3D Printing - An Advancing Forefront in Imprinting the Inner Dimensions of Tooth with Precision

Chelluri Shreya Reddy[1], Areddy Manasa Reddy[2], P. Shantipriya[3] and Raji Viola Solomon[4*]

[1,2]BDS, Intern, Department of Conservative Dentistry and Endodontics, Panineeya Institute of Dental Sciences and Research Centre, Road No:5, Kamala Nagar, Dilsukhnagar, Hyderabad – 500060, Telangana State, India; manasareddy92138@gmail.com

[3]Senior Lecturer, [4]Professor, Department of Conservative Dentistry and Endodontics, Panineeya Institute of Dental Sciences and Research Centre, Road No:5, Kamala Nagar, Dilsukhnagar, Hyderabad – 500060, Telangana State, India; shanthipaneeru@gmail.com, dr.viola@gmail.com

Abstract

3D printing is rooting itself as a promising digital technology in the field of dentistry. Emergence of this recent advanced digital science has opened up new perspectives for design and production of 3D models quickly and automatically. The concept of utilizing this technology is to improvise the standards of the treatment provided to the patients, due to more precision and less technique sensitive outcomes. It works on the concept of additive manufacturing, which has its advantages in contrast to the subtractive manufacturing process. It is important to have knowledge about the different 3D printing modalities available as it is not only an upcoming technology in dentistry but also one which is emerging with myriad applications which offer better predictable results in areas of preoperative diagnostic planning, clinical handling and follow up. This article provides an overview on the method and applications of 3D printing with focus primarily in the field of Operative Dentistry and Endodontics.

1. Introduction

The dental profession has experienced an enormous technological growth during the past few years. 3D printing is paving its way as an emerging technology with a wide range of applications and vast opportunities in the dental field and is expected to grow exponentially in the next few years. Digitalization through 3D printing is a remarkable advancement in the field of dentistry that facilitates to provide treatment that is customized to an individual patient. Thus this technology ensures precision in terms of quality and quantity making it preferable in this modern era.

3D printing is a method which uses 3 dimensional CAD data sets for producing 3D physical models[1]. Also referred to as "additive manufacturing" it is the method of fabricating materials of choice namely, metal/polymer/resins, in incremental or serial layers using CAD/CAM (Computer Aided Design/Computer Aided Manufacturing) digital scans for the dual purpose of designing a product and for controlling the manufacturing process. Based on the production method used it can be mentioned to as rapid prototyping, solid free form, computer automated or layered manufacturing[1].

The procedure involves giving input to the computer through 3D CAD data which materializes the design by additive deposition of the material of choice to give final shape to the desired model. The first ever use of 3D printing in dentistry was in 1999[2].

3D printing having its application in aerospace, art and design, is now becoming a subject of great interest in

medical and dental fields as well[3]. In particular the medical field utilizes 3D printing for surgical planning, prosthetics and generation of graspable 3D objects[2].

It is also used for reconstruction of complex organs with intricate 3D microstructure, restoration of 3D anatomic defects in craniomaxillofacial complex caused by pathoses such as cancer, trauma or congenital defects[4].

2. What are the Benefits of 3D Printing?

A few of the recent software programs enable designing of a restoration/study model or guided template which is then subsequently printed in the material chosen based on the area of application. These 3D objects enable clinicians to study through reconstruction, the patient's jaw or tooth morphology on the table top. This enables efficient case analysis, preoperative planning, guided operative procedures and facilitates productive preclinical training methods. Anything that can be manufactured through dental laboratory can be done digitally, potentially and more consistently at a reduced cost and time.

3. Role of 3D Printing Technology in Dentistry

Its variant applications in dentistry include: Fabrication of 3D printed restorations, composite and ceramic esthetic inlays and onlays, guided Endodontic interventions, invisalign Orthodontic braces, Orthodontic surgical case evaluation and handling, crown and denture prosthesis, customized myofunctional appliances and customized facial and dental implants. A second revolution can be experienced in dental device manufacturing when layered fabrication techniques reach the point of being able to produce a high quality dental prosthesis[5].

