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MODERN DIAGNOSTIC AND TREATMENT TECHNIQUES FOR MANDIBULAR AND MAXILLARY INJURIES - FROM RECONSTRUCTION TO INTERNAL FIXATION

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ABSTRACT

Background: Injuries of the mandible and maxilla contribute to a large part of maxillofacial trauma, which often require complex diagnostics and therapeutics. Recent developments in imaging, computer-aided design and manufacturing, biomaterials, and reconstructive methods have significantly affected clinical assessment and surgical outcomes.
Methods: This is a review of the evidence from 21 peer-reviewed studies published between 2014 and 2025, sourced through Scopus, PubMed, Web of Science, and publisher databases. Reconstruction, materials science and complication profiles are part of this series.
Results: Epidemiological trends and diagnostic jigsaw were uniformly emphasised across studies, in which CT, CBCT and 3D reconstruction were considered fundamental. The accuracy of fracture repositioning and reduction during image-guided or navigated surgery was significantly higher. The digital workflows, together with VSP and CAD/CAM drilling guides, enabled an accurate reconstruction of the mandible with improved functional and cosmetic results. Comparative studies demonstrated the superiority of ORIF over closed reduction for both condylar and mandibular fractures with delayed treatment, with a negative impact on functional outcome. Resorbable implants perform well as an alternative to titanium-level fixation systems, with reduced reoperation requirements and acceptable stability profiles.
Conclusion: Modern diagnostic and therapeutic procedures, such as high-resolution imaging, navigation, VSP, CAD/CAM technology, and bioresorbable fixation techniques, significantly enhance precision, reducing complications and promoting optimal functional rehabilitation with maximum facial symmetry in mandibular and maxillofacial trauma. The current evolution of digital workflows and materials is likely to enhance clinical outcomes.

KEYWORDS

Mandibular Fractures, Maxillary Fractures, Zygomaticomaxillary Complex Fractures, Facial Trauma

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Introduction

Fractures of the mandible and maxilla encompass a considerable portion of facial trauma and pose a significant therapeutic problem because of their functional, aesthetic, and biomechanical aspects. Fractures of the mandible are one of the most frequent facial fractures and are often related to interpersonal violence, traffic accidents, sporting injuries, or falls. The anatomic complexity and relationship to vital structures such as the inferior alveolar nerve, temporomandibular joint (TMJ), teeth, and airway necessitate precise diagnosis and treatment for the best results. According to Panesar and Susarla [13], these fractures commonly cause occlusal anomalies, difficulty in mastication, neurosensory defects, and facial asymmetry. Thus, indicating the necessity of a meticulous diagnostic evaluation and advancing the management therapy.

Mandibular and maxillary trauma fracture patterns range from uncomplicated linear fractures to complex condylar, angle, parasymphysial and mid-facial injuries as well as comminuted facial bone fractures. Uncommon anatomical anomalies, such as a bifid mandibular condyle, may also make the diagnosis difficult. Although rare, such anomalies, as reported by Borrás-Ferreres et al. [3], emphasize the role of advanced imaging in distinguishing congenital variants from post-traumatic or degenerative conditions. The zygomaticomaxillary complex (ZMC), an anatomical central unit in the middle third of the face, is at high risk for trauma and is vital for facial width, symmetry, and orbital support. Studies by Khan et al. [6] and Breik et al. [8] stress that malreduction or insufficient juxtaoperative fixation of ZMC fractures carries a risk of permanent deformation, visual impairment and chronic functional disability.

According to epidemiologic studies, mandibular fractures occur at the condyle, angle and symphysis, whereas midfacial injuries often involve the zygomatic complex (ZMC). Rahbin et al. [16] demonstrated the importance of accurate reduction and stable fixation for long-term patient satisfaction after ZMC fracture

repair, underscoring the benefit of recent operative planning systems. At various anatomic locations, common clinical problems are generally related to malocclusion, uncontrolled fracture segments, soft tissue displacement associated with muscle forces, alveolar involvement and possible neurosensory disturbances, especially of the inferior alveolar nerve, which was carefully evaluated by Sulistyani et al. [20].

The development of diagnostic devices has led to markedly better care for these injuries. With the development of CT, cone-beam CT, and 3-dimensional reconstruction, they have now become indispensable for not only identifying the type of fracture line but also for preoperative planning. Gutierrez et al. [7] found that image-guided and navigation-inspired processes improved the visualization of complex fracture morphology, leading to better surgical accuracy and postoperative symmetry. These developments have enabled the extensive application of VSP, CAD/CAM, patient-specific implants, and customized cutting guides in both primary and secondary reconstructions.

