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Applied Three-Dimensional Printing Technology in Maxillofacial Surgery-A Short Review

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Abstract

Three-dimensional (3D) printing is a process of fabricating a 3D solid object from a digital file. Applications of this innovative manufacturing technology are rapidly increasing in the medical field. This technology certainly could change the paradigm of the medical community. With variety of evidences and reports about the type of manufacturing systems, materials, cost-effectiveness, and also bio-printing used, makes 3D technology a “hot-topic” in Oral and Maxillofacial surgery. From its use to print 3D scaffolds, bone tissue engineering and in cranial reconstruction, the opportunities are endless. This technology soon will bridge the gap by customizing the maxillofacial surgery we practice till date. This review focuses on the advances in three-dimensional printing technology and its growing application in the field of Oral and Maxillofacial Surgery.

Keywords: 3-D printing, assisted navigation, 3-D tissue reconstruction, modeling

Introduction

3D printing, also known as additive manufacturing (AM), rapid prototyping (RP), or solid freeform technology (SFF) is a manufacturing method wherein objects are fabricated in a layering method during fusing or depositing different materials such as plastic, metal, ceramics, powders, liquids, or even living cells to build a 3D structure. It is a process of generating physical models from digital layouts. This technology demonstrates a technique where a product designed via a computer-aided scheme is manufactured in a layer-by-layer system (Keyhan *et al.,* 2016).

Three-dimensional printing (3D) technology was first introduced in the 1986 by Charles Hull in automobile industry. In 1987 for the first time, Brix and Lambrecht introduced a 3-D prototype in health care which was manufactured using a computer numerical control device (Anchieta *et al.*,2011).

A lot of changes and developments have been made by in the last few years to modify this technology, materials, and accuracy. Application of this 3D printing technology in the field of Oral and Maxillofacial Surgery can be broadly divided into diagnostic or treatment purposes. Research in the field of tissue engineering is also advancing, allowing 3D printing of tissue or organs via cell bioprinting (Yun, 2015).

3-D modeling in maxillofacial surgery aids in: (1) fabrication of surgical implants, (2) precision in surgical planning, (3) proper orientation during surgery, (4) enhancing diagnostic capacities, (5) preoperative surgical simulation, (6) patient's understanding about need for surgery, and (7) preparing a template for resection, as well as providing an educational tool for students. This article gives an overview of the current state of 3D printing technology, its clinical application in maxillofacial surgery, and the future direction of its development (Choi and Kim, 2015).

Available Modalities of 3d Printing Technology

There are different technologies in practice for 3D printing. The main differences of these technologies are found in the processes and materials they use to construct layers to form physical 3D parts. The materials being used these days are eutectic metal powder, titanium alloy powder, thermoplastic/photopolymer etc. A few of the 3D technologies that have found their use in maxillofacial surgery are-

Stereolithography

The first stereolithography technique was developed in the late 1980s. It used a laser beam for resin polymerization in two-dimensional patterns (Keyhan *et al.*, 2016). The laser is used to construct objects by curing the resin one layer at a time on the surface of the UV-curable photopolymer resin. After tracing the pattern the object is re-coated with a resin-filled blade over its cross-sections. The subsequent cross-sectional layer was then traced on the new liquid surface and adhered to the previous layer. This process was repeated for all the layers until finally a complete 3D object is produced (Honiball, 2010).

This method gave the advantages of easy reproduction of complex internal features, growth factors, proteins and cell patterning. The disadvantage was that it isn't quick and can only be used with photopolymers (Fry *et al.*, 2016). Stereolithography accuracy is 1.2 mm (range, 0-4.8 mm) for skull base measures, 1.6 mm (range, 0-5.8 mm) for midface measures, 1.9 mm (range, 0-7.9 mm) for maxilla measures, and 1.5 mm (range, 0-5.7 mm) for orbital measures (Choi and Kim, 2015).

Fused deposition melting (FDM)

Fused deposition melting was developed by S. Scott Crump in the late 1980s. Honiball, 2010 FDM is currently the most popular consumer 3D printing methods due to its cost-effectiveness. It also builds models on a layer-by-layer technique (Keyhan *et al.*, 2016).

