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Review Article

3D Printing: Towards the Future of Oral and Maxillofacial Surgery

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Abstract

This descriptive review focuses on the advanced revolution of the 3D printing technology in the field of oral and maxillofacial surgery (OMFS). This technology is now trending and growing popular throughout the different aspects of the specialty to include oral and maxillofacial diagnosis, treatment planning, surgical interventions and novel tissue engineering. Moreover, it has an interesting prospect in education and training of dental students.

Keywords: 3D Printing; 3D Planning; Oral and Maxillofacial Surgery; Tissue Engineering; Education

Introduction

The use of 3D printing also known as additive manufacturing or rapid prototyping in oral and maxillofacial surgery (OMFS) continues to show growing interest. 3D printing was initiated over thirty years ago. Today, this computerized revolution is gaining attention and popularity focusing especially on applications related to OMFS [1].

Process for 3D printing-based tactile models

Medical models or bio-models represent are obtained from 3D medical imaging such as computed tomography (CT) scan, cone beam computed tomography (CBCT) or magnetic resonance imaging (MRI). High quality volumetric 3D image data of the required anatomical structure can be obtained. Digital Imaging and Communications in Medicine (DICOM) format files are created and with the aid of computer aided design (CAD) software, converted to Standard Tessellation Language (STL) format files. These files are then uploaded into the 3D printer and a rapid prototyping (RP) model is then fabricated, guided by quality assurance of the model and ensuring its dimensional accuracy [2].

These previous steps require major expertise and understanding of medical imaging, 3D image processing and designing in addition to software manufacturing and engineering procedures. The construction of reliable, dimensionally accurate models necessitates a team of specialists as specialists in medical imaging, surgeons and engineers [3].

Current 3D printing techniques

Three-dimensional printing technology can be classified according to the techniques, aimed deposition process or the materials used. The techniques include fused deposition modeling (FDM), selective laser sintering (SLS), stereolithography (SL), Polyjet printing and bioprinting [4-6]. The aimed deposition process classification includes polyjet modeling based on drop-on-drop deposition, and fused deposition modeling based on continuous deposition [7].

The material classification includes thermoplastic, metal powder, ceramic powder, eutectic metals, alloy metal, photopolymer, paper, foil, plastic film, titanium alloys or even living cells in layers to produce a 3D object [8,9]. Only limited materials are compatible with the human body. 3D titanium-based implants were found to be the most acceptable causing no irritation to the recipient site [10].

Applications of 3D printing technology in OMFS

Preoperative treatment planning and simulation

Three-dimensional-virtual environment presents an important role in preoperative planning and surgery simulation. The virtual reality (VR) has the ability to rightfully contemplate the soft tissue and bony changes. It provides surgeons with the best possible scenario for preoperative treatment planning. It made it easy to plan and execute surgeries virtually with immediate loading of the prostheses [11]. These simulations allow surgeons to prepare the required instruments for execution of the procedure [12]. A simulated model of the planned outcome can be 3D printed, serving the patient to visualize the treatment outcome and also assisting in receiving the patient's consent before performing the surgery [13].

Cranio-maxillofacial reconstruction

Computer aided design-computer aided manufacturing (CAD-CAM) was first introduced to fabricate craniofacial anatomical models based on images from CT in 1987 [14]. A 3D printed model was used by Bill., *et al*. for planning of a surgery, in which an allogenic bone transplant was used for cranioplasty.

Skulls have irregular outlines, so it is tough to standardize a cranial implant [15]. Assessment of bony defects for grafting is crucial and throughout practice RP models were shown to be beneficial for recognizing the ideal donor site. For example, reconstruction of the skull can be accomplished using a split calvarial bone graft and the ideal donor area can be accurately located in advance to best harmonize with the ideal recipient calvarial bone curvature [16].

Three-dimensional titanium-based implants were found to be useful for the reconstruction of the calvarium and maxilla with excellent fit and design. The precise preoperative simulation serves to provide customized resection guides to accurately execute the resection [10,17].

Three-dimensional printing technology now allows the fabrication of surgical guides to aid fibular osteotomy for its use as a graft with the help of fixation guides to enable maxillary reconstruction [17,18].

Extensive resection of oral and maxillofacial tumors as mandibulectomy can be devastating for the patient. The reconstruction of the mandible to restore its contour can be quite challenging. Moreover, alteration in the alignment of the mandibular structure can negatively affect the function as a result of malocclusion [19].

Computer assisted simulation with the aid of CAD-CAM programs were able to solve these difficulties. A 3D printed RP model was developed and used to pre-bend titanium reconstruction plates. Excellent outcomes were reported from their use in mandibular reconstruction [20].

