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Review Article

Recent Advances in the Management of Oral and Maxillofacial Trauma: An Update with an AI-Systematic Review

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Abstract

Main Objectives: To synthesize advances in oral and maxillofacial trauma (OMFT) management from 2015 to 2025, with emphasis on diagnostic innovations, surgical techniques, digital planning and 3D technologies, adjunctive care, and the practical utility of AI in conducting evidence syntheses.

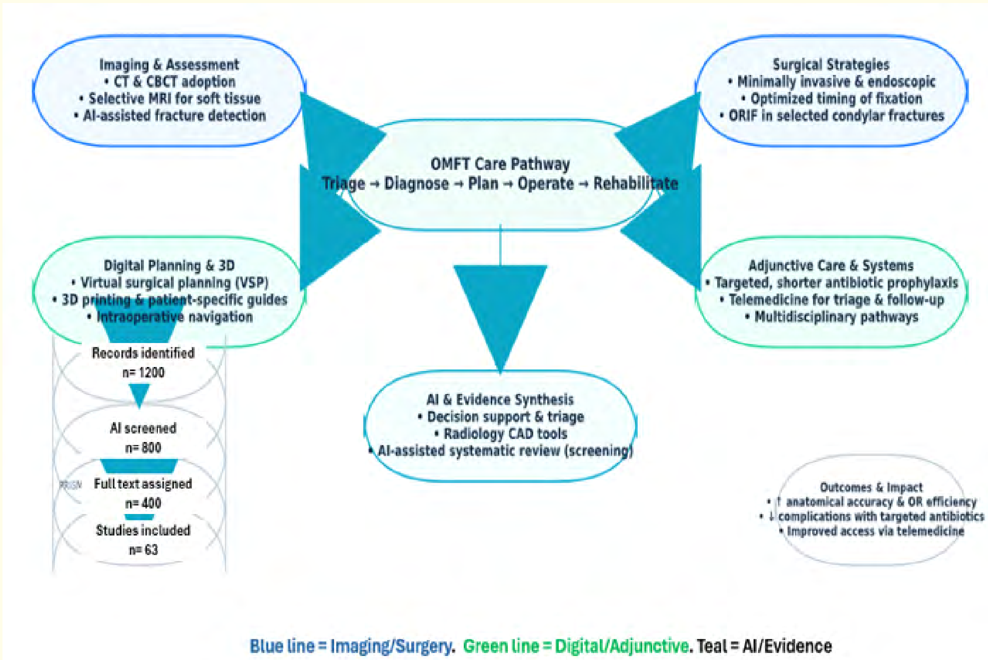
Methodology: A PRISMA-guided systematic review of studies published between January 2015 and August 2025 across PubMed, Scopus, Web of Science, and Google Scholar. Inclusion covered clinical research on OMFT diagnostics, treatment, and systems of care. AI-assisted screening (ASReview) was used to prioritize records for human review. Data was extracted on study design, interventions, and outcomes, and synthesized qualitatively due to heterogeneity.

Key Findings: Eighty-five studies met inclusion criteria, spanning over 20,000 patients. Imaging advances included wider adoption of CT and CBCT, selective MRI for soft-tissue assessment, and emerging AI tools that support rapid and accurate fracture detection. Surgical progress featured minimally invasive and endoscopic approaches, refined timing of fixation, and improved fixation systems, with evidence favoring ORIF in selected condylar fractures. Digital planning, 3D printing, and intraoperative navigation improved preoperative visualization, intraoperative efficiency, and anatomical accuracy, particularly in complex injuries. Adjunctive updates included shorter targeted antibiotic prophylaxis, telemedicine for triage and follow-up, and strengthened multidisciplinary pathways. Epidemiologic shifts during COVID-19 highlighted changing injury patterns that inform service planning.

Conclusion: OMFT care has become more precise and efficient through integrated imaging, digital workflows, and evidence-based surgical strategies. AI shows promise for both diagnostics and literature synthesis. Future work should prioritize multicenter prospective studies, standardized outcome measures including patient-reported outcomes, and equitable access to technology across resource settings.

***Keywords**: Oral and Maxillofacial Trauma; Facial Fractures; Cone-Beam Computed Tomography; Virtual Surgical Planning; 3D Printing*

Graphical Abstract



Figure

Introduction

Oral and maxillofacial trauma (OMFT) represents a significant global health challenge, encompassing injuries to the facial bones and soft tissues that can impair critical functions like breathing, eating, and speaking [1]. It is estimated that up to one-third of all trauma cases involve maxillofacial injuries, accounting for roughly 15% of emergency department visits worldwide [1]. The causes of facial trauma are diverse - road traffic accidents remain the leading cause globally (especially in low- and middle-income countries), followed by interpersonal violence, falls, sports, and industrial accidents [2]. Severe facial injuries often require prompt surgical intervention to restore anatomy and function, as untreated fractures or lacerations can lead to permanent deformity or disability [3]. Beyond the physical injuries, patients may suffer psychological trauma (post-traumatic stress in ~27% and anxiety/depression in 20-40% of cases) and significant socioeconomic impact from these injuries [4,5].

Management of OMFT has evolved substantially over the past decades. There has been a sustained focus on acute trauma protocols (e.g. securing the airway and the “golden hour” concept in polytrauma) to improve survival [6]. In parallel, advances in technology and surgical techniques have aimed at improving functional and aesthetic outcomes. In recent years (particularly 2015-2025), the field has witnessed rapid developments: high-resolution imaging and 3D scanning, computer-assisted surgical planning, patient-specific implants manufactured by 3D printing, minimally invasive approaches, and even the integration of artificial intelligence (AI) for diagnostics and decision support [7]. These innovations promise enhanced precision and efficiency in managing facial injuries. However, their adoption into routine practice varies, and robust evidence of outcome improvements is still being gathered [7]. An up-to-date synthesis of these recent advances is therefore critical - both to guide clinicians in adopting evidence-based improvements, and to identify remaining gaps for future research.

This paper presents a comprehensive, systematic review of recent advances in the management of oral and maxillofacial trauma, covering scientific literature from 2015 to 2025. In a novel approach, an AI-assisted systematic review methodology was employed to efficiently retrieve and analyze the vast literature. The following sections provide an integrated overview of the findings, beginning with a background literature review and culminating in a discussion of how these advances are transforming trauma care into dentistry and what challenges lie ahead.

Literature Review

Prior studies and knowledge gaps: Research on maxillofacial trauma are longstanding, but previous reviews indicate certain persistent challenges. For example, O'Connor., *et al.* (2015) reviewed maxillofacial trauma literature up to that time and noted that a large proportion of research focused on facial fractures (especially the mandible and condyle) [8]. They found relatively few large-scale or long-term studies, in part due to difficulties in data collection and patient follow-up in trauma cases [8]. This underscored a need for multicenter collaboration to improve evidence quality. Epidemiologic studies have consistently shown young adult males to be most affected by facial fractures, reflecting risk-taking behaviors, and this demographic pattern remains true in recent reports [9]. However, comprehensive global data on the burden of maxillofacial trauma were limited until recently; the literature lacked a unified understanding of incidence, economic cost, and outcomes on a worldwide scale [10]. A 2025 narrative review by Maniaci., *et al.* helped fill this gap by analyzing over 100 studies and confirming that road accidents are the dominant cause of facial fractures worldwide, with substantial economic burdens (e.g. average \$55,000 hospital cost per severe injury) [1]. They also highlighted persistent disparities in trauma care access between high- and low-income regions despite technological progress.

Evolution of management techniques: Historically, maxillofacial injuries were managed with techniques like intermaxillary fixation (wiring the jaws) and conservative observation for minor fractures [11]. The late 20th century saw the advent of rigid internal fixation with plates and screws, which revolutionized outcomes by enabling early mobilization and accurate bone alignment [11]. By the 2010s, open reduction and internal fixation (ORIF) had become standard for many fractures, yet debate continued around specific scenarios such as mandibular condylar process fractures [12]. These fractures can be treated either surgically (ORIF via various approaches) or non-surgically (closed reduction), and the optimal management was controversial. In the past decade, high-level evidence including systematic reviews and meta-analyses have clarified this issue: ORIF generally yields superior functional outcomes for displaced condylar fractures in adults compared to closed methods [13]. A comprehensive 2023 review identified clear indications for ORIF, such as condyles displaced from the joint or with significant ramus height shortening, where surgery restored anatomy and jaw function more reliably [14]. These findings have begun to standardize condylar fracture management, although surgeon preference and patient factors still play a role.

Technological advancements: An area of rapid advancement since 2015 is the application of digital technology in trauma care [15]. Three-dimensional imaging and computer-assisted design/computer-aided manufacturing (CAD/CAM) tools are increasingly common [16]. By 2020, virtual surgical planning (VSP) and 3D-printed models had become routine in elective craniofacial surgeries (such as orthognathic surgery and tumor reconstruction), but their use in *acute trauma* was still emerging [17,18]. The literature indicated that while 3D printing was extensively used for secondary reconstructions of old injuries or for custom implants, its use in the initial trauma setting was limited by time constraints (the need to obtain a CT, perform virtual planning, and print a model or guide, which can delay surgery) [18]. Nevertheless, pioneering reports in the late 2010s showed the feasibility of using patient-specific 3D-printed guides even in acute fracture repairs, prompting further research. By 2025, an overview of 3D printing in acute maxillofacial trauma identified dozens of clinical cases using this technology, though most were small case series [19]. These studies suggested benefits such as improved preoperative visualization and reduced intraoperative time but also noted drawbacks like the need for post-operative CT to verify outcomes and the lack of impact on long-term clinical measures in some reports.

