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Implications of Artificial intelligence in the form of 3D-printing in Endodontics: A Review

Abstract: - Three-dimensional (3D) printing has become an emerging technology in dentistry, and specifically in endodontics. This technology enables the creation of highly accurate and patient-specific 3D models, surgical guides, and custom-made instruments that have revolutionized endodontic treatment. This abstract provides an overview of the applications of 3D printing in endodontics, including preoperative planning, fabrication of surgical guides, production of custom-made instruments, and postoperative evaluation. The accuracy and precision of 3D-printed models have shown to improve the quality of endodontic treatment and reduce the risk of complications. The creation of new dental models is made possible by three-dimensional printing. 3D-printed teeth have been used in a lot of studies, however standards for standardised research are still being created. Although they have significant disadvantages, using real teeth is still the norm in ex vivo investigations and pre-clinical training. All the restrictions of natural teeth may be overcome by printed teeth. Printing technology uses 3D data and post-processing tools to create a 3D model, which is then used by 3D printers to create a prototype. The hardness of the resin and the correctness of the canal anatomy printing are the main issues with 3D-printed teeth. Future research is given direction in order to address the issues with 3D-printed teeth and create defined protocols in order to attain method standardisation. In the future, ex vivo investigations and endodontic training could use 3D-printed teeth as the gold standard. Furthermore, 3D printing has also facilitated communication between the dental team and the patient, leading to a better understanding of the treatment plan and enhancing the patient experience. This review intends to gather information regarding 3D-printed teeth on the following themes: (1) their benefits; (2) their manufacturing processes; (3) their issues; and (4) potential future research topics. In conclusion, 3D printing has the potential to enhance the accuracy and efficiency of endodontic treatment and improve clinical outcomes.

Keywords: 3D printing, Cone Beam Computed Tomography (CBCT), Endodontics, Artificial Intelligence (AI)

I. INTRODUCTION

Endodontics is a specialized branch of dentistry that involves the study and treatment of dental pulp and surrounding tissues. One of the latest technologies to emerge in this field is 3D printing. Customized dental appliances are precisely made using 3D printing technology and computer-aided design (CAD) software.

3D printing has been used in many aspects of dentistry, such as orthodontics, prosthodontics, and restorative dentistry. However, its use in endodontics is relatively new. 3D printing is an effective method for creating models and guides to assist endodontic procedures. 3D printing can be used to make templates for root canal treatment. These templates can be made to fit the unique anatomy of a patient’s mouth, allowing for more accurate and successful treatments. 3D printing technology is also used in making surgical guides for endodontic surgeries. These guides assist endodontists in navigating and reaching the affected area more precisely. They allow for a better understanding of the surgical site and hence, improve overall outcomes.

Additionally, 3D printing can be used to create physical replicas of a patient’s tooth for educational and training purposes. These models can be used to demonstrate the different stages of endodontic procedures.

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Technology has advanced since Charles (Chuck) Hull created the first 3D printing systems in 1984 up to the latest bioprinting technologies. Dental additive manufacturing is currently rising quickly in popularity.

ADDITIVELY MANUFACTURED DRIVEN WORKFLOW-

To create a workflow that is driven by additive manufacturing (Figure 1), all three of the fundamental technologies that make up the digital inventory must be accessible.

- 3D image acquisition using optical scanners, such as intraoral impression scanners, intraoral scan, cone beam computed tomography CT (CBCT). (1-3)
- A computer program for converting output files from scanners that provide data for DICOM (digital imaging and communications in medicine) into printable formats, such as STL files (standard tessellation language). (4-6)
- 3D printing system

Figure 1: Widely used 3D printers work using five basic mechanisms

Fused deposition modelling (FDM) **or** **Fused Filament Fabrication (FFF)**	• One of the earliest 3D printing technologies • Extrusion-based. Heat is applied to a thermoplastic material, such as ABS (acrylonitrile-butadiene-styrene), which is then extruded through a nozzle in the print head. • Affordable printing equipment and material costs.
Selective Laser sintering **(SLS)**	• Powder bed fusion technology used in SLS systems. • A laser is utilized, which the powder absorbs. This causes local heating, which causes the powder to melt and solidify at the area. • This technology's advantages include the isotropy of the printed objects and extremely high printing precision.
Stereolithography (SLA) **or** **Digital Light Processing (DLP)**	• Uses vat polymerization, which prints an object layer by layer by using light to polymerize the liquid resin in a tank. • DLP applies a voxel-based projector while SLA utilizes a point light beam, giving DLP a speed advantage.
Poly-jet printing	• Builds up the object by jetting layers at a time with liquid components that are subsequently polymerized by UV light. • Also, accuracy is the highest of all printing technologies.
Bioprinting	• Designed for the printing of products with living cells. • used in research to make complex in vitro models for tissue engineering methods.

