REVIEW ARTICLE

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Three dimensions of printing – deleting pitfalls in endodontic practice

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Abstract

Introduction and Objective. Digitalization in dentistry has its own platform towards success. 3Dimensional (3D) printing is one of the techniques having its own benefits in dentistry, especially endodontics. 3D printing has promoted the advancements of surgical and non-surgical endodontics. In current circumstances, digital teaching is the only mode of education and training. It has enhanced practices in endodontic training and education, and transformed teaching from typodont teeth to 3D-printed tooth models. Ques applications as well as limitations in endodontics. The aim of the study was to assess various 3D techniques, their applications and limitations in endodontics.
Review Methods. Data was collected from various review and research papers by using key words, such as 3D printing, dentistry, endodontics, 3D applications in endodontics, and 3D methods, from various data bases, e.g. Pubmed, Google scholar, Scopus, etc.
Brief description of the state of knowledge. 3D printing covers wide applications in dentistry, especially endodontics, and will be a power point in the near future with 4D dentistry on the way.
Summary. Modern dentistry is digitalized dental practice. 3D printing has wide applications in dentistry using various techniques, such as Fused Deposition Modeling (FDM), Stereolithography (SLA), Inkjet Printing, 3D Plotting/Direct Write Bio printing each having different applications in endodontic. 3D printing has transformed surgical and non-surgical endodontic practice, from typodont teeth to 3D-printed tooth models. The review itemizes 3D applications and their limitations in endodontics and dentistry, and the expected exponential growth in subsequent years.

Key words

dentistry, 3D printing, stereolithography, fused deposition modeling, CAD CAM, endodontics

INTRODUCTION

3D printing is the designing of a virtual image of an object to be constructed, followed by converting the information into a digital file [1] by creating an object through building one layer at a time followed by addition of successive layers. 3D printing can be precisely described as additive manufacturing (AM), rapid prototyping (RP), layered manufacturing or solid-free form fabrication, depending upon its production methods [2].

In 3D printing, the obtained geometric data is converted into layers by the manufacturing equipment under the control of computer until the final desired object or geometrical object is produced. Its versatile applications in the medical and dental fields have expanded its research base and generated better outcomes. 3D printing technology has brought a remarkable change, not only in the objects, but also in way they are made. It is an emerging and promising technology with diverse applications in several fields, including aerospace, art, design, defence, architecture, engineering, medicine and dentistry, providing an opportunity to personalize designs and fabrications. CAD/CAM (Computer Aided Design/ Computer Aided Manufacturing) technology has promoted 3D printing in the filed of dentistry [1]. This review aims to assess various 3D printing techniques and their applications as well as limitations in dentistry, especially in endodontics.

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History of 3D Printing. The history of 3D printing revolves around the year 1983 when Charles Hull printed a 3D object for the first time, and invented the first 3D printer named a 'stereolithography', which first became commercially available in 1988 when a 3D printer known as the SLA-250 was introduced [1- 3].

Process of 3D printing. The 3D modelling programme provides the virtual design for the compatible 3D printer which converts every slice (2D image) into a 3D object. This requires CAD (Computer Aided Design) software which enables the creation of objects from scratch. The 3D model is sliced and is ready to be fed into the 3D printer of a compatible brand and type via USB, SD or Wi-Fi. When a file is uploaded in a 3D printer, the object is ready to be 3D printed, layer by layer [4, 6].

DISADVANTAGES OF CAD/CAM TECHNOLOGY COMPARED TO 3D PRINTING

a. 3D printing is an Additive Manufacturing (AM) method, whereas CAD/CAM technology is a subtractive method.

b. Milling tools in CAD/CAM are susceptible to wear and abrasion which reduce their cycling time.
c. A large amount of raw material is wasted in CAD/CAM technology.
d. During the process of machining, microscopic cracks may appear due to the brittle nature of ceramic in CAD/CAM technology [7].

VARIOUS TECHNIQUES IN 3D PRINTING

Rapid prototyping (RP). Is a type of computer-aided manufacturing (CAM), also known as a generative manufacturing technique. This procedure is capable of making physical objects directly from 3D computer data by adding layer-upon-layer. Prior to final prosthesis fabrication, it allows the visualization and testing of objects, thereby minimizing costs, and has several applications in endodontic training and research. Other applications are transplantation, determining the size of apical lesion and root resorption, and complete visualization of a canal through digital technology[1, 8].