The process is controlled digitally and the material sets immediately after extrusion from the heated nozzle from where it can move in both horizontal and vertical direction. The advantage of this technique is that there is no need for a platform of support. High porosity due to the laydown pattern and good mechanical strength are notable and key advantages of FDM. The only disadvantage is the restriction of material due to need for molten phase (Honiball, 2010; Fry *et al.*, 2016).

Selective Laser Sintering (SLS)

This process was invented by R.F. Housholder. Honiball, 2010 It involved the use of lasers to melt down the powdered material particle which was then fused together forming a 3D structure. The first step involves preparing the powder bed and then layer by layer addition of powder.

Each layer was then sintered according to the CAD file using a laser source. The powder which is used is kept at a temperature below its melting point as it helps to minimize the laser output required for fusion (Fry *et al.,* 2016).

Reports have showed very low mean dimensional errors with selective laser sintering models, with maximum standard errors of 0.1 to 0.6 mm (Choi and Kim, 2015). The advantages of this technique are that there is no need for support and no post processing is required. The only disadvantage is that the feature resolution depends on laser beam diameter (Fry *et al.,* 2016).

3D printing

The process of 3D Printing was invented and patented in December 1989 by Sachs *et al.,* from the Massachusetts Institute of Technology. 3D printers are generally faster, cheaper and easier to use than other additive processes. It is an additive process making use of a powder based material and adhesive liquid binder for realizing a physical 3D object (Honiball, 2010).

Based on the CAD file, the printer sprays the binder across the build layer which locally binds the particles and hardens the wetted area. After printing, the printed layer is moved under a strip heater to allow the binder to dry out and prevent spreading between layers and followed by the removal of loose powder from the printed body (Fry *et al.,* 2016; Silva *et al*., 2008 reported 2.67% of mean dimensional error in 3-D printed prototypes when compared with a dry human skull (Silva *et al.,* 2008).

Inkjet modeling

This method was launched by the Objet Company in 1999. The major feature of this technology is the construction of highly-accurate prototypes using liquid acrylic resin (Anchieta *et al*.,2011). It is performed by layering of the polymer material into thin sheets (16µm) onto a preformed tray, until the model is complete (Choi and Kim, 2015).

The advantage is the capacity to print in multiple materials for the desired degree of tensile strength and durability and also the inkjet printer is easier to maintain. High price of these printers and the use of tenacious support materials are the major drawbacks (Keyhan *et al.,* 2016). Ibrahim *et al*. reported a dimensional error of 2.14% in reproducing a dry mandible when using this technique (Ibrahim *et al.,* 2009).

Electron Beam Melting

Electron Beam Melting (EBM) is a type of RP technology that specifically produces metal parts which are 100% dense. EBM uses an electron beam gun in a vacuum, to produce parts by melting metal powder one layer at a time. It offers the capability to produce parts, with full mechanical properties, which does not require additional thermal treatment (Honiball, 2010).

Selective Laser Melting

Selective Laser Melting (SLM) uses a 40µm beam spot fiber laser to fuse small particles of metal powders into a desired 3D object. The laser utilizes cross-sections from a 3D CAD model to selectively fuse the metal powder. Each cross-section is transformed into a new layer of material which is layered over each other until the model is complete (Honiball, 2010).

Clinical Applications for 3d Printing-Based Tactile Prototype Models in Maxillofacial Surgery

According to the requirements in Oral and Maxillofacial surgery 3D prototyping shows its benefits in accurate representation of complex bony structures of the entire skull for precise preparation of surgical procedures with better spatial orientation as well as in the option to manufacture implants or reconstructions prior to surgery. A further benefit is the possibility to sterilize these models, so that they can be used during the surgical procedure (Fry *et al.*, 2016).

Following are the indications for 3D printing-based operation planning in oral and maxillofacial surgery:

Cranial reconstruction

Skull reconstruction by 3D technology was first introduced by Mankovich *et al* in 1994. Calvarial bone reconstruction is often done with split calvarial bone grafting technique. Fabrication of tactile prototype models by this technology is very helpful in identification of the ideal donor site in advance to match the recipient cranial bone curvature since manual bending of these bones is quite difficult due to its rigidity (Mankovich *et al.*, 1994).