Concomitantly, significant advances in reconstructive methods, especially osteocutaneous flaps such as the fibula free flap (FFF), have revolutionised treatment for segmental mandibular defects. Digital planning is increasingly used in contemporary methods. Studies by Baecher et al. [1], Coppen et al. [5], Weitz et al. [21], and Van Gemert et al. [10] always confirmed that the quality of oral and maxillofacial reconstructions using digital guidance is featured by better anatomical reproduction, enhanced occlusion and more predictable functional results than in traditional methodology.

Improvements in fixation materials have also broadened treatment options. Despite open reduction and internal fixation (ORIF) with titanium, recent systematic reviews [4,17] report good clinical outcomes of resorbable implants that fulfill the requirements of a sufficient temporary stability without the necessity for implant removal. Concurrently, mounting evidence—including those of Shobha et al. [18], supports the benefit of ORIF versus closed reduction in most of the mandible fracture patterns, though not all and particularly including condyle fractures.

Prerequisites are fast changes in terms of diagnostics, virtual planning, navigation, techniques of osseous reconstruction and osteosynthesis material. The present review synthesizes elements from some recent peer-reviewed studies, which have documented recent diagnostic and therapeutic options in mandibular and maxillofacial trauma along with its advantages/disadvantages and clinico-therapeutic correlation.

Methods of Research

This review was done by the narrative-systematic method and included studies to summarise recent evidence regarding diagnostic as well as therapeutic modalities for both mandibular and maxillary injuries. The method was developed to ensure a full retrieval of the relevant scientific literature from January 2017 until January 2025, consistent with the standards adopted by Medical Science. Two additional seminal papers [8,6] were further incorporated due to their continued applicability from the perspective of historical and comparative benchmarks as regards the clinical evolution in the treatment of zygomaticomaxillary complex (ZMC) fractures.

Search Strategy

To include peer-reviewed work indexed in internationally well-known repositories, we conducted a systematic literature search using three major scientific databases PubMed, Web of Science and Scopus. Literature searches were performed in December 2024 and January 2025.

The search terms and Boolean operaters are as follows:

- mandibular fractures OR maxillary fractures
- diagnosis OR imaging OR ct OR 3D reconstruction
- virtual surgical planning OR VSP OR CAD/CAM
- ORIF Open reduction internal fixation OR ORIF_PORTS Angiography is generally performed to visualise MENISCUS The meniscus is trimmed with scissors.
- zygomaticomaxillary complex fractures
- fibula free flap or mandibular reconstruction
- navigation-assisted surgery
- resorbable implants OR bioresorbable osteosynthesis

Search filters Searching: human, full text available, English.

Eligibility Criteria

Inclusion criteria

- Studies: Original- but also systematic reviews, meta-analyses or high-quality narrative review.
- Report that were not diagnosed, studies evaluating imaging, surgical management, reconstruction materials and techniques (including biomaterials), navigation methods or outcomes of care in mandibular or maxillary fractures.
- Articles published between 2017–2025
- Papers reporting clinical results, complications, or technical development

Exclusion criteria

- Case series, letters, conference abstracts and non–peer-reviewed source_DOC material
- Articles that did not specifically involve mandible or maxilla trauma
- Articles referring to the pediatric population only and that did not address non-traumatic pathology of the jaw
- Animal or cadaveric investigations (unless combined with clinical evidence)

Study Selection

All titles and abstracts of the search results were screened by two reviewers independently. If abstracts were indeterminate or united the inclusion criteria, full texts were reviewed for eligibility.

A PRISMA-adapted workflow was followed:

- 312 studies identified
- 94 duplicates removed
- 146 excluded after title/abstract screening
- 50 full-text articles assessed
- 21 studies met all inclusion criteria and were included in this review

The last one consisted of a heterogeneous group of studies and was the highest quality with several SR/MA. Works by Shobha et al. [18], Choi et al. [4], Sanino-Zavala et al. [17], and Kostares et al. [11] attempted to offer strong methodologies and a focus on fixation, complications, and biomaterial performance.

Data Extraction and Synthesis

Data extracted from each study included:

- diagnostic imaging modalities
- surgery (e.g., ORIF, closed reduction, reconstruction)
- CAD/CAM, VSP and patient-specific implants
- results of fibula free flap reconstruction
- navigation-assisted surgical workflows
- postoperative complications such as infection or neurosensory deficits
- performance and stability of resorbable fixation systems

Because the included studies varied significantly in design and results, the results were synthesized to focus on recurring themes, comparative findings, and technological advances.

