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Role of 3D Printing in Oral Surgery

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ABSTRACT

The emergence of 3D printing technology has led to significant innovations in various fields, including medicine, dentistry, engineering, and education. Over the past three decades, 3D printing and prototyping has gained popularity among medical and dental professionals, as well as patients. 3D printing involves additive manufacturing techniques, where 3D objects are formed by laying material layer by layer. 3D printers can produce object representations planned with a CAD program or scanned with a 3D scanner. In the realm of oral and maxillofacial surgery (OMFS), 3D printing has helped improve treatment planning precision, surgical predictability, reduced operating times, and overall cost. Additionally, 3D printing has allowed for better surgical training, improved patient-physician relationships, and increased surgical outcomes. This review aims to summarize the impact of 3D printing technology in oral surgery.

Keywords: CAD, Dental, 3D printing, surgery, Recent Advances

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INTRODUCTION

Significant advancements have been made in the field of oral and maxillofacial surgery in recent years, particularly concerning diagnostic tools and management. Congenital or acquired deformities in the head and neck region can impact both aesthetics and functionality[1,2]. The introduction of three-dimensional (3D) models of the jaw and facial bones has been a game-changer in achieving better surgical outcomes. Rapid prototyping (RP) or additive manufacturing (AM), also known as 3D printing, was first introduced in 1986 and has since been widely used in various fields such as medicine, dentistry, engineering, and education[3-6]. The benefits of 3D printing include customization and personalization, detailed and accurate device and scaffold fabrication, cost efficiency, and enhanced productivity[7]. In the past decade, it has found multiple applications in the medical and surgical fields, including oral and maxillofacial surgery (OMFS). 3D printing is utilized in treatment planning, prosthesis implant fabrication, and medical training[8]. OMFS applications of 3D printing were first reported by Brix et al. and popularized by Mankovich et al.,[9] who used computed tomography (CT) scan simulations of bony anatomy to treat patients with craniofacial deformities. 3D printing is also used in CT-guided stent fabrication for precise drilling and placement of dental implants, as well as ablative and orthognathic surgeries for treatment planning and simulation. Furthermore, patient-specific implants are fabricated for facial bone fractures, and cutting guides are produced in reconstructive surgeries to ensure 3D accuracy in the reconstruction of facial and jaw defects. In cleft lip and palate surgeries, 3D printing is used for fabricating nasoalveolar molding plates and facial prostheses, such as those for the jawbone, temporomandibular joint (TMJ), ear, and eye[10,11]. This article narrates the role of 3D printing in oral surgery.

3D PRINTING IN FACIAL TRAUMA

Due to the wide range of trauma injuries IN ORAL SURGERY, there arises the need to shorten the time needed for pre-operative evaluation and treatment. To achieve this 3D technology is required which improves fixation accuracy, restores anatomically correct contours and reduces surgical complications[12].

In most mandibular fracture cases, printing of the appropriate anatomy with desktop FDM/SLA/Binder Jet 3D printers is performed and fixation plates are pre-bonded on models or custom plating is produced based on the Virtual stimulation. Virtual simulation allows us to accurately determine the position and direction of the fracture, the amount of bone fragments and the degree of dislocation of the bone segments. Preoperative, we can virtually reduce the number of fractured bone segments and transfer plans into the operating room using a variety of 3D printed models, guides and templates and a pre-programmed fixation method. Achieving 3DP POC facilities in the healthcare campus helps in time reduction for reduction and fix(GRF)[13,14].

Grafting can also be planned in bone segment loss cases. In trauma cases, 3D printed models and 3D printed help in planning osteotomy, bone reshaping and pre-bending of osteosynthesizing plates. The surgical simulation using these models improves precision and reduces the amount of time spent on the surgery. Cutting guides for mandibular reconstructions using 3D printed models are recommended to reduce the length of the surgery and improve the results. [15]

MECHANISM HOW 3D PRINTING WORKS:

The digital workflow for creating 3D-printed objects typically involves three stages: image acquisition, post-processing, and printing. DICOM files, obtained from CT scans, or STL files from superficial scans are the standard image sources. Post-processing is a critical step that involves creating digital files suitable for 3D printing, via rendering of the object in CAD software[16]. The VSP toolbox facilitates segmenting of the anatomy, creating a vectorial 3D model that is the foundation of advanced 3D analysis, planning, device design, finite element meshing, and printing[17]. The vectorial model is exported as an STL file for printing, and the printer creates the object by building it one layer at a time. VSP also allows for designing surgical occlusal splints, cutting and drilling guides, repositioning guides, customized plates, and skeletal reconstructive props. With VSP, bones can be segmented to create anatomical models.[19,20]

CAD/CAM

For decades, the usage of CAD/CAM technology in various industries has extended elaborately in producing precise tools, parts, and automobiles. In dentistry, the usage of CAD/CAM is evolving in a wide range of applications, from single-unit restorations to complex surgeries[21]. The availability of various scanners and printers has expanded their use in specialties such as orthodontics, prosthodontics, maxillofacial surgery, periodontics, and pediatric dentistry, leading to advancements in diagnosis and treatment options. Across these fields, clinical protocols have shifted towards integrating 3D technology. In oral and maxillofacial surgery (OMFS), computer-aided design (CAD) technologies play a crucial role in treatment planning, they enhance surgical predictability, resulting in fewer treatment-associated errors.[22-25]

3D PRINTING ROLE IN IMPLANTS:

Advancements in 3D Printing and Additive Manufacturing (3DP/AM) have revolutionized the world of industry over the last few decades. This technology provides a range of benefits, including predicting 3D spatial positioning of implants and reducing surgical time and morbidity[26-27]. By using VSP and 3D-printed surgical guides, minimal angular and linear deviations are allowed, thereby increasing the accuracy of dental implant placement. These implants can be made with titanium, titanium alloys, or ceramics. Metal particles arranged in a powder bed are fused by a high-powered laser beam, producing the implant layer-by-layer without the need for post-processing steps[28].