The various techniques under rapid prototyping are:

Fused Deposition Modeling (FDM). This is most commonly used 3D technology. It involves the deposition of thermoplastic materials in molten or semi-solid form, which become solid within 0.1sec and bonds to the previous layer. In this technique, a machine with nozzles is used through which the layers of material are deposited under thermal control, and the motion of the material is under computer control. It uses bioactive glass composites, biocompatible polymers and PMMA Poly (Methyl Methacrylate), requiring the removal of support structures, has a rough surface finish and does not have 100% density. Areas of its application are bone tissue engineering and craniofacial defects, printing of anatomic models avoiding complexity, such as the edentulous mandible [1, 8].

Stereolithography (SLA). Stereolithography was invented in the 1980s by Charles Hull. It is a type of additive manufacturing and available as a printer for rapid prototyping in which liquid material is converted into solid parts, followed by curing in layers by photopolymerization. In this technique, photo-curable materials must be used to initiate the photo cross-linking e.g. epoxies, acrylics, fabrication of titanium dental implants, etc. Stereolithography provides a good and smooth surface finish, high accuracy and mechanical strength. It can be used only for polymers, is costly and needs post-cure. Areas of its application are implant guides and surgical stent. Stereolithography technique can only be performed if UV (Ultra Violet) light-curable polymers are available [1, 8, 9–13].

Selective Laser Sintering (SLS). This technique sinters metal powder (titanium, cobalt, chrome, stainless steel) in layers in cold built chambers. It is preferred in areas which need high fracture toughness and mechanical strength, e.g. manufacturing metallic implants which facilitate bone ingrowths and regeneration. In this method, a high power laser is directed using a mirror at a substrate consisting of a fine layer of powder. When the beam hits the powder it forms a melt pool and the powder particles fuse together. Areas of its application are printing anatomical study models, cutting and drilling guides, implant bridge frameworks and Cobalt chromium RPD frameworks. Different types of materials are available and 100% density is possible, but the material and equipment are expensive [1].

Photopolymer Jetting. Photopolymer Jetting technique uses light cure resin materials with a dynamic print head which cures the materials, such as resins, waxes for casting and silicon rubber material laid in a stationary platform. Areas of its application are implant drill guides and manufacture of indirect orthodontic bracket splints [8].

Powder Binder Printers. In this technique, a modified ink jet head is used for printing which uses thermoplastic materials, which means it can only be used at room temperature. Water in the form of liquid droplets is used to print onto powder (Plaster of Paris) [8, 14].

Inkjet Printing. A simple technique in which the printer jets ink onto paper and dried naturally without any final cure. It can be utilized immediately, is cheap with fast fabrication, low toxicity and relative material variety, but has a lower strength of models and rough surface finish. Areas of its application are printing dental or anatomical study models, and implant drill guides [1, 15].

3D Plotting/Direct Write Bio printing. In this technique, various materials used: alginate, collagen, fibrin, PLGA Poly (Lactic Co-Glycolic Acid) and TCP (Tri Calcium Phosphate). Areas of its application are soft tissue scaffolds, polymers, 3Dimensional ceramics, and hydrogels [8].

APPLICATIONS OF 3D PRINTING IN ENDODONTICS

In dentistry, digitalization via 3D printing provides a facility for customized treatment and is an extraordinary development. The technology ensures precision in qualitative and quantitative terms, and is now becoming a subject of immense interest in the dental field along with several other applications (Fig. 1) described below.

Fabrication of a physical tooth model. A physical tooth model is fabricated by 3D printing which facilitates patient education. It helps in diagnosis to identify the presence of atypical root morphology, decision-making and management, helps in calcified canals as guided access preparation, determining and locating root resorption, as well as surgical planning and guided periapical surgeries. Such a physical model provides information regarding the size, location, involvement of cortical plates and combination of the involved root apices, together with their proximity to anatomical structures which is an additional diagnostic aid in routine radiographic examination [16].

Guided endodontic surgery. Guided endodontic surgery is an advanced choice of treatment regarding tissue damage. CBCT (Cone Meam Computed Tomography) scan helps in assessing anatomical structures and makes it possible to transform generated diagnostic data into a DICOM (Digital Imaging and Communication) file by using a digital software design programme. 3D printed endodontic surgery is more expensive and time consuming than conventional surgery, but the main advantage of this technique is bone preservation due to precise template extension over the lesion. In other words, the yield with 3D printing surgery is improved, which is a favourable factor for improved outcome and healing [16].

