Content available at: https://www.ipinnovative.com/open-access-journals

IP Indian Journal of Conservative and Endodontics

Journal homepage: https://www.ijce.in/

Review Article

Three-dimensional printing in endodontics: A review of literature

Jyoti Chauhan[1,*], Ida de Noronha de Ataide[1], Marina Fernandes[1]

[1]Dept. of Conservative Dentistry and Endodontics, Goa Dental College and Hospital, Bambolim, Goa, India

ARTICLE INFO

Article history:
Received 17-09-2021
Accepted 23-11-2021
Available online 28-12-2021

Keywords:
CBCT
DLP
FDM

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 biocompatibity. 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.

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 tray[1]. 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

* *Corresponding author.*
E-mail address: jyotiichauhan93@gmail.com (J. Chauhan).

https://doi.org/10.18231/j.ijce.2021.044

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 incuded 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 evaginatus[20] and obliterated mandibular incisors[21] 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

Continued on next page

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 apicoectoectomy	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	Mohmmed 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 resorption[70] 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 configuration[60]. 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 ability[62] and stress values[63] of different rotary file systems, centering ability of access preparations[64] and different obturation techniques for C-shaped canals[65] 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.

References

1. Noort R. The future of dental devices is digital. *Dent Mater*. 2012;28(1):3–12.
2. Abduo J, Lyons K, Bennamoun M. Trends in computer-aided manufacturing in prosthodontics: a review of the available streams. *Int J Dent*. 2014;p. 783948. doi:10.1155/2014/783948.
3. Torabi K, Farjood E, Hamedani S. Rapid prototyping technologies and their applications in prosthodontics, a review of literature. *J Dent*. 2015;16(1):1–9.
4. Kim GB, Lee S, Kim H. Three-dimensional printing: basic principles and applications in medicine and Radiology. *Korean J Radiol*. 2016;17(2):182–97. doi:10.3348/kjr.2016.17.2.182.
5. Atta T. Comparison between Selective Laser Melting (SLM) and Selective Laser Sintering (SLS) ; 2016. Available from: http://www.mechanic.com/2016/12/comparison-between-selective-laser.html.
6. Buican GR, Oancea G, Martins RF. Study on SLM manufacturing of teeth used for dental tools testing. In: MATEC Web of Conferences. vol. 94; 2017. p. 1.
7. Mankovich NJ, Cheeseman AM, Stoker NG. The display of two contemporary rotary systems in a preclinical student course setting. *Int End J*. 1990;.
8. Bill JS, Reuther JF, Dittman W, Kubler N, Meier JL, Pistner H. Stereolithography in oral and maxillofacial operation planning. *Int J Oral Maxillofac Surg*. 1995;24(1 Pt 2):98–103. doi:10.1016/s0901-5027(05)80869-0.
9. Erickson DM, Chance D, Schmitt S, Mathis J. An opinion survey of reported benefits from the use of stereolithographic models. *J Oral Maxillofac Surg*. 1999;57(9):1040–3. doi:10.1016/s0278-2391(99)90322-1.
10. Danforth RA. Cone beam volume tomography: a new digital imaging option for dentistry. *J Calif Dent Assoc*. 2003;31(11):814–5.
11. Cotton TP, Geisler TM, Holden DT, Schwartz SA, Schindler. Endodontic applications of cone-beam volumetric tomography. *J Endod*. 2007;33(9):1121–32.
12. Scarfe WC, Farman AG, Sukovic P. Clinical applications of cone-beam computed tomography in dental practice. *J Can Dent Assoc*. 2006;72(1):75–80.
13. Kvinnsland I, Oswald RJ, Halse A, Gronningsaeter AG. A clinical and roentgenological study of 55 cases of root perforation. *Int Endod J*. 1989;22(2):75–84.
14. Delivanis HP, Sauer G. Incidence of canal calcification in the orthodontic patient. *Am J Orthod*. 1982;82(1):58–61.
15. Sener S, Cobankara FK, Akgünlü F. Calcifications of the pulp chamber: prevalence and implicated factors. *Clin Oral Investig*. 2009;13(2):209–15.
16. Mccabe PS, Dummer P. Pulp canal obliteration: an endodontic diagnosis and treatment challenge. *Int Endod J*. 2012;45(2):177–97.
17. Van Der Meer WJ, Vissink A, Ng YL, Gulabivala K. 3D Computer aided treatment planning in endodontics. *J Dent*. 2016;45:67–72. doi:10.1016/j.jdent.2015.11.007.
18. Krastl G, Zehnder MS, Connert T, Weiger R. Guided endodontics: a novel treatment approach for teeth with pulp canal calcification and apical pathology. *Dent Traumatol*. 2016;32(3):240–6.
19. Shi X, Zhao S, Wang W, Jiang Q, Yang X. Novel navigation technique for the endodontic treatment of a molar with pulp canal calcification and apical pathology. *Aust Endod J*. 2018;44(1):66–70.
20. Mena-Alvarez J, Rico-Romano C, Lobo-Galindo AB, Zubizarreta-Macho A. Endodontic treatment of dens evaginatus by performing a splint guided access cavity. *J Esthet Restor Dent*. 2017;29(6):396–402.
21. Connert T, Zehnder MS, Amato M, Weiger R, Kühl S, Krastl G, et al. Microguided endodontics: a method to achieve minimally invasive access cavity preparation and root canal location in mandibular incisors using a novel computer-guided technique. *Int Endod J*. 2018;51(2):247–55.