Discussion

Injuries involving the mandible and maxilla are some of the most challenging injuries to treat in facial trauma, largely due to the complex anatomy of the middle third of the face, biomechanics involved in force transmission to the mandible, and functional significance of the masticatory system. In the last decade, there have been great advances in the diagnostic, planning and treatment protocols employed by clinicians with vascular trauma. Such advancements have included the incorporation of computer-assisted techniques (such as virtual surgical planning (VSP), intra-operative navigation, CAD/CAM-guided reconstructions, resorbable osteosynthesis systems, and improvements in open reduction internal fixation (ORIF). This review aims to consolidate recent literature to assess the impact of these advancements in terms of accuracy, patient outcomes, complication profiles and beyond that on the management algorithm for mandibular and maxillary trauma.

1. Advances in Diagnostic Techniques

Precise diagnosis forms the cornerstone of appropriate management in maxillofacial trauma. Conventional radiography has been predominantly supplanted by high-resolution computed tomography (CT) and cone-beam computed tomography (CBCT), which allow the characterization of fracture lines, displacement, comminution, and involvement of the dentoalveolar complex. Panesar and Susarla stressed that CT/CBCT should be the primary imaging facilities to spot condylar, angle, and symphyseal fractures over

conventional X-rays [13]. Their results corroborate the more general clinical impression that 3-D imaging enhances diagnostic accuracy and decreases the likelihood of missed fractures in mandibular as well as midfacial trauma.

Rahbin et al. showed that low reposition of ZMC fractures can lead to long-term complications, including facial asymmetry, enophthalmos, and masticatory disturbances [16]. Therefore, precise imaging is necessary at both time of diagnosis and also in the follow-up period to guarantee patient satisfaction on the long run. Khan and colleagues came to the same conclusion. [6] and Breik et al. [8] emphasized the importance of knowledge of the direction and the amount of ZMC displacement for selecting the appropriate fixation method to prevent postoperative complications.

Rare anatomical variations present another diagnostic obstacle. Borrás-Ferreres et al. reported cases of double mandibular condyle and emphasized the importance of differentiating congenital variation from post-trauma change [3]. These variations have implications for the interpretation of the condylar region and treatment planning.

Advances in technology have allowed for even more diagnostic options. Gutierrez et al. showed that image-guided surgery and three-dimensional reconstructions facilitate visualization of articular comminuted fracture patterns, especially in complex or hard-to-approach anatomical areas such as comminuted fractures [7]. They demonstrated that the devices improve surgical precision and make it easier to restore symmetry to a patient's face.

In conclusion, there is heavy consensus in the literature that modern imaging - particularly CT, CBCT and IG3P – which underpin accurate diagnosis of maxillofacial trauma. These instruments aim to aid physicians in understanding the complex nature of fractures, anticipate potential complications and decide on surgery.

2. Management of Mandibular Injuries

2.1 ORIF versus Closed Reduction

The choice between open reduction and internal fixation (ORIF) and closed reduction has long been a matter of discussion, particularly for condylar and subcondylar fractures. Shobha et al. conducted a systematic review and meta-analysis demonstrating that ORIF provides superior outcomes in terms of occlusal stability, mandibular mobility, and long-term function [18]. Their study also demonstrated lower rates of mandibular deviation, chronic pain, and postoperative malocclusion in patients treated with ORIF. These results support the view that ORIF is the preferred approach for displaced fractures, bilateral condylar injuries, or cases in which occlusion is significantly compromised.

However, timing is critical. Singh et al. found that delays in performing ORIF-whether due to late referral, limited access to surgical care, or patient comorbidities-significantly increase the likelihood of postoperative complications such as malunion, infection, and prolonged rehabilitation [19]. Their findings highlight the importance of early diagnosis and timely surgical intervention whenever possible.

2.2 Neurosensory Complications

Inferior alveolar nerve (IAN) injury is a common and clinically significant complication associated with mandibular fractures. Sulistyani et al. examined postoperative neurosensory disturbances following ORIF and identified several risk factors, including the proximity of the fracture to the mandibular canal, compression from fixation hardware, and insufficient fracture reduction [16]. Their review emphasizes that although ORIF generally improves functional outcomes, the procedure must be performed with attention to nerve preservation.

These results are consistent with Panesar and Susarla's observations that the IAN is vulnerable during both the traumatic event itself and subsequent surgical management [10]. Careful preoperative imaging, precise reduction, and atraumatic handling of tissues are therefore essential components of minimizing neurosensory complications.

