3D Printing and its applications in oral and maxillofacial surgery

Harshita Gupta[1*], Sumit Bhateja[2], Geetika Arora[3]

[1]Dental Surgeon, [2]HOD, [3]Reader, [2]Dept. of Oral Medicine & Radiology, [3]Dept. of Public Health Dentistry, [1,2]Manav Rachna Dental College, Faridabad, Haryana, [3]Inderprastha Dental College & Hospital, Ghaziabad, Uttar Pradesh, India

***Corresponding Author:** Harshita Gupta
Email: harshitag149@gmail.com

Abstract
3D printing has revolutionized the world in so many ways. From building 3D printed housing projects to plant-based meat, it has left no stone unturned. Similarly, 3D printing has changed the medical and dental field in many ways. In this article, we will briefly discuss 3D printing and its applications in the field of Oral and Maxillofacial surgery, along with dentistry as a whole.

Keywords: 3D Printing, History, Technology, Materials, Applications in oral and maxillofacial surgery, Dentistry.

Introduction[1]
3D printing, also known as additive manufacturing, is the process of building a solid three-dimensional object, from a computer-aided design (CAD) model by successively adding material layer by layer.[2] 3D printing is now being used widely for research and clinical purposes, especially in healthcare for the purpose of building personalized medical devices and implants; and making models for medical education, training, simulation, research and for pre-operative planning. Not only this, 3D printing is also being used for making organ replacements using biological materials. The additive nature of 3D printing makes it a better alternative for manufacturing organic medical model shapes, instead of subtractive manufacturing techniques like CNC (Computer Numerical Control). There has been development of different 3D printing technologies like Stereolithography, Power Bed Fusion, Fusion Deposition Modeling; along with development of different material types, colors and physical properties. Now the technology has become so advanced that building multi-material and multi-component models has become possible. 3D printing is associated with and dependent upon medical imaging techniques for building good quality, accurate and viable patient specific models; as these imaging techniques are responsible for collecting the data for printing. 3D printing is associated with medical field on four levels:

1. Medical imaging provides data to build realistic 3D models
2. It establishes optimal scanning and image processing workflows to get accurate image segmentation outcome
3. 3D models are used for radiation and imaging studies
4. Models are used to provide education about medical anatomy

3D models must always be geometrically perfect; i.e. their surface should be 'watertight', there should be no gaps and there must be a minimum wall thickness, for them to be printed.

History and development of 3D printing[3]
Believe it or not, 3D printing is not as new an invention as most people think. In fact, the first ever 3D model was built in 1981 by Hideo Kodama in Nagoya Municipal Industrial Research Institute by using photopolymers. Then in 1984, Charles Hull invented stereolithography, i.e. process of building 3D models using digital data. This new technology was instantly popular with inventors, who could now build and test their prototypes without paying a hefty manufacturing fee. Then in 1992, the world's first Stereolithographic Apparatus (SLA) machine was built, which made it possible to build complex parts, layer by layer; along with the world's first Selective Laser Sintering (SLS) machine, which could shoot laser at a powder instead of photopolymer liquid.

In 1999, the world's first 3D printed organ was transplanted in humans, when scientists at Wake Forest Institute for Regenerative medicine 3D printed synthetic scaffolds of a human bladder and coated them with human cells. The newly formed tissue was then transplanted into patients, with no rejections as the organ was made of their own cells. Within the next ten years scientists from all over the build built a functional miniature kidney, then a prosthetic leg and then bioprinted the first blood vessels. In 2008, Darwin a self-replicating 3D printer was built.

The first SLS machine became commercially viable in 2006, and then Object built a 3D printer that could print in multiple materials. Then Shapeways and Makerbot were formed, which provided designers with DIY kits for manufacturing along with feedback from consumers. And in the most recent decade, designers are no longer restricted to printing with plastic. 3D printing has achieved heights never dreamed of before, from printing engagement rings using gold and silver to building an entire unmanned aircraft and housing projects. In medical field, 3D printing is being used for making smart robotic arms, bone replacements, etc.

