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3D PRINTING IN ORAL AND MAXILLOFACIAL SURGERY

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ABSTRACT

Maxillofacial surgery is one of areas that pioneered the use of the 3D printing concept. Patients requiring craniofacial surgery tend to have very specific malformations or deformities. A 3D printing prototype model can greatly assist with preoperative evaluation and intraoperative procedures. Medical modeling in craniofacial surgery based on 3D printing has mainly been developed over the last 15 years and can incorporate aiding in the production of surgical implants and improving surgical planning. The technology of 3D printing is promising and allows for individualized medicine that is currently progressing. Researchers are continuing to improve and develop the deficits seen with tissue 3D bioprinting. Ultimately, 3D printing technology is likely to become, not far from now, an essential tool for maxillofacial, plastic and reconstructive surgeons potentially to improve facial reconstruction surgical outcomes, along with patient satisfaction and the quality of life of patients.

KEYWORDS: 3D printing, Maxillofacial surgery, implants, reconstruction.

INTRODUCTION

Modern imaging techniques are an essential component of preoperative planning in plastic and reconstructive surgery. However, conventional modalities, including three-dimensional (3D) reconstructions, are limited by their representation on 2D workstations. 3D printing, also known as rapid prototyping or additive manufacturing, was once the province of industry to fabricate models from a computer-aided design (CAD) in a layer-by-layer manner. The early adopters in clinical practice have embraced the medical imaging-guided 3D-printed biomodels for their ability to provide tactile feedback and a superior appreciation of visuospatial relationship between anatomical structures. With increasing accessibility, investigators are able to convert standard imaging data into a CAD file using various 3D reconstruction softwares and ultimately fabricate 3D models using 3D printing techniques. Significant improvements in clinical imaging and user-friendly 3D software have permitted computer-aided 3D modeling of anatomical structures and implants without outsourcing in many cases. These developments offer immense potential for the application of 3D printing at the bedside for a variety of clinical applications.[1-3]

Among the various medical fields, craniofacial surgery is one of areas that pioneered the use of the 3D printing concept.[4,5] Patients requiring craniofacial surgery tend to have very specific malformations or deformities. A 3D printing prototype model can greatly assist with preoperative evaluation and intraoperative procedures. Medical modelling in craniofacial surgery based on 3D printing has mainly been developed over the last 15 years and can incorporate aiding in the production of surgical implants, improving surgical planning, acting as an orientation aid during surgery, enhancing diagnostic quality, assisting preoperative simulation, achieving a patient's consent prior to surgery, and preparing a template for resection for surgeons, as well as providing an educational tool for medical students and residents.[6-10]

HISTORY OF 3D PRINTING[11-16]

3-D printing techniques have been existed since 30 years ago. This technology is first introduced and invented by Charles Hull in 1986, and at first, it was utilized in the engineering and automobile industry for manufacturing polyurethane frameworks for different models, pieces, and instruments. Since 1986, this process has started to accelerate and has gained recognition globally and has influenced different arenas, such as medicine. The

development of 3-D desktop printers encourages wide-ranging experimentations in that subject. Generally, medical indications of these printers are such as treatment planning, prosthesis, implant fabrications, medical training, and other usages. Having being used in military, food industry, and art, rapid prototyping is receiving a lot of attention in the field of surgery in the last 10 years. The pioneering usage of 3-D printing in oral and maxillofacial surgery was by Brix and Lambrecht in 1985. Later this technique was used by them for treatment planning in craniofacial surgery.

In 1990, 3-D printing was used by Mankovich et al. for treating patients having craniofacial deformities. They used it to simulate bony anatomy of the cranium using computed tomography with complete internal components. By aiding in complex craniofacial reconstructions, 3-D printing has recently earned reputation in medicine and surgical fields.

Today, maxillofacial surgery can benefit from additive manufacturing in various aspects and different clinical cases. This technique can help with bending plates, manufacturing templates for bone grafts, tailoring implants, osteotomy guides, and intraoperative occlusal splints. Rapid prototyping can shorten surgery duration and simplify pre and intraoperative decisions. It has enhanced efficacy and preciseness of surgeries.

3D PRINTING TECHNIQUES[17-21]

The process begins with capturing anatomical scans using imaging techniques such as magnetic resonance imaging (MRI) and computed tomography (CT) scans; then, a computer aided design (CAD) model is processed and optimized using specific computer techniques. Then, the CAD model is transformed into a standard triangulation or tessellation language (STL) file and imported into an AM setup. The AM machine constructs the 3D model layer-by-layer according to a specific and precise programmed parameters, the built object is removed from the building platform and followed by post-processing procedures (such as polishing, coating, or thermal treatment) to obtain a functional part.

