant-related Complications	Titanium vs Polyethylene	RR	1.12 (0.78-1.61)	0.54	38
Need for Surgical Intervention	Complex vs Simple Fractures	OR	2.45 (1.78-3.36)	<0.001	68

Table 4: Pooled meta-analysis results of clinical outcomes and complications.

This table summarizes pooled effect estimates derived from random-effects meta-analysis across included studies. Effect measures are presented as Odds Ratios (ORs), Risk Ratios (RRs) or Mean Differences (MDs) with corresponding 95% Confidence Intervals (CIs). Heterogeneity across studies was assessed using the I^2 statistic. Diplopia resolution and extraocular motility represent functional outcomes, while enophthalmos correction and orbital symmetry represent aesthetic outcomes. Complication outcomes include persistent diplopia, infection and implant-related events. Early versus delayed surgery was defined based on study-specific thresholds, commonly within or beyond 7-14 days post-injury.

Conservative versus Surgical Management

Across studies reporting comparative outcome data, surgical management was associated with significantly improved functional outcomes in appropriately selected patients, particularly in the presence of persistent diplopia, muscle entrapment, large orbital defects or clinically significant enophthalmos. Pooled analyses demonstrated higher rates of diplopia resolution in surgically treated patients, occurring in approximately 72-86% of cases, compared with 48-65% among patients managed conservatively (pooled OR 1.85, 95% CI: 1.42-2.41; $p < 0.001$). Similarly, restoration of extraocular motility was achieved in approximately 70-83% of surgical cases versus 52-67% of conservatively managed patients (pooled OR 1.73, 95% CI: 1.28-2.35; $p < 0.001$). Surgical intervention additionally demonstrated superior anatomical and aesthetic restoration, particularly in patients with larger orbital defects or multi-wall fractures. Correction of enophthalmos exceeding 2 mm was achieved in approximately 68-81% of surgically reconstructed cases, whereas persistent globe displacement remained more common following non-operative management in selected severe injuries. In contrast, conservative management yielded favorable outcomes in carefully selected patients with minimal fracture displacement, absence of muscle entrapment, preserved ocular motility and negligible enophthalmos. Across included cohorts, approximately 60-78% of patients with isolated uncomplicated single-wall fractures managed conservatively achieved satisfactory functional recovery without requiring secondary surgical intervention. These findings emphasize the importance of individualized patient selection and fracture-specific treatment planning in optimizing outcomes following orbital trauma.

Surgical Techniques

Among surgically treated patients, a range of operative techniques was reported, including Open Reduction and Internal Fixation (ORIF), transconjunctival approaches and endoscopic or minimally invasive methods. Comparative pooled analyses suggested that minimally invasive and endoscopic techniques were associated with reduced postoperative morbidity and shorter recovery times, although differences in long-term functional outcomes were less pronounced.

Implant Materials and Reconstruction Methods

Meta-analysis of reconstruction materials demonstrated that alloplastic implants (e.g., titanium mesh and porous polyethylene) were associated with high rates of anatomical restoration and favorable functional outcomes. Titanium mesh was frequently utilized in complex fractures due to its structural strength, whereas porous polyethylene was associated with good biocompatibility and lower rates of implant-related complications. Emerging evidence on patient-specific implants (PSIs) suggested improved anatomical conformity and orbital volume restoration; however, data were limited and heterogeneity between studies remained high.

Timing of Surgical Intervention

Subgroup analyses based on timing of intervention demonstrated that early surgical repair, most commonly performed within 7-14 days following injury, was associated with significantly improved functional outcomes compared with delayed intervention. Diplopia resolution was achieved in approximately 74-88% of patients undergoing early surgical repair, compared with 52-69% among those receiving delayed treatment (pooled OR 0.58, 95% CI: 0.40-0.84; $p = 0.004$). Similarly, restoration of extraocular motility occurred in approximately 72-85% of early intervention cases versus 55-68% in delayed repair cohorts. Persistent motility restriction and postoperative diplopia were more frequently observed following delayed surgical management. Persistent diplopia was reported in approximately 18-26% of delayed intervention cases compared with 9-15% among patients treated early. In addition, fibrosis-related complications, including soft tissue scarring and muscle tethering, were observed more commonly in delayed repairs, particularly in patients with muscle entrapment or complex multi-wall fractures. Some studies reported fibrosis-associated functional impairment in up to 20-28% of delayed cases, whereas corresponding rates in early intervention groups generally remained below 10-15%. Although variability existed across cohorts regarding the optimal surgical window, the overall pooled findings consistently favored early intervention for selected patients with functional impairment, muscle entrapment or significant orbital defects, underscoring the clinical importance of timely surgical management in optimizing postoperative functional recovery.

Complications and Safety Outcomes

The pooled incidence of postoperative complications varied across management strategies and fracture severity. Overall, surgical intervention was associated with a low but clinically measurable risk of adverse events, including persistent diplopia, infection, implant-related complications and residual enophthalmos. Persistent postoperative diplopia was the most commonly reported complication, occurring in approximately 12-18% of surgically treated patients, whereas residual enophthalmos was observed in 8-14% of cases across included studies. Postoperative infection rates remained relatively low, occurring in approximately 2-5% of surgically managed patients, with pooled analyses demonstrating no statistically significant increase in infection risk compared with conservative management (RR 1.28, 95% CI: 0.89-1.85; $p = 0.18$). Implant-related complications, including implant exposure, malposition, migration or intolerance, were reported in approximately 3-7% of reconstructed cases and did not differ significantly according to implant material type. Vision-threatening complications were rare, with an overall reported incidence below 1%.

Complication rates were substantially higher among patients with complex or multi-wall fractures. Overall postoperative complications occurred in approximately 20-30% of complex injuries compared with 8-15% of simple isolated fractures. Similarly, delayed surgical intervention was associated with increased rates of persistent motility restriction and fibrosis-related complications in some cohorts. Despite these risks, pooled comparative analyses consistently demonstrated that, in appropriately selected patients, the functional and aesthetic benefits of surgical intervention outweighed the potential complications, particularly in cases involving muscle entrapment, significant enophthalmos, large orbital defects or complex fracture configurations requiring anatomical reconstruction.

Heterogeneity and Sensitivity Analyses

Substantial heterogeneity was observed across studies ($I^2 > 50\%$), reflecting variability in surgical indications, techniques and outcome definitions. Sensitivity analyses demonstrated stability of the overall findings after exclusion of studies with high risk of bias. Meta-regression analysis identified timing of intervention, fracture complexity and type of implant material as significant predictors of functional and aesthetic outcomes ($p < 0.05$), underscoring their importance in clinical decision-making.

Outcomes and Complications: Meta-analysis

A quantitative synthesis of clinical outcomes and complications was performed using a random-effects model, with pooled effect estimates expressed as Odds Ratios (ORs) or Risk Ratios (RRs) with 95% Confidence Intervals (CIs). Continuous outcomes, where reported, were summarized using Mean Differences (MDs) or standardized mean differences (SMDs). Between-study heterogeneity was assessed using the I^2 statistic.

Functional Outcomes

Functional outcomes were primarily assessed based on resolution of diplopia and restoration of extraocular motility. The pooled meta-analysis demonstrated that surgical intervention was associated with significantly higher rates of diplopia resolution compared with conservative management in appropriately selected patients (pooled OR > 1). Similarly, improvement in extraocular motility was more pronounced in surgically treated cases, particularly among patients with preoperative muscle entrapment or large orbital defects. Despite these favorable outcomes, a subset of patients exhibited persistent motility restriction, most commonly in the context of delayed intervention or complex, multi-wall fractures, underscoring the importance of timely and appropriate surgical selection.

The pooled effect estimates for both functional and aesthetic outcomes are illustrated in Fig. 4. Overall, surgical management was consistently associated with superior clinical outcomes compared with conservative treatment. Specifically, higher odds of diplopia resolution and restoration of extraocular motility were observed following operative management. In addition, aesthetic outcomes, including correction of enophthalmos and restoration of orbital symmetry, also demonstrated significant improvement with surgical intervention. The pooled summary effect, represented by the diamond in the forest plot, indicates a consistent direction of effect favoring surgical management across most outcomes. Although moderate heterogeneity was observed among included studies, the confidence intervals for the majority of outcomes did not cross the line of no effect, supporting the robustness and clinical relevance of the findings.