CASE REPORTS

a) A novel treatment approach for the removal of cortical bone and root-end during periapical surgery with 3D printing technology, CBCT and CAD (Computer Aided Design). In this case, a template was used to locate root-ends and a lesion area was fabricated using a 3D printer following virtually designing. A template guided precise removal of overlying cortical bone and root-end. At a 6-month follow-up, the patient was clinically asymptomatic. At 12 months post-surgery, the lesion had healed well [17]. The guided endodontics in maxillary molars is an excellent way to locate calcified root canals, even in complex cases.
b) A case was reported with pain in the upper left molar region and apical periodontitis. In this case, conventional endodontic treatment was not easy due to difficulty in accessing the root canals. Intraoral scanning and CBCT scan was used to plan access to the calcified canals by means of implant planning software. Rapid prototyping was used to fabricate guides and orientation of a cylindrical drill to locate calcified canals, followed by root canal treatment. Pain subsided and periapical lesion was reduced after 120 days with maintenance at the 1-year follow-up [18].
c) The patient reported with pain, yellowish discoloured lower incisors, and tender to percussion; negative electrical and thermal tests. CBCT and an intra-oral surface scan allowed the virtual planning of optimal access cavities up to the apical third of the root. In this technique, a 3D-printed template guided a customized drill to the orifice of the root canal, followed by conventional root canal treatment. This case reported micro-guided endodontics in the form of minimal invasive and apically extended access cavities [19].
d) This case made use of a surgically-operating microscope and CBCT for root canal treatment of a left maxillary first molar with 3 roots and 7 canals. Right maxillary first molar was also confirmed with 3 roots and 7 canals by CBCT. Thus, the unusual anatomy of a tooth was diagnosed and endodontic treatment was successfully carried out [20].

Guided endodontics. In the case of challenging root canal morphologies, 3D printed virtual templates have been used to gain guided access to root canals. When other factors, such as root canal anomalies, challenge a difficult access for cavity preparation, disinfection and obturation, 3D printing creates additively-manufactured tooth model with internal root canal structures which can be used to print a guide [8]. It has been found from *in vitro* research studies that 3D template-guided endodontic procedures can provide precise access for cavity preparation up to an apical 3rd of the root. A digitally designed 3D guided access stent minimizes the chances of iatrogenic errors with minimally invasive endodontic access and fits each particular tooth [21–23].

It has been proved as new treatment strategy for root canal treatment of teeth with calcified pulp canal and apical pathology using special drills and surgical templates. Guided endodontic is a secure, predictable, quick, clinically possible technique to locate root canal and avoid perforation in teeth with pulp canal calcification thus preventing failures in these cases. Negative aspect of this technology is the space requirement for the template and difficulty in placement of instrument posteriorly. It can be used only in straight canals and up-to the straight portions of apically curved canals [1, 24].

Simulation of data from extracted tooth. With the help of CBCT data from an extracted tooth or from a patient, a clinician can provide a physical model of a tooth possessing morphology similar both externally and internally to the natural tooth for treatment planning. 3D printed models can be used for *ex vivo* study and reduce the bias resulting from use of extracted teeth. Recent 3D printing technology uses modified resin as the raw material to enhance cutting efficiency [25].

Bench manufacturing. 3D models facilitate clinicians to study the patient's tooth morphology or jaw via reconstruction, on the top of bench. This application promotes case analysis in a well-organized pattern, guided operative procedures, preclinical training methods, and facilitates preoperative planning. Other applications in endodontics include fabrication of 3D printed restorations, guided endodontic interventions, composite and ceramic aesthetic inlays and onlays. This saves time and cost since manufacturing that can be carried out in a dental laboratory is possible digitally, potentially and more consistently [26].

Increased precision of dental laboratory. 3D printing has appreciably increased quality, a success rate and precision of dental operations. Its impact on dental practice is so positive that one can operate in a quick and efficient way. Dental laboratory personnel can improve marketing strategy and increase clientele, since it will help them in comparing and selecting those dentists who are using the new technology. This allows comfortable diagnosis and faster results, compared to those using traditional technology [8].