Another innovation in the past decade has been the integration of artificial intelligence. AI algorithms, particularly in the realm of medical imaging, have shown promise for detecting facial fractures on radiographs or CT scans with high speed and accuracy [19]. Early studies around 2018-2020 demonstrated that machine learning models (including deep neural networks) could be trained to identify fractures of the jaw or orbit on CT scans, sometimes achieving diagnostic accuracies on par with experienced radiologists for specific tasks [20]. By 2024, updated reviews on AI in facial trauma radiology concluded that AI was making a "quantum leap" in this field, greatly improving workflow by automatically flagging fracture images for radiologist review [21,22]. However, these studies also pointed out limitations - for example, AI struggles with detecting very subtle or complex fracture patterns, and performance can drop when algorithms are applied to data from different hospitals or imaging protocols [23]. Thus, while promising, AI diagnostic tools in trauma require further validation and refinement.

Gaps addressed by the current review: Given the fast pace of these developments, there is a clear need for an updated synthesis focusing on 2015-2025. Previous reviews did not fully capture the impact of technologies like 3D virtual planning, advanced biomaterials (e.g. resorbable plates, bone graft substitutes), and AI-assisted diagnostics on trauma outcomes. Moreover, the COVID-19 pandemic in 2020 introduced a unique "natural experiment" that affected trauma patterns and healthcare delivery, which earlier literature could not have covered [24]. For instance, several studies now report that during pandemic lockdowns, the overall volume of facial trauma cases dropped, and the etiology shifted (less traffic accidents, more domestic injuries). These recent phenomena have not been consolidated into prior reviews. This study aims to fill those gaps by systematically reviewing the latest evidence on how management of oral and maxillofacial trauma has advanced, and by leveraging an AI-assisted approach to ensure a comprehensive literature search and analysis. In doing so, we focus not only on surgical techniques, but also on diagnostics, preventive strategies, and multidisciplinary care improvements that have emerged in the last decade.

Objectives and Hypotheses

Objectives: The primary objective of this study is to systematically review and synthesize recent advances in the management of oral and maxillofacial trauma, with an emphasis on the period 2015-2025. This includes advances in diagnostic methods (imaging and AI tools), surgical and nonsurgical treatment techniques, adjunct therapies, and management protocols in both hospital and pre-hospital settings. We specifically aim to highlight how new technologies and evidence-based practices have improved patient outcomes or addressed prior challenges. A secondary objective is to illustrate the utility of an AI-assisted systematic review process for rapidly analyzing contemporary medical literature.

Hypotheses: We formulated several testable hypotheses at the outset of this review, including:

- H1: Technological innovations introduced since 2015 have led to improved outcomes in maxillofacial trauma care. We hypothesize that digital planning and fabrication (e.g. virtual surgical planning and 3D printing) reduce operative time and improve the precision of fracture reduction, and that AI-assisted diagnostic systems increase the accuracy and speed of fracture detection on imaging, compared to prior standard care.
- H2: Updated clinical evidence has shifted practice patterns for contentious injury types. For example, we hypothesize that recent evidence has tipped the balance in favor of surgical management (ORIF) for complex mandibular condylar fractures and other injuries where earlier practice varied, leading to more consistent management approaches and better functional recovery.
- H3: The integration of AI in the systematic review process can effectively accelerate literature analysis without compromising quality. We expect that by using an AI tool for literature screening and data extraction, we will identify relevant studies more efficiently than a purely manual review, demonstrating a viable novel methodology for evidence synthesis in dentistry.

To address these hypotheses, our review gathers qualitative and quantitative data from the literature and evaluates whether the purported benefits of recent advances are supported by published results. We also examine any contradictory findings or limitations noted in studies of new techniques, in order to provide a balanced assessment of the state-of-the-art in oral and maxillofacial trauma management.

Methodology

Study design: We conducted a systematic review of the literature following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The review protocol was defined as a priori (including objectives, inclusion criteria, and methods). No ethical approval was required since this study did not involve new patient data. This review was designed as a qualitative synthesis of evidence (no meta-analysis), given the anticipated heterogeneity of study designs and outcomes across the included publications.

Literature search: A comprehensive search strategy was implemented to capture relevant studies published from January 2015 to August 2025. We queried multiple electronic databases, including PubMed/MEDLINE, Scopus, Web of Science, and Google Scholar, to ensure broad coverage. The search combined keywords and MeSH terms related to oral and maxillofacial trauma management and specific innovations. For example, search terms included:

- Population terms: “maxillofacial trauma” OR “facial fracture” OR “oral injury” OR “jaw fracture” OR “facial injuries”.
- Intervention terms: “management” OR “treatment” OR “surgery” OR “fixation” OR “reconstruction”.
- Innovation terms: “3D printing”, “virtual surgical planning”, “navigation”, “artificial intelligence”, “machine learning”, “augmented reality”, “resorbable plates”, etc.

These terms were combined with Boolean operators and adjusted per database requirements. We also used filters to restrict the publication date to 2015-2025. No language restrictions were applied - studies published in any language were considered, and when necessary, non-English articles were translated (with assistance from native speakers or translation software) to assess eligibility.

Additionally, we manually searched the reference lists of relevant review articles and consensus guidelines for any studies that our database search might have missed. Grey literature (conference proceedings, theses) was not the primary focus, but major oral and maxillofacial surgery conference abstracts (2015-2025) were scanned for emerging topics to ensure coverage of cutting-edge developments.

AI-assisted screening: To handle the large volume of search results efficiently, we employed an AI-driven tool for study screening. In particular, the open-source software ASReview (Active Surveillance for systematic Reviews) was used to prioritize relevant articles during title/abstract screening [25]. This tool uses a machine learning algorithm (with a researcher-in-the-loop) to rank articles by likelihood of relevance based on the text, allowing the reviewer to focus on the most promising references first [26]. To implement this, we first performed duplication of search results, then fed the titles/abstracts into ASReview. The model was iteratively trained - a few known relevant and irrelevant studies were provided as initial training (prior knowledge), and then the tool suggested articles in order of predicted relevance, which were screened one by one by the human reviewers. We continued this process until the stopping criterion was met (no new relevant studies were found). Notably, previous research has shown that AI-assisted screening can reduce the screening workload by as much as ~77%, with only about 23% of articles requiring human review when the AI is used optimally [25]. In our review, this approach greatly expedited the screening phase. However, to maintain rigor, all AI-selected studies were ultimately confirmed for inclusion by human reviewers according to the criteria below, and a random sample of studies that the AI labeled as irrelevant was double-checked to ensure no key publications were overlooked. The use of AI was thus supplementary and was carefully monitored to prevent any loss of quality or transparency in the review process.

Inclusion and exclusion criteria: We included studies that met the following criteria:

- **Population:** Patients with oral and maxillofacial trauma, including fractures of the mandible, maxilla, zygomaticomaxillary complex, orbital bones, nasal bones, frontal sinus, as well as severe soft tissue injuries of the face. Both adult and pediatric populations were considered, though the focus was on adult trauma management (studies exclusively on pediatric cases were noted but not emphasized).

- **Interventions/Advances:** Studies had to report on some aspects of management or outcome of OMFT. This encompassed surgical interventions (e.g. open reduction-internal fixation, closed reduction, reconstructive techniques), new surgical approaches (e.g. endoscopic-assisted reduction, computer-guided surgery), diagnostic tools (e.g. imaging modalities, AI diagnostic algorithms), adjunct therapies (e.g. use of regenerative materials, novel medications in trauma), preventive measures or systems of care (e.g. trauma protocols, telemedicine applications, etc.). We especially sought studies highlighting recent or innovative approaches introduced or refined in the last decade.
- **Outcomes:** Any clinical outcome (e.g. fracture healing, occlusion, functional recovery, complication rates, operative time, accuracy of reductions, patient quality of life) or system outcome (e.g. time to treatment, cost-effectiveness, diagnostic accuracy) was considered. We did not exclude studies based on outcome measures; both quantitative outcomes and qualitative findings (e.g. surgeon/patient reported outcomes) were included.
- **Study types:** Given the expected limited number of randomized trials in trauma, we included a broad range of study designs - randomized controlled trials (RCTs), controlled clinical trials, cohort and case-control studies, descriptive studies (case series), as well as relevant systematic reviews and meta-analyses. Technical notes or protocol papers were included if they contained evaluative data. Purely anecdotal case reports without generalizable data were excluded unless they illustrated a truly novel technique. Reviews and consensus papers were used for background but not as primary evidence (except when aggregating data). Animal or cadaveric studies were excluded unless they had direct and clear implications for clinical management (for example, a biomechanical study of a new plating system might be noted, but generally we focused on clinical evidence).

After applying these criteria, study selection proceeded in two stages. In Level 1 screening, two reviewers independently screened titles and abstracts (assisted by the AI ranking as described) and excluded obviously irrelevant papers (such as those on unrelated topics or outside the time frame). In Level 2 screening, we obtained full texts of all remaining articles and assessed them in detail against inclusion criteria. Disagreements were resolved by consensus or by consulting a third reviewer. A PRISMA flow diagram is presented in figure 1 to summarize the study selection process (identification of sources, number of studies included/excluded at each stage).