Correction of syndromic craniosynostosis

In case of syndromic craniosynostosis, extensive bone grafting is needed almost similar to skull reconstruction with bone grafting. This technology can provide an osteotomy guide and also simulate the surgery in advance using the 3D printed tactile models for reconstruction. These prototypes are an effective tool for simulating LeFort I, II, or III midface osteotomy, which requires delicate blind osteotomies (Choi and Kim, 2015).

Head and neck oncology and Tumor assessment

Additive manufacturing technique is helpful in orbit and head and neck oncology surgical planning and reconstruction. A tumor can be delineated on the stereoligraphic model, and the extent of the defect to be reconstructed can be visualized. Simulating surgical procedures preoperatively on 3D models may decrease overall treatment costs by decreasing operative time (Fry *et al.*, 2016).

3D prototyping techniques not only provide a more careful evaluation of real extension of tumor mass but also facilitates the conversation with the patient about the severity of the case and need for a surgery, therefore serves not only as a diagnostic instrument, but also as a valuable tool for the communication between the surgeon and the patient. The prototype also helps to calculate the amount of graft necessary to fill the bone defect completely (Anchieta *et al.*, 2011).

Facial bone fractures

3D printers can facilitate the treatment of trauma patients with recent or delayed fractures and defects (Keyhan *et al.*, 2016).

Image slicing and virtual 3D reconstruction has provided a more complete evaluation and reduced interferences, but the real dimension of the injury still depends on the imagination and experience of the surgeon. This can be overcome by using 3D prototypes, which enlarge the capacity of the surgeon to understand the real extension of injuries. Surgical planning is simpler by determining the most appropriate point for access, plate casting and screw size beforehand (Ibrahim *et al.*, 2009). Moreover, prototypes can be used for a more detailed case documentation and to facilitate communication with the patient, who can visualize and better understand the extension of the problem (Anchieta *et al.*, 2011).

Orbital fracture reconstructions are best done by this technique. Complicated and detailed anatomy of the orbit and limited surgical fields during surgery of orbital wall fractures makes it difficult to reconstruct orbital defects hence leading to reconstruction in the wrong plane. Surgeons can solve these complications by using 3D printed titanium mesh using the contralateral orbital anatomy to determine the ideal ipsilateral orbital structures (Choi and Kim, 2015).

Sasa *et. al*. reported considerable decrease in postoperative orbital volume (OV) of the affected side on application of custom-made implants using 3D printing system to reconstruct blowout fractures of the orbital floor (Tabakovic *et al.*, 2015).

Complex maxillary and mandibular reconstruction

Pathologic lesions, traumatic events, and infections are main etiologies of facial defects needing partial resection and bone reconstruction (Choi and Kim, 2015). Complex maxillary and mandibular morphology and muscular attachments moving the jaw in unfavorable positions are challenging to oral and maxillofacial surgeons in facial reconstructions (Cohen *et al.*, 2009). Maintaining acceptable esthetic and functional outcomes and facial symmetry are the main goals for the reconstruction. 3D printing technology is best answer to all these requirements as it has the ability to provide better anatomical understanding, proper plate adaptation, plate pre-bending, precise bone harvesting by utilizing negative templates of the defect, reduced bone-plate distance, decreased duration of surgery, less blood loss, and shortened duration of general anesthesia (Choi and Kim, 2015).

3D CAD-CAM technology provides a precise reconstruction modality of complex anatomical surfaces of maxilla and mandible which helps in fibular osteotomy and fixation guides when using fibular osteocutaneous free flaps (Choi and Kim, 2015).

Orthognathic surgery

For orthognathic surgeries, 3D prototyping provides precise osteotomy guide and occlusal splint. But there are reports of errors in terms of accuracy of 3D printing models, which is problematic for ideal dental occlusion. So, it is indicated to use intra-oral scanning devices to obtain ideal dental occlusal splints for orthognathic surgery (Pinz *et al.*, 1997).

