



3D RECONSTRUCTION PLATES: ENHANCING OUTCOMES IN MAXILLOFACIAL SURGERY

Maxillofacial Surgery

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ABSTRACT

Reconstructing complex maxillofacial defects is challenging due to the intricate anatomy and dual demands of function and aesthetics in oral and maxillofacial surgery (OMFS). The introduction of 3D reconstruction plates, guided by advanced imaging, virtual surgical planning (VSP), and additive manufacturing, has transformed personalized surgical care. This review evaluates their effectiveness, fabrication, advantages, and challenges. Techniques such as stereolithography, selective laser sintering, and fused deposition modeling produce custom implants tailored to complex defects from trauma, tumors, or congenital anomalies. Clinical applications in mandibular and midface reconstruction, orthognathic surgery, and temporomandibular joint replacements show better precision, reduced operating time, and improved outcomes compared to traditional methods. Innovations like surgeon-led design and bioprinting promise further improvements in reconstructive success in OMFS.

KEYWORDS

3D Printed Reconstruction Plates, Maxillofacial Surgery, Patient-Specific Implants, Additive Manufacturing

1. INTRODUCTION

Reconstructing craniomaxillofacial defects remains a challenging aspect of oral and maxillofacial surgery (OMFS), involving restoration of vital functions such as vision, mastication, and speech, along with facial aesthetics and symmetry. Defects may arise secondary to trauma, tumor resection, infection, congenital anomalies, or genetic disorders, greatly impacting patient quality of life. Precise surgical planning and tailored reconstruction are imperative to optimizing outcomes [1]. Three-dimensional (3D) technologies have emerged as transformative tools to address these challenges by allowing accurate replication of patient anatomy from computed tomography (CT) or magnetic resonance imaging (MRI) data. These models enable surgeons to pre-bend plates, customize implants, design cutting guides, and simulate surgeries with increased accuracy, thus improving reconstruction efficiency and results [2]-[5]. The advent of virtual surgical planning (VSP) and additive manufacturing (AM) techniques such as stereolithography (SLA), selective laser sintering (SLS), and fused deposition modeling (FDM) permits fabrication of patient-specific 3D reconstruction plates (PSPs) for complex maxillofacial defects. This manuscript reviews the principles, fabrication technologies, clinical applications, outcomes, and future directions for 3D reconstruction plates in OMFS.

2. Methodology

A structured literature review and clinical data analysis were conducted to evaluate the principles, fabrication technologies, and outcomes of 3D reconstruction plates in oral and maxillofacial surgery (OMFS). Data were collected from peer-reviewed publications (2010–2025) via PubMed, Scopus, and Web of Science. Studies focusing on 3D-printed, patient-specific maxillofacial implants were included; non-English or non-3D studies were excluded. Extracted variables included fabrication methods, materials, planning protocols, clinical uses, and results, synthesized qualitatively to assess clinical trends and efficacy.

3. Principles and Technologies of 3D Reconstruction Plates

Fabrication Technologies

3D reconstruction plates are produced using various additive manufacturing (AM) technologies, each with distinct merits and drawbacks that influence their clinical application. Understanding these fabrication methods is essential to selecting the appropriate technique for patient-specific implant production.

- Fused Deposition Modeling (FDM): Involves extruding thermoplastic filaments layer by layer. It is cost-effective and suitable for PEEK and other non-metal implants, but offers lower surface finish and reduced accuracy compared to SLA or SLS [3],[6],[7]. (Fig. 1 C)
- Selective Laser Sintering (SLS): Employs a high-energy laser to fuse metal or polymer powders into dense, strong constructs. SLS

is widely adopted for custom titanium plates and implants due to its ability to generate strong, complex geometries without support structures [3],[8],[9]. (Fig. 1 D)

- Stereolithography (SLA): Uses a UV laser to polymerize resin layer by layer, producing highly accurate and detailed models optimal for surgical guides and anatomical templates, though it comes with higher costs and needs for post-processing [10]-[12]. (Fig. 1 E)
- PolyJet Modeling: Jets and cures multiple liquid photopolymers simultaneously, enabling multi-material prints with varied strength and flexibility. However, the technology is associated with higher setup and operating costs [2],[4]. (Fig. 1 F)