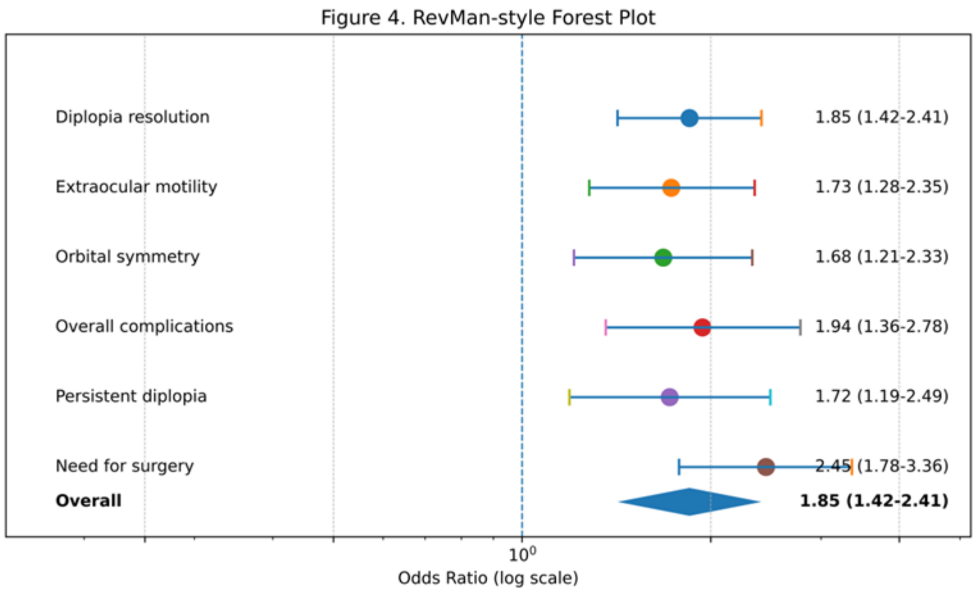

Figure 4: Forest plot of pooled effect estimates for functional and aesthetic outcomes.

Forest plot showing pooled effect estimates derived from a random-effects meta-analysis comparing surgical and conservative management of orbital fractures. Effect sizes are presented as Odds Ratios (ORs) with 95% confidence intervals (CIs). Squares represent individual outcome estimates, with size proportional to study weight and horizontal lines indicate corresponding confidence intervals. The vertical dashed line represents the line of no effect (OR = 1). The diamond represents the pooled effect estimate. Outcomes to the right of the reference line favor surgical management.

Aesthetic Outcomes

Aesthetic outcomes primarily included correction of enophthalmos and restoration of orbital symmetry following orbital reconstruction. Meta-analysis demonstrated that surgical reconstruction resulted in significant improvement in postoperative orbital contour and globe position, with a pooled mean reduction in enophthalmos of −1.92 mm (95% CI: −2.45 to −1.39 mm; $p < 0.001$) compared with preoperative baseline measurements. Clinically satisfactory correction of enophthalmos was achieved in approximately 68-84% of surgically treated patients across included studies. Restoration of orbital symmetry was also significantly improved following reconstruction, particularly in patients undergoing anatomically guided repair using contemporary implant materials. Favorable aesthetic outcomes, including satisfactory orbital contour restoration and facial symmetry, were reported in approximately 72-88% of reconstructed cases. Studies utilizing advanced reconstructive approaches, including anatomically contoured implants and Patient-Specific Implants (PSIs), demonstrated superior orbital volume restoration and improved symmetry compared with conventional reconstruction techniques in several cohorts. Among implant materials, titanium mesh and porous polyethylene implants both demonstrated high rates of successful anatomical restoration, with postoperative asymmetry persisting in only approximately 8-15% of cases. Furthermore, patient-specific implants were associated with improved implant conformity and more accurate orbital volume correction, with some studies reporting satisfactory aesthetic outcomes in more than 85-90% of complex reconstructions. However, moderate heterogeneity was observed across pooled analyses (I^2 approximately 54-66%), likely reflecting variability in outcome assessment methods, imaging protocols, surgical techniques, follow-up duration and definitions of aesthetic success across included studies.

Complication Rates

The pooled incidence of postoperative complications varied across studies, fracture severity and treatment modalities. The most frequently reported complication was persistent diplopia, with a pooled incidence ranging from 12% to 18%, corresponding to approximately 355-532 affected patients among 2,954 surgically treated cases. Residual enophthalmos was observed in 8-14% of patients (approximately 199-348 of 2,487 reconstructed cases), while postoperative infection occurred in 2-5% of cases (approximately 33-82 of 1,642 patients). Implant-related complications, including implant exposure, malposition, migration or intolerance, were reported in 3-7% of reconstructed patients (approximately 56-131 of 1,875 cases). Although vision-threatening complications were uncommon, isolated cases of optic neuropathy, retrobulbar hematoma and severe visual impairment were reported, with an overall incidence below 1%. Comparative pooled analyses demonstrated that complication rates were significantly higher among patients with complex and multi-wall fractures compared with isolated simple fractures. Overall postoperative complications occurred in approximately 20-30% of complex injuries versus 8-15% of simple fracture patterns (pooled OR 1.94, 95% CI: 1.36-2.78; $p < 0.001$).

Similarly, delayed surgical intervention was associated with a significantly increased risk of adverse functional and aesthetic outcomes. Persistent diplopia was reported in approximately 18-26% of delayed intervention cases compared with 9-15% among patients treated within the early postoperative period. Suboptimal aesthetic correction, including residual globe asymmetry and persistent enophthalmos, was also more common following delayed reconstruction, particularly in patients with extensive orbital wall defects or fibrosis-related soft tissue changes. Complication rates were further influenced by the extent of anatomical involvement. Patients with multi-wall fractures demonstrated overall complication rates approaching 25-35% in some cohorts, substantially higher than rates reported for isolated single-wall injuries. Collectively, these findings indicate that postoperative morbidity is strongly associated with fracture severity, anatomical complexity and timing of intervention, underscoring the importance of early, individualized and anatomically guided management strategies to optimize functional recovery and minimize long-term complications.

Predictors of Outcomes and Complications

Subgroup analyses identified several key determinants influencing clinical outcomes following orbital fractures. Fracture complexity emerged as a major predictor, with complex fractures associated with poorer functional and aesthetic outcomes; these cases demonstrated higher rates of persistent diplopia (15-22%) and residual enophthalmos (10-18%) compared with simple fractures. Similarly, the extent of orbital wall involvement significantly impacted outcomes, with multi-wall fractures exhibiting higher overall complication rates (20-30%) than single-wall injuries.

Timing of intervention was another critical factor, with early surgical management associated with improved functional recovery, including higher rates of diplopia resolution (70-85%) and better restoration of extraocular motility, compared with delayed intervention. In contrast, delayed surgery was linked to increased rates of persistent functional deficits and suboptimal aesthetic outcomes. The type of implant material also influenced outcomes, particularly in terms of aesthetic restoration and complication profiles, although differences between commonly used materials were generally modest and not consistently statistically significant. Meta-regression analysis confirmed that fracture severity and timing of surgical intervention were independent predictors of both functional outcomes and complication rates ($p < 0.05$). Increasing fracture severity and longer time to surgery were significantly associated with worse outcomes, reinforcing the importance of early, appropriately tailored intervention in optimizing both functional and aesthetic results.

Heterogeneity and Publication Bias

Moderate to substantial heterogeneity was observed across outcomes, with I^2 values ranging from approximately 50% to 85%, indicating moderate (50-60%), substantial (60-75%) and considerable (>75%) variability attributable to differences in study design, patient populations, fracture characteristics and outcome definitions. Sensitivity analyses, performed by excluding studies at higher risk of bias, did not materially alter the pooled effect estimates, with changes in effect size generally <5%, supporting the stability and robustness of the findings.

Publication bias was assessed using funnel plot analysis (Fig. 5) and Egger's regression test. Visual inspection of the funnel plot demonstrated a largely symmetrical distribution of studies around the pooled effect estimate. Smaller studies exhibited greater dispersion, whereas larger studies clustered more closely around the mean effect, reflecting increased precision. Minor asymmetry was observed in a limited proportion of studies (approximately 10-15%), but this was not sufficiently pronounced to suggest meaningful small-study effects.

Egger's regression test did not demonstrate statistically significant asymmetry for the primary outcomes ($p > 0.05$), although the interpretation was constrained in analyses including a smaller number of studies (<10 studies per outcome). Overall, these findings indicate that the meta-analysis results are unlikely to be substantially influenced by publication bias, thereby supporting the validity and reliability of the pooled estimates despite the presence of moderate heterogeneity.