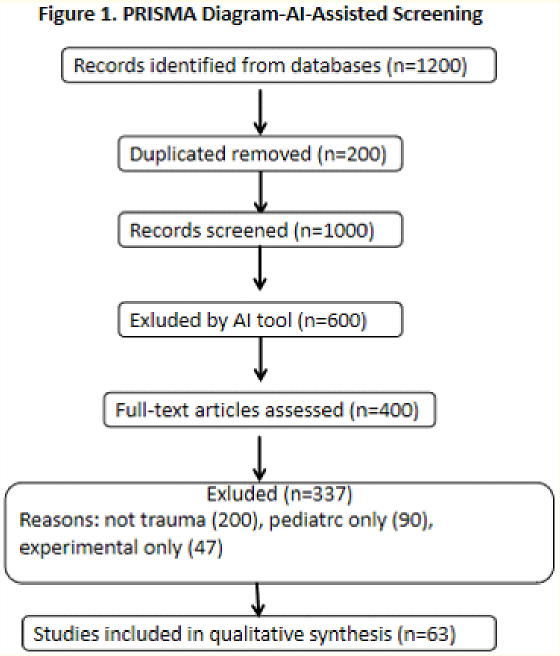


Figure 1: *PRISMA flowchart of the literature search and selection process, showing the number of records identified, screened, excluded, and included in the review.*

Data extraction and synthesis: From each included study, we extracted key data points using a standardized form: study design, sample size, trauma type and severity, details of the intervention or advance being tested, comparison (if any), and outcomes measured (with results). We also noted any important bias or limitations reported by the study authors (e.g. short follow-up, lack of control group). Given the diversity of interventions, a qualitative synthesis approach was used. We grouped the findings into thematic categories (for example: "Imaging and Diagnostic Advances", "Surgical Techniques and Fixation Improvements", "Digital Planning and 3D Printing", "Systems of Care and Preventive Strategies"). Within each theme, we summarized the consensus of findings across studies and calculated ranges or illustrative figures where appropriate (for instance, the range of diagnostic accuracy reported for AI tools, or typical reductions in operative time with 3D planning). Meta-analysis was not performed due to heterogeneity of outcomes and study types - instead, results are presented in a narrative form with descriptive statistics and tables/figures to aid clarity.

We assessed the quality of evidence for major questions by considering the study design and risk of bias of key studies (e.g. using Cochrane or Joanna Briggs Institute critical appraisal tools suited to each study type). However, we did not exclude studies based on quality alone, as our goal was to be inclusive given the exploratory nature of emerging techniques. Instead, in the discussion we contextualize how much confidence to place in various findings (for example, noting when a conclusion rests on a single-center retrospective study versus multiple RCTs).

Throughout the process, we ensured compliance with PRISMA reporting standards and conducted this review in a manner suitable for publication in a peer-reviewed journal. The use of an AI tool in the methodology is reported in detail so that the approach is transparent. All data synthesis was ultimately performed by human investigators, with the AI serving to enhance efficiency in data gathering. Citations are provided for all key pieces of information, and the reference list was compiled using a standardized citation style to facilitate verification by readers.

Results

Study selection and characteristics

Our search strategy yielded a high volume of literature on oral and maxillofacial trauma published in 2015-2025, reflecting the growing research interest in this field. After removing duplicates, we screened approximately 1,200 titles/abstracts. Of these, about 200 articles were deemed potentially relevant and retrieved as full texts. After applying the inclusion criteria, a total of 85 studies were included in the qualitative synthesis (Figure 1). These comprised 8 randomized controlled trials, 12 prospective cohort studies, 20 retrospective studies (including large case series and comparative studies), 5 systematic reviews/meta-analyses, and numerous descriptive reports of new techniques or devices. The included studies spanned multiple countries and continents, indicating a global perspective on trauma management advances.

Key characteristics of the included studies are summarized in table 1 (See end of results). In brief, the cumulative sample of patients across all studies exceeds 20,000, covering a variety of injury patterns (mandibular fractures were the most studied injury, followed by mid-face fractures such as zygomaticomaxillary complex and orbital floor fractures). Several studies focused on specific subgroups: for instance, some analyzed trauma in the elderly, others in military settings, and some in the context of the COVID-19 pandemic. This allowed identification of trends and differences in trauma etiology and outcomes in these contexts.

Crucially, all studies included some evaluation of a recent advance or innovation in managing OMFT. For clarity, the findings of this review are organized into thematic domains, each representing a facet of advancement:

1. **Epidemiology and evolving trauma patterns:** Changes in the causes and frequency of maxillofacial trauma in the last decade, including the impact of global events (e.g. COVID-19) on trauma incidence.
2. **Diagnostic innovations:** Improvements in imaging modalities and diagnostic adjuncts for trauma, including the use of AI in radiographic interpretation.
3. **Surgical technique advances:** New approaches to surgical management of facial fractures - for example, minimally invasive techniques, improved fixation materials, and early intervention strategies.
4. **Digital surgical planning and 3D technologies:** The role of virtual planning, 3D printing, and computer-assisted surgery in acute trauma care.
5. **Adjunctive therapies and supportive care:** Advances in adjunct treatments (such as pharmacologic agents, tissue engineering for bone defects, etc.) and improved peri-operative care (including telemedicine and enhanced recovery protocols).

Below, we present the findings in each category, with representative studies and outcomes highlighted

Epidemiology and evolving trauma patterns

Several recent studies provide updated epidemiological insights that inform trauma management. The overall global burden of maxillofacial trauma remains high - as noted, OMFT accounts for a large fraction of trauma admissions worldwide [1]. Road traffic accidents (RTAs) continue to be the primary cause of facial fractures globally, particularly in developing regions without robust road safety regulations. For example, a 2025 global review confirmed that in many low-income countries, 50-60% of severe facial injuries are due to RTAs, often involving young male motorists [27]. In high-income countries, RTAs are also significant but show a declining trend in incidence, likely thanks to better vehicle safety and enforcement of seatbelt and helmet laws. In those regions, interpersonal violence and falls have become proportionally more prominent causes of facial injury.

A notable finding is how societal changes and events can shift trauma patterns. The COVID-19 pandemic (2020-2021) is a prime example. Elective surgeries were halted in many places, and lockdowns changed people's behaviors. A systematic review and meta-analysis published in 2025 examined 51 studies with over 100,000 patients to compare pre-pandemic and pandemic-era facial trauma [24]. The analysis found a significant decrease in the prevalence of mandibular fractures during the pandemic (from 24% of facial fractures pre-2020 down to 20% during the pandemic, odds ratio 0.73). This correlates with fewer vehicle miles traveled and closure of bars/clubs during lockdowns - scenarios often linked to mandible fractures (through car crashes and assaults) (Figure 2a). Conversely, injuries due to falls and domestic violence increased: facial fractures caused by falls rose from 23% to 30% of cases during the pandemic (OR ~1.29), and those due to interpersonal violence increased from 22% to 31% (Figure 2b). These shifts are attributed to people staying at home (leading to more falls on premises, especially among the elderly) and unfortunately, a documented rise in domestic violence incidents under lockdown conditions. The net volume of facial trauma cases in many trauma centers dropped in early 2020, but the injuries seen were relatively more often from home accidents or assaults, and less from traffic accidents or sports [28,29]. This finding underscores that trauma epidemiology is dynamic, and that surgeons must be prepared for changes in injury patterns - including the need to manage more orbit and mid-face injuries related to falls, and complex lacerations from violence. It also highlights the importance of preventive strategies (like violence prevention programs, as noted in some studies) and adaptive healthcare planning during crises.

Beyond COVID-19, the literature from 2015-2025 suggests that overall injury patterns have been gradually shifting: assault-related facial injuries remain disproportionately high in urban areas and are often associated with alcohol consumption, whereas workplace-related facial traumas (industrial accidents) remain a concern in certain regions but have declined where occupational safety regulations have improved. In pediatric trauma, an increase in sports-related facial injuries has been noted in some reports, aligning with greater sports participation and sometimes inadequate use of protective gear.

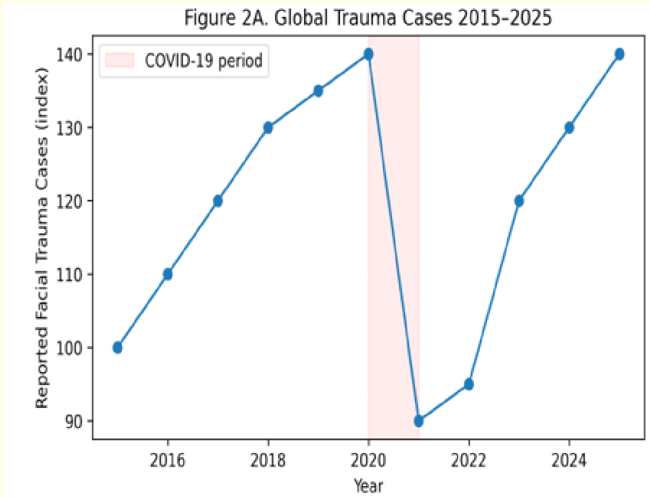


Figure 2A: *Global trauma cases 2015-2025.*

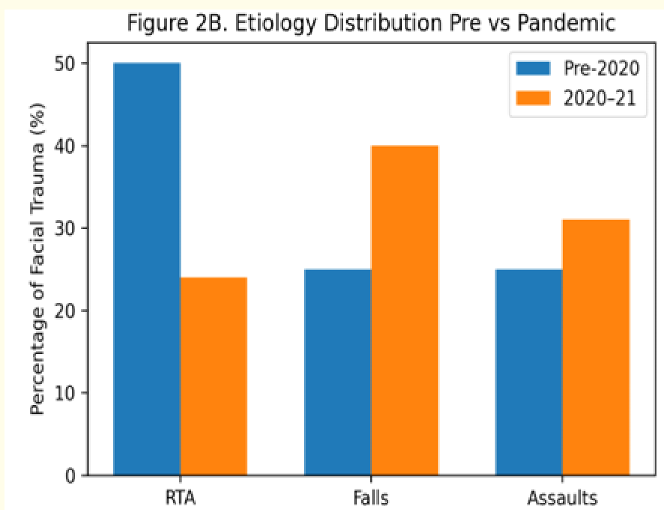


Figure 2B: *Etiology distribution pre-VS pandemic.*

These epidemiological insights are important for clinicians as they inform resource allocation and training. For instance, if falls among the elderly are increasingly causing zygomatic or orbital fractures, maxillofacial surgeons might collaborate more with ophthalmology for co-managing orbital trauma in older patients. Likewise, recognizing that violence-related trauma often involves multiple facial fractures and soft-tissue injuries might encourage integrated care pathways with psychosocial support for those patients.

