Review Article

Three-dimensional printing in endodontics: A review of literature

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ABSTRACT

Three-dimensional (3D) printing is a fast evolving technology and is being increasingly used in dentistry. Compared to the older and traditional (lost-wax technique) methods, 3D printing has an upper hand. A wider variety of raw materials can be utilized with 3D printing. Even though this technology has been known for over 30 years, but its assimilation into practice was slow as it relied on the availability of the right materials, which give accurate prints and have optimal biocompatibility. 3D printing technology can use Cone beam computed tomography (CBCT) data for fabrication of guides used in surgical and non-surgical endodontics. This article assesses applications of 3D printing in endodontics.

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1. Introduction

3D printing is an additive manufacturing process which involves incremental deposition of material. This is an improvement from subtractive manufacturing procedures like CAD/CAM where an object is cut from a block of material.^{1,2}

Limited option of materials and orientation requirements of CAD/CAM have led to their limited use in dentistry.¹⁻³ 3D printing proves to be useful in cases where subtractive manufacturing is inadequate.

In the field of dentistry, one of the following techniques can be used for 3-D printing: stereolithography apparatus (SLA), fused deposition modelling (FDM), MultiJet printing (MJP), PolyJet printing, ColorJet printing (CJP), digital light processing (DLP) and selective laser sintering (SLS), also known as selective laser melting (SLM).^{3,4}

SLA is most commonly used in dentistry.⁴ Here, the exposure path of a UV laser is directed onto the surface of a vat of photosensitive resin. Subsequently curing starts from the bottom of the object, the layers bind together to

form a solid mass.^{1,4} FDM printing has less precision than other methods. It involves deposition of layers of molten material from a filamentous nozzle and solidification within 0.1 second.^{1,3,4} MultiJet printing and PolyJet printing take place by the spraying the polymer in very thin layers, each layer is cured after depositing onto a tray¹. CJP involves selective dispersion of binder onto layers of powder.⁴ In DLP printing, a vat of photosensitive resin is exposed to a two-dimensional image; the object is printed as the base is manipulated. The resin is cured from the bottom as the platform moves up.^{1,4} SLS and SLM printers use a computer directed laser and roller, where powdered material is dispensed in layers which are then melted or sintered.^{1,3-6}

In the 1990s, Computed Tomography (CT) was used to 3D print surgical planning models.⁷⁻⁹ When the FDA approved the first CBCT for dental use in 2000, it was found that in contrast to CT voxel, where axial height is determined by slice thickness, the CBCT voxel is cubic, allowing for higher resolution and hence more accurate measurements in multiple planes.^{1,10,11} CBCT is therefore a more precise source of data for 3D printing, and has the added advantage of reducing radiation exposure, scan time

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as well as cost.^{11,12}

1.1. Review of Endodontic Applications

A literature search of PubMed and Scopus was done with the following terms: 3D printing, stereolithography, guided endodontic access, guided endodontic surgery, surgical guide, rapid prototyping, autotransplantation rapid prototyping. Articles were included if: (i) article described an application of 3D printing in endodontics, (ii) published in English. Fifty-seven articles met inclusion criteria and were utilized. Documented solutions to endodontic challenges include: guided endodontic access, applications in autotransplantation, pre-surgical planning, and for educational models.

1.2. Guided endodontic access

Pulp canal obliteration is insinuated in up to 75% of perforations during attempted location and negotiation of calcified canals.¹³ In these cases, canals must be located in more apical portions of progressively narrowing roots.^{14–16} The risk of perforation can be reduced by producing a true path of canal access and instrumentation.

In a case series, digital impressions and CBCT scans were recorded, these were merged to form an STL (stereolithography) file showing bony architecture for teeth in cases of pulp canal obliteration in maxillary incisors. Following this, access guides were printed and used to target burs to canal spaces without creating perforations.¹⁷ Also, case reports narrating the use of 3D printed guides to access an obliterated maxillary incisor,¹⁸ a mandibular molar,¹⁹ type V dens evaginatus²⁰ and obliterated mandibular incisors²¹ establish the practicality of this approach. In ex vivo investigations of accuracy, stent guided access preparations were assessed by superimposing a post access CBCT upon a pre-operative designed access.^{22–24} The mean deviation of the access cavities were found to be lower than 0.7 mm.²² Small deviations from the intended access (0.12– 0.34 mm at the tip of the bur) and a mean angular deviation of less than 2 degrees was reported.^{23,24} These examinations demonstrate that 3D printed access guides provide an coherent and safe method for both chemo-mechanical debridement and conservation of tooth structure.