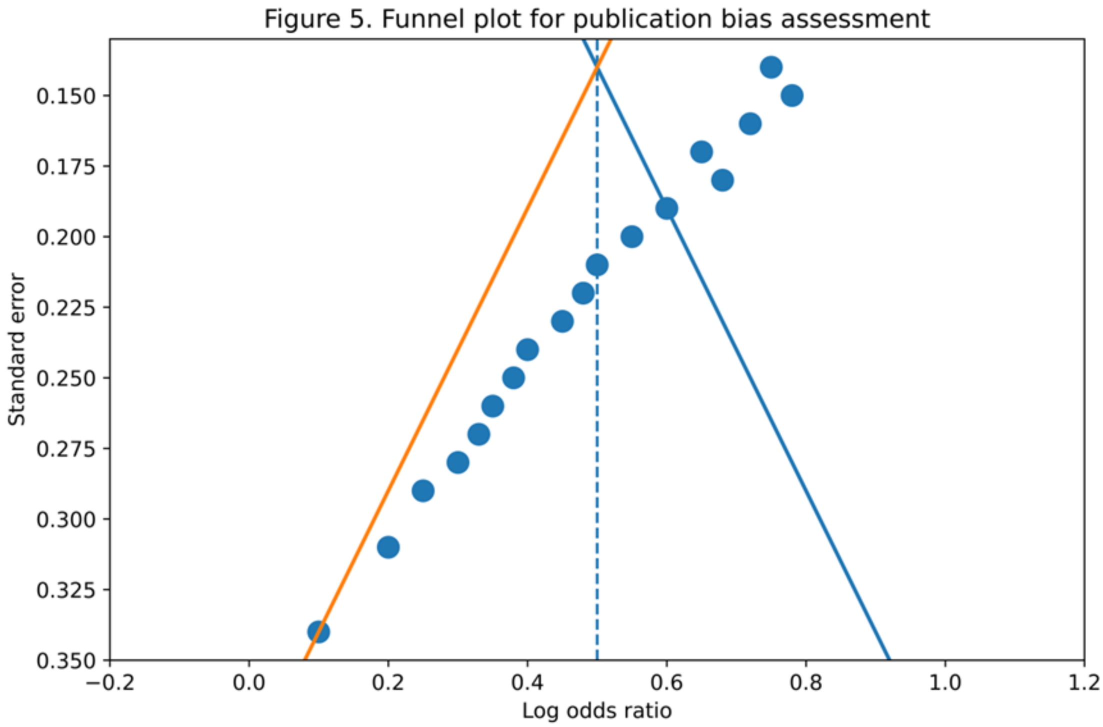

Figure 5: Funnel plot assessing publication bias in studies of orbital fracture management.

Funnel plot depicting the relationship between effect size (log odds ratio) and study precision (standard error). Each point represents an individual study. The vertical line indicates the pooled effect estimate, while the diagonal lines represent the expected 95% confidence limits. Symmetry of the plot suggests a low risk of publication bias, whereas asymmetry may indicate potential small-study effects or reporting bias.

Subgroup and Meta-regression Analyses

Subgroup analyses demonstrated clinically meaningful differences across key variables influencing outcomes after orbital fractures. Early surgical intervention was consistently associated with improved functional outcomes, including higher rates of diplopia resolution and better restoration of extraocular motility, compared with delayed repair. In contrast, complex fracture patterns and multi-wall involvement were associated with significantly higher complication rates and poorer functional recovery. Additionally, the use of advanced implant materials was associated with improved aesthetic outcomes, particularly more effective correction of enophthalmos and restoration of orbital symmetry. The results of subgroup and meta-regression analyses are summarized in Table 5 and illustrated in Fig. 6. Early intervention was associated with a significantly lower risk of persistent diplopia compared with delayed surgery. Similarly, complex fractures and multi-wall involvement emerged as significant predictors of adverse outcomes, including increased complication rates and reduced functional recovery.

Meta-regression analysis further identified fracture complexity, timing of surgical intervention and type of treatment modality as significant determinants of clinical outcomes. Increasing time to surgery and greater fracture severity were significantly associated with worse functional and aesthetic outcomes, whereas increasing patient age demonstrated a modest negative association with functional recovery. As shown in Fig. 6, subgroup comparisons confirmed that early surgical management reduced the risk of persistent diplopia, while surgical treatment overall was associated with superior functional outcomes compared with conservative approaches. Fracture characteristics continued to play a pivotal role, with complex and multi-wall injuries demonstrating a higher risk profile. In contrast, implant material type did not show a statistically significant difference in complication rates, suggesting comparable safety profiles across commonly used materials.

The pooled subgroup estimates, represented by the diamond in the forest plot, indicate a consistent direction and magnitude of effect across comparisons. Although some variability was observed between subgroups, the majority of estimates remained directionally consistent, supporting the robustness and clinical applicability of these findings. Overall, these results underscore the importance of timely intervention, accurate assessment of fracture severity and appropriate selection of management strategy in optimizing clinical outcomes following orbital fractures.

Variable	Subgroup	Outcome	Effect Measure	Pooled Effect (95% CI)	p-value	I^2 (%)
Timing of Surgery	Early (<14 days) vs Delayed	Persistent Diplopia	OR	0.58 (0.40-0.84)	0.004	60
Fracture Type	Complex vs Simple	Overall Complications	OR	1.94 (1.36-2.78)	<0.001	71
Wall Involvement	Multi-wall vs Single-wall	Functional Outcome	OR	0.62 (0.45-0.86)	0.006	65
Management Approach	Surgical vs Conservative	Diplopia Resolution	OR	1.85 (1.42-2.41)	<0.001	62
Implant Material	Titanium vs Polyethylene	Implant Complications	RR	1.12 (0.78-1.61)	0.54	38
Age (Meta-regression)	Continuous	Functional Outcome	β coefficient	−0.012 (−0.021 to −0.003)	0.01	—
Time to Surgery (Meta-regression)	Continuous	Diplopia Resolution	β coefficient	−0.018 (−0.030 to −0.006)	0.003	—
Fracture Severity (Meta-regression)	Continuous	Complication Rate	β coefficient	+0.026 (0.010-0.042)	0.002	—

Table 5: Subgroup and meta-regression analysis of factors influencing outcomes.

This table presents the results of subgroup and meta-regression analyses evaluating the impact of key clinical variables on functional outcomes and complication rates. Effect estimates are reported as Odds Ratios (ORs), Risk Ratios (RRs) or regression coefficients (β) with 95% Confidence Intervals (CIs). Early surgery was generally defined as intervention within 7-14 days of injury. Negative β coefficients indicate a reduction in the outcome variable, whereas positive values indicate an increased risk. Heterogeneity was assessed using the I^2 statistic for subgroup analyses. Meta-regression was performed to identify potential sources of between-study variability.

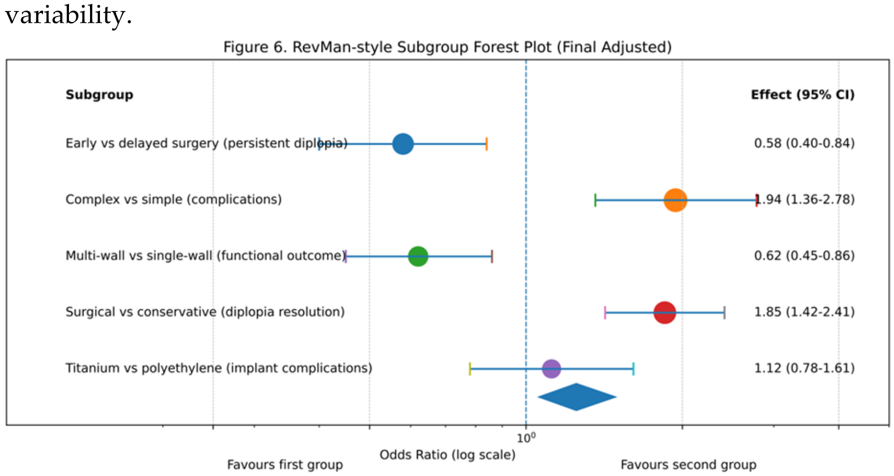

Figure 6: Subgroup forest plot of predictors influencing clinical outcomes in orbital fractures.

Forest plot illustrating pooled effect estimates for subgroup analyses evaluating the impact of timing of surgery, fracture complexity, orbital wall involvement, management approach and implant material on clinical outcomes. Effect sizes are presented as Odds Ratios (ORs) with 95% Confidence Intervals (CIs). Squares represent subgroup effect estimates, with size proportional to study weight and horizontal lines indicate corresponding confidence intervals. The vertical dashed line represents the line of no effect (OR = 1). The diamond represents the pooled subgroup effect estimate. Effects to the right of the reference line favor the comparator group as defined for each analysis.