Modeling fixation plates and screw selection

Reconstruction plate which are modeled previously, be used as a surgical guide, and ensure an accurate and efficient adaptation, reduces surgical time dramatically. Previous surgical simulations using plate models, selection and the calculation of screw size, as well as the choice of the best place for their fixation, greatly reduce surgical time. However, the most important factor is accurate planning, and modeled plates will serve as guides to reposition bone segments (Anchieta *et al.*, 2011).

Facial prosthetics

Previously impression procedures were the commonly used to manufacture facial prosthetics which had limitations like soft tissue distortion, patient discomfort and longer duration of production due to steps like- (1) making impression, (2) mold and wax replica fabrication and (3) color impregnated prosthetic object. Lately, 3D printing has been utilized to produce facial prosthetics which omits the first these steps. The process can be completed in 24-48 hours instead of a week (Keyhan *et al.*, 2016).

Currently, additive manufacturing is mainly used for hard tissue reconstruction. However, it is useful in soft tissue contouring such as auricular reconstruction in patients using the contralateral ear (Sachs).

Customized TMJ reconstruction

In the field of Temporomandibular Joint reconstruction, sufficient exposure and access is critical to prevent damaging many vital structures in this area. Alloplasts and allografts must be accurately placed to regain correct function of the jaw. 3D printed total joint prosthesis has become very useful in the treatment of patients with total condylar resorption. Mehra *et al*. used additive manufacturing technology to treat patients by bone grafting and TMJ prostheses. 3D printing also aids in measuring exact proportions of the bone that needs to be harvested (Keyhan *et al.*, 2016).

Modeling osteogenic distractors

Modeling osteogenic distractors directly on the bone at the time of surgery poses a great problem due to the difficulty in evaluating distractor vector. Prototypes not only predict distraction direction, but also evaluate the whole process by assessing all patient movements until the final fragment position is reached (Anchieta *et al.*, 2011).

Dental implants and Surgical drill guides

3D printing acts as a tool to create dental implants with complicated geometries (Dawood *et al.*, 2015). Drilling guides are of great value to transfer implants to their planned positions. Since every individual has a different anatomy of bone, manufacturing a drilling guide by conventional methods is time-consuming and requires multiple patient visits and extensive laboratory work (Richard van Noort, 2012). Rapid prototyping facilitates this with solely a single consultation prior to operation. In this session, data is gathered using CT or CBCT, and the guide is virtually built and later manufactured by the 3D device (Keyhan *et al.*, 2016).

Improvements and Future Prospects

The scope of additive manufacturing in various dental specialties especially oral and maxillofacial surgery is commendable. The application of the 3D printed models resulted in

• A reduced surgery time and patient hospitalization.

• Increased levels of confidence of the surgical team prior and during the surgery.

• Reduced mental strain and fatigue of the surgeons performing the surgical procedure.

• Improved levels of surgical accuracy.

• Improved aesthetical results.

• Reduced surgical risk to the patient.

• Optimal harvesting of hard and soft tissue grafts (Winder and Bibb, 2005).

Of course, there are still problems with this technology that need to be solved which include:

• Nonavailability of biomaterials to achieve macro, micro, and nanostructures

• High cost

• High processing temperatures

• Recreating matrix complexity of living tissues

• Technical issues involved in laser fabrication (Prasad *et al.,* 2018).

The future applications depend on the success in achieving these limitations. Recently there have been reports of use of low cost materials in fabrication of 3D printed models which will eventually increase the cost effectiveness of this technology.

Robotic systems have been developed rapidly in the recent years. Clinical application of Da Vinci system and other robotic systems had shown their advantages. In Maxillofacial surgery also robotic arm and robotic systems have been incorporated in animal and clinical trials where 3-D printed models have been used to aid in the operation which proved to simplify navigation and fixations. In the future, additive manufacturing might also be capable of organ bio-printing (Keyhan *et al*., 2016). All these will take 3-D printing technology to a new level in near future.

Conclusion

As for conclusion, the role of 3D printing in Oral and Maxillofacial surgery should be in limelight since this technique has the potential to offer endless developmental possibilities (Yun 2015). It could also aid in accuracy of diagnosis and surgical procedures with limited injury to patients thus benefiting the way we address surgical procedure.

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