This technique also allowed accurate adaptation of the reconstruction plate therefore, undergoing minimal handling during the operation, preserving the strength of the plate and reducing operating time considerably. Moreover, excellent mandibular symmetry was easier to accomplish [21].

Maxillofacial fractures

Three-dimensional printing technology significantly impacted both the patients and the surgeons. Preoperative assessment of traumatic cases in addition to predesigning of customized fixation devices led to the production of precise 3D printed prothesis and implants for the treatment of traumatic defects. The surgery time, wound exposure time are reduced and postoperative complications were lowered [22].

Dessoky N., *et al*. have used 3D planning for virtual reduction of mandibular fractures and milling for the production of custom-made poly-ether-ether ketone (PEEK) plates. They showed precise and accurate results which led to reduced operating time since the plates were previously pre-bent showing successful surgical outcomes [23].

Furthermore, the custom-made prosthesis has shown high accuracy thus improving the patient's esthetics as well as the psychological status since it resulted in correct symmetry of the facial contour [13]. The mirror imaging of the unaffected contralateral side can impressively improve the accuracy of the reconstruction [24].

A 51 years old patient had a delayed craniofacial reconstructive surgery after trauma at Lake Hospital in Baton Rouge, but it resulted in a residual defect in the fronto-orbital region and an inferiorly displaced zygomatico-maxillary complex with increased orbital volume. The defect couldn't be reconstructed with an ocular prosthesis, leaving the patient with an unesthetic defect. A 3D CT was done and a stererolithographic model was printed for better assessment of the defect and a custom-made PEEK implant was fabricated and put in place. The patient was left with a reliable, functional and esthetic result [25].

Surgical guides and templates for guided implant placement

Due to the advances in 3D CT and the computer-based software programs, surgeons have developed their strategies in the treatment planning phase. Remarkably, it also allows surgeons to do the surgery virtually and to check the treatment options. Also, saving time for planning the surgery and improving precision [26].

Rapid prototyping means producing models of anatomical areas of interest accurately from CAD data [27,28]. CAM software are used to make implant surgical guides and anatomic models. Images obtained from CT are transferred to the computer to plan the surgical guide with a computer software. 3D models made of acrylic resin and surgical guides are then printed. Once it is set, the guides have spaces for stainless steel drill-guiding tubes. Metal cylinders are put into the spaces, and then the guides are ready to be used clinically [29].

The used sleeves in the surgical guide are for accurate drilling and implant placement. This gives good results for the patient and the clinician. The existing bone can be used wisely and bone grafting avoided. The implant position can be placed in the best angulations, position and depth by merging the digital data of the bone with the planned restoration. A provisional or permanent restoration can be fabricated preoperatively on the cast which can be used as an immediate provisionalization. The outcomes of this procedure are predictable and precise, and hence the final restoration [30].

Fabrication of custom prosthesis for orthognathic surgery and dentofacial deformities

Personalized orthognathic surgical guides (POSG) can be manufactured using 3D printing technique preoperatively which allows accurate osteotomies, positioning of bone segments, drill holes and screws. The custom titanium plates can be placed only if the bony segments are in the correct position, ensuring the right placement of bone segments [31].

Three-dimensional printed models have been popularly used for planning distraction osteogenesis (osteotomies, vector of distraction). The ability to customize fixation plates of a distractor based on the 3D printed model. The plates can be easily adapted during surgery for their high accuracy of fit at the predicted positions. Also, parallel alignment the connecting pins was facilitated, thus confirming the proper transmission of distraction forces [32].

Three-dimensional printing technology can also help in correcting craniosynostosis by providing osteotomy guides that are very helpful in the process of reconstruction. Additionally, the surgery can be simulated by 3D tactile models [33]. Le Forte I, II, or III midface osteotomies can be simulated effectively using 3D printed prototypes models, as they need delicate blind osteotomy [34].

Three-dimensional printed models permit planning and testing of orthognathic surgeries preoperatively. Evaluation of the relationship between proximal and distal mandibular segments after bilateral sagittal split osteotomies became applicable. These planned movements in addition to the fabrication of osteotomy guides as well as occlusal splints increased the accuracy during operation [35].

As for genioplasties, the ability to create a surgical guide for transferring osteotomies from the 3D printed model to the operation in addition to pre-bending of the titanium plates on 3D models can deliver accurate results intraoperatively [3].