Technologies of 3D printing[4]

3D printing is an umbrella term that encompasses a group of 3D printing processes such as SLS, FDM, DLP, etc. Different types of additive manufacturing procedures have been established which have brought forth different types of 3D manufacturing technologies. Some examples of types of printers and technology used by them are:

Table

Processes	Technologies
1. Material extrusion	i. Fused deposition modeling (FDM) or Fused filament fabrication ii. Robocasting or MIG Welding 3D Printing or Direct Ink Writing (DIW) iii. Composite Filament Fabrication (CFF)
2. Light polymerized printers	i. Stereolithography (SLA) ii. Digital Light Processing (DLP) iii. Continuous Liquid Interface Production (CLIP)
3. Power Bed Fusion	i. Powder bed and inkjet head 3D printing (3DP) ii. Electron-beam melting (EBM) iii. Selective laser melting (SLM) iv. Selective heat sintering (SHS) v. Selective laser sintering (SLS) vi. Direct metal laser sintering (DMLS)
4. Laminated printers	i. Laminated object manufacturing (LOM)
5. Power fed printers	i. Directed Energy Deposition
6. Wire printers	i. Electron beam freeform fabrication (EBF^3)

Materials used[5]

1. Plastic: It is the most commonly used material as it has a high appeal due to its firmness, flexibility, smoothness and a wide range of colors. Plastic products are made in FDM printers. Plastics used for 3D printing are made using one of the following- Polyastic Acid (PLA), Acrylonitrile butadiene styrene (ABS), Polyvinyl alcohol plastic (PVA) or polycarbonate (PC). PLA is the most eco-friendly option as it is made from sugar cane and corn starch and hence, is biodegradable.
2. Powder: Most common powders used are Polyamide (Nylon) and Alumide.
3. Resins: These are of three types- high detail resins, paintable resins and transparent resins
4. Metal: It is the second most popular material. Metals generally used are- Stainless-Steel, Bronze, Gold, Nickel, Aluminium and Titanium.
5. Carbon fiber: It is mostly used in combination with plastics.
6. Graphite and graphene: Graphene has high strength and conductivity, so is preferred for making solar panels, touch screens etc.
7. Nitinol: Due to its super elasticity, it is used to make medical implants.
8. Paper: Paper printed designs are far more realistic than flat illustrations and so are preferred for demonstrations.

Development process of 3D printing[6]

Steps for fabricating a 3D prosthesis are:

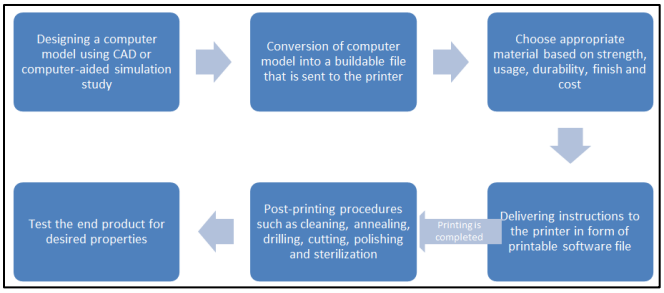

Fig. 1

Applications in oral and maxillofacial surgery[7,8]

3D printing is mostly used in dentistry for three functions- making surgical 3D models, surgical guides, prostheses and patient specific implants. Life-sized anatomic models that are printed by 3D printers provide a good educational tool for doing mock surgeries and getting familiarized with the anatomy and instrumentation for aspiring surgeons. 3D models are very effective in preoperative surgical planning, esp. for fields like vascular surgery, for endovascular aneurysm repair; in cardiac surgery for tumor resections and repair of congenital defects; in neurosurgery for navigation training; and in orthopedic surgeries for tumor resections and treatment of trauma injuries.

