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Three-dimensional Printing and Its Purpose in Oral and Maxillofacial Surgery

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ABSTRACT

Three Dimensional printing also popularly known as 3-D printing has taken surgical field by storm. It has made it easier for surgeons to plan as well as execute a surgery while providing adequate function and esthetics to the patient. Here, we have reviewed the literature discussing evolution, applications and future prospects of three dimensional printing in oral and maxillofacial surgery.

Keywords: *Three-dimensional printing, Rapid prototyping, Oral surgery, Maxillofacial surgery*

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INTRODUCTION

Ongoing swift innovations in the field of technology have braved the surgical arena to adapt new techniques with enthusiasm. Three-dimensional (3-D) printing is somewhat still in the budding stages of acceptability by the surgical professionals. Rapid prototyping (RP) mainly refers to techniques that form a shape by gradual addition of solid material. Medical RP is defined as the manufacture of dimensionally accurate physical models of human anatomy derived from medical image data using a variety of RP technologies. It has been applied to a numerous specialties, including oral and maxillofacial surgery (OMFS), implantology, neurosurgery and orthopedics [1-2].

Of various surgical fields, craniofacial surgery is one of areas that lead the way for the use of 3-D printing. Craniofacial defects occur as a consequence of trauma, oncological resection, or congenital defects, they cause soft tissue and bone loss or deficits. These defects are particularly difficult to treat because of the importance of aesthetics. The major tasks of using customary reconstructive surgical methods to treat large craniofacial defects are donor-site morbidity and harvesting sufficient donor tissue with the similar properties as the recipient tissue in order to restore proper anatomy as well as physiology [3].

3-D printing has an immense potential to improve the field of science and the expertise of the surgeons, the patient and surgeon relationship, level of understanding of the involving disease, and the customized implants and regulate the surgical process as well as the expense. Here, we present a review of the evolution as well as present development of 3-D printing in the field of OMFS.

DEVELOPMENTS ON 3-D PRINTING TECHNOLOGY

3-D printing technology is also referred to as additive manufacturing (AM) or rapid prototyping or solid-freeform technology. It was first established in 1986, this ground-breaking technology has gained immense attention since then, particularly within the head and neck surgical specialties contributed to its capacity to create complex structures with high accuracy [4].

History

Hideo Kodama, in 1981, published about RP system using photopolymers, but he did not file the full patent specifications needed. In 1984, Charles Hull invented stereolithography (SL) and in 1992, developed the first 3-D printer, called a stereolithography apparatus, which made it possible to fabricate complex structures. SL technique comprised of adding layers of liquid photopolymers layer by layer and curing with ultra-violet lasers. He also developed the revolutionary STL file format, which allows the operator to convert 3-D digital files to 3-D printed structures. Hull originally designed the 3-D printer to improve the performance of manufactured goods, but had anticipated his brainchild to do much more[5]

Evolution

3-D printing was first used to manufacture custom prosthetic devices and dental implants. Scientists have been able to build organs from patient's own cells supported on a 3-D printed scaffold, now they aim at growing fully functional organs without scaffold support. Scientists produced the first 3-D prosthetic leg, in 2008. A manufacturing company in Holland named Layer Wise has been able to manufacture a 3-D printed jaw, in 2012[6].

Over the last 20 years, new technological advancements have accompanied in a new era in the Oral and Maxillofacial Surgical field. Use of newer surgical techniques has allowed the contemporary oral and maxillofacial surgeons to successfully achieve these goals. Brix and Lambrecht, in 1985, pioneered the use of SL in OMFS, Mankovich *et al.*, in 1990, used SL for treating craniofacial deformities [7]. Today, maxillofacial surgery uses 3-D printing for bending plates, producing scaffolds for bone grafts, developing customized implants, Temporomandibular reconstruction, tissue engineering, osteotomy guides as well as intra-operative occlusal splints for orthognathic surgeries.

Concept

The theory behind 3-D printing in the surgical field is to first use magnetic resonance imaging (MRI) and computed tomography (CT) scans or light scanning to obtain patient's scan, in craniofacial sculpting from CT scan, slice thickness should be 0.5 -1 mm.Spatial model data is generated and stored in the DICOM format (Digital Imaging and Communications in Medicine). The process of 3-D printing originates with the use of computer-aided design (CAD) software to create a virtual prototype. CAD programs allow operators to transfer the designs as files that are harmonious with 3-D printers, one of the most used type of file is the .STL file where STL stands for stereolithography, also known as standard triangle language or standard tessellation language. 3-D printers then use this data to develop customized implants and tools using AM that is layer by layer deposition of the material [8].