22. Buchgreitz J, Buchgreitz M, Mortensen D, Bjørndal L. Guided access cavity preparation using cone-beam computed tomography and optical surface scans - an ex vivo study. *Int Endod J*. 2016;49(8):790–5.
23. Zehnder MS, Connert T, Weiger R, Krastl G, Kühl S. Guided endodontics: accuracy of a novel method for guided access cavity preparation and root canal location. *Int Endod J*. 2016;49(10):966–72.
24. Connert T, Zehnder MS, Weiger R, Kühl S, Krastl G. Microguided endodontics: accuracy of a miniaturized technique for apically extended access cavity preparation in anterior teeth. *J Endod*. 2017;43(5):787–90.
25. Tsukiboshi M. Autotransplantation of teeth: requirements for predictable success. *Dent Traumatol*. 2002;18(4):157–80.
26. Verweij JP, Jongkees FA, Moin DA, Wismeijer D, Van Merkesteyn J. Autotransplantation of teeth using computer-aided rapid prototyping of a three-dimensional replica of the donor tooth: systematic literature review. *Int J Oral Maxillofac Surg*. 2017;46(11):1466–74.
27. Kim E, Jung JY, Cha IH, Kum KY, Lee SJ. Evaluation of the prognosis and causes of failure in 182 cases of autogenous tooth transplantation. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2005;100(1):112–9. doi:10.1016/j.tripleo.2004.09.007.
28. Strbac GD, Schnappauf A, Giannis K, Bertl MH, Moritz A, Ulm C, et al. Guided autotransplantation of teeth: a novel method using virtually planned 3-dimensional templates. *J Endod*. 2016;42(12):1844–50.
29. Lee SJ, Jung IY, Lee CY, Choi SY, Kum KY. Clinical application of computer-aided rapid prototyping for tooth transplantation. *Dent Traumatol*. 2001;17(3):114–9.
30. Lee SJ, Kim E. Minimizing the extra-oral time in autogeneous tooth transplantation: use of computer-aided rapid prototyping (CARP) as a duplicate model tooth. *Restor Dent Endod*. 2012;37(3):136–41.
31. Keightley A, Cross DL, Mckerlie RA, Brocklebank L. Autotransplantation of an immature premolar, with the aid of cone beam CT and computer-aided prototyping: a case report. *Dent Traumatol*. 2010;26(2):195–9.
32. Honda M, Uehara H, Uehara T. Use of a replica graft tooth for evaluation before autotransplantation of a tooth. A CAD/CAM model produced using dental-cone-beam computed tomography. *Int J Oral Maxillofac Surg*. 2010;39(10):1016–9. doi:10.1016/j.ijom.2010.06.002.
33. Pang NS, Choi YK, Kim KD, Park W. Autotransplantation of an ectopic impacted premolar with sinus lift and allogenic bone graft. *Int Endod J*. 2011;44(10):967–75.
34. Shahbazian M, Jacobs R, Wyatt J. Accuracy and surgical feasibility of a CBCT-based stereolithographic surgical guide aiding autotransplantation of teeth: in vitro validation. *J Oral Rehabil*. 2010;37(11):854–9.
35. Shahbazian M, Wyatt J, Willems G, Jacobs R. Clinical application of a stereolithographic tooth replica and surgical guide in tooth autotransplantation: A case study is presented of the use of a stereolithography-fabricated model donor tooth and several guides to facilitate pre-operative planning as well as surgery in the case of tooth auto transplantation in a 10-year old child. Virtual and Physical Prototyping. 2012;7(3):1–8. doi:10.1080/17452759.2012.711681.
36. Park YS, Baek SH, Lee WC, Kum KY, Shon WJ. Autotransplantation with simultaneous sinus floor elevation. *J Endod*. 2012;38(1):121–4.
37. Park YS, Shon JMH, J W. Autotransplantion of a displaced mandibular second premolar to its normal position. *Am J Orthod Dentofacial Orthop*. 2013;143(2):274–80.
38. Cross D, El-Angbawi A, Mclaughlin P. Developments in autotransplantation of teeth. *Surgeon*. 2013;11(1):49–55.
39. Jang JH, Lee SJ, Kim E. Autotransplantation of immature third molars using a computer-aided rapid prototyping model: A report of 4 cases. *J Endod*. 2013;39(11):1461–6.
40. Lee Y, Chang SW, Perinpanayagam H. Autotransplantation of mesiodens for missing maxillary lateral incisor with cone-beam CT-fabricated model and orthodontics. *Int Endod J*. 2014;47(9):896–904.