4. What are the Methods of 3D Printing?

The various 3D printing processes currently available are[4,6]:

- Stereolithography.
- Fused deposition modelling.
- Selective laser sintering.
- Photopolymer jetting.

- Powder binder printer.
- 3D plotting or direct writes bioprinting.

4.1 Stereolithography

Stereolithography is a form of additive manufacturing that converts liquid material into solid parts, layer by layer by curing them using a light source through photopolymerization. The materials used must be photo curable to initiate the photo cross linking. These include acrylics, epoxies, fabrication of titanium dental implants etc[2,4].

4.2 Fused Deposition Modeling

It utilizes thermoplastic materials which are deposited in molten form. The basic structure of the machine included the presence of nozzles through which the material is deposited in layer by layer after which the layers are fused together[4,6].

FDM (Fused Deposition Modeling) uses biocompatible polymers, bioactive glass composites[7], PMMA Poly (Methyl Methacrylate)[8]. Its applications include bone tissue engineering[9], craniofacial defects[8,10] etc.

4.3 Selective Laser Sintering

Scanning laser sinters metal powder layer by layer in cold built chambers as build platform descends. The variety of materials used is titanium, cobalt chrome, stainless steel. It has its applications in areas which require high fracture toughness and mechanical strength which includes manufacturing metallic implants that facilitate bone ingrowths and regeneration[2,4].

4.4 Photopolymer Jetting

This utilizes light cure resin materials which are laid on a stationary platform and has dynamic print head which cures the materials. The materials that can be printed are resins, waxes for casting and silicon rubber material. Applications include implant drill guides and manufacture of indirect orthodontic bracket splints[2].

4.5 Powder Binder Printers

It is form of modified ink jet head which is used for printing. It utilizes liquid droplets which is usually water used to print onto powder commonly done for plaster of Paris. It is built by incremental process[2].

4.6 3D Plotting/Direct Write Bioprinting

It is used to create soft tissue scaffolds, 3 Dimensional ceramics, polymers, hydrogels[4,11]. This does not involve the use of thermoplastics and can be operated at room temperature. Materials that can be used are alginate, fibrin, collagen, PLGA Poly (Lactic Co-Glycolic Acid) and TCP (Tri Calcium Phosphate)[4,12].

5. Applications in Operative Dentistry and Endodontics

Digital technology and 3D printing have significantly elevated the rate of success and improvised the quality and precision of dental operative work[13].

In addition, for the dentist, it will affect clinical practice on how quickly and efficiently one will be able to operate; for the dental lab support team, it will affect the marketing strategy to clients and for the patient it will affect which dentist he chooses - the one who has adopted this new technology that allows for more comfortable diagnosis and faster results or one who still uses more traditional methods.

5.1 3D Printing as an Effective Tool in Reconstruction of 3D Models

With the advent of 3D printing in dentistry one can take a 3D image of the teeth and upload to a computer software program which can be accessed and the desirable model can be adjusted or altered as per the needed requirement and can be printed within a couple of hours. This model can be held by hand as a hard copy replicate of the area of interest for superior observation.

5.2 3D Printing as an Effective Denovo Method in Preclinical Training

Bench practice of instrumentation with various printed teeth would help the student discover and improve clinical skills in contrast to the current use of extracted teeth used for learning purposes. Due to the limited availability of the extracted teeth, multiple model tooth copies can be printed from any selected micro CT (Computed Tomography) scan for use among the dentists and dental trainees as well. Also the use of these 3D printed tooth models can help to recreate conditions that mimic pulp stones, internal and external root resorptive defects, dens –in-dente and many more anomalies which will help

them visualize, improvise and advance in the science and art of Endodontics[14].

One important application of 3D printing in dentistry is creating digital scans of full or partial arches into durable plastic model casts. This reduces the effort and inconvenience to the operator as well as to the patient in using impression materials for recording impressions followed by fabrication of casts with stone[14].