A. Stereolithography: In stereolithography (SLA), the 3D model is fabricated in a series of layers that correspond to the axial image slices of the CT scan. The technology is classified as a vat photopolymerisation AM process in which an ultraviolet (UV) light is projected on a bath of curable photopolymeriser resin. After the first layer is built, it either moves, gradually, out of the bath or descends depending on the production configuration, and the focused energy beam renders the next layer, according. Typically, each layer is polymerized at a thickness of 0.05–0.15 mm. This process is continued until each corresponding slice of the CT image is duplicated in the resin model.

B. Laser Sintering: Laser sintering (LS) and related techniques (i.e., selective laser sintering, direct metal laser sintering, laser melting and others) are classified as a powder bed fusion process of AM that is currently employed, widely, in medical disciplines. The process is based on the same principle of layer-by-layer AM. The system normally consists of a laser, an automatic powder layering apparatus, a computer system for process control and some accessorial mechanisms such as gas protection systems and powder bed preheating systems. The function of a LS system employs a focusing of a high-powered energy laser into a powdered substrate, causing a fusion of the substrate into the desired shape. Once a layer of substrate has been sintered, a new layer of substrate is added on the top of the developing construct, and energy is applied again. Different types of laser are used for this purpose (including CO2, Nd:YAG, fiber lasers, disc lasers and others) and selected based on to the laser absorptivity of the specific material used and the operative metallurgical mechanism of the powder densification. The process is include firstly a leveling and fixation of the substrate on the building platform, followed by deposition of a thin layer of loose powder on the substrate. Subsequently, a laser beam scans the powder bed surface to form a layer according to the CAD data. The procedure is repeated, in a layer-by-layer manner, until a complete highly accurate and nearly a full density functional part is produced.

C. Extrusion Printing: Extrusion printing is another widely available process for 3D printing of biological and non-biological materials and considered among the most widely used AM processes, especially when dealing with polymers and thermoplastic composites. This process includes, mainly, the fused deposition modeling (FDM) technique and the fused filament fabrication (FFF). The basic principle of material extrusion additive technology involves the loading and liquefaction of a printed material. The material moves through a nozzle or orifice by applying a pneumatic pressure, followed by plotting of the liquefied material according to a pre-defined path in a controlled manner, and layer-by-layer bonding of the material to itself or a secondary build material to form a coherent solid structure. Once a layer is formed, the build platform moves down or the extrusion head moves up, and a new layer of material is deposited and adhered onto the previous layer.

MATERIALS USED IN 3D PRINTING[22-27]

Polymers: Polymers are a versatile material that has shown to be both biocompatible and biodegradable, with the ability to change its mechanical properties by altering its chemical structure. It can be highly viscous, such as hydrogel polymer, or it can be stiffer to produce a stronger scaffold, such as polycaprolactone (PCL). Yet, the mechanical properties of the polymer depend on the tissue it is replacing and the method of 3D printing. If inkjet printing is used, stiff bioink can clog the nozzle of the printer as the ink is deposited. This could be managed by depositing unpolymerized ink that solidifies and cross-links after deposition. Polymer materials are either

natural or synthetic. Natural polymers include proteins (e.g. silk, gelatin and collagen) and polysaccharides (e.g. alginate, agarose and chitosan). Polysaccharide polymers provide a lower antigenicity, but also have lesser mechanical properties than protein polymers. On the other hand, polyhydroxy acids are synthetic polymers, such as polylactic acid (PLA), polyglycolic acid (PGA) and polylactic-glycolic acid (PLGA).

Bioceramics: Ceramics are inorganic materials in the form of bioactive glass (BG), metal oxides or bioactive ceramics developed for medical and dental use to replace bone. BGs are composed of silicon dioxide or silicate with sodium dioxide, calcium oxide and phosphorus. They induce hydroxyapatite (Hap) formation after contacting biological fluid, thus enhancing osteogenesis and bone healing. On the other hand, bioactive glass ceramics (e.g. Hap and tricalcium phosphate) are materials that bond directly with bone without the formation of an intermediate fibrous connective tissue layer. Bioceramic materials are brittle, have a low mechanical strength and low fracture toughness and thus cannot be used solely for scaffold fabrication.