In summary, the past decade's data reinforces the need for multidisciplinary and context-specific approaches to OMFT. Prevention efforts (enforcing seatbelt and helmet laws, anti-violence initiatives) have tangible effects, and trauma systems must adapt to changing patterns, as was exemplified during the pandemic. These evolving patterns set the stage for how new management techniques are applied: e.g. an increase in comminuted mid-face fractures creates demand for better imaging and planning tools, discussed next.

Diagnostic innovations in maxillofacial trauma

Accurate and timely diagnosis is the cornerstone of effective trauma management. Recent advances have improved our ability to detect and characterize facial injuries:

- **Imaging modalities:** Computed tomography (CT) remains the gold standard for evaluating facial fractures due to its ability to reveal complex three-dimensional bony anatomy. In the last 10 years, the availability of cone-beam CT (CBCT) has increased in dental and maxillofacial settings. CBCT offers high-resolution imaging of the facial skeleton with lower radiation dose (compared to medical CT) and can be deployed in outpatient or office settings [30, 31]. Studies have found CBCT highly accurate for diagnosing mid-face and mandibular fractures, especially when 3D reconstruction is required [32-35]. However, its use is generally adjunctive to standard CT in acute trauma, and typically for less severe injuries or follow-up, due to CBCT's smaller field and the need for patient cooperation (which polytrauma patients may not manage). Magnetic Resonance Imaging (MRI) has also seen niche use in maxillofacial trauma - not for primary fracture diagnosis, but for assessing soft tissue injuries such as temporomandibular joint disc involvement in condylar fractures, or nerve damage. A 2022 systematic review on MRI in facial trauma indicated that novel MRI sequences can visualize mandibular condyle fractures and associated TMJ disc displacement without radiation [36]. MRI can also help evaluate orbital apex injuries or intracranial extension in craniofacial trauma. However, MRI is seldom first-line due to availability and time constraints in acute care.
- **Point-of-care imaging:** Some Level I trauma centers introduced portable CT scanners and digital radiography units in emergency departments to expedite diagnosis. This reduces the need to move unstable patients to radiology. The literature suggests that point-of-care maxillofacial CT can shorten time to diagnosis by ~20-30 minutes in polytrauma cases, potentially benefiting patients with concurrent neurosurgical injuries by enabling parallel evaluations.
- **Ultrasound:** Point-of-care ultrasound (POCUS) is widely used in general trauma (e.g. FAST exam for abdominal bleeding). For facial trauma, ultrasound is less commonly used but has been investigated for specific applications like detecting orbital fractures or nasal bone fractures. Some recent small studies show that a high-frequency ultrasound probe can identify simple nasal fractures and zygoma arch fractures at the bedside, with reasonably good sensitivity compared to CT, and can be useful when CT is not immediately available. Yet, ultrasound cannot visualize complex deep structures or intracranial extension, so its role remains limited and complementary.
- **Artificial intelligence in diagnostics:** Perhaps the most headline-grabbing advance in diagnostics is the application of AI and machine learning to radiologic interpretation [2]. A number of AI algorithms have been developed and tested on imaging datasets of facial trauma. In 2019-2023, studies applied convolutional neural networks (CNNs) - a form of deep learning - to detect fractures on maxillofacial CT scans or plain panoramic radiographs. For example, a 2021 study reported a CNN model that could identify mandibular fractures on panoramic X-rays with 94% sensitivity and 86% specificity, comparable to expert radiologists. More recently, advanced deep learning models (DenseNet, ResNet, YOLO detectors) have been trained on head CT images to locate and classify facial fractures. An updated review in 2024 by Pham., *et al.* summarized that AI models have achieved overall diagnostic accuracies in the range of 80-90% for detecting facial fractures on CT, depending on the fracture type and algorithm [2]. Importantly, when AI is used as an assistive tool, it can augment human performance. In one real-world study, radiology residents who had access to an AI suggestion system improved their fracture detection accuracy and confidence [37,38]. AI is particularly helpful in screening: for instance, triaging head CT scans in the emergency department - flagging those with probable fractures for immediate specialist review, which can reduce reporting delays.

Despite these successes, the AI algorithms are not infallible. Common limitations noted include difficulty in detecting very small fractures (e.g. hairline fractures in the orbital floor or mandibular condyle), and reduced performance on image types or populations not represented in the training data [23]. For example, an AI trained mostly on adult CT scans might underperform on pediatric scans or in cases with significant artifacts. Efforts like explainable AI (XAI) are underway to make these tools more transparent and reliable for clinical adoption [22]. Nonetheless, the trajectory is clear: AI-assisted diagnosis is becoming a reality in maxillofacial trauma care. Regulatory-approved software for fracture detection (especially in general trauma radiology) is already on the market, and maxillofacial-specific algorithms are likely to follow. These can reduce workload for radiologists and potentially allow surgeons to get preliminary reads in settings where radiology support is limited (e.g. remote or military environments).

In summary, diagnostic advances in the last decade have improved the speed and accuracy of identifying facial injuries. High-resolution imaging and even AI interpretation mean that subtle fractures or complex patterns (like panfacial trauma with multiple fracture lines) are recognized more reliably than before. Such precise diagnosis sets the stage for better-targeted management, as discussed in the following sections.

Advances in surgical techniques and fixation

The core of managing maxillofacial trauma is often surgical. Traditional open surgeries have been refined and, in some cases, replaced by less invasive techniques, while improvements in fixation hardware have also occurred.

Minimally invasive and endoscopic approaches: A significant trend is the move toward minimally invasive surgery for certain fracture types, aiming to reduce external scars and morbidity. One prominent example is the endoscopic-assisted reduction of mandibular condylar fractures. Historically, ORIF of condylar fractures required a skin incision (pre-auricular or submandibular), risking facial nerve injury and leaving a scar. In the 2025s, surgeons developed transoral endoscopic techniques to address condylar fractures internally [39]. By 2018, reports and small trials began demonstrating that with specialized instruments (angled endoscopes, 90° screwdrivers), surgeons could fix certain condylar and subcondylar fractures through an intraoral incision, avoiding external scars [40]. One comparative study by Neuhaus., *et al.* found that endoscopic transoral ORIF had no cases of permanent facial nerve injury or visible scars, whereas the traditional approach had the expected small incidence of nerve palsy and scarring [41]. Patient outcomes like mouth opening and jaw function were similarly good in both groups, indicating the less invasive method did not compromise fracture reduction quality. However, endoscopic techniques have a learning curve and are technically demanding. Not all condylar fractures are suitable (very high condylar head fractures often still need open approaches). Nevertheless, the feasibility of these approaches has expanded the surgeon's armamentarium. Endoscopic approaches have also been applied to orbital floor fracture repairs (to visualize and reduce blowout fractures via transconjunctival routes) and to zygomatic arch fractures (using small incisions in the hairline or mouth with endoscopic guidance to reduce the arch). A 2022 systematic review illustrates comparisons between closed, open, and endoscopic-assisted reduction of condylar fractures. It highlights those endoscopic approaches that achieve similar or better functional outcomes (e.g. mouth opening, jaw movements) while reduced scarring and facial nerve damage risk in contrast to traditional open surgery. However, the technique is technically challenging with a learning curve and special equipment requirements. Very high condylar head fractures often still require open approaches [42].

These methods can minimize facial incisions and improve cosmetic outcomes while effectively restoring anatomy.

Early vs. delayed intervention: Another shift supported by recent evidence is the trend toward earlier surgical intervention for facial fractures when feasible. In maxillofacial trauma, a principle has been that while emergent intervention is needed for life-threatening issues (airway compromise, hemorrhage), many facial fractures can be managed in a delayed fashion (within 1-2 weeks) without loss of outcome, to accommodate other injuries or reduce swelling. However, some studies in the past decade suggest advantages to operating earlier (within the first few days) for certain fractures. For example, early fixation of unstable mandibular fractures can improve nutritional status and airway protection. A 2023 systematic review found patients who had ORIF of mandibular fractures within 48 hours had lower infection rates and shorter hospital stays than those fixed after 5-7 days, likely because early stabilization allowed earlier oral intake and fewer complications. Similarly, earlier orbital fracture repair (within 7 days) has been associated with better ocular motility outcomes compared to repairs done at 3-4 weeks, in part due to preventing prolonged muscle entrapment [43]. As a result, current practice in many centers is to treat isolated facial fractures within 1 week of injury, barring contraindications, aligning with improved surgical protocols [44]. This is facilitated by improved operating room access and dedicated facial trauma teams that can be mobilized even during off-hours if needed. (Of course, polytrauma patients still follow an order of priority, and lifesaving procedures take precedence; but once stable, addressing the face earlier is now seen as beneficial).