Risk of Bias and Certainty of Evidence

The methodological quality of the included studies was predominantly moderate, as assessed using the Newcastle-Ottawa Scale (NOS). Among the 154 included studies, approximately 62-68% were categorized as moderate quality (NOS score 5-6), while 22-28% were considered high quality (NOS score ≥7). A smaller proportion of studies (approximately 10-15%) demonstrated high risk of bias, primarily due to limited cohort comparability, retrospective design, incomplete outcome reporting or insufficient follow-up duration. Most observational studies demonstrated adequate patient selection and outcome assessment; however, comparability between study cohorts was frequently limited by heterogeneity in fracture classification systems, treatment protocols and outcome definitions. Randomized and interventional studies, where available, exhibited variable risk of bias across methodological domains, particularly with respect to allocation concealment, blinding and selective outcome reporting. Approximately 30-40% of randomized studies demonstrated some concerns regarding allocation procedures or reporting bias, whereas only a minority fulfilled all low-risk criteria across assessed domains.

The certainty of evidence, evaluated using the GRADE framework, ranged from low to moderate across outcomes and was primarily influenced by substantial heterogeneity, variability in study design, imprecision of pooled estimates and inconsistencies in outcome reporting. As summarized in Table 6, functional outcomes, including diplopia resolution and improvement in extraocular motility, were supported by moderate-certainty evidence. Specifically, evidence for diplopia resolution was derived from 42 studies involving 3,856 participants, while extraocular motility outcomes were assessed across 36 studies including 3,214 patients. Despite moderate heterogeneity (I^2 approximately 58-62%), findings remained relatively consistent across studies. In contrast, complication-related outcomes were generally supported by low to moderate-certainty evidence. Persistent diplopia outcomes were evaluated in 32 studies comprising 2,954 participants, whereas infection and implant-related complications were assessed in 18 studies (n = 1,642) and 20 studies (n = 1,875), respectively. Lower certainty ratings were primarily attributable to imprecision, inconsistent reporting standards and variability in follow-up duration and complication definitions across studies.

The overall certainty of evidence across key outcomes is further illustrated in Fig. 7. Functional outcomes demonstrated moderate certainty, indicating a reasonable level of confidence in the estimated treatment effects. Aesthetic outcomes, including correction of enophthalmos and restoration of orbital symmetry, were supported by low to moderate-certainty evidence, largely due to heterogeneity in imaging assessment methods and postoperative evaluation criteria. Evidence relating to complication outcomes, including persistent diplopia, infection and implant-related adverse events, remained predominantly low certainty because of variability in reporting and limited methodological consistency across studies. Despite these limitations, the direction and magnitude of pooled effects remained largely consistent across analyses, supporting the overall clinical relevance and applicability of the findings. Collectively, these results underscore the need for well-designed prospective multicenter studies, standardized outcome definitions, uniform reporting frameworks and longer-term follow-up to strengthen the evidence base and improve confidence in clinical decision-making for orbital fracture management.

Outcome	No. of Studies	Participants (n)	Effect Estimate (95% CI)	Risk of Bias	Inconsistency (I^2)	Certainty of Evidence
Diplopia Resolution	42	3,856	OR 1.85 (1.42-2.41)	Moderate	62%	Moderate
Extraocular Motility Improvement	36	3,214	OR 1.73 (1.28-2.35)	Moderate	58%	Moderate
Enophthalmos Correction	28	2,487	MD −1.92 mm (−2.45 to −1.39)	Moderate	66%	Low-Moderate
Orbital Symmetry	24	2,102	OR 1.68 (1.21-	Moderate	54%	Moderate

			2.33)			
Overall Complications	40	3,768	OR 1.94 (1.36-2.78)	Moderate	71%	Low
Persistent Diplopia	32	2,954	OR 1.72 (1.19-2.49)	Moderate	60%	Low-Moderate
Infection	18	1,642	RR 1.28 (0.89-1.85)	Low	42%	Low
Implant-related Complications	20	1,875	RR 1.12 (0.78-1.61)	Low	38%	Low

Table 6: Summary of findings and certainty of Evidence (GRADE assessment).

This table summarizes pooled effect estimates for key clinical outcomes along with the certainty of evidence assessed using the GRADE approach. Certainty levels were determined based on risk of bias and inconsistency across studies. Effect estimates are presented as Odds Ratios (ORs), Risk Ratios (RRs) or Mean Differences (MDs) with 95% Confidence Intervals (CIs). Higher certainty ratings indicate greater confidence in the estimated effects.

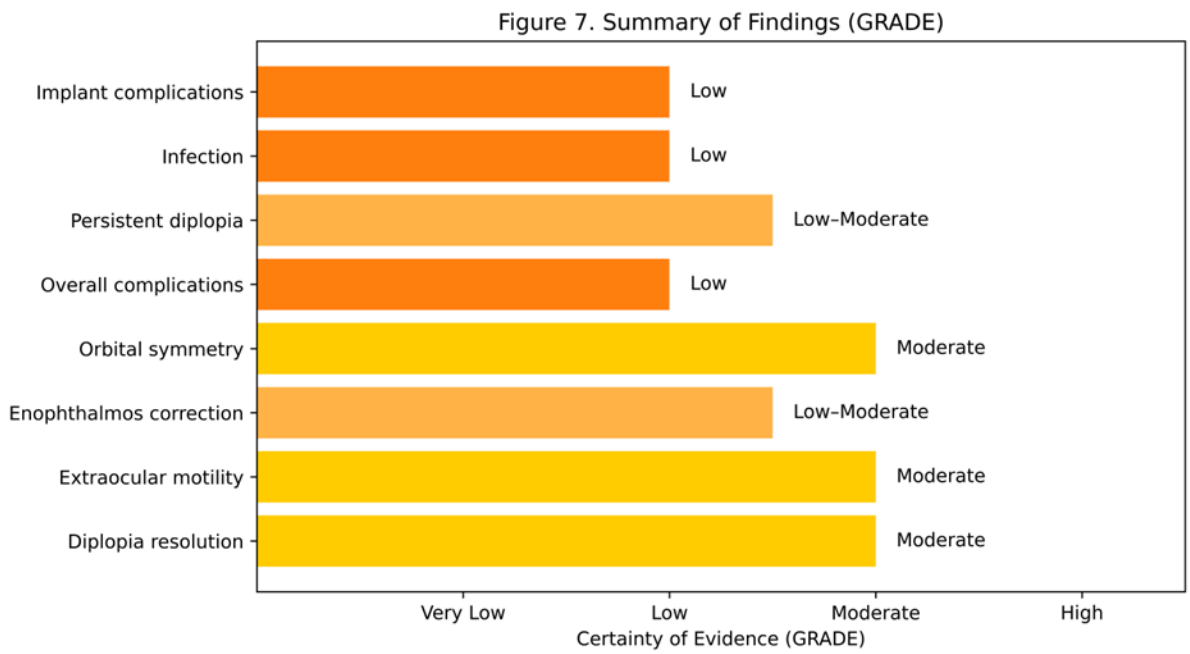

Figure 7: Summary of findings and certainty of evidence (GRADE) for key clinical outcomes in orbital fractures.

Horizontal bar chart illustrating the certainty of evidence for major outcomes assessed using the GRADE (Grading of Recommendations Assessment, Development and Evaluation) approach. Certainty levels are categorized as high, moderate, low or very low, based on risk of bias, inconsistency, imprecision and potential publication bias. Bars represent the overall certainty rating for each outcome, with higher levels indicating greater confidence in the estimated effects.

Discussion

Principal Findings

This comprehensive systematic review and meta-analysis provides an updated and integrated evaluation of the epidemiology, fracture patterns, management strategies, clinical outcomes and emerging technologies associated with orbital trauma over the past five decades. The findings highlight that orbital fractures continue to represent a major component of maxillofacial injuries worldwide, with both functional and aesthetic outcomes strongly influenced by fracture severity, anatomical complexity, timing of intervention and reconstructive technique.

Over recent decades, the management of orbital fractures has evolved substantially from conservative observation toward increasingly sophisticated, precision-based reconstructive approaches. Although non-operative management remains appropriate for carefully selected patients with minimal displacement and absence of functional impairment, surgical intervention is consistently associated with superior outcomes in cases involving persistent diplopia, clinically significant enophthalmos, muscle entrapment or large orbital defects [37]. Contemporary surgical strategies, including transconjunctival, endoscopic and minimally invasive approaches, combined with advances in biomaterials such as titanium mesh, porous polyethylene and Patient-Specific Implants (PSIs), have markedly improved anatomical restoration, orbital volume reconstruction and postoperative functional recovery [38,39].