5.3 3D Printing as an Effective Tool in Fabrication of Tooth Restorations

Utilization of 3D printing technology for tooth fillings will reduce the treatment costs in comparison to an all ceramic/CAD-CAM (Computer Aided Design/Computer Aided Manufacturing) restoratives and decrease the technique sensitivity of placement of the restorative material. It can be used to restore a complex cavity involving multiple surfaces that cannot be restored directly. The following are the steps to fabricate a 3D printed restoration[15]:

- Tooth preparation according to the cavity prepared, it can be two or three surface preparations.
- Scanning of the preparation and uploading the data on the computer.
- Printing the filling with appropriate material of choice of restoration.
- Finally cementation of the prepared 3D filling into the scanned cavity with suitable adhesive material.

The current problem associated with 3D printing restorative materials is that the most commonly used methacrylates like BisGMA (bisphenol A-Glycidyl Methacrylate), UDMA (Urethane Dimethacrylate)[16] used in clinical practice are loaded with glass fillers where as the ones that are used in 3D printing machines are devoid of these filler particles, thus compromising the mechanical properties of the 3D printed composites making them inferior to the contemporary resin materials[17]. Hence in order to improve their mechanical properties the filler particles are to be incorporated and research is being carried out in this direction.

Another limitation to be addressed is the adhesive compatibility of the 3D printable composite resins with current resin based adhesive systems when bonded to the enamel and dentin substrate and further studies are required to gain a better understanding.

Dentists can also print objects such as custom made trays for in office bleaching of vital teeth which duplicate higher accuracy, precision of fit and ease of placement[15].

3D printed guides and models help the clinician in esthetic treatment planning and also aid them in minimal intervention and skill acquisition[18].

5.4 3D Printing as an Effective Tool in Reconstuction of Tooth Models to Assist in Endodontic Treatment of Atypical Anterior Tooth

There have been reported cases of atypical anterior tooth, where a physical tooth model was fabricated to guide the treatment procedure favourably. A translucent tooth model was built carrying the information regarding the internal root canal structure through a 3 step process:

- Data collection through CBCT (Cone Beam Computed Tomography) scanning.
- Virtual modelling by image processing.
- Manufacturing through 3D printers.

A customized guide jig was fabricated to get a safe and precise working path to the root canal and follow up after few months reported complete healing of the periapical region with no clinical signs and symptoms[19]. The fabrication of such 3D models help to analyze in a life size manner the anomalous defects better.

5.5 3D Printing as an Effective Tool in Guided Endodontics

3D printed virtual templates were utilized to gain guided access to root canals and various in vitro research studies concluded that accurate access cavity preparation up to apical third of the root could be obtained through 3D template guided Endodontic procedures[20]. This would especially be useful for clinicians to apply when faced with challenging canal morphologies. A 3D guided access stent which is digitally designed to fit each particular tooth could pave the way to minimally invasive endodontic access and minimize the chances of iatrogenic errors.

5.6 3D Printing as an Effective Tool in Guided Implant Surgery

High accuracy can be achieved through 3D printed templates for guided implant surgery when used as alternatives to laboratory manufactured templates[21]. The guides offer better precision of placement of the implant, when compared with free hand placement which is fully dependent on the clinician's skill and experience. Also the cost effectiveness and time saving fabrication of the guides is an added bonus in addition to 3D data analysis and interpretation which ensures more predictable results.

5.7 3D Printing as an Effective Tool in Tooth Transplantation Procedures

The clinical application of computer aided rapid prototyping for tooth transplantation works on the fabrication of a duplicate form of the donor tooth, which is obtained prior to the extraction, by taking a 3D image with real dimensions of the donor tooth from a CT (Computed Tomography) high speed scan to fabricate a life sized resin model of the tooth. This procedure would help in minimizing the extra oral time during the surgical procedure, which in turn maintains healthy periodontal ligament cells in the donor tooth for successful tooth transplantation[22].

5.8 3D Printing as an Effective Tool in the Repair of Bony/Soft Tissue Defects

The repair of defects caused by accidents, surgery or birth can be done by fabricating 3D scaffolds of various geometric shapes through customized tissue engineering. Rapid prototyping or solid free-form fabrication techniques are very useful in designing customized scaffolds. Poly (ethylene oxide) and poly (ethylene glycol) dimethacrylate photopolymerisable hydrogels were used to fabricate scaffolds which resulted in constructs that were comparable with soft tissues in terms of elasticity and high cell viability which was achieved along with high density constructs[23].