VIRTUAL SURGICAL PLANNING IN CRANIOMAXILLOFACIAL RECONSTRUCTION

Due to three dimensional configuration, craniomaxillofacial reconstruction has intrinsic and inimitable challenges and it is important to reestablish speech, deglutition, mastication and facial symmetry. Virtual surgical planning (VSP) is a new technology in this direction which has increase the precision of surgery, enhanced patient satisfaction and definite simplicity of use in a spectrum of scenarios starting from trauma to oncologic reconstruction. The process includes virtual planning using patient's CT scans followed by production of 3-D models which are used for production of surgical guides, contouring of plates and construction of PSI. Immediate as well as delayed dental rehabilitation with endosseous implants have also become likely with VSP. Approximately 40%-50% of patients who undergo reconstruction of a jaw defect, usually obtain a dental prosthesis as compared to 15%-20% who undergo non–VSP-guided surgery [9].

Application of 3-D Printing in Oral and Maxillofacial Surgery

1. Anatomic Models

   Procurement of highly precise anatomic models to simplify preoperative surgical planning as well as improve postoperative facial symmetry, as in case of jaw or orbit reconstruction. This can help operators to study patient anatomy preoperatively, perform model surgery and thus subsequently reduce the time of surgery and diminish operative errors. These models are useful in patient education as well [10-11].
2. Trauma

   3-D modeling enables precise intra-operative reduction of craniomaxillofacial bony injuries, while CAD/CAM is used to produce occlusal splints. Pre-bent fixation plates decrease operative time, promotes accuracy of anatomic reduction and limit mucoperiosteal dissection, thus preventing avascularization of fractured fragments. 3-D printing can be used for the treatment of both recent as well as delayed fractures and defects. Orbital fractures are the best contenders for 3-D printing. Customized 3-D printed titanium mesh can be used for reconstruction. Complicated structure of the orbit makes it challenging for the surgeon to reduce as well asreconstruct after trauma. Enophthalmos or diplopia persist post-operatively if proper management is not done. These complications can be avoided by using 3-D printed titanium mesh which is tailored using the anatomy of the opposite normal orbit. Sasˇa et al. assessed the application of custom-made implants using 3-D printer to reconstruct orbital floor in case of blowout fractures. Post-operatively, mean orbital volume of the ipsilateral side markedly reduced, and was in accordance with the normal side. ChandanJadhav et al. reconstructed medial orbital wall fractures in three patients, using 3-D printing. They used the 3-D model as a scaffold to measure as well as harvest bone graft from iliac crest, resulting in precise alteration of graft at the recipient site and reduced operation time[12-13].
3. Temporo-mandibular joint (TMJ) reconstruction

Conventional TMJ reconstruction is a two-step process, in which gap arthroplasty is done as first surgery followed by implant placement at a second stage. VSP and CAD/CAM enable single stage TMJ reconstruction as gap arthroplasty virtual surgery and TMJ implant pre-fabrication can also be donepre-operatively on a virtual 3-D model. Stereolithographic models are also used for imitation of TMJ movements and occlusion prior to implant placement, this results in improved functional as well as aesthetic outcomes [14]