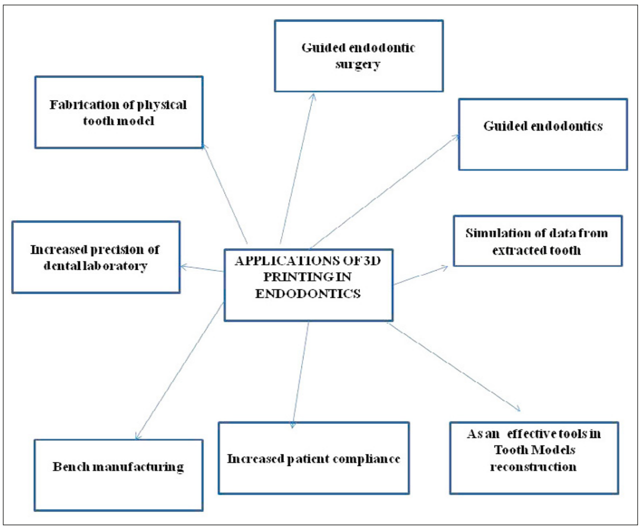

Figure 1. Applications of 3D printing in endodontics

An effective tool in Tooth Models reconstruction. 3D Printing is an effective tool in the reconstution of tooth models, especially when endodontic treatment of an atypical anterior tooth is needed. In such a case, the treatment protocol involves 3 steps: 1) data collection through CBCT (Cone Beam Computed Tomography) scanning; 2) virtual modeling by image processing; and 3) manufacturing through 3D printers [5,7].

Typodont teeth and 3D-printed tooth models. It has transformed teaching from typodont teeth to 3D-printed tooth models using computerized-tomographic images of extracted teeth, generating a natural and comfortable approach. 3D-printed models have improved the skills of an endodontist. 3D printing has versatile roles in dentistry having unlimited applications in endodontics [30].

Regenerative endodontics. In regenerative endodontics additive manufacturing saves the natural tooth without the need for replacement by prosthesis. The principle of 3D printing has various applications in the delivery of stem cells, pulp scaffolds, injectable calcium phosphates, growth factors and endodontic gene therapy [27]. A literature review has suggested that through 3D printing, several varieties of calcium phosphate cements have been developed thus generating porous scaffolds for regeneration of the pulp-dentin complex [28]. Results of *in vitro* studies have proved an improvement in osteogenic activity with the application of 3D-printed polycaprolactone coated with freeze-dried platelet-rich plasma to dental pulp cells [29]. In the scaffold based approach, tissue anatomically resembling a tooth has been created using 3D printed poly-epsilon-caprolactone and hydroxyapatite scaffolds. Bioprinting approaches have also generated using dentin-derived bionics. For scaffold-free approaches, dental pulp cell-derived spheroids have shown regenerative potential [30].

Increased patient comfort. The most important consideration in dentistry, and especially in endodontics, is patient care. 3D printing has been proven to have greater than before precision and accuracy, thereby enhancing patient comfort. 3D printing has contributed much to improve and enhance patient care, generating a patient centric approach [31].

Future aspects of 3D printing in endodontics. 3D printing has a wide role in the future advancements of surgical and non-surgical endodontics. Additive manufacturing enhances practices in endodontic training and education. [30].

3D printed models evolve into futuristic 4D printing. 4D printing could produce self-adjustable restorative materials that can avoid micro-leakage and over-hanging margins. It may produce materials with retention and better fit than conventionally used or 3D printed materials [31].

Limitations of 3D printing. Where there is scope there are also limitations:
- 3D printing requires a 3D scanner which itself is a very costly machine and beyond the scope of a normal practicing dentist.
- It is a technique sensitive procedure and requires the skills of a trained professional.
- Ethical and legal issues are worrisome.
- It is time consuming to finish the final product.
- Since 3D printing involves successive deposition of material on top of the first layer, it creates the staircase effect which causes inherent weakness [16, 32].

CONCLUSIONS

3D printing has shown its roots in research, dental treatment and education practices. This technique is not possible in every set-up as procurement and availability of skilled technicians with experience poses a major problem. Unavailability or lack of resources acts as a barrier in dentistry, especially endodontic practice.

Conflicts of interest
The authors declare there are no conflicts of interest.

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