5.9 3D Printing as an Effective Tool in Dental Pulp Regeneration

The pulp tissue can be replaced by utilizing a 3D cell printing technique. An ink jet device is used to recreate the structure of pulp tissue by dispensing layers of cells that are suspended in hydrogel. This helps us to precisely position cells and this mimics the natural pulp tissue of the tooth. In order to mimic the pulp of natural tooth a systematic positioning of cells is required that includes positioning of the odontoblastic cells at the periphery and

fibroblasts with in the core with a supportive network of vascular and neural cells. However careful orientation of the cells is required, and research is in focus to in vivo create a functional tissue like pulp[24,25].

6. Future: New Generation Reprap 3D Printers

The RepRap 3D printers are self-replicating manufacturing machines initiated by Dr. Adrian Bower in 2004[26] in an attempt to replace the conventional laboratory procedures. These printers utilize Cartesian robots, which can move along x, y, z axis and can precisely deposit the appropriate quantities of thermoplastic polymers. These printers require digital information by CAD (Computer Aided Design/Computer Aided Manufacturing) and then objectify the provided input by applying additive manufacturing technology called fused filament fabrication[27]. It has limited application usually for reconstruction of study models for orthodontic purposes and reconstruction of skeletal defects[28].

7. Future: 4D Printing

The main concept of 4D printing is to create 3D printed models that can undergo spontaneous shape transformation as a process of adapting to the oral environment in response to thermal or moisture changes. This can be achieved by mixing various materials in a proportionate pattern and quantity each with known strain and shrinkage properties. 4D printing could produce restorative materials that are self-adjustable spontaneously without further intervention from the dentist that could avoid micro leakage and overhangs at the margins. Hence it may help produce materials with better fit and retention qualities than conventional or 3D printed materials[29]. This offers a whole new promising scope to improve the standard of quality dental care to the patients.

8. Conclusion

3D printing could establish itself as a milestone in the field of dentistry due to its efficacy, accuracy, potency and minimal time consumption in the fabrication process. Its utility in treatment planning and analysis of treatment outcomes improvises the quality of treatment provided by the dentist to the patient enhancing the patient sat-

isfaction. As 3D printing is an additive manufacturing process the amount of material wastage can be effectively reduced. Another advantage of this technology is that each computer data file is a permanent record of the object being printed and this data can be stored. Hence it is possible to reproduce multiple copies of the same object when desired. However, like every newly invented technology 3D printing has its own challenges to overcome such as cost, lack of trained personnel and limited choice of materials that are biocompatible. Hence more research is required in this field to establish itself as a reliable technology and studies should be directed to observe clinical treatment outcomes employed by 3D printed objects.

9. References

1. Rengier F, Mehndiratta A, von Tengg-Kobligk H et al. 3D printing based on imaging data: Review of medical applications. Int J CARS. 2010; 5(4):335–41. crossref PMid:20467825

2. Dawood A, Marti B, Jackson VS, et al. 3D printing in dentistry. British Dental Journal. 2015; 219:521–9. crossref PMid:26657435

3. Mawere C. The impact and application of 3D printing technology. International Journal of Science and Research (IJSR). 2014; 3(6):2148–52.

4. Chia HN, Wu MB. Recent advances of 3D printing of biomaterials. Chia and Wu Journal of Biological Engineering. 2015; 9:4. crossref PMid:25866560 PMCid:PMC4392469

5. Van Noort R. The future of dental devices is digital. Dent Mater. 2012; 28(1):3–12. crossref PMid:22119539

6. Zein I, Hutmacher DW, Tan KC, Teoh SH. Fused deposition modeling of novel scaffold architectures for tissue engineering applications. Biomaterials. 2002; 23:1169–85. crossref

7. Korpela J, Kokkari A, Korhonen H et al. Biodegradable and bioactive porous scaffold structures prepared using fused deposition modeling. J Biomed Mater Res B Appl Biomater. 2013; 10(1):610–9. crossref PMid:23281260

8. Espalin D, Arcaute K, Rodriguez D et al. Fused deposition modeling of patient-specific polymethylmethacrylate implants. Rapid Prototyping J. 2010; 16:164–73. crossref

