3D printing in the head area

Milkov Mario P., MD, PhD, Dzhendov Dzhendo A. PhD,

Department of Dental Materials Science and Propaedeutic of Prosthetic Dental Medicine

Prof." Paraskev Stoyanov " Medical University of Varna, Bulgaria

Faculty of Dental Medicine, 84 " Tzar Osvoboditel"BG-9000 Varna, Bulgaria

Abstract

Digital technologies are evolving at a very high pace in science and technology. They are also increasing their influence in the fields of dental and general medicine. The processes are inevitable and irreversible. The advantage of these technologies is that they can create medical devices with a complex geometric shape, in a shorter time and with greater accuracy. The materials from which the sites are built go through constant development and improvement. In dental medicine, printing is expressed in the manufacture of prosthetic dental structures of removable and non-removable type, training models, production of artificial prostheses for the needs of oral and maxillofacial surgery. In the field of otorhinolaryngology, 3D printing is used for the production of ectoprostheses in the removal of various inflammatory and tumor processes of the nose and ears, or as a result of occupational or traffic accidents. Printing also finds a place in ophthalmology for making eye prostheses. Regardless of the field of application, these technologies pose a challenge in their use in everyday clinical practice and are subject to constant monitoring by physicians and patients.

Objective: To study the application of 3D printing in the head and in particular in otorhinolaryngology.

Keywords: 3D printing, ectoprostheses, application, advantages, disadvantages.

Introduction

It is crucial that 3 D printing is evolving in to the medical field as well apart of the industrial area with a variety of applications including and not limited to tissue designs, tissue engineering, organ printing, diagnostic platforms, dentistry, biomedical devices, anatomical models, drug designing, and delivery systems. (3,4)

This technology is used also to replace and repair defective organs and in creating new organs that will have the same functioning as the original ones. (6)

It is a methodology where materials such as powder, metal, alloy, thermoplastics, polymeric, ceramic, wood, paper multimaterial, and biological materials (living cells) are positioned successively into layers on top of each other (bottom-up approach) thus enabling the fabrication of desired 3D object in a controlled manner. (7)

In contrast, 3D printing is a technique where objects are constructed additively by placing specific material in to layers one cross-sectional layer at a time. (8)

History

Charles Hull was working on the development of plastic devices utilizing photopolymers In early 1980s but the existant limitations in technology at the time (lengthy procedures, less accuracy) motivated him to improve the technology of prototype development. Soon after in 1984 he invented ap-

paratus for a new layer-by-layer printing technology named “stereolithography” and in 1986 Hull founded the company “3D systems” and provided the term .STL that was compatible with the existing CAD software to design the 3D object. 1987 was the year when, SLA-1 3D printer was introduced and in 1988 the company came up with the first commercially available 3D printer (SLA-250). (2) Deckard, graduate student at the University of Texas in 1989 introduced another important technology- selective laser sintering (SLS). (11) Not long after in 1992 Scott Crump patented another modified 3D printing technology, that is, fused deposition modeling (FDM). (12)

In 1993 E. Sachs and M. Cima at Massachusetts Institute of Technology (MIT) developed inkjet printing based “3D printer” for printing complex shapes of polymer, metal, ceramic, plastic, etc. (2,13)

The use of 3D printing in dental medicine started in the late 1990s by allowing the printing of various dental implants. (2)

Technology

There are varieties of 3D printing technologies ranging from well-established methods, which have been employed in industrial settings for years, to more recent techniques under development in research laboratories that are used for more specific applications. (14)

Each technology has its own pros and cons according to the desired application. The choice of 3D printing technology for a particular application is highly important and generally governed by the material parameters (type, compatibility, and availability), desired feature size, resolution, throughput, speed, and the manner how the layer to be bonded together in final object. (9,10,15)

Photopolymerization, that is, light-induced polymerization, is a form of 3D printing where materials (photopolymers, radiation-curable resins, and liquid) collected in a vat are successively cured into layers one layer at a time by irradiating with a light source thereby providing a 2D patterned layer. This involves techniques such as stereolithography (SLA), digital light processing (DLP), and continuous direct light processing (CDLP). Among these, SLA was the first 3D printing technology invented in 1986 by Chuck Hull. In 1994 SLA was first utilized in medicine as a surgical tool for alloplastic implant surgery. (1,4,18) Fig.1.