1.3. Autotransplantation

The success of this procedure is dependent on viability of periodontal ligament (PDL) cells and appropriate adaptation of the transplanted tooth to the recipient site.^{25,26} Traditionally, the donor tooth is used as a template for preparation of the recipient site, which leads to multiple adjustments to the alveolar bone and hence an increased extra-oral time and increased risk of damage to the PDL.^{25–28} Therefore, attempts have been made to improve

outcomes of autotransplantation. In two studies Computer Aided Rapid Prototyping (CARP) was used to print replicas of teeth and manipulation of the recipient bone sites was completed prior to extraction of the donor teeth.^{29,30} A number of case reports, clinical studies and in vitro studies provide evidence that preoperative CARP of transplant teeth decreases extra-oral time and improves outcomes.^{31–49} In a case report, the autotransplantation of immature premolars in a maxillary incisor avulsion case using a completely digital workflow has been described.²⁸ Here CAD was used to select the appropriate donor teeth. Prototype teeth were modified to accommodate the dimensions of Hertwig's epithelial root sheath and to minimize damage to the apical papilla. Osteotomy guides were created using the CAD software and this led to more accuracy and efficiency in the surgical procedure. In a case report, CAD was used to print surgical instruments customized for the transplanted tooth, achieving an apical deviation of less than 1mm from the planned final tooth position in a human mandible.⁴⁵ A systematic review has reported an overall success rate of 80-91% when rapid prototyping was used, leading to a reduction in extra-oral time to less than one minute in some cases.²⁶

1.4. Surgical guides

In clinical scenarios it is difficult to gauge the right orientation, angulation and depth. Due to advancements in magnification, equipment and materials, endodontic microsurgery (EMS) has been accepted as a predictable procedure,^{50–52} also targeted osteotomy and root end resection is a pre-requisite for EMS. Osteotomy diameter can be as small as 3 mm, which has been correlated with shorter healing time, decreased postoperative pain, and improved outcomes.^{50,53} Clinicians often find it difficult to carry out procedures in posterior molar area or if important anatomic structures are close to the root end. 3D printed stents can reduce the risk by avoiding invasion of neurovascular structures.

It has been reported that guides designed from CBCT produced more accurate osteotomies than the traditional free-hand technique in an in vitro model.⁵⁴ Case reports have described the use of a 3D printed guide for traditional root-end surgery,⁵⁵ as well as for designing a stent defining the upper and lower margins of the osteotomy, as well as the root resection site and angulation, resulting in increased clinical efficiency and precision, minimizing risk of sinus perforation.⁵⁶ Use of a 3D printed custom tissue retractor to enhance visualization and soft tissue handling during EMS on a maxillary incisor has also been described.⁵⁷

Table 1:

Endodontic Application	Teeth/ material studied	Author/year	Type of study	3D printer
Guided Endodontic Access	Not stated	Van der Meer WJ et al. 2016 ¹⁷	Case series	Not stated
Guided Endodontic Access	Maxillary incisor	Krastl G et al. 2016 ¹⁸	Case report	PolyJet
Guided Endodontic Access	Mandibular molar	Shi X et al. 2017 ¹⁹	Case report	MJP
Guided Endodontic Access	Type V dens evaginatus	Mena-Alvarez J et al. 2017 ²⁰	Case report	SLA
Guided Endodontic Access	Mandibular incisors	Connert T et al. 2018 ²¹	Case report	PolyJet
Guided Endodontic Access	48 extracted Teeth (undisclosed)	Buchgreitz J et al. 2016 ²²	Ex vivo study	Not stated
Guided Endodontic Access	60 single Rooted human teeth	Zehnder MS et al. 2016 ²³	Ex vivo study	PolyJet
Guided Endodontic Access	60 mandibular anterior teeth	Connert T et al. 2017 ²⁴	Ex vivo study	PolyJet
Tooth autotransplantation	Mandibular third molar	Lee S-J et al. 2001 ²⁹	Case series	Not stated
Tooth autotransplantation	Third molars	Lee S-J et al. 2012 ³⁰	Case series	Not stated
Tooth autotransplantation	Immature premolar	Keightley A et al. 2010 ³¹	Case report	CJP
Tooth autotransplantation	Right Mandibular Third molar	Honda M et al. 2010 ³²	Case report	Not stated
Tooth autotransplantation	Maxillary left Second premolar	Pang NS et al. 2010 ³³	Case report	Not stated
Tooth autotransplantation	Premolar and Third molar	Shahbazian M et al. 2010 ³⁴	Pre-clinical	SLA
Tooth autotransplantation	Undisclosed	Shahbazian M et al. 2012 ³⁵	Case report	SLA
Tooth autotransplantation	Mandibular Right third molar	Park Y-S et al. 2012 ³⁶	Case report	Not stated
Tooth autotransplantation	Mandibular Second premolar	Park Y-S et al. 2013 ³⁷	Case Report	Not stated
Tooth autotransplantation	Immature Third molars	Jang J-H et al. 2013 ³⁹	Case series	Not stated
Tooth autotransplantation	Mesiodens	Lee Y et al. 2014 ⁴⁰	Case report	Not stated
Tooth autotransplantation	Third molar	Park J-M et al. 2014 ⁴¹	Case report	PolyJet
Tooth autotransplantation	Maxillary left Central incisor	Vandekar M et al. 2015 ⁴²	Case report	DLP
Tooth autotransplantation	Maxillary Right second premolar	Van der Meer WJ et al. 2016 ⁴³	Case report	Not stated
Tooth autotransplantation	Mandibular premolars	Khalil W et al. 2016 ⁴⁴	In vitro study	PolyJet
Tooth autotransplantation	Mandibular Left canine	Anssari Moin D et al. 2016 ⁴⁵	Ex vivo	Not stated