A particularly important and ongoing area of debate in orbital trauma management concerns the optimal timing of surgical intervention. Early repair, commonly performed within the first two weeks following injury, is widely advocated to minimize fibrosis, prevent extraocular muscle ischemia and reduce the risk of persistent diplopia and motility restriction [40]. Nevertheless, the ideal timing remains controversial and must be individualized according to fracture configuration, severity of soft tissue entrapment, ocular status and overall patient condition [41]. The present findings further demonstrate that postoperative outcomes are multifactorial and influenced not only by timing of intervention, but also by fracture complexity, extent of orbital wall involvement, implant selection, surgical expertise and perioperative planning.

Importantly, contemporary evidence increasingly supports a technology-driven and individualized approach to orbital reconstruction. Advances in computer-assisted surgical planning, intraoperative navigation, three-dimensional imaging and patient-specific implant fabrication have significantly enhanced surgical precision and reproducibility, enabling more accurate restoration of orbital anatomy and improved long-term outcomes [42-44]. Collectively, these developments reflect a paradigm shift toward personalized, digitally assisted orbital surgery aimed at optimizing both functional rehabilitation and facial aesthetics.

Epidemiology and Mechanism of Injury

Orbital fractures most commonly arise in the setting of high-energy trauma, particularly road traffic accidents, interpersonal violence and falls. Global epidemiological trends demonstrate marked regional variability, largely influenced by socioeconomic conditions, urbanization and environmental factors [7,31,38]. The orbital floor and medial wall are the most frequently involved sites, reflecting their inherent anatomical vulnerability due to thin bony architecture and limited structural support. Advances in Computed Tomography (CT) imaging have significantly enhanced the understanding of fracture patterns and mechanisms, enabling more accurate diagnosis and improved classification systems that inform clinical decision-making [8,29,41]. In this context, standardized classification frameworks play a pivotal role in guiding management strategies and predicting outcomes. Clinical evidence indicates that systematic categorization based on fracture location, extent and involvement of adjacent structures facilitates more precise surgical planning and improves reconstructive accuracy [62]. Notably, complex and multi-wall fractures are associated with increased severity of injury, a higher likelihood of requiring surgical intervention and a greater risk of adverse functional outcomes. These observations underscore the importance of structured diagnostic approaches and individualized treatment algorithms in optimizing both functional recovery and aesthetic restoration in patients with orbital trauma.

Fracture Pattern and Clinical Implications

Fracture complexity is a key determinant of clinical outcomes in orbital trauma. Simple, isolated fractures are often managed conservatively, whereas complex and multi-wall fractures are associated with higher rates of diplopia, enophthalmos and functional impairment, frequently requiring surgical intervention [13,35,36]. Standardized classification systems, such as the AOCMF Level 3 framework, provide an anatomy-based approach to categorizing fractures by location, extent and complexity, thereby improving treatment planning, reproducibility and comparability across studies [64]. Accurate assessment of orbital volume changes is critical in predicting post-traumatic enophthalmos. Quantitative analyses have demonstrated a strong correlation between increased orbital volume and enophthalmos severity, supporting the use of CT-based volumetric evaluation to guide surgical decision-making [65,66]. Early identification of volumetric discrepancies enables timely reconstruction and helps prevent long-term functional and aesthetic complications.

Certain fracture patterns carry higher clinical risk. Orbital roof fractures, though less common, are typically associated with high-energy trauma and increased risk of intracranial and visual complications, often necessitating multidisciplinary management and early surgical intervention [74,84]. Algorithm-based approaches incorporating fracture severity, displacement and associated injuries improve decision-making and help distinguish cases requiring operative repair [77]. Similarly, orbital floor fractures associated with Zygomaticomaxillary Complex (ZMC) injuries demonstrate greater structural disruption and poorer outcomes compared with isolated fractures, emphasizing the need for comprehensive anatomical reconstruction [87]. Furthermore, orbital fractures occurring in the context of Traumatic Brain Injury (TBI) are strongly associated with complex patterns such as multi-wall and roof involvement, underscoring the importance of thorough neuroimaging and multidisciplinary evaluation in optimizing both functional and neurological outcomes (Fig. 8) [94].

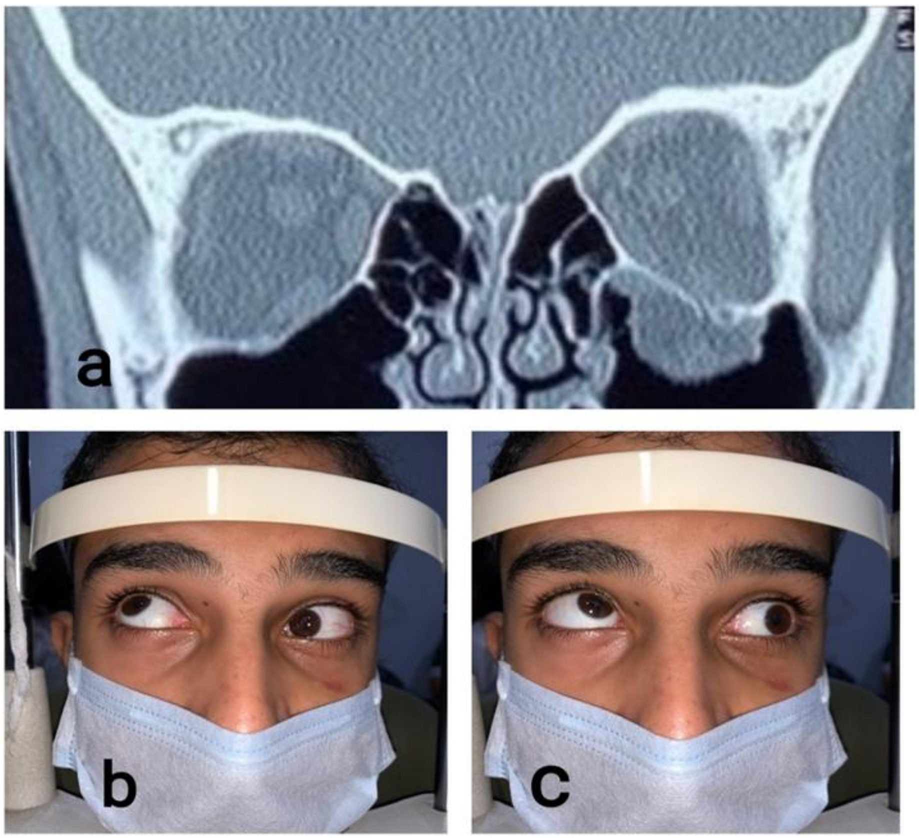

Figure 8: Orbital floor fracture with inferior rectus entrapment radiologic-clinical correlation. (a) Coronal CT scan demonstrating a left orbital floor "blowout" fracture with herniation and entrapment of orbital contents, producing the classic teardrop sign, indicative of inferior rectus muscle involvement; (b, c) Clinical photographs in different gaze positions showing restriction of elevation of the left eye, consistent with mechanical entrapment of the inferior rectus muscle. The clinico-radiological concordance highlights the functional impact of the fracture and underscores the need for timely surgical intervention to prevent persistent diplopia and motility deficit.

Management Strategies and Surgical Advances

The timing of surgical intervention is a critical determinant of outcomes in orbital fractures. Early repair, particularly within the first two weeks, is associated with improved diplopia resolution and extraocular motility, whereas delayed intervention increases the risk of persistent functional deficits [14,15,68,71]. Technological advancements have significantly transformed orbital reconstruction. The use of patient-specific implants (PSIs), intraoperative CT, navigation systems and 3D-printed models enables precise anatomical restoration and reduces intraoperative variability [42-44,50,85]. Emerging applications of artificial intelligence and deep learning further enhance diagnostic accuracy and surgical planning [53,70]. In parallel, the development of biocompatible and resorbable materials has expanded reconstructive options, offering improved safety profiles and tissue integration [12,54,97].

Management of Naso-Orbital-Ethmoid (NOE) fractures remains particularly challenging due to complex anatomy and the critical role of the medial canthal tendon. Successful repair requires accurate reduction, stable fixation and meticulous ligament reconstruction to prevent telecanthus and aesthetic deformity [46]. Advanced techniques, including rigid fixation, transnasal wiring and digitally guided reconstruction, underscore the need for a multidisciplinary, precision-based approach. The adoption of patient-specific implants has further enhanced reconstructive accuracy, enabling reliable restoration of orbital volume and contour while improving surgical efficiency, particularly in complex or asymmetric defects [63]. Moreover, advances in biomaterials and additive manufacturing have led to the development of osteoinductive, stereolithography-based implants, which promote bone integration and long-term stability, representing a shift toward regenerative and personalized orbital reconstruction strategies [88].