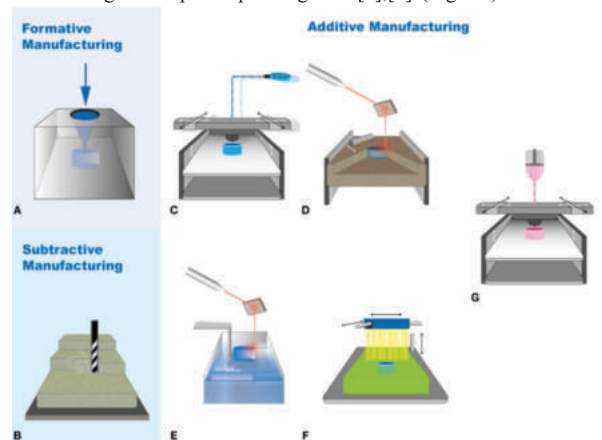


Fig. 1 Overview on the different manufacturing approaches. Conventional approaches comprising (A) Formative, (B) Subtractive manufacturing; widely applied additive manufacturing methods including (C) Fused deposition modeling (FDM), (D) Selective laser sintering (SLS), (E) Stereolithography (SLA), (F) Polyjet and (G) Bioprinting. Adopted from [Knowlton et al., 2015; Ji and Guvendiren, 2017; Ligon et al., 2017] [5]

Titanium remains the metal of choice for 3D printed maxillofacial reconstruction plates owing to its excellent mechanical strength, corrosion resistance, and proven biocompatibility. Meanwhile, polymers like PEEK are gaining interest for their favorable mechanical properties and lower weight, providing promising alternatives for non-metallic implants [11].

Design Considerations

Patient-specific reconstruction plates start with virtual surgical

planning (VSP), which uses high-resolution CT or cone beam CT scans to create accurate 3D models of the craniofacial skeleton. Specialized software allows surgeons to visualize, manipulate, and simulate osteotomies, designing implants that precisely fit the defect [2],[13],[14].

Surgeon-led design improves efficiency by enabling clinicians to outline plate paths and place screw holes tailored to each case. These designs are then converted into digital prototypes for manufacturing using CAD/CAM workflows [15].

Patient-specific cutting guides, matching the implants, ensure precise bone cuts and screw placements during surgery. The guides and plates undergo stringent fabrication, finishing, sterilization, and quality control before use, guaranteeing optimal fit and function [9],[10].

4. Clinical Aspects of 3D Reconstruction Plates

The clinical use of 3D reconstruction plates in oral and maxillofacial surgery has significantly changed the management of complex defects. These plates are designed patient-specifically with 3D virtual surgical planning and advanced imaging like high-resolution CT or cone beam CT, enabling superior anatomical fit, better load distribution, and enhanced integration compared to conventional plates [11].

In facial trauma, 3D printed plates can be pre-bent on anatomical models or directly printed to facilitate precise fracture fixation. This approach reduces surgical and anesthesia time, which is crucial in emergencies. Off-the-shelf plates often fail to accommodate the complex 3D contours of the maxillofacial skeleton, risking malocclusion or implant failure—issues mitigated by personalized plates replicating anatomical landmarks [11]-[16].

In oncologic resections such as mandibulectomy or maxillectomy, 3D models guide tumor excision with precise cutting guides, preserving normal bone. Custom plates combined with vascularized bone flaps restore mandibular shape and function, improving rehabilitation [9].

Orthognathic surgery benefits from 3D planning for accurate skeletal movements and surgical splints, reducing operation times and enhancing outcome predictability [6],[7],[15].

For temporomandibular joint replacement, patient-specific 3D printed prostheses mimic native anatomy, enable accurate fixation, and lower complications when integrated with virtual planning [10].