2.3 Functional Rehabilitation

Restoring function - including: mastication, speech, and mandibular range of motion - is a key objective of mandibular fracture treatment. Petronis et al. highlighted the importance of structured postoperative rehabilitation, including early physiotherapy and individualized exercise protocols [1]. Their systematic review demonstrated that functional outcomes depend not only on the surgical technique but also on consistent, well-planned rehabilitation, especially in patients with condylar fractures or those requiring longer periods of immobilization.

3. Reconstruction of Mandibular Defects

Severe mandibular trauma may lead to segmental bone loss, requiring reconstruction to restore both function and facial form. Over the past decade, fibula free flap (FFF) reconstruction has become the gold standard for these cases. Baecher et al. provided a detailed overview of the clinical and translational challenges associated with FFF, emphasizing the importance of thorough preoperative assessment, ensuring flap viability, and incorporating digital planning to optimize surgical outcomes [1].

One of the most important breakthroughs in reconstruction is the implementation of CAD/CAM technology and virtual surgical planning VSP. Coppen et al. showed that by the use of a titanium insert the accuracy in VSP-guided fibular osteotomies can be increased and so could reduce the number of intraoperative repositioning [5]. This higher precision allows better recreation of mandibular contours and functional occlusion.

Weitz et al. compared standardised, partly adjustable sawing templates with individual CAD/CAM-designed guides and reported a significantly better 3D accuracy in the latter [21]. Osteotomy and flap design: CAD/CAM systems minimize the error in osteotomies and soft tissue, improving the predictability of reconstructions and saving time.

This is even more obvious with the use of double-barrel fibula flaps as assessed by von Viebahn et al. [10,4], who showed that VSP can enhance vertical bone height significantly, resulting in better osseointegrated implant position. This method is particularly useful in trauma patients with a need for significant height restoration to optimize prosthetic rehabilitation and facial symmetry.

The combination of these findings presents compelling support for the routine implementation of digital planning, patient-specific instrumentation and CAD/CAM constructs in mandibular reconstruction. These advances have improved anatomic and esthetic detail, decreased operating times, and improved function results over the past several decades, and therefore, they mark one of the most important achievements in modern complex mandibular trauma treatment.

4. Management of Zygomaticomaxillary Complex (ZMC) Injuries

Fractures of the zygomaticomaxillary complex (ZMC) have a significant impact on facial width and symmetry and orbital function, making accurate diagnosis and precise surgical correction essential. Rahbin et al. found that long-term patient satisfaction is closely related to the accuracy of anatomical reconstruction of these regions [16]. Even subtle postoperative asymmetries can negatively affect facial aesthetics and function, highlighting the importance of meticulous reduction and fixation.

Khan et al. emphasized that ZMC fractures show substantial variability in their morphology, which means that fixation strategies must be tailored to the specific fracture pattern [6]. According to their observation, accurate delineation of the displacement vectors and orbital involvement would be a prerequisite examination protocol for surgery. Supporting these, Breik et al. showed that the quantity and position of screw fixation points seriously affect the stability after surgery [8]. Their systematic review confirmed that multi-point fixation, especially three-point fixation, reduces the risk of secondary displacement and improves long-term outcomes.

Further advancements in the management of ZMC injuries include the introduction of patient-specific implants (PSI) and custom surgical guides. Lentge et al. evaluated secondary reconstruction of malunited or inadequately treated ZMC fractures and showed that personalized surgical guides and implants result in far better symmetry compared to conventional approaches [12]. Their findings support the growing movement toward individualized reconstruction in complex midfacial trauma.

Iqbal et al. compared two-point fixation with three-point fixation and found that the latter has better biomechanical stability, especially on displaced fractures [9]. This further supports previous evidence indicating that repair over a longer segment results in better functional and cosmetic results.

Current literature supports an anatomically focused approach to the treatment of ZMC fractures. Accurate reduction, multi-point stabilization and when necessary, patient-specific implants contribute to stability, symmetry and patient satisfaction.

5. Innovations in Osteosynthesis Materials

Titanium plates and screws have long been considered the gold standard for internal fixation in maxillofacial trauma. However, recent studies indicate increasing interest in the use of bioresorbable materials as potential alternatives. Choi et al. conducted a systematic review showing that resorbable materials can provide sufficient stability for selected mandibular fractures while eliminating the need for secondary hardware removal [4]. Their analysis found that complication rates associated with resorbable systems are comparable to those observed with titanium fixation, making them an attractive option in appropriate clinical scenarios.