Composites: A composite material is a mixture of two or more different materials with the intent to manipulate the mechanical properties of the end material utilizing the properties of the initial materials used. The composite is formed of polymer mixtures or polymer-ceramic mixture. For example, mixing PCL with Hap enhances the brittleness of the Hap and decreases the hydrophobicity of the PCL, thus increasing cell attachment and cell infiltration into the scaffold.

SOFTWARES USED IN 3D PRINTING[28-35]

3D Reconstruction Software: In order to fabricate a 3D biomodel, two types of software are required; firstly, a "3D modeling" software that translates the DICOM (digital imaging and communications in medicine) files from CT/MRI scans into a CAD file, and secondly, a "3D slicing" software that divides the CAD file into thin data slices suitable for 3D printing.

3D Modeling Software: A range of 3D modeling softwares is available; however, early ones, such as Mimics (Materialise NV, Leuven, Belgium), would incur a high cost for the initial purchase and for the ongoing software updates. Driven by the consumerization of 3D printing and an increasing number of both professional and community software developers, free open-source softwares, such as Osirix and 3D Slicer, have become widely utilized. Our group prefers using them due to the latter's expansive developer community base, called the Slicer Community, a plethora of plug-in functions, and a user interface that is intuitive to an individual with no engineering background.

3D Slicing Software: 3D slicing softwares digitally "slice" a CAD file into layers suitable for 3D printing. However, they are also useful for altering the orientation of the CAD file relative to the printer build plate to give an optimal direction, which minimizes the requirement for the support structures and, in turn, reduces the amount of material used and therefore also reduces the printing time. This process can be readily performed using proprietary softwares that accompany the 3D printers at no extra cost and usually possess a simple graphic user interface, such as Cube software (3D Systems) and MakerBot Desktop (MakerBot Industries).

LIMITATIONS[36,37]

Despite the potential cost limitation, the price of 3D technology is continuing to be driven down in terms of the price of devices, materials and software.3 It would be more objective, however, to evaluate this using some cost-efficiency methods. The accuracy of these models, however, is still a challenge to completely alternate human tissue and this yet to be an ongoing concern. In terms of its surgical application, there is a significant need to design randomised clinical trials to prove the superiority of adopting 3D planning over the classical surgical approaches. This includes the time required to capture anatomical scans, create a virtual 3D prototype, 3D print of the material layer by layer and finally modify the final structure.

FUTURE PROSPECTS OF 3D PRINTING IN CRANIOFACIAL SURGERY[38-40]

One of the significant developments in 3-D bioprinting is to manufacture cell microenvironments from molecular to macroscopic scales, which are requested and suitable for tissue engineering and regenerative medicine. As novel methods and technologies introduced in recent years for 3-D printing of biomaterials, promising overview of future appears to manufacture scaffolds for tissue engineering that reach the gold standards and also better comprehensions of stem cells microenvironments and interactions. By aid of various novel technologies, such as microfluidic systems, biopatterning, and layer-by-layer assembly, researchers are now able to biomanufacture microtissue constructs within scaffolds and even also within scaffold-free environments.

To be clear in regeneration of hard (e.g., bone) and soft (e.g., vascular grafts) tissues, modulus of elasticity is a crucial parameter that desires improvement. Furthermore, the development of a totally closed bioprinting system that integrates printing and post-printing processes such as in-vitro culture and maturation of tissue constructs continues to be a challenge.

With advances in near future, which help finding solutions for the challenges mentioned above, bioprinting technologies will potentially help improvements of rapid clinical solutions and advances in medical implants. Further, we envision that the integration of cells and biomaterials through bioprinting with microfluidic technologies are likely to create unique microenvironments for various applications in cancer biology, tissue engineering, and regenerative medicine.

CONCLUSION

3D printing technology enables more effective patient consultations, increases diagnostic quality, improves surgical planning, acts as an orientation aid during surgery, and provides a template for surgical resection. In addition, as bio-cell printing technology further evolves, tissues or organs might one day be made using 3D printing methods. The technology of 3D printing is promising and allows for individualized medicine that is currently progressing. Researchers are continuing to improve and develop the deficits seen with tissue 3D bioprinting. Ultimately, 3D printing technology is likely to become, not far from now, an essential tool for maxillofacial, plastic and reconstructive surgeons potentially to improve facial reconstruction surgical outcomes, along with patient satisfaction and the quality of life of patients.

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