Research on the physical and chemical properties of 3DP/AM titanium implants has been extensive. Later on, in vitro studies were conducted to examine the cell response to the surface of these implants, and animal and human histologic/histomorphometric studies were conducted to document the bone response after 3DP/AM titanium implants were placed. Biologically and histologically, these implants have demonstrated high stability and a high percentage of bone-to-implant contact (BIC). Additionally, depending on the material selected and the surface modifications proposed, it is possible to improve the osseointegration process. However, the limitations of this technology depend on the materials chosen and their biological and biomechanical responses. At present, no clinical data is demonstrating any long-term advantage of 3D-printed dental implants[29-31].

One of the significant advantages of 3DP/AM is the ability to customize implant design, length, diameter, and abutments for each patient's specific needs, bridging the gap between standard design and customization. Guided implants demonstrate similar or greater survival rates and provide an advantage through flapless surgeries, producing less pain and fewer post-operative complications for patients[32,33].

ROLE OF 3D IMAGING IN OTHER ORAL SURGERY PROCEDURES:

The advent of 3D printing technology has opened up new possibilities in the field of personalized tissue regeneration therapy. In particular, there have been significant developments in 3D printing technology for bone tissue engineering (BTE). Researchers have conducted a range of studies combining various scaffolds, biomaterials, cell sources, and bioactive factors in bone tissue construct designs, with preclinical studies demonstrating bone regeneration with controlled patterns and biomimetic architectures. 3D-printed scaffolds offer a range of benefits in terms of patient-specific adaptability, customized shapes, complex architecture, and design while remaining cost-effective by utilizing patient imaging data. However, clinical applications of 3D printing present a range of challenges in BTE, such as the reconstruction of critical and irregular defects, vascularization, neural regeneration, and adequate mechanical properties. Before the clinical use of 3D-printed customized bone scaffolds can become widespread, limitations such as the lack of legal regulations, standardized procedures, randomized controlled trials, and vascularization must be addressed and extensively discussed[34,35].

In TMJ total replacement, 3D-printed guides can be used to perform accurate condylectomy and prosthetic placement within the same operation. This eliminates the need for a second evaluation, where a post-operative CT scan is taken to plan for the prosthesis based on the remaining mandibular and temporal bone, and a second surgery to implant the TMJ device. Not only does this reduce treatment time, but it also minimizes patient morbidity. VSP technology is utilized to determine the osteotomies, design guides, and plan the intraoperative placement of each system component[36]. 3D printing technologies are increasingly being used to produce devices and scaffolds, highlighting the need for improved regulatory science. Experts continue to discuss the best approach to assess the safety and efficacy of these devices and scaffolds. Although personalized TMJ replacement prostheses have been demonstrated to have better longevity and clinical outcomes than stock joints, data on 3D-printed TMJR is still limited.[36]

Orthognathic surgery often involves the use of VSP and 3D printing to create 3D models, interocclusal splints, guides, and custom fixation devices. This approach provides the clinician with additional anatomical data that is not available through traditional 2D orthognathic treatment plans. With VSP, clinicians can visualize the occlusal cant and dental midlines with greater accuracy, which helps in planning and educating patients on the nuances of a surgical plan[19,20].

Moreover, stone model surgery fails to capture the entire bony anatomy, making it difficult to plan adjunctive aesthetic treatments, such as custom malar or angle implants. Using VSP, chin asymmetries can be gauged and assessed for bone grafts or reduction before the surgery. Additionally, 3D-printed models reproduce the anatomy and the location of critical landmarks, such as the inferior alveolar nerve canal. These models help plan the orthognathic procedure, and pre-bend osteosynthesis plates, and aid in patient communication. CAD/CAM orthognathic occlusal splints are another essential tool in orthognathic surgery. They are less time-consuming and more accurate than conventional lab-fabricated splints, enhancing the position of segments during fixation, reducing errors, and improving surgical outcomes[37,38].

CONCLUSION:

The influence of 3D printing is apparent in numerous aspects of the Oral and Maxillofacial Surgery field. The use of 3D printing and prototyping has become increasingly popular among professionals and patients alike due to its efficiency, affordability, accessibility, speed, and accuracy. It eliminates the need for manual dental lab modelling, and the digital process ensures that all cases can be kept for as long as required without the need for bulky physical models. 3D-printed models also provide a wide range of opportunities for surgical training, thanks to their cost-effectiveness and potential for case selection and pathological customization.

After an initial clinical assessment, 3D models can help patients understand complex disease states and demonstrate the objectives of recommended surgical treatments through a tangible, physical dimension. With ongoing research and technological improvements, rapid prototyping will become a widely used technique for 3D reconstructions in the dental laboratory, which will help businesses grow.
As 3D printing technology becomes more prevalent in the next few years, we can expect to see more developments in newer materials and refinements in printing methodologies that will overcome some of the current obstacles faced by medical providers and researchers.

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