1. 3D printing helps in facial reconstruction surgeries. The implant for the surgery is shaped on 3D surgical model before the surgery, reducing trauma to the tissue and the operating time.[9]
2. Similarly, in cranio-maxillofacial surgeries, 3D printed models are used for pre-bending of reconstruction titanium plates on a 3D model prior to skull resections, help us restore the correct position of remaining bones accurately and reducing the surgery time.
3. 3D models are also used for preoperative distraction osteogenesis drive selection.
4. 3D models are extremely accurate prototype models that help new surgeons ease into preoperative planning and improving postoperative esthetics and facial contour symmetry, for example, the reconstruction of maxilla, mandible and orbits. This helps to inspect anatomy preoperatively, practice different treatment modalities, and reduce surgery time and minimize errors.
5. 3D models serve as surgical guides for surgical resections or osteotomies based on preoperative imaging to provide higher Patient Safety Indicators, which is even more important in metal implant surgeries.
6. Surgical guides in cranio-maxillofacial surgery are also used for bone resections and free flap construction using a fibula free flap.
7. 3D printed surgical guides are also used for accurate treatment planning for rib grafting and fixation in mandibular ramus deficiencies.
8. 3D models are also used in orthognathic surgeries. Orthognathic surgery is a type of corrective surgery done to restore proper anatomy and functional relationship in patients with dentofacial skeletal anamolies. 3D models help achieve preplanned operations for performing accurate osteotomies and perfect positioning of unaligned jaw. Printing of cutting guides for osteotomies and 3D printed patient specific fixating plates for accurate positioning of jaws, greatly reduce mistakes made due to human error.
9. 3D printed intraoperative dental splints are used for accurate repositioning of jaw/midface with 3D preoperative planning in case of facial fractures.
10. 3D printed models make for high-accuracy prostheses that enhance the aesthetic and psychological states of a patient suffering from poor aesthetics due to scarring, deformation or asymmetry.
11. 3D printing is also used to make patient-specific implants (PSI), based on 3D imaging to provide perfectly fitting implants to restore proper anatomy, symmetry, relation and function. After mandibular resections and avulsion injuries, titanium implants, for load-bearing reconstruction, combined with autogenous bone grafts and PSI integrated with dental implants are used for dental arch and occlusion restoration.
12. Polyether ether ketone (PEEK) implants are used to restore zygomatico-orbital complex and mandibular angle deficiencies for trauma injuries, orbital wall defects and in syndromic patients.
13. PSI are used in orthopedics for printing customized external fixators to treat fractures, and in cervical spine reconstruction.

14. PSI are used in neurosurgery in cranioplasty for reconstructing skull defects. Similarly, in thoracic surgery, PSI are used to reconstruct chest wall and in ophthalmology for ocular prosthesis.
15. 3D printed models are also being used in research to study the origin and treatment of cancer.

Other applications in dentistry[10,11]

1. 3D printers can be used to print crown or bridge copings, implant abutments and bridge structures.
2. 3D printing can be used for fabricating RPD framework.
3. Fixed partial dentures can be fabricated using robocasting.
4. 3D printed models can be used to fabricate restorarions such as veneers, etc.
5. 3D printing can form temporary crown restoration with a greater accuracy than conventional methods.
6. 3D printing can be used to print special drills for rot canal location for guided endodontics to locate root canal without perforation in case of pulp canal calcification.
7. 3D printing is used in orthodontics to fabricate a set of dentures ,called 'aligners' that can be used to realign teeth instead of fixed orthodontics using the Invisalign system.
8. 3D printers can be used to form patient specific mouthguards or nightguards.

Advantages and Limitations of 3D printing[12]

Advantages

1. 3D printing is used to manufacture complex objects in a short time with fine details and different materials.
2. Fabricating objects with 3D printing helps with a lot of waste reduction, as the unused material at the end can be reused again.
3. It is easy to print small movable parts of the final object.
4. Product designs can be easily shared over internet for printing, instead of having to transport the entire object.
5. Some objects are preferably printed as materials used in 3D printing are better in terms of strength and finishing details, then materials used in traditional procedures.
6. 3D printing reduces the possibility of human error.
7. 3D printing helps to reduce overall wastage of construction material resource, energy consumption and environmental pollution.
8. 3D printing can lead to formation of new jobs in new areas related to 3D printing like supplying materials, designing products, etc.