Computer-assisted genioplasty by combining the use of 3D cephalometry, a 3D RP model, and pre-bent titanium plates was described to have a valuable outcome [7]. However, 3D printed models can show some errors related to accuracy, which can affect the ideal dental occlusion in orthognathic surgery. Consequently, scanning devices are indicated to obtain ideal dental occlusal splints particularly for regions involving dentition [36].

Customized temporomandibular joint (TMJ) reconstruction

Some TMJ pathologies involve the condyle and the ramus of the mandible. These conditions require joint resection followed by total joint prosthesis with reliable treatment outcomes [37].

At Melbourne University, a 3D printed prosthesis was fabricated for a 32-year-old patient who lost a part of his left mandible involving the condyle, following a childhood trauma. The functional status of the patient was compromised causing him pain and affecting his chewing ability. The 3D-printed prosthesis was composed of a titanium part and a plastic jaw joint. For the condylar part, the titanium resembled the patient anatomical condyle. Using the CT scan images, the technicians also printed a 3D plastic model of the patient's skull and then the titanium part was refined to attain a flawless fit. With the aid of computer simulations, the printed prosthesis was subjected to loading forces mimicking the actual loads to test the prosthesis and to guarantee that it doesn't fail during function [38].

In a study by C Lee Ventola who created a custom 3D titanium TMJ for a patient with a history of sclerodema. The patient suffered spontaneous bilateral pathologic fracture of the mandible which resulted in an open bite. The 3D custom made prostheses was successful alleviating the patient's agony [39].

Fabrication of tissue engineered scaffolds

Three-dimensional printing has been used in experimental approaches such as bone grafting in reconstructive surgery. With the known types of available grafts; autogenous, autologous and allogenic grafts, the allogenic grafts are the best used since they have no ethical, infection and size limit and no donor site morbidity problems. On the other hand, they don't have the gold standards of the autogenous grafts which have osteogenic and osteoinductive properties [40].

Thanks to the novel technology, 3D printing technique has adequately evolved bio-cell printing for creation of 3D scaffolds for tissue engineering [6]. The triad for tissue engineering process encompasses cell, scaffold, and growth factor. Using this technology, reconstruction of the fracture regions or other mandibular deficient areas can be accomplished. These scaffolds were used to generate bone and tissue using biocompatible material. The scaffolds can be accurately fabricated according to the required shape and dimensions predesigned by the 3D planning. In a study by Mehra., *et al*. a portion of autogenous bone was obtained from a patient suffering from osteoporosis and subsequent mandibular fractures. These cells were then isolated, and cultivated in a special laboratory, then incorporated in a customized biodegradable poly (D, L-lactic-coglycolic acid) (PLGA) scaffold which was constructed according to the existing defect at the time of reconstructive surgery. Afterwards, this 3D bio-cell printed scaffold was secured to the patient's mandible with rigid fixation. The postoperative radiographs showed healing of the fractures, a well incorporated scaffold with new bone formation and an overall increase in bone volume [41].

Also, the properties of the scaffold such as porosity, texture and design are all easily adjustable by the program. Another advantage was the ability to add osteoinductive factors like bone morphogenic proteins to stimulate osteogenic differentiation thus increasing the integration between the printed scaffold and the recipient bone [42].

Three-dimensional printed cell culture for tissue engineering were developed to produce artificial tissues *in vitro* models [43,44] Incorporating stem cells into the 3D cultures for transplantation and tissue regeneration was achievable [45]. 3D printed cell cultures aided in the formation of sufficient human bone as well as skin grafts *in vitro* [46].

Providing an educational tool for medical students and residents.

Generating a three-dimensional model by 3D printing were easily manufactured to be used for education and have been helpful to dental students [47]. Three-dimensional printing can replicate the soft and hard tissue with high precision resulting in a training jaw for students to design incisions and practice surgical resections [48,49].

Fabrication of customized medical protective equipment

Even though 2020 has been a time of crisis due to the spread of Covid 19 virus. Many individuals spent the lockdown time searching for ways to benefit medical staff and dentists around the world. With 3D printers being accessible in several homes and centers, time was spent fruitfully bringing 3D printed face masks N 95 respirators and face shields to light. The masks were fabricated from a more durable material with longer shelf lives than the ordinary ones which require constant changing of the filters. Moreover, fabrication of various sizes of the frame was feasible. To our knowledge, this is the first time for 3D medical protective equipment to be reported [50].

Conclusion

In conclusion, 3D printing technology has revolutionized the field of OMFS in many aspects. It saves time and effort with eminent outcomes. Also, it's growing popular for its ability to produce personalized implants and devices with high accuracy and fit. This novel and trendy technique is now favored by many dentists and is increasingly appealing to various patients.

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