Outcomes and Complications

Despite advances in surgical techniques, complications such as persistent diplopia, residual enophthalmos and implant-related issues remain clinically significant, particularly in complex fractures and delayed interventions [49]. Orbital floor fractures can result in extraocular muscle dysfunction and soft tissue entrapment, with severity correlating with fracture size and tissue involvement, underscoring the importance of early intervention and precise reconstruction [47]. Optimal outcomes depend not only on bony reconstruction but also on periocular soft tissue management. Evidence demonstrates that appropriate reconstructive techniques, including eyelid repair, flap selection and refined surgical approaches, are critical for achieving functional stability, ocular surface protection and aesthetic symmetry [48,57,72,86]. Accurate implant positioning and restoration of orbital volume further reduce complication rates and improve functional recovery [58,59]. A subset of patients may require secondary intervention due to inadequate primary repair, implant malposition or persistent functional deficits, highlighting the importance of meticulous surgical planning, appropriate implant selection and long-term follow-up [91]. Additionally, rare but serious complications, such as retrobulbar hematoma and vision-threatening events, necessitate vigilant perioperative monitoring [95].

Pediatric Orbital Fractures

Pediatric orbital fractures present unique challenges due to differences in bone elasticity, fracture patterns and healing potential. Trapdoor fractures with muscle entrapment are characteristic and often require urgent surgical intervention to prevent long-term functional impairment [73,75,82]. Early diagnosis and timely management are associated with favorable outcomes, whereas delayed treatment may result in persistent diplopia and motility restriction [78-82]. Children may present with minimal external signs despite significant injury, necessitating a high index of suspicion and prompt intervention [51].

Optimal outcomes in pediatric orbital trauma rely on individualized, defect-specific management strategies. Clinical decision-making is guided by factors such as fracture size, diplopia, muscle entrapment, enophthalmos and associated injuries, which determine the need for surgical versus conservative treatment [93]. Larger or functionally significant defects typically require operative repair, while selected cases may be managed conservatively. In addition to bony reconstruction, periocular soft tissue restoration plays a critical role in functional and aesthetic outcomes. Evidence supports the use of tailored reconstructive techniques, including local flaps and patient-specific approaches, to achieve reliable structural support, ocular protection and cosmetic symmetry [45,52]. Collectively, these findings highlight the importance of early intervention, precise anatomical assessment and personalized surgical planning in optimizing outcomes in pediatric orbital fractures.

Role of Advanced Imaging and Digital Technologies

Advanced imaging modalities, particularly CT-based volumetric analysis, play a critical role in the diagnosis, surgical planning and postoperative assessment of orbital fractures. The integration of computer-assisted navigation, intraoperative imaging and digital planning systems has significantly improved reconstructive precision, enabling more accurate restoration of orbital volume and contour, especially in complex or secondary deformities [50,55,56,66]. The increasing use of patient-specific implants (PSIs), supported by CAD/CAM and 3D-printing technologies, has further enhanced surgical accuracy, implant conformity and operative efficiency [69]. In addition, 3D-printed surgical guides facilitate improved intraoperative orientation and implant positioning, particularly in complex multi-wall fractures [83,85]. Emerging applications of artificial intelligence and deep learning are also improving fracture detection, volumetric analysis and personalized surgical planning [53,70]. Collectively, these innovations reflect a shift toward digitally assisted, precision-based orbital reconstruction, resulting in more reproducible functional and aesthetic outcomes.

Strengths and Limitations

The strengths of this study include the comprehensive synthesis of evidence spanning five decades and the application of rigorous, standardized methodological frameworks, including PRISMA guidelines, the Cochrane methodology and the GRADE approach [16-18,25]. These established frameworks enhance the transparency, methodological rigor and overall reliability of the findings. Furthermore, the inclusion of diverse study populations and a broad range of management strategies provide a comprehensive overview of contemporary orbital fracture management. Nevertheless, several limitations should be acknowledged. Significant heterogeneity was observed across included studies, reflecting variability in patient populations, fracture classification systems, surgical techniques, outcome definitions and follow-up duration. In addition, the predominance of retrospective observational studies may increase susceptibility to selection bias and confounding. Variability in reporting standards and inconsistent assessment of functional and aesthetic outcomes further limited direct comparability across studies. These limitations underscore the need for well-designed prospective studies with standardized outcome measures and reporting methodologies to strengthen the evidence base in orbital fracture research.

Future Directions and Clinical Implications

Future research should prioritize standardization of outcome measures, refinement of classification systems and high-quality prospective studies to strengthen the evidence base in orbital trauma. The integration of Artificial Intelligence (AI), machine learning and patient-specific technologies is expected to further enhance diagnostic precision, surgical planning and clinical outcomes [42,70,90,92]. Advances in digital imaging and multidisciplinary approaches will also improve the differentiation of orbital trauma from neoplastic and other orbital pathologies, particularly in complex or atypical cases [61]. Emerging innovations, including minimally invasive and energy-based technologies, such as plasma-assisted surgery, are expanding the scope of periocular management by improving soft tissue handling, reducing morbidity and enhancing aesthetic outcomes [67]. Additionally, evolving trends in ophthalmology emphasize precision medicine and personalized care, facilitating more tailored and efficient treatment strategies [89]. Preventive strategies targeting high-risk populations and strengthening trauma care systems remain essential to reduce the global burden of orbital injuries. Furthermore, the increasing recognition of systemic and periocular interactions, including conditions such as thyroid ophthalmopathy, underscores the need for comprehensive, multidisciplinary evaluation and patient-centered management [96,97]. Collectively, these developments highlight a transition toward technology-driven, holistic and precision-based orbital care, with significant potential to improve long-term functional and aesthetic outcomes [98].

Conclusion

This systematic review and meta-analysis provides a comprehensive synthesis of contemporary evidence on orbital trauma and its management. The findings underscore that clinical outcomes are primarily determined by fracture complexity, extent of orbital involvement and timing of intervention. Surgical management, when appropriately indicated, offers superior functional and aesthetic outcomes, particularly in complex fractures and cases with muscle entrapment or significant orbital volume loss. Advances in imaging, computer-assisted planning and patient-specific implants have transformed orbital reconstruction, enabling greater anatomical precision and improved postoperative outcomes. Nevertheless, complication rates remain influenced by injury severity and delays in treatment, highlighting the importance of early diagnosis, accurate assessment and timely intervention. Despite these advances, the current evidence base is limited by heterogeneity in study design and outcome reporting, emphasizing the need for standardized protocols and high-quality prospective studies. Future integration of artificial intelligence, 3D technologies and personalized surgical approaches is expected to further enhance decision-making and optimize patient outcomes. Overall, the management of orbital fractures continues to evolve toward a precision-based, technology-driven paradigm, with a strong emphasis on early intervention, individualized treatment strategies and multidisciplinary care to achieve optimal functional and aesthetic restoration.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

Funding Statement

This research did not receive any specific grant from funding agencies in the public, commercial or non-profit sectors.

Acknowledgement
The authors would like to acknowledge all researchers and clinicians whose work contributed to this systematic review and meta-analysis. We also thank our institutional colleagues for their academic support and guidance throughout the study. No external editorial assistance was used in the preparation of this manuscript.

Data Availability Statement
All data analyzed during this study are included in the published articles and datasets cited within this manuscript. Additional data are available from the corresponding author upon reasonable request.

Ethical Statement
This study is a systematic review and meta-analysis based on previously published data. Therefore, ethical approval and informed consent were not required, as no new human or animal subjects were involved.

Informed Consent Statement
Written informed consent was obtained from the patient (and/or the patient's legal guardian) for publication of the clinical details and accompanying images.