41. Park JM, Tatad J, Landayan M, Heo SJ, Kim SJ. Optimizing third molar autotransplantation: Applications of reverse-engineered surgical templates and rapid prototyping of three-dimensional teeth. *J Oral Maxillofac Surg*. 2014;72(9):1653–59.
42. Vandekar M, Fadia D, Vaid NR, Doshi V. Rapid protoyping as an adjunct for autotransplantation of impacted teeth in the esthetic zone. *J Clin Orthod*. 2015;49(11):711–5.
43. Van Der Meer WJ, Jansma J, Delli K, Livas C. Computer-aided planning and surgical guiding system fabrication in premolar autotransplantation: a 12-month follow up. *Dent Traumatol*. 2016;32(4):336–40.
44. Khalil W, Ezeldeen M, Van De Casteele E. Validation of cone beam computed tomography-based tooth printing using different three-dimensional printing technologies. *Oral Surg Oral Med Oral Pathol Oral Radiol*. 2016;121(3):307–15.
45. Moin DA, Derksen W, Verweij JP, Van Merkesteyn R, Wismeijer D. A novel approach for computer-assisted template-guided autotransplantation of teeth with custom 3D designed/printed surgical tooling. An ex vivo proof of concept. *J Oral Maxillofac Surg*. 2016;74(5):895–902.
46. Moin DA, Verweij JP, Waars H, Van Merkesteyn R, Wismeijer D. Accuracy of computer assisted template-guided autotransplantation of teeth with custom three-dimensional designed/printed surgical tooling: a cadaveric study. *J Oral Maxillofac Surg*. 2017;75(5):925.e1–7.
47. Cousley RRJ, Gibbons A, Nayler J. A 3D printed surgical analogue to reduce donor tooth trauma during autotransplantation. *J Orthod*. 2017;44(4):287–93.
48. Kim MS, Lee HS, Ho N, Choi SC. Autotransplantation: a reliable treatment modality for severely malpositioned teeth. *J Clin Pediatr Dent*. 2017;41(5):388–91.
49. Verweij JP, Moin DA, D W, Van Merkesteyn J. Replacing heavily damaged teeth by third molar autotransplantation with the use of cone-beam computed tomography and rapid prototyping. *J Oral Maxillofac Surg*. 2017;75(9):1809–16.
50. Kim S, Kratchman S. Modern endodontic surgery concepts and practice: a review. *J Endod*. 2006;32(7):601–23.
51. Tsesis I, Rosen E, Schwartz-Arad D, Fuss Z. Retrospective evaluation of surgical endodontic treatment: traditional versus modern technique. *J Endod*. 2006;32(5):412–6.
52. Tsesis I, Rosen E, Taschieri S, Strauss YT, Ceresoli V, Fabbro MD, et al. Outcomes of surgical endodontic treatment performed by a modern technique: An updated meta-analysis of the literature. *J Endod*. 2013;39(3):332–9.
53. Arx TV, Hänni S, and SSJ. Correlation of bone defect dimensions with healing outcome one year after apical surgery. *J Endod*. 2007;33(9):1044–8.
54. Pinsky HM, Champleboux G, Sarment DP. Periapical surgery using CAD/CAM guidance: preclinical results. *J Endod*. 2007;33(2):148–51.
55. Liu Y, Liao W, Jin G, Yang Q, Peng W. Additive manufacturing and digital design assisted precise apicoectomy: a case study. *Rapid Prototyping J*. 2014;20(1):33–40. doi:10.1108/RPJ-06-2012-0056.
56. Strbac GD, Schnappauf A, Giannis K, Bertl MH, Moritz A, Ulm C, et al. Guided autotransplantation of teeth: a novel method using virtually planned 3-dimensional templates. *J Endod*. 2016;42(12):1844–50.
57. Patel S, Aldowaisan A, Dawood A. A novel method for soft tissue retraction during periapical surgery using 3D technology: a case report. *Int Endod J*;50(8):813–22.
58. Kfir A, Telishevsky-Strauss Y, Leitner A, Metzger Z. The diagnosis and conservative treatment of a complex type 3 dens invaginatus using cone beam computed tomography (CBCT) and 3D plastic models. *Int Endod J*. 2013;46(3):275–88.
59. Kato H, Kamio T. Diagnosis and endodontic management of fused mandibular second molar and paramolar with concrescent supernumerary tooth using cone-beam CT and 3-D printing technology: a case report. *Bull Tokyo Dent Coll*. 2015;56(3):177–84.
60. Marending M, Biel P, Attin T, Zehnder M. Comparison of two contemporary rotary systems in a pre-clinical student course setting. *Int Endod J*. 2015;49(6):591–8.