Fig. 1. 3D printer

Powder-based 3D printing technologies include a thermal source to selectively fuse or melt the powdered materials (wax, metal, nylon, polymer, plastic, ceramic, composite) held in a tray into thin layers sequentially to provide the final 3D structure. These comprise techniques such as electron beam melting (EBM), selective laser melting (SLM), selective laser sintering (SLS), polymer laser sintering (PSL), and direct metal laser sintering (DMLS) depending on the type of energy source and the powder materials. (19,20) EBM utilizes the energized electron beam directed by electromagnetic coils while others use high power laser beams directed by mirrors as the energy source. In these, SLS was the first introduced powder-based technology by Carl Deckard and Joseph Beaman in 1989 at the University of Texas. In the SLS process, a high power laser beam (Nd:YAG or CO₂) is focused onto a powdered bed having uniformly distributed material with the help of a roller to scan the surface and to heat the material at a temperature beyond its glass transition temperature and less than the melting point. Powdered materials are then fused together in a specific 2D pattern onto which subsequent layers of materials can be laid down, distributed, and sintered sequentially to build the final 3D object. (1,17,20,21)

Material jetting also known as multijet modeling (MJM) is a photopolymer-based inkjet printing technique where the complete 3D object is built in a layer-by-layer manner by dispensing droplets of liquid photopolymer material via an array of inkjet printheads having multiple nozzles (9)

In material extrusion-based 3D techniques, material collected in a reservoir is dispensed through a

heated nozzle or by utilizing a mechanical or pneumatic system. In recent years, extrusion-based technologies have drawn considerable interest, as these are affordable, mechanically simple, and cost-effective printing techniques. (22) Extrusion-based techniques can broadly be classified into two categories: (1) techniques based on material melting and (2) techniques without material melting. (1,23)

3D printing technologies have recently been utilized as a printing tool in the surgical field to create multicolored and multimaterial anatomical models for surgical planning and practicing. The 3D printed anatomical models are being utilized as an alternative to human cadavers for anatomy teaching. (5,24) These models provide the detailed information about the individually varied anatomic structures by creating the multicolored 3D model.

Principles of production

The first step in making prostheses through 3D printing is their design with CAM software. The second one is related to the generation of an STL file. Following by setting the system number of layers and the production time. The real printing process follows, obtaining the final product.

Dentistry application

In the field of dentistry, 3D printing is used for the production of removable and non-removable prosthetic structures. With their help the defects of the tooth and the defects of the dentitions are restored. With the help of stereo lithography, single crowns or bridge prosthetic structures are produced from liquid polymers. Parts and whole removable dentures can also be made. Intraoral splints and surgical dispensers can be produced by 3D printing. Recently, these technologies have been used as well to obtain laboratory and diagnostic models in the process of making prosthetic structures. (Fig. 2)

Fig.2. Products made by stereolithography.

SLM is used to construct removable and non-removable prosthetic constructions from metal alloys as well as prostheses replacing bone structures, after resection of the jaws from injuries and inflammatory oncological conditions. (Fig 3)

Fig.3. Maxillofacial prosthesis (Luthra V.2016)

In the field of otorhinolaryngology, printing can be used to make ectoprostheses for the nose and ear. The main processes are through stereolithography, as structures of the nose and auricle can be made, and as an infrastructure for bioprinting with epithelial cells.

Another major role of printing in medicine and dentistry may be related to models and specimens of organs and prostheses in the teaching of the respective disciplines. In this way, the trainees get a real idea of the shape, size and structure of a certain organ and can be trained in different types of manipulations.

Advantages and disadvantages

Medical devices can be created with a complex geometric shape, in a shorter time and with greater accuracy. Reduce patient discomfort when working in a real clinical conditions, reduced production time. The materials from which the prostheses are made go through constant development and improvement. The disadvantages are the high cost of products and devices for use all over in medicine. Need for qualified staff training. The technological regimes recommended by the manufacturing companies do not always guarantee the required dimensional accuracy, the absence of defects and deformations.

Conclusion

Regardless of the field of application, these technologies pose a challenge in their use in everyday clinical practice and are subject to constant monitoring by physicians and patients. They are part of the present and will develop rapidly in the future. This is the main reason, which is very important for

their knowledge and rational application.