Limitations

1. 3D printing is a very expensive endeavor.
2. With the development of virtual treatment planning technology, usage of 3D printed models for treatment planning has lessened.
3. There is no legislation or regulation regarding 3D printing to stop criminals from buying 3D printers and printing guns, weapons etc to commit crimes.
4. There are no parental controls to stop children from misusing it.
5. 3D printed objects can sometimes be of a lower quality than if they were traditionally manufactured, like lower functionality and resistance.
6. Mass printing of objects instead of manufacturing via traditional methods can lead to an economic imbalance.
7. As 3D printing is a computer-controlled technique, it reduced human labour and work force requirement, which lead to unemployment.
8. This will also affect import of construction materials used in traditional methods as different materials are used for 3D printing.

Conclusion

Use of 3D printed models in oral and maxillofacial surgeries is a must to study for all surgeons, as it provides for a much safer, less traumatic and time consuming treatment modality. This increases the standard of care of patients and hence, these techniques should be adapted more and more surgeons. As the technology develops, it will become more versatile and easier to use, so we should all become familiar with it.

Source of Funding
None.

Conflict of Interest
None.

References
1. Squelch A. 3D printing and medical imaging. *J Med Radiat Sci* 2018;65(3):171–2.
2. 3D printing. Wikipedia.org. 8/10/2019. Available at: https://en.wikipedia.org/wiki/3D_printing
3. Goldberg D. History Of 3D Printing: It's Older Than You Are (That's If You Are Under 30). Autodesk.com. 13/4/2018. Available at: https://www.autodesk.com/redshift/history-of-3D-printing/
4. 3D printing processes. Wikipedia.org. 30/9/2019. Available at: https://en.wikipedia.org/wiki/3D_printing_processes
5. What materials are used for 3D printing? Surface treatment experts. Cited: 8/10/2019. Available at: https://www.sharrettsplating.com/blog/materials-used-3D-printing/
6. Sharma S, Goel S. 3D Printing and its Future in Medical World. *J Med Res Innov* 2019;3(1):e000141. DOI: 10.15419/jmri.141
7. Aldaadaa A, Owji N, Knowles J. Three-dimensional Printing in Maxillofacial Surgery: Hype versus Reality. *J Tissue Eng* 2018;9:2041731418770909. Published 2018 Apr 20. doi:10.1177/2041731418770909
8. Shilo D, Emodi O, Blanc O, Noy D, Rachmiel A. Printing the Future-Updates in 3D Printing for Surgical Applications. *Rambam Maimonides Med J* 2018;9(3):e0020. Published 2018 Jul 30. doi:10.5041/RMMJ.10343
9. Holub B. 3D Printing in Medicine: Facial Reconstruction Surgery. Zortrax.com. 19/6/2018. Available at: https://zortrax.com/blog/3D-printing-medicine-facial-reconstruction-surgery/
10. Dawood, Andrew & Marti, Begoña & Sauret-Jackson, V. & Darwood, Alastair. 3D printing in dentistry. BDJ 2015;219;521-529. 10.1038/sj.bdj.2015.914.
11. Jawahar A, Maragathavalli G. Applications of 3D Printing in Dentistry – A Review. *J Pharm Sci Res* 2019;11(5):1670-5.
12. Alexandru Pîrjan & Dana-Mihaela Petroşanu. "The impact of 3d printing technology on the society and economy," *Rom Econ Business Rev, Rom-Am Univ* 2013;7(2):360-70.

How to cite this article: Gupta H, Bhateja S, Arora G. 3D Printing and its applications in oral and maxillofacial surgery. *J Surg Allied Sci* 2019;1(3):48-52.