61. Robberecht L, Chai F, Dehurtevent M. A novel anatomical ceramic root canal simulator for endodontic training. *Eur J Dent Educ*. 2017;21(4):e1–6.
62. Ordinola-Zapata R, Bramante CM, Duarte M, Cavenago BC, Jaramillo D, Versiani MA, et al. Shaping ability of Reciproc and TF Adaptive systems in severely curved canals of rapid micro CT based prototyping molar replicas. *J Appl Oral Sci*. 2014;22(6):509–15.
63. Eken R, Sen OG, Eskitascioglu G, Belli S. Evaluation of the effect of rotary systems on stresses in a new testing model using a 3-Dimensional printed simulated resin root with an oval shaped canal: a finite element analysis study. *J Endod*. 2016;42(8):1273–8.
64. Yahata Y, Masuda Y, Komabayashi T. Comparison of apical centering ability between incisal shifted access and traditional lingual access for maxillary anterior teeth. *Aust Endod J*. 2017;43(3):123–8.
65. Gok T, Capar ID, Akcay I, Keles A. Evaluation of different techniques for filling simulated C-shaped canals of 3-dimensional printed resin teeth. *J Endod*. 2017;43(9):1559–64.
66. Mohmmed SA, Vianna ME, Hilton ST, Boniface DR, Ng YL, Knowles JC, et al. Investigation to test potential stereolithography materials for development of an in vitro root canal model. *Microsc Res Tech*. 2016;80(2):202–10. doi:10.1002/jemt.22788.
67. Spenst A, Kahn H. The use of a plastic block for teaching root canal instrumentation and obturation. *J Endod*. 1979;5(9):282–4.
68. Nassri MRG, Carlik J, Silva CD, Okagawa RE, Lin S. Critical analysis of artificial teeth for endodontic teaching. *J Appl Oral Sci*. 2008;16(1):43–9.
69. Bahcall JK. Using 3-dimensional printing to create presurgical models for endodontic surgery. *Compend Contin Educ Dent*. 2014;35(8):29–30.
70. Kim E, Kim KD, Roh BD, Cho YS, Lee SJ. Computed tomography as a diagnostic aid for extracanal invasive resorption. *J Endod*. 2003;29(7):463–5.
71. Lee SJ, Jang KH, Spangberg LSW. Three-dimensional visualization of a mandibular first molar with three distal roots using computer-aided rapid prototyping. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2006;101(5):668–74. doi:10.1016/j.tripleo.2005.06.013.

Author biography

Jyoti Chauhan, Post Graduate Student

Ida de Noronha de Ataide, Professor and HOD

Marina Fernandes, Professor

Cite this article: Chauhan J, Ataide IN, Fernandes M. Three-dimensional printing in endodontics: A review of literature. *IP Indian J Conserv Endod* 2021;6(4):198-204.