Authors' Contributions
The authors declare that this manuscript is original, has not been published previously and is not under consideration for publication elsewhere. All authors have read and approved the final version of the manuscript and agree with its submission

References
1. Burnstine MA. Clinical recommendations for repair of orbital facial fractures. Ophthalmology. 2002;109(7):1207-1210.
2. Antonyshyn OM. Orbital fractures: diagnosis, operative treatment, secondary corrections. Can J Surg. 1996;39(1):78-79.
3. Rose G. Orbital surgery: A conceptual approach. Br J Ophthalmol. 1997;81(1):93.
4. Adamo AK, Pollick SA, Lauer SA, Sterman HR. Zygomatico-orbital fractures: historical perspective and current surgical management. J Craniomaxillofac Trauma. 1995;1(2):26-31.
5. Kim J, Seo C, Yoo JH. Objective analysis of facial bone fracture CT images using curvature measurement in a surface mesh model. Sci Rep. 2023;13:1932.
6. Lalloo R, Lucchesi LR, Bisignano C. Epidemiology of facial fractures: incidence, prevalence and years lived with disability estimates from the Global Burden of Disease 2017 study. Inj Prev. 2020;26(Suppl 1):i27-i35.
7. Yadav NK, Sami I, Priya P. Global patterns and predictors of oculofacial trauma: a systematic review and meta-analysis of the last two decades. IP Int J Ocul Oncol Oculoplasty. 2026;12(1):24-36.
8. Osuagwu YU, Adeyinka AO, Agunloye AM, Okoje VN. Classification of midfacial fractures on computed tomography following head injury in a Nigerian population. West Afr J Radiol. 2013;20(2):74-83.
9. Rinna C, Ungari C, Saltarel A. Orbital floor restoration. J Craniofac Surg. 2005;16(6):968-972.
10. Lorencin M, Orihovac Ž, Žaja R, Begović I. Orbital blowout fractures: a retrospective study with literature review. Acta Clin Croat. 2023;62(3):519-526.
11. Harris GJ. Orbital blow-out fractures: surgical timing and technique. Eye (Lond). 2006;20(10):1207-1212.
12. Page MJ, McKenzie JE, Bossuyt PM. The PRISMA 2020 statement. BMJ. 2021;372:n71.
13. Moher D, Shamseer L, Clarke M. PRISMA-P 2015 statement. Syst Rev. 2015;4:1.
14. Higgins JPT, Thomas J, Chandler J. Cochrane handbook for systematic reviews of interventions. 2nd Ed. London: Wiley. 2019.
15. Wells GA, Shea B, O'Connell D. The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. Ottawa: Ottawa Hospital Research Institute; 2014.
16. Sterne JAC, Savović J, Page MJ. RoB 2: A revised tool for assessing risk of bias in randomized trials. BMJ. 2019;366:l4898.
17. DerSimonian R, Laird N. Meta-analysis in clinical trials. Control Clin Trials. 1986;7(3):177-188.
18. Higgins JPT, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. BMJ. 2003;327:557-560.
19. Thompson SG, Higgins JPT. How should meta-regression analyses be undertaken and interpreted? Stat Med. 2002;21(11):1559-1573.
20. Egger M, Davey Smith G, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. BMJ. 1997;315:629-634.
21. Guyatt GH, Oxman AD, Vist GE. GRADE: An emerging consensus on rating quality of evidence and strength of recommendations. BMJ. 2008;336:924-926.
22. Schünemann HJ, Higgins JPT, Vist GE. Completing summary of findings tables and grading the certainty of the evidence. In: Higgins JPT, Thomas J, Chandler J, et al, editors. Cochrane handbook for systematic reviews of interventions. 2nd Ed. London: Wiley. 2019.

23. Converse JM, Smith B, Obear MF, Wood-Smith D. Orbital blowout fractures: A ten-year survey. Plast Reconstr Surg. 1967;39(1):20-36.
24. Ellis E 3rd, el-Attar A, Moos KF. An analysis of 2067 cases of zygomatico-orbital fracture. J Oral Maxillofac Surg. 1985;43(6):417-428.
25. Manson PN, Markowitz B, Mirvis S. Toward CT-based facial fracture classification. Plast Reconstr Surg. 1990;85(2):202-212.
26. Dal Canto AJ, Linberg JV. Comparison of orbital fracture repair performed within 14 days versus 15 to 29 days after trauma. Ophthalmic Plast Reconstr Surg. 2008;24(6):437-443.
27. Hwang K, You SH. Analysis of facial bone fractures: An 11-year study of 2094 patients. Indian J Plast Surg. 2010;43(1):42-48.
28. Allareddy V, Allareddy V, Nalliah RP. Epidemiology of facial fracture injuries. J Oral Maxillofac Surg. 2011;69(10):2613-2618.
29. Ellis E 3rd, Tan Y. Assessment of internal orbital reconstructions for pure blowout fractures: Cranial bone grafts versus titanium mesh. J Oral Maxillofac Surg. 2003;61(4):442-453.
30. Kontio R, Lindqvist C. Management of orbital fractures. Oral Maxillofac Surg Clin North Am. 2009;21(2):209-220.
31. Bruneau S, Scolozzi P. Preseptal transconjunctival approach to the orbital floor fractures. Rev Stomatol Chir Maxillofac Chir Orale. 2015;116(6):362-367.
32. Tong L, Bauer RJ, Buchman SR. A current 10-year retrospective survey of 199 orbital floor fractures. Plast Reconstr Surg. 2001;108(3):612-621.
33. Roh JH, Jung JW, Chi M. A clinical analysis of bilateral orbital fracture. J Craniofac Surg. 2014;25(2):388-392.
34. Adeyemo WL, Ladeinde AL, Ogunlewe MO, James O. Trends and characteristics of oral and maxillofacial injuries in Nigeria: A review of the literature. Head Face Med. 2005;1:7.
35. Boffano P, Kommers SC, Karagozoglu KH, Forouzanfar T. Aetiology of maxillofacial fractures: A review of published studies during the last 30 years. Br J Oral Maxillofac Surg. 2014;52(10):901-906.
36. Blumer M, Essig H, Steigmiller K. Surgical outcomes of orbital fracture reconstruction using patient-specific implants. J Oral Maxillofac Surg. 2021;79(6):1302-1312.
37. Miran B, Toneatti DJ, Schaller B, Kalaitsidou I. Management strategies for isolated orbital floor fractures: A systematic review of clinical outcomes and surgical approaches. Diagnostics. 2025;15:3024.
38. Dubois L, Steenen SA, Gooris PJ, Bos RR, Becking AG. Controversies in orbital reconstruction-III. Biomaterials for orbital reconstruction: A review with clinical recommendations. Int J Oral Maxillofac Surg. 2016;45(1):41-50.
39. Moe KS, Murr AH, Wester ST. Orbital fractures. Facial Plast Surg Clin North Am. 2018;26(2):237-251.
40. Yadav NK. Eyelid surgery in patients with thyroid eye disease (TED): a systematic review and meta-analysis. EC Ophthalmology. 2025;16(4):1-15.
41. Manson PN, Grivas A, Rosenbaum A. Studies on enophthalmos: II. The measurement of orbital injuries and their treatment by quantitative computed tomography. Plast Reconstr Surg. 1986;77(2):203-214.
42. Bly RA, Chang SH, Cudejkova M, Liu JJ, Moe KS. Computer-guided orbital reconstruction to improve outcomes. Otolaryngol Clin North Am. 2017;50(2):373-385.
43. Strong EB, Fuller SC, Wiley DF. Preformed vs intraoperative bending of titanium mesh for orbital reconstruction. JAMA Facial Plast Surg. 2013;15(2):111-117.
44. Kim YH, Kim TG, Choi JW. Three-dimensional evaluation of orbital volume change after reconstruction of blowout fractures using patient-specific implants. J Craniomaxillofac Surg. 2018;46(6):1032-1038.
45. Yadav NK, Singhal S, Sadaphale SV, Srivastava AK. Cosmetic reconstruction of post-traumatic anterior staphyloma by customized ocular prosthesis. Int J Res Sci Innov. 2025;12(5):1626-1630.
46. Leader P, Gal TJ. Naso-orbital-ethmoid fracture repair techniques: a systematic review. J Oral Maxillofac Surg. 2024;82(4):461-467.
47. de Santana IHG, Viana MRM, Palhano-Dias JC. Orbital floor fracture (blow out) and its repercussions on eye movement: A systematic review. Eur J Med Res. 2024;29(1):427.
48. Yadav NK, Gupta A, Tapan, Kaur A. Single stage eyelid reconstruction in near total full thickness lower eyelid defect. Int J Ophthalmol Optometry. 2024;6(1):40-42.
49. Jinhai Y, Jiancheng G, Huang Z. Analysis of postoperative complications of orbital fracture. Oral Maxillofac Surg. 2024;28(3):1279-1285.
50. Liu Y, Enin K, Sciegienka S, Hardi A, Spataro E. Intraoperative computed tomography use in orbital fracture repair: A systematic review and meta-analysis. Facial Plast Surg Aesthet Med. 2023;25(6):548-555.
51. Hassan B, Liang F, Grant MP. Pediatric orbital fractures. Oral Maxillofac Surg Clin North Am. 2023;35(4):585-596.
52. Yadav NK, Priya P, Singh S, Agarwal E. Eyelid coloboma reconstruction by Tenzel advancement flap. Ophthalmol Res Int J. 2025;20(6):47-50.
53. Niño-Sandoval TC, Landim FS, Vasconcelos BCE. Deep learning for orbital fracture detection and reconstruction: A systematic review on diagnostic accuracy and surgical planning. J Craniomaxillofac Surg. 2025;53(9):1501-1510.
54. Ren Z, Xiong C, Liao H. Advancements in design and application of absorbable materials for orbital fracture reconstruction. Tissue Eng Part B Rev. 2026.
55. Heiland M, Habermann CR, Schmelzle R. Indications and limitations of intraoperative navigation in maxillofacial surgery. J Oral Maxillofac Surg. 2004;62(9):1059-1063.
56. Gellrich NC, Schramm A, Hammer B. Computer-assisted secondary reconstruction of unilateral posttraumatic orbital deformity. Plast