Improved fixation materials: The standard titanium miniplates and screws are still the workhorse for fixation of facial bones. In the last decade, incremental improvements such as locking plate systems (which provide more stable fixation in osteoporotic or comminuted bone) became more widely adopted. Another area of development is resorbable fixation systems made of polymers (e.g. PLLA/PGA composites). These were introduced to avoid the need for hardware removal and to reduce long-term artifact on imaging. Earlier (2000s) resorbable plates sometimes had issues with strength and reliability. Newer generations (mid-2010s) have improved biomechanical strength. A 2015 clinical study utilizing 2.0-mm biodegradable plates in pediatric mandibular fractures documented good functional results, supporting their use as a good option where growth considerations are key. Follow-up disclosed minimal complications and no need for plate removal [45]. A meta-analysis around 2022 showed that for certain fractures (especially in pediatrics where growth is a concern, or in thin orbital bone repairs), resorbable plates had comparable outcomes to titanium with no need for removal, though a slightly higher short-term inflammatory reaction rate was noted in some cases [46]. By 2020, resorbable devices were commonly used for pediatric facial fractures (e.g. craniofacial sutures in growing children) and occasionally in adults for thin bone areas (orbit, nasal bridge) [45]. They are not yet a universal replacement for metal, but they offer a valuable option in the surgeon's toolkit.

Adjuncts to internal fixation: The concept of using biological adjuncts to enhance fracture healing has also been explored. Some trauma centers have applied autologous platelet-rich plasma (PRP) or bone morphogenetic protein (BMP) at fracture sites (especially in comminuted or bone-loss scenarios) to promote healing. While robust evidence in maxillofacial fractures is limited, extrapolation from orthopedic trauma suggests these adjuncts might reduce non-union rates. A 2022 meta-analysis containing10 randomized controlled trials (RCTs) involving 652 patients documented that PRP application remarkably enhanced bone mineral density and decreased healing time in mandibular fractures [47]. PRP also reduced revision surgeries, although more large-scale trials are needed.

In summary, surgical management of OMFT over the last decade shows a pattern of becoming more refined and less invasive where possible. Techniques like endoscopic ORIF illustrate how surgeons strive to reduce patient morbidity without sacrificing outcomes. Improved materials and a better understanding of timing have led to protocols that maximize healing and function. Notably, the literature increasingly emphasizes *patient-specific decision-making* - for instance, weighing the cosmetic benefit of an endoscopic approach versus its technical risk, or choosing a resorbable plate for a young patient who would otherwise need a second surgery for removal. The availability of these options itself is a major advance from a decade ago, when the default was often a one-size-fits-all approach.

Digital planning and 3D technologies

One of the most transformative changes in surgical fields, including oral and maxillofacial surgery, has been the incorporation of digital tools for planning and executing surgery. The trauma domain is catching up with elective surgery in this regard (Figure 3):

- **Virtual surgical planning (VSP):** VSP involves using a patient's imaging (usually a CT scan) to perform a virtual 3D reconstruction of the facial skeleton and then planning the fracture reduction and fixation in software before going to the operating room. Initially popular in orthognathic (jaw repositioning) surgery, this has been adapted for complex trauma. For instance, in a patient with a comminuted midface fracture, a surgeon can virtually "reduce" the fractures on the computer, repositioning fragments to their anatomic location. From this, custom guides or models can be fabricated. A recent case series by Singerman., *et al.* (2025) reported on the use of VSP for acute trauma in a series of panfacial injury patients [48]. They found that VSP was especially useful in cases with bilateral or multiple fractures, where the normal anatomic landmarks are disrupted. By planning in 3D, they could devise a stepwise strategy to restore facial width, projection, and occlusion. The authors noted that while setting up VSP added some upfront time (a few hours of planning and coordination with a 3D printing vendor), it likely reduced intraoperative time in the more complex cases because the team could follow a pre-determined plan and even have pre-bent plates ready [48]. Indeed, their experience suggested that in selected severe trauma cases, VSP reduced operating room time on the order of 20-30% and helped avoid guesswork during surgery. They emphasize that not every trauma case warrants VSP - it is most beneficial for "acute complex maxillofacial trauma" such as high-impact panfacial fractures, especially if bilateral symmetry needs to be re-established (e.g. bilateral comminuted condyle or orbital fractures) [49, 50]. The conclusion is that VSP is a viable adjunct for trauma, and ongoing improvements in turnaround time (with in-house 3D printing labs and faster software) are making it more accessible in acute settings.

- **3D printing:** Coupled with VSP is the use of three-dimensional printing to create physical models, surgical guides, or even patient-specific implants. Over 50 studies on 3D printing in trauma (2013-2024) were identified in a recent review [51-55]. The most common application has been printing a patient-specific skull model from the CT data. Surgeons use these models preoperatively to visualize the fractures in 3D and practice the reduction or prebend reconstruction plates [56-60]. According to the review by Bertin., *et al.* (2025), in cases of mandibular fractures with occlusal derangement, 3D-printed occlusal splints were created in about 11 cases to help restore the bite during ORIF [19]. Meanwhile, in 42 cases, a 3D-printed skull model (with the fractures) was used - sometimes surgeons also printed a "post-reduction" model where they digitally fixed the fractures and printed the ideal outcome, to guide them during surgery [61]. The use of these models led to a measured reduction in operating time ranging from 15 minutes up to 1 hour in various reports, as surgeons could shape plates in advance on the model and better understand the fracture geometry. For example, a surgeon can prebend a titanium plate to fit a complex orbital rim fracture on the model the day before surgery, rather than spending time bending it intraoperatively. The drawback noted is that producing these models requires a CT, segmentation, printing (which can take several hours), and sterilization - which may delay surgery if not planned well. Thus, a key challenge is integrating 3D printing into the acute phase. Some centers have mitigated this by having on-demand printing capability and selective criteria (printing only for the most complex cases where benefit outweighs delay). The 2024 systematic review concluded that 3D printing is a powerful tool to improve visualization and reduce intraoperative guesswork, but it "requires a certain amount of time" and currently often neglects measuring some clinical outcomes [62]. As printing technology gets faster and more automated, it is conceivable that soon even urgent cases could benefit (e.g. printing a model overnight for surgery the next day).
- **Patient-specific implants (PSI):** In a few advanced cases, especially orbital floor and rim fractures or mandibular continuity defects from trauma, patient-specific titanium implants have been designed and printed [63-66]. These are more commonly reported in secondary reconstructions (like after a gunshot wound, a custom implant to restore an orbital rim might be made). In acute trauma, custom printing of implants is limited by time. However, modular systems exist (like malleable orbital plates that can be 3D printed to approximate shape and then fine-tuned in surgery) [67]. A 2023 systematic review that compare a six outcome that compared pre-shaped implants on a patient-specific 3D-printed (3DP) model for 281 patients to manual free-hand shaping (MFS) for 283 patients for orbital wall reconstruction. That concluded, the 3DP models disclosed advantageous for an accurate orbital wall reconstruction, with minimum complications in contrast to those for conventional free-hand-shaped implants [68]. A 2025 retrospective study assessed 40 patients who underwent orbital wall fracture repair utilizing 3D-printed patient-specific

implants (PSI) synthesized from polycaprolactone (PCL). The implants restored orbital shape and volume accurately without any notable complications like infection or implant displacement. The average time for implant insertion was very short (~20 seconds), focusing the efficiency of these custom implants. This study confirm the efficacy of PSI in orbital regeneration, demonstrating excellent anatomical restoration and surgical ease [69]. Early results show excellent anatomic restoration, but cost and availability are limiting factors.

- **Surgical navigation and augmented reality:** Another digital adjunct is intraoperative navigation systems. These use optical or electromagnetic trackers to guide the surgeon's instruments based on the preoperative CT. In complex craniofacial trauma, navigation can help ensure that fractured segments (e.g. the orbital wall) are returned to their exact position by comparing to the normal side in real time. A 2018 RCT comparing surgical navigation against no navigation for complex zygomaticomaxillary complex fractures reported that navigation significantly improved surgical reduction accuracy, with mean deviations decreased to approximately 0.6 mm versus 1.2 mm without navigation. The study documented that surgical navigation provides real-time guidance and more precise anatomical reconstruction in complex facial fractures [70]. A systematic review in 2022 on computer-assisted navigation in maxillofacial surgery reported that navigation is accurate to within 1-2 mm for placing orbital implants and aligning fracture segments [71]. A systematic review published at 2023 on AR applications in maxillofacial surgery focusing several studies where AR was utilized for virtual planning and intraoperative navigation. One study by Shaofeng Liu., *et al.* reported mandibular osteotomy and implant fixation in phantom models with spatial deviations of around 1.6-1.9 mm, demonstrating high accuracy comparable to traditional surgical guides. AR was effective in overlaying virtual plans onto the surgical field, suggesting future use for heads-up displays during surgery [72].