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Table 1 continued

Tooth autotransplantation	Mandibular Incisors, canines, premolars	Anssari Moin D et al. 2017 ⁴⁶	Ex vivo	Not stated
Tooth autotransplantation	Maxillary Second premolar	Cousley RRJ et al. 2017 ⁴⁷	Case report	CJP
Tooth autotransplantation	Maxillary Right canine	Kim MS et al. 2017 ⁴⁸	Case report	Not stated
Tooth autotransplantation	Third molar	Verweij JP et al. 2017 ⁴⁹	Systematic review	Not stated
Guided EMS	All mandibular teeth	Pinsky HM et al. 2007 ⁵⁴	Pre-clinical	Not stated
Guided apicoectomy	Mandibular Right premolar	Liu Y et al. 2014 ⁵⁵	Case report	PolyJet
Surgical guides	Maxillary central incisor	Strbac GD et al. 2016 ⁵⁶	Case report	PolyJet
EMS soft tissue retraction	Maxillary left central incisor	Patel S et al. 2017 ⁵⁷	Case report	Not stated
Simulation exercises	Right Maxillary central incisor	Kfir A et al. 2013 ⁵⁸	Case report	PolyJet
Pre-treatment simulation	Mandibular second molar and paramolar	Kato H et al. 2015 ⁵⁹	Case report	FDM
Research simulation	Mandibular Molar replicas	Marending M et al. 2016 ⁶⁰	Pre-clinical	Not stated
Research simulation	Replicas of teeth extracted for orthodontic, periodontic or prosthetic reasons	Robberecht L et al. 2017 ⁶¹	Pre-clinical	SLA
Research simulation	Replicas of mandibular molars	Ordinola-Zapata R et al. 2014 ⁶²	Pre-clinical	MJP
Research simulation	Mandibular Second premolar	Eken R et al. 2016 ⁶³	Pre-clinical	PolyJet
Research simulation	Resin models of maxillary central incisors	Yahata Y et al. 2017 ⁶⁴	Pre-clinical	MJP
Research simulation	Replicas of mandibular molars	Gok T et al. 2017 ⁶⁵	Pre-clinical	DLP
Research simulation	Sheets of Photopolymer material	Mohammed SA et al. 2017 ⁶⁶	In vitro	SLA

1.5. Educational models and clinical simulation

Most dental educational institutes use extracted teeth, human cadavers, or commercially available resin teeth for preclinical exercises.^{67,68} Though extracted teeth can provide a clinical simulation close to reality, but it is difficult to find teeth with the required properties and disinfection, storage etc. can change the properties. Commercially available resin teeth are an alternative to the natural dentition but can be expensive.

Tooth prototypes can be used for simulation exercises and have multiple benefits over extracted teeth.^{58–61,69} Earlier CT slices and starch were used to reconstruct exigent clinical cases such as extracanal invasive resorption⁷⁰ and a molar with three distal roots.⁷¹ In a case report clear tooth replica was used to simulate ideal access, instrumentation and obturation preoperatively in a complex type 3 dens invaginatus scenario, before treating the clinical case.⁵⁸ In an evaluation of dental student file preferences, commercially available 3D printed molar replicas (RepliDens, Zurich, Switzerland) were used to avoid variance in initial canal configuration⁶⁰. A porous, radiopaque hydroxyapatite-based matrix with hardness similar to dentin to print ceramic models for endodontic lab exercises has been developed.⁶¹

3D printing can be used to manufacture a large number of identical prototypes and hence can be utilized in pre-clinical research. Variables like the shaping ability⁶² and stress values⁶³ of different rotary file systems, centering ability of access preparations⁶⁴ and different obturation techniques for C-shaped canals⁶⁵ have been investigated with uniformly controlled canal configurations. Growth of *Enterococcus faecalis* biofilms on SLA materials comparable to dentin has been demonstrated and subsequently this was applied in vitro model to evaluate irrigation techniques.⁶⁶

2. Conclusion

The literature on use of Three-dimensional printing in Endodontics is limited to case reports and pre-clinical studies. Also, acquiring technical expertise within endodontic practices is an obstacle to its widespread use. Hence, consideration should be given to include 3D printing within the curriculum. More studies need to be done at a larger scale with long term follow ups which will help endodontists in making informed decisions regarding the use of this technique in clinical practice.

3. Conflict of Interest

The author declares no potential conflicts of interest with respect to research, authorship, and/or publication of this article.

4. Source of Funding

None.

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