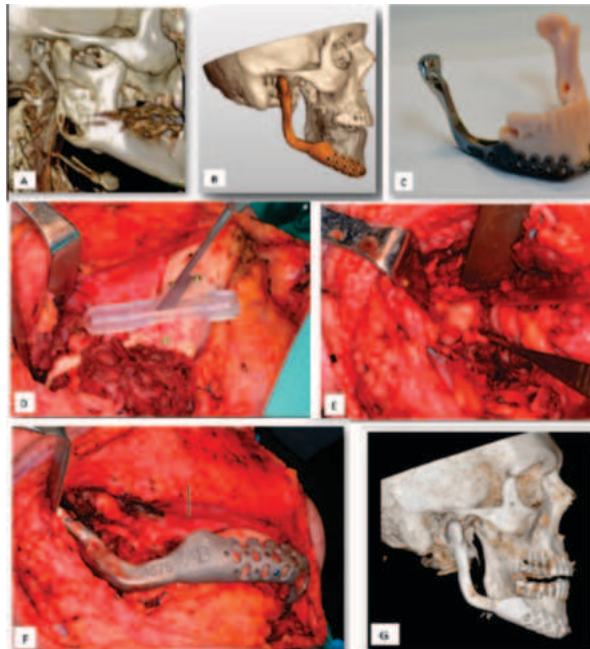


Fig 2. (A) A pre-operative 3D CT show the position and dimensions of the metastatic lesion. (B) 3D Planning including virtual removal of tumor and the virtual construction of the right temporomandibular joint (TMJ). (C) 3D printed stereolithic model and metal implant after virtual removal of Tumor in the right mandibular ramus. (D) The use of the cutting guide for accurate resection based on virtual cutting plan.

(E) Removal of the tumor. (F): the placement of the printed TMJ implant. (G) Postoperative CT shows the accurate position of the TMJ implant [4].

5. DISCUSSION

The advancement of 3D reconstruction plates represents a paradigm shift within oral and maxillofacial surgery, driven by the integration of virtual surgical planning and additive manufacturing. Their ability to conform to patient-specific anatomy not only improves fit and reduces intraoperative adjustments but also enhances biomechanical stability and functional rehabilitation [11].

Clinical evidence shows that pre-bent and custom plates significantly decrease surgical duration and improve accuracy in trauma reconstruction, orthognathic corrections, tumour resections, and joint replacements. This has favourable implications on anaesthesia time, patient morbidity, and overall outcomes, particularly in extensive or complex reconstructions [9],[11].

Material science advances, particularly the adoption of titanium alloys and emergence of polyether ether ketone (PEEK), have broadened implant options offering improved strength, biocompatibility, and infection resistance. However, hypersensitivity, stress shielding, and limited tissue integration remain concerns that drive ongoing research into surface modification and bioactive coatings [12].

Limitations of 3D reconstruction technology include high production costs, requirement for multidisciplinary expertise for virtual surgical planning, and lack of standardized manufacturing protocols resulting in variable accuracy and consistency between centres. Postoperative complications, such as infection and implant failure, underscore the importance of patient and implant selection criteria, operative technique, and perioperative management [15].

Future efforts aim to make 3D reconstruction plates more accessible by lowering costs and enhancing surgeon-led designs, with artificial intelligence accelerating planning and optimization. Bioprinting holds great promise for creating bioactive scaffolds that support bone and soft tissue regeneration, potentially revolutionizing maxillofacial reconstruction. Regulatory approval and clinical trials to verify safety, efficacy, and long-term outcomes are essential for widespread adoption. Meanwhile, 3D plates remain a valuable and rapidly evolving tool for oral and maxillofacial surgeons striving for precise, personalized, and predictable reconstruction.

6. CONCLUSION

3D reconstruction plates have significantly advanced maxillofacial surgery by enabling patient-specific, highly precise reconstruction of complex craniofacial defects. The integration of virtual surgical planning with additive manufacturing has optimized implant fit, reduced operative time, and enhanced clinical outcomes. Despite persisting challenges related to cost, technical expertise, and standardization, ongoing innovations particularly in bioprinting and intelligent planning systems are poised to further refine reconstructive strategies and shape the future of maxillofacial surgery.

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