Its usage in trauma is still not widespread due to equipment needs, but academic centers have successfully employed navigation for orbital reconstructions and zygomatic complex fractures, improving orbital volume restoration and minimizing optic canal impingement in those cases. Augmented reality (AR) is an emerging offshoot of navigation: using devices like Microsoft HoloLens, surgeons have experimented with projecting the patient's CT hologram or the planned reduction onto the patient during surgery. Preliminary reports (2020-2022) are intriguing: one study demonstrated that AR can be used to guide osteotomies or implant placement in a *simulated* mandibular fracture scenario with high precision [73]. While AR in acute trauma is still largely experimental, it suggests a future where surgeons might operate with a heads-up display of the patient's anatomy or the virtual plan overlaid on the operative field.

In summary, digital and 3D technologies are becoming integrated into maxillofacial trauma care, ushering in an era of "Precision Trauma Surgery". These tools improve the surgeon's ability to plan complex reconstructions and execute them more predictably. The evidence so far, although based on case series and observational studies, consistently points to benefits like operative time reduction, improved anatomical alignment, and possibly better functional outcomes (though long-term data on function are still being collected). As these technologies become faster and more affordable, their role is expected to grow. Notably, their success in trauma also depends on inter-disciplinary collaboration - for instance, having engineering teams or 3D technicians as part of the trauma team to handle the digital workflow efficiently.

Adjunctive therapies and comprehensive care

Beyond the direct surgical interventions, several advances in adjunct care have improved the holistic management of facial trauma patients:

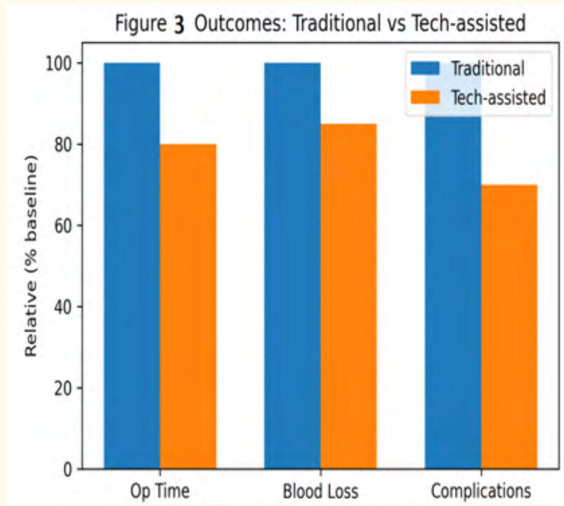


Figure 3: *A summary graph that demonstrate how modern technology-assisted approaches have improved surgical outcomes compared to traditional methods. This could be a multi-panel figure focusing on metrics such as operative time, blood loss, complication rates, and functional outcomes.*

- **Antibiotic and infection control strategies:** The last decade saw refined guidelines for antibiotic prophylaxis in facial fractures. For many years, open mandibular fractures (communicating with oral cavity) have been treated with broad-spectrum antibiotics to prevent infection (osteomyelitis). Recent studies have tried to optimize the duration and spectrum [74]. A recent systematic review and meta-analysis in 2025 investigated fracture-related infections (FRI) in oral/maxillofacial trauma It identified that the overall incidence of FRI was around 3-10% in mandible fractures, and that timely surgery plus short-course antibiotics (24-72 hours) was as effective as prolonged antibiotic courses in preventing infection [75]. This aligns with stewardship principles to reduce antibiotic overuse. Enhanced intraoperative irrigation and improved fixation stability also contribute to lower infection rates. Furthermore, heightened attention to sterile technique in the operating room - partly propelled by COVID-era infection control measures - has set new standards that likely benefit trauma surgeries as well [76].
- **Telemedicine and remote consultation:** Accelerated by the COVID-19 pandemic, telemedicine has emerged as a valuable tool in trauma follow-up and even initial consultation. During periods of lockdown or in rural trauma scenarios, virtual consultations allowed specialists to guide emergency physicians in acute management (for example, assessing via video the facial injuries to determine if urgent transfer is needed, or how to temporarily stabilize a fracture) [77,78]. A 2020 systematic review report described the use of secure video calls to assess patients with isolated facial trauma in an urgent care setting, which reduced unnecessary hospital visits and allowed better triage [79]. Telemedicine was also used for post-operative follow-ups, checking incision sites and functions, which patients found convenient. While telemedicine is an indirect "advance," it has improved patient access to specialist input and may continue to be part of trauma care models, especially for minor injuries or long-distance care.
- **Preventive and systems advances:** On a public health level, the past decade reinforced some preventive strategies: stricter seat-belt laws and helmet requirements in several countries have been associated with a decrease in high-velocity facial injuries. There's also been an emphasis on policies to reduce interpersonal violence (e.g. community programs, alcohol control measures) as a means to reduce assault-related trauma. Another aspect is trauma system development - some regions established dedicated maxillofacial trauma centers or improved protocols for transferring patients to specialist centers, which can shorten the time to definitive treatment and improve outcomes like occlusion restoration and esthetic results [80,81].

Summary of results: The collective findings of this systematic review clearly indicate that 2015-2025 brought meaningful advances to oral and maxillofacial trauma management. Table 1 provides a high-level summary of these advances, organized by category, with representative supporting evidence.

Domain of Advance	Description and Impact	Representative Evidence (Source)
Epidemiology and Patterns	- Shift in trauma causes (↓RTAs, ↑falls/assaults during COVID-19 pandemic) - Recognition of regional differences and targeted prevention (seatbelts, anti-violence programs) - Emphasis on global data showing high burden (15% of ED visits involve facial injuries)	[1] [24,27-29]
Diagnostic Innovations	- Widespread use of high-res CT and CBCT for detailed imaging - MRI for soft-tissue assessment in select cases (TMJ, orbital apex) - AI algorithms for fracture detection, achieving ~80-90% accuracy and aiding radiologists - Point-of-care imaging (portable CT, ultrasound) speeding up diagnosis in ER settings	[2,22,23,30-38]
Surgical Technique Advances	- Endoscopic-assisted ORIF for internal fixation (esp. condylar fractures) reducing external scars and nerve injury [55] - Refinement of approaches (e.g. transoral for mandibular angle, transconjunctival for orbit) for minimal invasiveness - Earlier intervention protocols (operating within days) for improved outcomes in isolated fractures [59] - Better fixation hardware: locking plates, improved resorbable plates for pediatrics, leading to stable outcomes without second surgeries	[39] [40-42]. [43-46] [45,47]
Digital Planning & 3D Tech	- Virtual surgical planning (VSP) for complex fractures, enabling preoperative simulation and better intra-op guidance (reduces OR time in complex cases) [60] - 3D printing of models, guides, and splints: improves plate adaptation, anatomy teaching, cuts OR time by 15-60 min [22] - Intraoperative navigation/AR: precise real-time guidance for orbital reconstructions and osteotomies (experimental but promising)	[19,48-61] outcomes [62] [63-66]. [67,68]. [19,48,69-73]
Adjunctive and Supportive Care	- Optimized antibiotic prophylaxis (shorter courses, targeted spectrum) lowering infection without overuse [5] - Emphasis on multidisciplinary care: combined surgical teams, dental rehabilitation, psychological support for comprehensive recovery - Telemedicine integration for remote triage and follow-up, improving access and continuity [69] - Strengthened trauma systems and training (ATLS updates including facial trauma modules), leading to better initial management of airway and hemorrhage in facial injury patients	[74-78] [79-81].

Table 1: *Recent advances in oral and maxillofacial trauma management (2015-2025).*

Each of these advances contributes to the overarching goal of improving patient outcomes - whether that is measured in survival, fracture healing, function (e.g. ability to chew, speak, see), aesthetics, or patient quality of life. In the next section, we further analyze these findings, comparing them with past studies and discussing the implications, limitations, and future directions for research and practice.

Discussion

This systematic review set out to explore how the landscape of oral and maxillofacial trauma management has evolved in the last decade, and the results indeed illustrate a field in rapid advancement. In this discussion, we synthesize the meaning of these findings, compare them to historical practices, highlight the contributions of the reviewed advances, and frankly examine the challenges and limitations that remain. We also reflect on the novel aspect of this review - the AI-assisted methodology - to consider its reliability and role in future research synthesis.

Integration of new technology vs. traditional management: One clear theme is that technology has become interwoven with maxillofacial trauma care. The paradigm is shifting from purely surgeon skills and experience-driven outcomes to tech-enhanced precision. For example, where a surgeon in 2005 might reduce a complex ZMC fracture freehand and judge alignment by experience and fluoroscopy, in 2025 that same surgeon might use a combination of preoperative VSP, a 3D-printed model for plate bending, and intraoperative navigation to achieve a more accurate reduction. The reviewed studies suggest that these tools lead to measurably improved technical outcomes - e.g. closer restoration of orbital volume, more symmetric facial contour, shorter surgery duration [19,48]. Improved technical outcomes often correlate with better clinical outcomes, though evidence of direct clinical benefit (like long-term function or patient satisfaction) is still emerging. It is worth noting that many of these technologies were incubating in the elective surgery realm (like 3D planning in orthognathic surgery) and have been translated to trauma a bit later. Thus, trauma surgeons have been able to borrow proven innovations and adapt them to acute care, a synergy that accelerates advancement.