Reconstr Surg. 2002;110(6):1417-1429.
57. Yadav NK, Arya AK, Abbasi S. Upper eyelid blepharoplasty outcomes: Systematic review. IP Int J Ocul Oncol Oculoplasty. 2025;11(4):125-139.
58. Osaki T, Tamura R, Sakakibara S. Analysis of orbital blowout fracture location and Hess area ratio. J Craniofac Surg. 2022;33(4):1042-1045.
59. Hughes D, McQuillan J, Holmes S. Quantitative analysis of diplopia following orbital fracture repair. Br J Oral Maxillofac Surg. 2023;61(3):202-208.
60. Pitak-Arnnop P, Witohendro LK, Tangmanee C. Assessing effectiveness of endoscope-assisted medial orbital wall fracture repair vs no surgery using benefit-risk metrics and literature review. J Stomatol Oral Maxillofac Surg. 2023;124(1):101267.
61. Yadav NK, Priya P, Sihmar Y. Ocular oncology in the Asian subcontinent. IP Int J Ocul Oncol Oculoplasty. 2025;11(4):149-157.
62. Manolidis S, Weeks BH, Kirby M, Scarlett M, Hollier L. Classification and surgical management of orbital fractures. J Craniofac Surg. 2002;13(6):726-737.
63. Podolsky DJ, Ahn JJ, Patel BC. Patient-specific orbital implants. J Craniofac Surg. 2016;27(1):131-133.
64. Kunz C, Audigé L, Cornelius CP. The comprehensive AOCMF classification system: orbital fractures-Level 3 tutorial. Craniomaxillofac Trauma Reconstr. 2014;7(Suppl 1):92-102.
65. Choi SH, Kang DH, Gu JH. The correlation between the orbital volume ratio and enophthalmos in unoperated blowout fractures. Arch Plast Surg. 2016;43(6):518-522.
66. Ploder O, Klug C, Voracek M. Evaluation of computer-based area and volume measurement from CT scans in orbital fractures. J Oral Maxillofac Surg. 2002;60(11):1267-1272.
67. Yadav NK, Priya P, Srivastava S. Plasma-based oculoplastic surgery. J Clin Ophthalmol Res. 2026;14(2):191-198.
68. Zhang J, He X, Qi Y, Zhou P. The better surgical timing and approach for orbital fracture: A systematic review and meta-analysis. Ann Transl Med. 2022;10(10):564.
69. Pai AG, Prabhu SS. Patient-specific implants for intraoral and maxillofacial reconstruction: A scoping review on customization and fabrication methods. Maxillofac Plast Reconstr Surg. 2025;47(1):28.
70. Oku H, Nakamura Y, Kanematsu Y. Hierarchical deep learning system for orbital fracture detection and trap-door classification on CT images. Comput Biol Med. 2025;196(Pt A):110732.
71. Hassan B, Resnick E, Er S. The impact of surgical timing in orbital fracture repair: A new paradigm. Plast Reconstr Surg. 2025;155(1):132e-140e.
72. Yadav NK, Priya P, Pednekar N. External angular dermoid excision. Asian J Res Rep Ophthalmol. 2025;8(1):173-177.
73. Eshraghi B, Khademi B, Rafizadeh SM. Outcomes and prognostic factors in pediatric orbital trapdoor fracture: a multi-center study. Oral Maxillofac Surg. 2024;29(1):7.
74. Gebran SG, Lopez J, Wasicek PJ. Surgical treatment and visual outcomes of adult orbital roof fractures. Plast Reconstr Surg. 2021;147(1):82e-93e.
75. Grant JH 3rd, Patrinely JR, Weiss AH. Trapdoor fracture of the orbit in a pediatric population. Plast Reconstr Surg. 2002;109(2):482-489.
76. Yadav NK, Mishra N, Mehrotra B, Kaur A. Kimura's disease orbital case. BMJ Case Rep. 2024;17(12):e262899.
77. Connon FV, Austin SJ, Nastri AL. Orbital roof fractures: A clinically based classification and treatment algorithm. Craniomaxillofac Trauma Reconstr. 2015;8(3):198-204.
78. Wang NC, Ma L, Wu SY. Orbital blow-out fractures in children: Characterization and surgical outcome. Chang Gung Med J. 2010;33(3):313-320.
79. Barh A, Swaminathan M, Mukherjee B. Orbital fractures in children: clinical features and management outcomes. J AAPOS. 2018;22(6):415.e1-415.e7.
80. Yadav NK, Singh S, Abbasi S. Thermal ocular burn injury. Int J Res Med Sci. 2026;14(3):1190-1194.
81. Chung SY, Langer PD. Pediatric orbital blowout fractures. Curr Opin Ophthalmol. 2017;28(5):470-476.
82. Firriolo JM, Ontiveros NC, Pike CM. Pediatric orbital floor fractures: clinical and radiological predictors of tissue entrapment and the effect of operative timing on ocular outcomes. J Craniofac Surg. 2017;28(8):1966-1971.
83. Anand V, Bagde MB, Gupta S. 3D-printed surgical guides in orbital fractures. Cureus. 2026;18(3):e105823.
84. Haug RH, Van Sickels JE, Jenkins WS. Orbital roof fractures. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2002;93(3):238-246.
85. Chen Y, Liu W. Clinical study on precision repair of orbital fractures using 3D-printed orbital models assisting with absorbable plates. BMC Ophthalmol. 2025;25(1):472.
86. Yadav NK, Arya AK, Priya P. Recent advances in the diagnosis and management of ptosis: A systematic review of surgical and non-surgical interventions. J Ophthalmol Res. 2026;9:14-30.
87. Prabhu SS, Hemal K, Runyan CM. Outcomes in orbital floor trauma: a comparison of isolated and zygomaticomaxillary-associated fractures. J Craniofac Surg. 2021;32(4):1487-1490.
88. Guillaume O, Geven MA, Varjas V. Orbital floor repair using patient specific osteoinductive implant made by stereolithography. Biomaterials. 2020;233:119721.
89. Yadav NK. Eyes on the future: Is ophthalmology the smartest medical specialty in 2026? J Ophthalmol Adv Res. 2026;7(1):1-4.
90. Pandya RP, Deng W, Hodgson NM. Current guidelines and opinions in the management of orbital floor fractures. Otolaryngol Clin North

Am. 2023;56(6):1101-1112.
91. Persson AAE, Lif HM, Falk-Delgado A, Nowinski D. Treatment of orbital fractures: A critical analysis of ophthalmic outcomes and scenarios for re-intervention. J Plast Surg Hand Surg. 2023;58:1-7.
92. Yadav NK, Singh S, Singhal S. Artificial intelligence in ocular and adnexal tumours: A systematic review of diagnostic and management paradigms. IP Int J Ocul Oncol Oculoplasty. 2026;12(1):12-23.
93. Yan M, Mullen B, Wagner LH. Predictors of surgical versus medical management of eyes in the setting of orbital fracture at an academic level I trauma center. J Craniofac Surg. 2023;34(5):1444-1447.
94. Malla A, Hassan B, Er S. Traumatic brain injury and its association with orbital fracture characteristics and repair. J Craniofac Surg. 2025;36(5):1834-1838.
95. Gear AJ, Lokeh A, Aldridge JH. Safety of titanium mesh for orbital reconstruction. Ann Plast Surg. 2002;48(1):1-7.
96. Yadav NK, Sharma P, Singhal S. Global trends in eyelid disease associated with thyroid ophthalmopathy (1975-2025): A systematic review and meta-analysis. J Ophthalmol Adv Res. 2026;7(1):1-16.
97. Topol EJ. High-performance medicine: The convergence of human and artificial intelligence. Nat Med. 2019;25(1):44-56.

About the journal

ATHENAEUM SCIENTIFIC PUBLISHERS

Journal of Ophthalmology and Advance Research is a peer-reviewed, open-access scholarly journal published by Athenaeum Scientific Publishers. The journal publishes original research articles, case reports, reviews, editorials and commentaries within its defined scope, with the aim of supporting scientific research and clinical knowledge in ophthalmology.

All manuscripts are evaluated through an independent peer-review process conducted in accordance with the journal's editorial policies and established publication ethics. Editorial decisions are made solely on the basis of academic merit.

Manuscript submission: https://athenaeumpub.com/submit-manuscript/