CREATION OF JAWBONE RECONSTRUCTION MODELS USING 3D PRINTING FROM METAL AND PLASTIC MATERIALS

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Abstract

This study examines modern approaches to the use of 3D printing technologies in jawbone reconstruction. In particular, it focuses on the development of patient-specific anatomical models produced from metal and plastic materials, their manufacturing processes, and their clinical significance. Based on international experience, the study highlights the role of 3D-printed models in improving surgical accuracy, reducing operative time, and minimizing the risk of complications. Furthermore, a comparative analysis of material properties is presented, emphasizing the strength and biocompatibility of metal materials alongside the cost-effectiveness and versatility of polymer-based materials. The findings indicate that 3D printing technologies significantly enhance individualized treatment strategies and contribute to improved functional and aesthetic outcomes in maxillofacial surgery.

Keywords

3D printing, jawbone reconstruction, biomodels, titanium implants, polymer materials, patient-specific implants, maxillofacial surgery, CAD/CAM technology, biocompatible materials, additive manufacturing.

In recent decades, rapid advancements in digital technologies and biomedical engineering have significantly transformed the field of maxillofacial surgery. Among these innovations, three-dimensional (3D) printing has emerged as a powerful tool for the precise planning and execution of complex surgical procedures, particularly in jawbone (mandibular and maxillary) reconstruction. The integration of 3D printing technologies into clinical practice enables surgeons to create patient-specific anatomical models, surgical guides, and customized implants, thereby improving surgical accuracy and outcomes.

Jawbone reconstruction remains a challenging task due to the complex anatomical structure, functional requirements, and aesthetic considerations associated with the craniofacial region. Traditional reconstruction methods often rely on intraoperative decision-making and standard implants, which may not fully correspond to individual patient anatomy. In contrast, 3D printing allows for the production of highly accurate physical models derived from medical imaging data such as computed tomography (CT) or cone-beam computed tomography (CBCT). These models facilitate preoperative planning, simulation of surgical procedures, and the fabrication of personalized implants.

The use of different materials in 3D printing, particularly metals and polymers (plastics), plays a crucial role in determining the functionality and application of the produced models. Metal-based materials, such as titanium and its alloys, are widely utilized for permanent implants due to their high strength, biocompatibility, and resistance to corrosion. On the other hand,

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polymer-based materials, including biocompatible plastics, are commonly used for prototyping, surgical planning models, and temporary guides due to their cost-effectiveness, ease of processing, and versatility.The combination of these materials within 3D printing technologies provides new opportunities for enhancing the effectiveness of reconstructive procedures. By enabling the creation of anatomically precise and patient-specific models, this approach contributes to reduced surgical time, minimized risk of complications, and improved functional and aesthetic results.

Therefore, the present study focuses on the development and application of jawbone reconstruction models using 3D printing technologies, specifically employing both metal and plastic raw materials. The study aims to analyze the technological processes, material characteristics, and clinical relevance of these models in modern maxillofacial reconstructive practice.

MAIN PART

The application of three-dimensional (3D) printing in jawbone reconstruction has been extensively studied and implemented in leading medical centers worldwide, demonstrating significant improvements in surgical precision, patient outcomes, and procedural efficiency. The integration of digital imaging, computer-aided design (CAD), and additive manufacturing technologies has enabled a paradigm shift from standardized treatment approaches to highly individualized surgical solutions.

One of the key stages in creating jawbone reconstruction models is the acquisition and processing of high-resolution medical imaging data. In advanced clinical settings across countries such as the United States, Germany, and Japan, computed tomography (CT) and cone-beam computed tomography (CBCT) are routinely used to obtain detailed anatomical information. These data are then converted into Digital Imaging and Communications in Medicine (DICOM) formats and further processed using specialized software such as Mimics, 3D Slicer, or Materialise. Through segmentation and reconstruction processes, accurate three-dimensional digital models of the patient's craniofacial structures are generated. This digital workflow ensures that the final printed models precisely replicate the patient's anatomical features, including bone defects and asymmetries.

International experience shows that polymer-based (plastic) models are widely used in the preoperative phase. For example, in clinical centers in South Korea and the Netherlands, surgeons utilize 3D-printed plastic models to simulate surgical procedures, plan osteotomies, and determine optimal implant positioning. These models are typically produced using materials such as polylactic acid (PLA) or acrylonitrile butadiene styrene (ABS), which are cost-effective and easy to process. Studies conducted in European maxillofacial clinics indicate that the use of such models can reduce surgical time by up to 20–30% and significantly improve the accuracy of bone segment alignment.

In contrast, metal-based 3D printing has revolutionized the fabrication of patient-specific implants (PSIs). Titanium and its alloys, particularly Ti-6Al-4V, are the most commonly used materials due to their excellent biocompatibility, mechanical strength, and osseointegration properties. Technologies such as selective laser melting (SLM) and electron beam melting (EBM) are employed to produce complex, porous structures that closely mimic natural bone architecture. In countries like Germany and the United States, these techniques are routinely used for reconstructing large mandibular defects caused by trauma, tumors, or congenital anomalies.

A notable example of successful implementation can be observed in clinical practice at leading institutions such as the Mayo Clinic and Charité – Universitätsmedizin Berlin, where patient-specific titanium implants are designed based on digital models and manufactured using advanced 3D printing systems. Clinical outcomes from these centers demonstrate improved implant fit, reduced intraoperative adjustments, and enhanced functional recovery. Furthermore, the porous structure of 3D-printed titanium implants promotes better vascularization and bone ingrowth, which are critical for long-term stability.

Another important aspect of global experience is the use of hybrid approaches combining both plastic and metal materials. In Japan and Switzerland, for instance, surgeons often begin with plastic prototypes to validate surgical plans and then proceed to fabricate definitive metal implants. This two-stage approach minimizes errors and allows for precise customization. Additionally, surgical guides produced from biocompatible polymers are used intraoperatively to ensure accurate cutting and positioning, further enhancing surgical outcomes.

From a technological perspective, the accuracy and success of 3D-printed models depend on several factors, including printer resolution, material properties, and post-processing techniques. International standards and guidelines, such as those established by the International Organization for Standardization (ISO) and the U.S. Food and Drug Administration (FDA), regulate the production and clinical use of 3D-printed medical devices. Compliance with these standards ensures safety, reliability, and reproducibility of the models and implants.

Moreover, recent advancements in biofabrication and tissue engineering are expanding the potential applications of 3D printing in jawbone reconstruction. Research conducted in countries like China and the United Kingdom is exploring the use of biocompatible scaffolds combined with stem cells and growth factors to promote bone regeneration. Although these approaches are still largely experimental, they represent a promising direction for future clinical practice.

In conclusion, the global experience clearly demonstrates that the use of 3D printing technologies, incorporating both metal and plastic materials, has become an integral component of modern jawbone reconstruction. The combination of precise digital modeling, advanced manufacturing techniques, and high-performance materials enables the creation of patient-specific solutions that significantly enhance surgical accuracy, reduce complications, and improve overall patient outcomes.

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