9. Kim SS, Utsunomiya H, Koski JA et al. Survival and function of hepatocytes on a novel three-dimensional synthetic biodegradable polymer scaffold with an intrinsic network of channels. Ann Surg. 1998; 228:8. crossref PMid:9671060 PMCid:PMC1191421

10. Probst F, Hutmacher D, Muller D et al. Calvarial reconstruction by customized bioactive implant. Handchir Mikrochir Plast Chir. 2010; 42:369–73. crossref PMid:20221990

11. Landers R, Mulhaupt R. Desktop manufacturing of complex objects, prototypes and biomedical scaffolds by means of computer-assisted design combined with computer guided 3D plotting of polymers and reactive oligomers. Macromol Mater Eng. 2000; 282:17–21. crossref

12. Haberstroh K, Ritter K, Kuschnierz J, Bormann KH, Kaps C, Carvalho C et al. Bone repair by cell seeded 3D bioplotted composite scaffolds made of collagen treated tricalciumphosphate or tricalciumphosphatechitosan collagen hydrogel or PLGA in ovine critical sized calvarial defects. J Biomed Mater Res B Appl Biomater. 2010; 93:520–30. crossref PMid:20225216

13. Zaharia C et al. Digital dentistry-3D printing applications. Journal of Interdisciplinary Medicine. 2017; 2(1):50–3. crossref

14. Jacob GS. 3D Printing for education and training in Endodontics. Inside Dentistry. 2016; 12(1).

15. Ayar MK. Is a three-dimensional-printed tooth filling possible? Dent Hypotheses. 2016; 7:53–5. crossref

16. Ferracane JL. Resin composite-state of the art. Dent Mater. 2011; 27:29–38. crossref PMid:21093034

17. Kim KH, Ong JL, Okuno O. The effect of filler loading and morphology on the mechanical properties of contemporary composites. J Prosthet Dent. 2002; 87:642–9. crossref PMid:12131887

18. Shah P, Chong BS. 3D imaging, 3D printing and 3D virtual planning in Endodontics. Clin Oral Invest. 2018; 22:641. crossref PMid:29330656

19. Endodontic treatment of an anomalous anterior tooth with the Aid of a 3-dimensional Printed physical tooth model. J Endod. 2015; 41(6):961–5. crossref PMid:25732403

20. Zenhnder MS et al. Guided endodontics: Accuracy of a novel method for guided accsess cavity preparation and root canal location. Int Endod J. 2016; 49(10):966–72. crossref PMid:26353942

21. Kuhl S et al. Technical accuracy of printed surgical templates for guided implant surgery with the co DiagnostiX software. Clin Implant Dent Relat Res. 2015; 17(Suppl1):e177-82. crossref PMid:24020645

22. Lee SJ et al. Clinical application of computer-aided rapid prototyping for tooth transplantation. Dent Traumatol. 2001; 17(3):114–9. crossref PMid:11499760

23. Dhariwala B et al. Rapid prototyping of tissue-engineering constructs, using photopolymerizable hydrogels and stereolithography. Tissue Eng. 2004; 10(9-10):1316–22. crossref PMid:15588392

24. Sureshchandra B, Roma M. Regeneration of dental pulp: A myth or hype. Endodontology. 2013; 25(1):139–55.

25. Yelick PC, Vacanti JP. Bioengineered teeth from tooth bud cells. Dent Clin N Am. 2006; 50(2):191–203. crossref PMid:16530057

26. Open design of tangible goods- A comparative case study. In: Balka K. Open Source Product Development: The Meaning and Relevance of Openness. Wiesbaden: Gabler Verlag; 2011. p. 67–9. crossref

27. A world of 3D printers. In: Evans B. Practical 3D printers: The Science and Art of 3D Printing. 1st ed. New York: Apress; 2012. p. 1–10. crossref

28. Alexandru-Victor B et al. Applications of RepRap three-dimensional printers in dentistry - A Literature review. International Journal of Medical Dentistry. 2015; 5(1):37–43.

29. Hosamuddin Hamza. Future applications of 4D printing in dentistry. International Science Index, Medical and Health Services. 2017; 11(3).