References

1. Ashish, M.TECH • Nabeel Ahmad, PHD • P. Gopinath, PHD • Alexandr Vinogradov, PHD. 3D Printing in Medicine: Current Challenges and Potential Applications. Applications of Biomedical Engineering in Dentistry. Springer 2020
2. Gross BC, Erkal JL, Lockwood SY, Chen C, Spence DM. Evaluation of 3D Printing and its Potential Impact on Biotechnology and the Chemical Sciences. ACS Publications; 2014.
3. Chia HN, Wu BM. Recent advances in 3D printing of biomaterials. J Biol Eng. 2015;9:4.
4. Liaw C-Y, Guvendiren M. Current and emerging applications of 3D printing in medicine. Biofabrication. 2017;9:024102.
5. Rengier F, Mehndiratta A, Von Tengg-Kobligh H, et al. 3D printing based on imaging data: review of medical applications. Int J Computer Assist Radiol Surg. 2010;5:335–341.
6. Schubert C, Van Langeveld MC, Donoso LA. Innovations in 3D printing: a 3D overview from optics to organs. Br J Ophthalmol. 2014;98:159–161.
7. Randolph SA. 3D Printing: What Are the Hazards?. Workplace health & safety; 2018:2165079917750408.
8. Campbell T, Williams C, Ivanova O, Garrett B. Could 3D Printing Change the World, Technologies, Potential, and Implications of Additive Manufacturing. Washington, DC: Atlantic Council; 2011.
9. Hwang HH, Zhu W, Victorine G, Lawrence N, Chen S. 3D-Printing of Functional Biomedical Microdevices via Light-and Extrusion-Based Approaches, Small Methods; 2017
10. Patwardhan A. How 3D printing will change the future of borrowing lending and spending?. Handb Blockchain Digital Finance Inclusion. 2017;2:493–520. Elsevier.
11. Deckard CR. Method and Apparatus for Producing Parts by Selective Sintering. Google Patents; 1989.
12. Crump SS. Apparatus and Method for Creating Threedimensional Objects. Google Patents; 1992.
13. Sachs EM, Haggerty JS, Cima MJ, Williams PA. Threedimensional Printing Techniques. Google Patents; 1993.
14. ACFoAM Technologies, ACFoAMTSFo Terminology. Standard Terminology for Additive Manufacturing Technologies. ASTM International; 2012.
15. YE C, du Toit LC, Kumar P, Kondiah PP, Pillay V. 3Dprinting and the effect on medical costs: a new era? Expert Review of Pharmacoeconomics & Outcomes Research. 2016;16:23–32
16. Vijayavenkataraman S, Fuh JY, Lu WF. 3D printing and 3D bioprinting in pediatrics. Bioengineering. 2017;4:63.
17. Jose RR, Rodriguez MJ, Dixon TA, Omenetto F, Kaplan DL. Evolution of bioinks and additive manufacturing technologies for 3D bioprinting. ACS Biomater Sci Eng. 2016;2:1662–1678.
18. Kim GB, Lee S, Kim H, et al. Three-dimensional printing: basic principles and applications in medicine and radiology. Korean J Radiol. 2016;17:182–197
19. SFS Shirazi, Gharekhani S, Mehrli M, et al. A review on powder-based additive manufacturing for tissue engineering: selective laser sintering and inkjet 3D printing. Sci Technol Adv Mater. 2015;16:033502.
20. Kumar S. Selective laser sintering: a qualitative and objective approach. JOM (J Occup Med). 2003;55:43–47.
21. Fina F, Goyanes A, Gaisford S, Basit AW. Selective laser sintering (SLS) 3D printing of medicines. Int J Pharm. 2017;529:285–293.
22. Provaggi E, Kalaskar DM. 3D printing families: laser, powder, nozzle based techniques. 3D Print Med. 2017:21–42. Elsevier.
23. Vaezi M, Seitz H, Yang S. A review on 3D micro-additive manufacturing technologies. Int J Adv Manuf Technol. 2013;67:1721–1754.
24. Ballard DH, Trace AP, Ali S, et al. Clinical applications of 3D printing: primer for radiologists. Acad Radiol. 2018;25:52–65.