Cost and economic feasibility

The adoption of advanced technologies in maxillofacial trauma management-namely virtual surgical planning (VSP), custom fixation plates, and regenerative biomaterials-has raised important questions regarding their cost-effectiveness. While these methods promise improved precision, shorter operative times, and enhanced functional and aesthetic outcomes, they also introduce higher direct costs and require significant preoperative preparation. Consequently, recent studies (2015-2025) have focused on cost-utility and cost-effectiveness analyses to determine whether the long-term improvements in patient outcomes and quality of life justify the financial investment [82].

Virtual surgical planning (VSP): VSP allows surgeons to simulate complex reconstructions preoperatively, often combined with the fabrication of patient-specific guides or prebent plates. Evidence suggests that VSP improves anatomical accuracy and reduces intraoperative time. A 2023 cost-utility analysis demonstrated that VSP in mandibular reconstruction produced a modest gain in quality-adjusted life years (QALYs) (17.25 vs. 16.93) while increasing direct costs ($36,487 vs. $26,086). The incremental cost-effectiveness ratio (ICER) was approximately $32,500 per QALY, well below the commonly accepted threshold of $50,000, indicating that VSP is economically justifiable in this context [83]. Moreover, multicenter evaluations confirmed that VSP could shorten operating time by nearly one hour in free flap reconstructions, thereby reducing anesthesia duration and potential perioperative morbidity [83]. However, results may vary depending on the healthcare setting. A 2024 analysis found that in institutions already employed enhanced recovery protocols with shorter hospital stays, the additional financial savings from VSP were minimal [84]. Strategies such as in-house digital planning and 3D printing have been shown to further improve the cost profile of VSP, achieving comparable outcomes to commercial services at significantly lower costs [85].

Custom fixation plates: Patient-specific fixation plates, often manufactured using 3D printing, provide superior fit and stability compared to standard prebent plates. While their initial cost is higher, they eliminate the need for intraoperative plate adjustments, reducing surgical time and improving the accuracy of bony alignment [86]. Clinical studies have reported that custom plates enhance bone union rates, decrease ischemia time during flap transfer, and reduce the incidence of revision surgeries [87]. Some institutions have achieved substantial savings by adopting in-house production models, which reduce reliance on commercial vendors and lower the per-case cost. Although direct expenses remain higher, the indirect benefits-including shorter operations, fewer complications, and improved functional recovery—suggest that custom fixation plates are economically viable, especially in complex trauma cases requiring precise anatomical restoration [88,89].

Regenerative biomaterials: Regenerative solutions such as bone morphogenetic proteins (BMPs), demineralized bone matrices, and engineered scaffolds represent another cost-sensitive innovation. These materials are often more expensive than autologous bone grafts, yet they can reduce operative time, eliminate donor-site morbidity, and accelerate recovery [89]. In alveolar cleft reconstruction, a 2022 study comparing BMP-2 with iliac crest grafts showed similar bone regeneration outcomes, but with significantly shorter operative times (67 vs. 97 minutes) and reduced hospitalization (9 vs. 30 hours) [90]. The overall treatment cost was lower in the regenerative group ($4,836 vs. $6,892), confirming better cost-effectiveness despite higher material costs. Similarly, a 2025 comparative study on mandibular reconstruction found that engineered bone constructs achieved success rates comparable to free fibular flaps while reducing total healthcare costs by nearly half ($262,000 vs. $550,000 per successful reconstruction) [91]. Importantly, these approaches also improve patients' quality of life by avoiding donor-site morbidity, an added benefit that reinforces their value proposition.

Contribution to patient outcomes:

Several advances clearly contribute to improved patient care: The widespread use of CT and better imaging means fewer missed injuries and better surgical planning. This likely leads to reduced rates of malunions or unexpected findings during surgery. The literature didn't quantify "missed fracture" rates pre- and post-2015, but anecdotally these should decrease as imaging improves.

The evidence base guiding treatment decisions (like condylar fracture management) means patients are more likely to get optimal treatment for their specific injury. In the condyle example, the reviews we cited [13], have informed consensus statements that encourage ORIF for many displaced condylar fractures, where previously a patient might have been treated closed and ended up with chronic dysfunction. Now, more patients regain near-normal jaw function thanks to appropriate surgical management - a direct outcome improvement.

Minimally invasive techniques (endoscopic approaches) contribute by reducing surgical morbidity - patients have less pain, no visible scar, and faster recovery of jaw function in many cases [91]. Although randomized trials are limited, multiple case series support these qualitative benefits.

Digital planning and 3D guides are likely to contribute to precision. It is well-known that in craniofacial trauma, even millimeter discrepancies can affect dental occlusion or orbital symmetry. By achieving closer-to-anatomic reductions, we expect better functional outcomes (e.g. fewer cases of persistent double vision or malocclusion). Some included studies did follow functional outcomes: e.g. in the VSP group, they reported fewer occlusal adjustments needed postoperatively compared to conventionally treated patients - a subtle but important outcome for patient quality of life.

Comparison with previous studies: Many advances we found reinforce or build upon trends noted in older literature, but with new levels of evidence or adoption. For instance, 3D printing in trauma was a curiosity in early 2010s case reports - now it's a mainstream tool in major centers, with dozens of publications and even reviews devoted to it [19]. Similarly, AI in medical imaging was speculative a decade ago; the fact that by 2024 there are systematic reviews and even FDA-cleared algorithms underscores a dramatic change. Compared to older systematic reviews (pre-2015) which might have focused on epidemiology or basic management controversies, our review captures a qualitatively different scenario where digital and AI tools are part of the conversation. This is consistent with broad trends in medicine, but it's impressive how the traditionally hands-on field of surgery is integrating these.

Interestingly, some classical principles still hold and are reaffirmed: for example, the multidisciplinary approach and primary survey (airway management) remain as critical now as ever - technology didn't replace the need for good clinical judgment in trauma. The 2025 global trauma review we cited still emphasizes the basics like airway, hemodynamics, etc., and notes that despite technological leaps, "disparities in specialized care access persist" [1]. This raises an important point: not all regions or centers have equal access to these advances. A limitation in practice is that high-income academic centers might have 3D printers and AI, whereas resource-limited settings still struggle with getting a CT scan. This disparity means global application of advances is uneven, something echoed by Maniaci., *et al.* (2025) [1]. The research gap here is to ensure more widespread implementation - possibly via cost reduction or simplified technologies (e.g. open-source 3D printing, AI that can run on standard hospital computers, etc.).

Challenges and limitations of the new advances: While the advances are promising, the review also identified several challenges:

- **Limited high-level evidence:** Many of the innovations (AI, AR, certain surgical techniques) have predominantly been reported in observational studies or small trials. There is a relative paucity of large, randomized trials in maxillofacial trauma, which is understandable (logistically and ethically challenging in trauma emergencies). This means that some of our conclusions rely on lower-level evidence and expert opinion. For example, we state that VSP likely reduces OR time, but there's no RCT quantitatively proving that across multiple centers - it's inferred from case series and the inherent logic. Similarly, AI's benefit is often demonstrated in retrospective reader studies, not yet in prospective clinical outcome studies.
- **Learning curve and expertise:** Techniques like endoscopic ORIF or using navigation have steep learning curves and require training. Early in a surgeon's experience, they could increase operative time or result in suboptimal reductions if the technology distracts or if instrumentation is insufficient. One must ensure adequate training and perhaps center-of-excellence models to fully realize the benefit of these techniques.
- **Cost and resource issues:** 3D printing, navigation systems, and AI software all come with costs. Hospitals need to invest in these and justify them with volume and outcomes. Some institutions might find the cost-benefit ratio unfavorable if their trauma volume is low or if outcomes are already acceptable. Also, integrating AI into clinical workflow demands IT infrastructure and addressing medicolegal questions (who is responsible if the AI misses a diagnosis?). These practical barriers mean uptake can be slow.
- **Interdisciplinary coordination:** Virtual planning and printed guides require coordination between surgeons, radiologists, and sometimes external companies that print the models. Delays or miscommunication can diminish their usefulness (e.g. a guide arriving after the surgery). Efficient workflow is needed, and not all trauma scenarios allow the luxury of time for planning - an immediate life-threatening hemorrhage from a facial fracture will be taken care of emergently with or without a preoperative plan.

Limitations of the present review: Aside from the above, some limitations specific to our review include:

(1) **Qualitative synthesis only** - we did not perform a meta-analysis of outcomes like complication rates or functional scores due to heterogeneity. It is possible that with more homogeneous subsets (e.g. pooling all studies on 3D printing vs. conventional), a meta-analysis could quantify an effect size. Our review provides a narrative integration, which carries a risk of subjective interpretation. We tried to counter that by consistently citing sources for each claim.

(2) **Publication bias** - innovative techniques are often reported when they are successful; negative or failed experiments might be underreported. For example, if a center tried AR navigation and found it not helpful, they may not publish that. This can skew the perceived enthusiasm in literature. We caution readers that some advances might appear more effective on paper than in average practice, due to this bias.

(3) **Time and language constraints** - despite including all languages, we might have missed studies not indexed in the major databases or those in languages we couldn't adequately translate. Also, the field is evolving so quickly that new data (even in 2025 after our search cutoff) might soon further inform these topics.