Sanino-Zavala et al. concluded that resorbable osteosynthesis systems represent a promising alternative in specific patient groups [17]. These include individuals sensitive to titanium, patients with thin soft-tissue coverage, and pediatric populations, where long-term skeletal growth may be impacted by permanent hardware. Despite these advantages, the authors emphasize that careful case selection is essential, as resorbable materials may not provide adequate stability in high-load anatomical areas, such as the mandibular angle or in comminuted fractures.

The evidence indicates a growing role for bioresorbable fixation devices in contemporary maxillofacial trauma care. These materials, though not universally applicable in all cases and sites, do extend treatment options and qualify for individualised osteosynthesis. If successful, increased understanding of material properties and longer prospective clinical studies may define their role in different fracture types.

6. Postoperative Complications and Outcomes

Infection is still one of the most common morbidities after open reduction and internal fixation (ORIF). Kostares et al. conducted a meta-analysis and showed several contributing risk factors, such as smoking, altered therapeutic intervention, poor oral hygiene, and extensive soft-tissue damage [11]. Their findings highlight the need for early intervention, careful patient selection, and strict adherence to aseptic protocols to minimize postoperative infection rates.

Functional outcomes after mandibular and maxillary fracture treatment are influenced by multiple factors, including the accuracy of diagnosis, the quality of preoperative planning, fixation technique, and postoperative rehabilitation. Jeong et al. demonstrated that intraoperative navigation improves the precision of fracture reduction, which contributes directly to improved long-term outcomes [2]. When applied in conjunction with the VSP and CAD/CAM workflows, navigation helps to improve the reproducibility of surgery outcomes and minimize the chances for postoperative asymmetry or malocclusion.

In summary, the available studies acknowledge that a coordinate employment of innovative diagnostic and surgical approaches is mandatory in order to obtain good patient results. To reduce these complications, a comprehensive management system is needed to provide accurate imaging evaluation, precise surgical performance, stable internal fixation and postoperative rehabilitation.

Conclusions

Injuries to the mandible and maxilla continue to present a challenging technical aspect of maxillofacial surgery. Optimal management should include accurate diagnosis, personalized planning and reconstructive options. There is increasing evidence between 2014 and 2025 that there has been a paradigm move towards very digitalized methods.

From the old two-dimensional study, diagnostic images have developed to CT, CBCT, 3D reconstructions, and image-guided analysis. These techniques have provided the clinician with an objective method for determining fracture shape and level of displacement, and the presence of comminution. Techniques that facilitate preoperative and interoperative alignment (VSP, navigation, and CAD/CAM-generated models) reinforce the relationship between diagnostic accuracy and surgical performance as regards malreduction risk and development of postoperative asymmetry [7,2,13,21,15].

Latest published data still favour open reduction and internal fixation (ORIF) as the best treatment modality for displaced mandibular fractures, especially for the condyle, angle and parasymphysis. Systematic reviews have shown that ORIF allows better functional recovery, a lower incidence rate of temporomandibular dysfunction and more predictable occlusal restoration compared with conservative treatment [18]. Furthermore, early surgical intervention reduces postoperative complications, emphasizing the importance of timely and accurate diagnosis [19]. Attention to potential neurosensory disturbances, especially involving the inferior alveolar nerve. It remains essential, reinforcing the need for precise imaging and careful surgical technique [20,13].

Reconstruction of segmental mandibular defects has undergone major improvements with the adoption of fibula free flap (FFF) reconstruction supported by CAD/CAM and patient-specific digital planning. Current evidence demonstrates that digitally guided FFF reconstruction offers superior anatomical accuracy, improved implant integration and more predictable functional and aesthetic results [5,1,21,10]. Double-barrel fibula techniques further enhance vertical bone height and support prosthetic rehabilitation [14].

Management of zygomaticomaxillary complex (ZMC) fractures also benefits from these technological advances. Long-term patient satisfaction depends heavily on accurate three-dimensional repositioning [16], and the literature supports multi-point fixation as well as increasing use of patient-specific implants for secondary reconstructions [6,8,12,9]. These developments align with a broader shift toward personalized, anatomically driven care.

The development of bioresorbable osteosynthesis materials might be a promising alternative for titanium in selected cases, with comparable stability and the added advantage of eliminating the need for hardware removal [17,4]. Although not suitable for all fracture patterns, these materials expand the available therapeutic options.

Modern treatment of mandibular and maxillofacial trauma is based on technological integration, precise diagnostics, and digital surgical guidance. Advances in imaging, CAD/CAM technology, navigation, VSP, improved ORIF methods, and innovative reconstructive strategies combine to improve accuracy, reduce complications, and improve long-term outcomes. The next generation of maxillofacial trauma treatment may be shaped by continuing this process and standardizing digital workflows.

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