4. Reconstruction with Free Fibula Flaps
The management of maxillofacial defects can be challenging as variability in tissue necessities and the intricacy of anatomy in this region. Both donor and recipient sites are first scanned using CT, then virtual osteotomy cuts are made in the fibula according to the defect size. To assist in the accuracy of harvesting as well as positioning the fibula graft, cutting guides are manufactured. Compared to reconstruction plate, customized titanium mesh tray provides more satisfying 3-D morphology and stability as it can be molded to as per the contour of the mandible. However, repeated molding decreases the mechanical strength of titanium mesh. 3-D printed mandible model can also be used to manipulate customized mesh tray from titanium sheet. Calvarial Defects Depressed or asymmetrical defects of calvaria can affect social interaction of the patient[15].
5. Calvarial reconstruction should be such that it provides biomechanical stability, restoration of contour as well as protection to cranial contents. Autologous bone can be used for small defects but for large defects synthetic materials are required. A major challenge in calvarial reconstruction is the complex anatomy which can affect both pre-operative planning as well as post-operative aesthetic outcomes. With the help of CAD and 3-D printing, customized titanium implants can be fabricated [16-17]
6. Orthognathic Surgery
Traditional orthognathic surgery (OGS) consists of cephalometric analysis followed by model surgery planning. The success of OGS depends upon this. Digital models have proven to be a better substitute to conventional study models in the treatment planning. Fabrication of surgical wafers involves simulated repositioning of digital images using intraoral scanners and then fabrication of a wafer using software which are 3-D printed. Another technique is to plan the position of maxilla with the help of a 3-D software, and then use stereotactic navigation intraoperatively. The advantage is that the maxilla is placed straight from the 3-D plan with no chance of faults[18-19].
7. Implants, Prosthesis, Splints, and External Fixators
RP provides a matchless ability to customize dental implants, prosthetics, splints, and external fixators to be customized. Recently, 3-D printing has been employed to manufacture facial prosthetics in order to lessen the restrictions of impression techniques such as longer duration of production, soft tissue distortion, and patient discomfort.
3-D printing is also used to generate dental implants with complicated geometries. Drilling guides are of significance to relocate implants from their pre-planned positions. Manufacturing a surgical guide by conservative methods is time taking, requires multiple patient sittings and extensive laboratory work. RP facilitates this with just one sitting prior to operation, scans are taken and later manufactured by using 3-D printer [20, 21].
8. Surgical instrumentation and guides
The 3-D printing of surgical instrumentation and surgical guides has changed the face of surgery. It allows the use of patient specific surgical guides and customized surgical instruments in areas where procurement of such equipment is not possible. Concerning the use of surgical guides, 3-D printed templates have been used for the management of osteochondroma of the mandibular condyle, mandibular reconstruction with a fibula free flap, genioplasty, cutting guides for maxillary repositioning, mandibular osteotomy, and surgical guides for fracture reduction of the mandible and condyle. Hanasono and Skorackil reported that 3-D printing reduces surgery duration up to 1.4 hour [22].
9. Patient Education
Accomplishing patient anticipations is important to have efficacious post-surgical outcomes. In pre-operative meetings, patients can be made to understand the details of surgery, expected results as well as possible complications. Literature has revealed that 3-D printed models result in better training of residents as well as patient education. Pre-operative and post-operative 3-D printed models of particular surgeries can benefit clinicians to justify expectations of patients [23].

Materials of choice in craniofacial region

In craniofacial region, major application of AM is to fabricate maxillofacial bone scaffold. Many polymers are printable and are being used as synthetic scaffolds nowadays. Poly lactic acid (PLA) was first used as scaffold material in 1996. Other polymeric scaffolds being used are have been increasingly developed in

AM techniques, such as Polycaprolactone (PCL), Poly Glycolic Acid (PGA), Poly propylene fumarate (PPF),Polyetheretherketone (PEEK), poly lactic-co-glycolic acid (PLGA), poly trimethylene carbonate (PTMC) etc. Recently, the use of PEEK in maxillofacial reconstruction has increased for patient specific implant (PSI) as it does not cause any magnetic interference hence it is MRI compatible, is chemically resistance and its degree of elasticity can be adapted according to the demand. As regards metals, titanium being FDA approved, is in great demand due to its non-corroding and biocompatible properties. It is light weight, durable and has minimum chances of infection. Ti6Al4V (Ti-64) is the preferred alloy. Its high elastic modulus however does not match to that of human bone, therefore it can cause a stress shielding effect which might lead to loss of prosthesis. Also, streak artifacts as seen in the CT scan images due to x-ray beam absorption by the implant, is disadvantageous [24]

Barriers and controversies

Despite many prospective benefits that 3-D printing may provide, anticipations are often overstated. While it is assured that the surgical field will be one of the most productive arenas for 3-D printing advances, it is imperative to appreciate that great achievements have been made without expecting that technology to change our lives within such short time frame. 3-D printing has also given rise to safety concerns, thus its safety clearly needs to be monitored. Seeking approval from authorities is another noteworthy obstacle that may hinder the common application of 3-D printing.

FUTURE TRENDS

The future lies in 3-D bio printing of living cells which will form the missing hard and soft tissue. Although the field of bio printing is in its initial stage of development, certain tissues and organs have already been printed like kidney tissues, skin, vascular tissue, cartilage, and aortic valve. Vascularization is a major task in tissue engineering and bio-printing, it is a necessary step form long term viability of printed tissues. Another anticipated innovation is in-situ printing that is implants or viable tissues can be printed within the human body during surgery, portable and handy 3-D printer for in-situ use is requirement of the future. Improvements in robotic bio-printers and robotic surgery may also be vital to the progress of 3-D printing technology. With the convenience of economical 3-D printers, the future surgeons would be able to produce 3-D PSI in the hospitals. This would be a boon for surgical planning, hence saving a lot of time as well as money compared to the manufacture by a third-party [25].

CONCLUSION

Personalized treatment modalities have revolutionized the modern surgical practice. The ultimate goal is to provide the patient with tailor-made customized implants. The fine tuning of radiological technologies together with the proficiency to manufacture patient specific tools and implants, has given an exponential rise to contemporary substitutes against conventional techniques.

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