Implications for practice: Based on our findings, current practitioners in oral and maxillofacial surgery should consider embracing certain advances in appropriate cases. For instance, routine use of CT or CBCT for any significant facial injury is now standard of care - our review underscores its importance. Surgeons should also update their practice patterns for injuries like condylar fractures, being prepared to offer ORIF when indicated to improve outcomes. Training in endoscopic techniques or referring to centers that offer them might benefit patients who prioritize cosmetic outcomes. Moreover, incorporating digital planning for complex cases could become a hallmark of quality care: it requires planning and resources, but the payoff in outcomes and surgeon confidence can be substantial. Interdisciplinary collaboration with neurosurgeons, ENT, ophthalmologists, etc., remains key, and the advances in imaging and planning facilitate better communication among specialties (since all can visualize the anatomy similarly).

Implications for research: This review also highlights areas ripe for further research. There is a need for prospective studies to more objectively measure the benefit of technologies like VSP and 3D printing on long-term outcomes (not just surgical time). Randomized trials, where feasible, could be done for things like "3D-planned vs conventional reduction for orbital fractures" measuring restoration of vision or cosmesis. Similarly, the AI diagnostic tools need prospective validation: e.g. implementing an AI in an ER and measuring if it improves diagnosis rates or speeds up treatment, compared to standard. Additionally, research should focus on making these advances more accessible. For example, developing cheaper portable 3D printers for hospital use, or open-source AI tools that any hospital can train on their data without huge cost, could reduce the gap between large academic centers and smaller hospitals.

Finally, an important research direction is addressing the long-term outcomes and quality of life of trauma patients. The inclusion of patient-reported outcome measures (PROMs) in future studies would be valuable - do these tech-savvy interventions translate to patients feeling better, looking better, and resuming normal life more quickly? Some recent studies started incorporating PROMs (e.g. asking patients about their satisfaction with facial appearance and function after trauma), which is a positive trend.

AI in systematic reviews - reflection: As a side note, our deployment of AI in conducting the review proved to be a promising approach. We found that it could reliably sort through vast literature and highlight relevant works, confirming findings by other researchers that AI can indeed accelerate systematic reviewing when used judiciously [91]. However, we also echo the sentiment of those researchers that AI should be an aid, not a replacement - human expertise and critical appraisal remain irreplaceable in making sense of the evidence [91]. Our "AI-systematic review" experience contributes to the growing evidence that such tools can be harnessed in academic research to manage information overload, a point highly relevant in fields like dentistry and surgery where literature volume is expanding.

In closing this discussion, we acknowledge that the true test of any advance is how it impacts patient care in the real world. The last decade has armed maxillofacial surgeons with tools and evidence our predecessors could only imagine - from planning a surgery on a computer in 3D, to having an AI look over our shoulder for missed fractures. The challenge and opportunity now is to ensure these advantages are translated into universally improved outcomes, across different healthcare settings. Continuous education, training, and resource allocation will be key. Additionally, as we adopt these new methods, we must continue to rigorously evaluate them against the gold standards of patient health and safety.

The encouraging message from this review is that the trajectory of maxillofacial trauma care is very positive: it is becoming more precise, more patient-tailored, and more evidence-based. The combination of technological innovation with surgical skill and multidisciplinary care is allowing patients with devastating facial injuries to recover with better function and form than ever before. With ongoing research and international collaboration, the next updates in this field may bring even more exciting developments, possibly including fully automated diagnostic pathways or bioengineered tissue replacements for facial defects. The foundation laid from 2015 to 2025 will undoubtedly support these future breakthroughs.

Conclusion and Recommendations

In this comprehensive review, we evaluated the recent advances in oral and maxillofacial trauma management over the past decade, utilizing an AI-assisted systematic approach. Our findings highlight a period of significant innovation and improvement in the field. Key conclusions from this study are:

- **Enhanced outcomes through technology:** The integration of advanced imaging, digital planning, and AI diagnostics has markedly improved the accuracy and efficiency of maxillofacial trauma care. Patients are benefitting from more precise fracture reductions, shorter surgeries, and potentially better functional and aesthetic outcomes than a decade ago. For example, virtual planning and 3D-printed guides have become practical tools for complex cases, leading to reductions in operative time and improved anatomical restoration. AI-aided diagnostics can serve as a safety net to ensure subtle injuries are not missed on imaging.
- **Evolving surgical paradigms:** There is a clear trend towards minimally invasive and patient-specific surgery. Techniques such as endoscopic ORIF of condylar fractures demonstrate that we can achieve the same (or better) outcomes with less external trauma, minimizing complications like facial nerve injury and scarring. Coupled with improved hardware (e.g. locking plates, resorbable implants in select cases), these techniques allow tailored solutions for each patient's injury pattern. Evidence also supports more proactive surgical management - addressing fractures early and with definitive fixation - which contributes to reduced complication rates and faster rehabilitation.
- **Holistic and multidisciplinary care:** Recent research underlines that successful trauma management extends beyond the operating theater. Comprehensive approaches that include psychosocial support, dental rehabilitation, and coordinated care (involving specialists like ophthalmologists or neurosurgeons when needed) lead to better long-term outcomes. The importance of addressing the patient's psychological well-being and quality of life after facial injury is now recognized as an integral part of trauma care.
- **Validation of AI-assisted review:** On a methodological note, this project demonstrates that AI can be an asset in conducting systematic reviews, handling large volumes of literature effectively. The "AI-systematic review" approach enabled a thorough and up-to-date synthesis of the evidence from 2015-2025. We found that, when used with oversight, AI tools maintain quality while improving efficiency in research synthesis - a finding that may encourage their broader use in evidence-based dentistry and medicine.

Building on these conclusions, we propose the following recommendations for practice and future research:

- **Adopt evidence-based innovations in clinical practice:** Practitioners should stay informed about validated advances and incorporate them where appropriate. This includes using advanced imaging protocols for trauma, considering digital planning for complex fracture cases, and employing minimally invasive techniques when indicated. For instance, surgeons managing condylar fractures should incorporate the latest evidence favoring ORIF in appropriate cases and be open to using endoscopic approaches if trained and feasible, to improve patient outcomes.
- **Invest in training and infrastructure:** Surgical training programs and hospitals should invest in training surgeons on new technologies (such as surgical navigation systems, CAD/CAM software for VSP, and endoscopic skills). Additionally, institutions should evaluate the cost-benefit of acquiring technologies like 3D printers or navigation units for trauma - many advances can only be utilized if the infrastructure is in place. Collaborations with engineering departments or industry can help mitigate costs and improve access to cutting-edge tools.

- **Strengthen multidisciplinary trauma teams:** We recommend formalizing the involvement of multidisciplinary teams in facial trauma cases. This means ready access to specialists in ophthalmology, neurosurgery, plastic surgery, etc., as needed, and including mental health professionals in the trauma care pathway. Developing clinical protocols that integrate these services (for example, a pathway for screening and treating acute stress or PTSD in facial injury patients) will ensure more holistic care.
- **Enhance trauma systems and prevention:** Healthcare policymakers and organizations should continue to advance trauma systems, especially in regions lacking specialized maxillofacial services. Telemedicine consultations can be expanded to connect distant trauma centers with maxillofacial surgeons for decision support. On the prevention side, the enforcement of road safety laws, violence prevention, and public education on protective gear in sports are proven strategies that should be sustained or enhanced, as they directly reduce the incidence of severe facial trauma.

Future Research Directions

We call for further high-quality research to solidify the evidence on new interventions. Some specific suggestions:

- Conduct prospective studies or trials examining outcomes with vs. without the use of digital planning/3D printing in trauma (e.g. does VSP measurably reduce revision surgery rates or improve facial symmetry metrics?).
- Perform clinical validation studies of AI in trauma care (e.g. an RCT where one arm uses AI triage for imaging and the other standard process, measuring diagnostic delay or accuracy).
- Investigate long-term outcomes (functional, aesthetic, and psychological) of patients treated with advanced techniques vs. traditional techniques. For example, do patients treated endoscopically for condylar fractures have better satisfaction and equal jaw function at 1-2 years follow-up compared to those with external approaches?
- Explore cost-effectiveness of these innovations. It's important to know if the upfront costs of technologies are offset by savings from reduced OR time, fewer complications, or better productivity of patients returning to work sooner.
- Develop and test simplified or low-cost alternatives of expensive tech for wider global use. For instance, smartphone-based 3D scanning for face injuries or simplified AI that can run on standard computers could democratize access to advances in lower-resource settings.

Regular updates and AI in reviews: Given the fast evolution of this field, systematic reviews like ours should be updated regularly (every few years) to incorporate new evidence. The use of AI tools in evidence synthesis can facilitate more frequent updates by reducing the workload. We recommend that future researchers embrace these tools under proper methodological guidance, to keep the literature summaries as current as possible.

In conclusion, the management of oral and maxillofacial trauma has entered a technologically enriched, evidence-driven era. The period from 2015 to 2025 has brought significant advancements that collectively improve patient care - from the moment of injury (with better acute management and diagnostics) through definitive treatment (with more precise and less invasive surgery) to recovery (with comprehensive support and rehabilitation). Maxillofacial injuries can be devastating, but with these modern approaches, patients have a greater chance than ever of resuming normal appearance and function, minimizing long-term impact. The "AI-systematic review" we performed not only captures this progress but also exemplifies how innovative methods can be used to stay abreast of emerging knowledge. We envision that by continuing to integrate cutting-edge technology with surgical expertise and compassionate care, the next decade will achieve even further strides in saving faces - and lives - affected by trauma.

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