POSTPROCESSING

- After printing, the gluing traces as well as the print waviness and other flaws can be eliminated. Models must be cleaned, dried, taken out of the support structure, and post cured using UV light curing equipment after printing. (Figure 2)

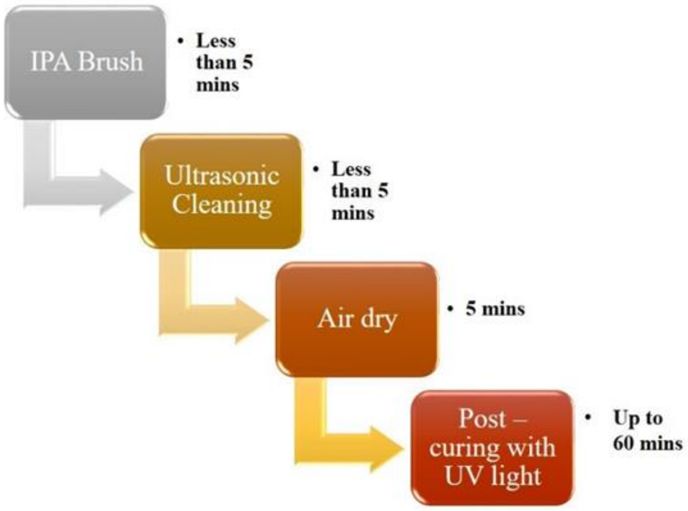

Figure 2: Postprocessing

THE USES OF 3D PRINTED TEMPLATES AND MODELS IN ENDODONTICS:

- Patient Education
- To Understand Internal Complex Anatomy of the Root Canal/Surrounding Area
- Using clear tooth technology for preclinical work
- Guided Access Cavity Preparation for calcified tooth
- As Simulator
- For Research Purpose
- As surgical guide/Reflector
- For Auto-transplantation (7)

3D printed models

Plaster models are used to create custom guides or splints, retain records, assess potential treatment challenges, and as teaching aids for patients and students. Plaster models cannot, however, accurately mimic the internal anatomical features because they can't be made with distinct colors, textures, and levels of transparency.

Models created using 3D printing can fulfill the similar functions of plaster models and get over the aforementioned shortcomings. The file is simple to duplicate, store, and transmit electronically. Models can be produced in a variety of textures, colors, transparencies, and mechanical qualities appropriate for sterilization or simulation. Plaster models and 3D printed models offer similar levels of accuracy. The models can also be coloured differently during production or stained to help distinguish between various tissue types. (8)

Dental students can learn more about tooth, root, and canal morphology and practice accessing cavities and preparing root canals using 3D-printed models. PBP-produced and 3D-printed models with resin infusion have a bone-like texture and may be the best choice for practicing osteotomies. Therefore, the undergraduate students can utilise these models as a teaching tool to simulate surgical procedures. The validity and reproducibility of measurements on sterolithographic models and 3D digital dental models created using intraoral scanner were established in an article by Anne Margeet et al. (2012). (9)

Monitoring the health effects of employing 3D printed models for simulated activities is necessary due to the potential exposure to chemicals and dust. Studies will be required to determine the safety of using 3D printed models in managing and teaching endodontic treatments in addition to their accuracy. (8)

II. 3D PRINTED GUIDES

A 3D endodontic guide, also known as an endoguide, is used to plan and visualize the location, length, and shape of the root canal(s) before the actual procedure is performed. This helps the dentist to identify any potential complications and avoid unnecessary damage to the tooth or surrounding structures. The 3D endodontic guide can also be used during the root canal procedure to ensure that the dentist is accurately positioning the instruments within the tooth, minimizing the risk of perforation or over-instrumentation. Overall, the use of a 3D endodontic guide can help to improve the accuracy and efficiency of root canal therapy, leading to better outcomes for patients.(10) Two categories of clinical cases, including cracked teeth and tooth decay, were reported in case series by Juan Xia et al. (2018). In both cases, the direct epoxy composite restoration of the maxillary anterior teeth was carried out using a 3D-printed guide. With the help of the 3D-printed guide, the maxillary incisors were aesthetically restored and the desired outcomes were obtained.(11) (Figure 3)

Figure 3: Types of Endodontic Templates

Depending on their application in endodontic therapy:

Non-surgical Endodontics Templates	Surgical Endodontics Templates
• Used to find calcified canals or apically extended access opening cavities	• Used for root end resection procedures
• Tooth supported templates (Rests over dentition of the patient)	• Bone supported templates (Rests on bone surface after flap reflection eg. template for cortical, bone trephination and root end resection.

Figure 3: Types of Endodontic Templates [10]

STEPS TO PLAN AND DESIGN 3D GUIDE:

A. CBCT Scan of the Affected Tooth

Obtain a high-resolution, confined field-of-view CBCT scan. (Figure 4) Scanning requires standard exposure conditions, minimum movement of patient, limited slice thickness, and minimal artefacts. For the guide to sit firmly on the tooth during scanning, it is important that the tooth has a smooth surface.

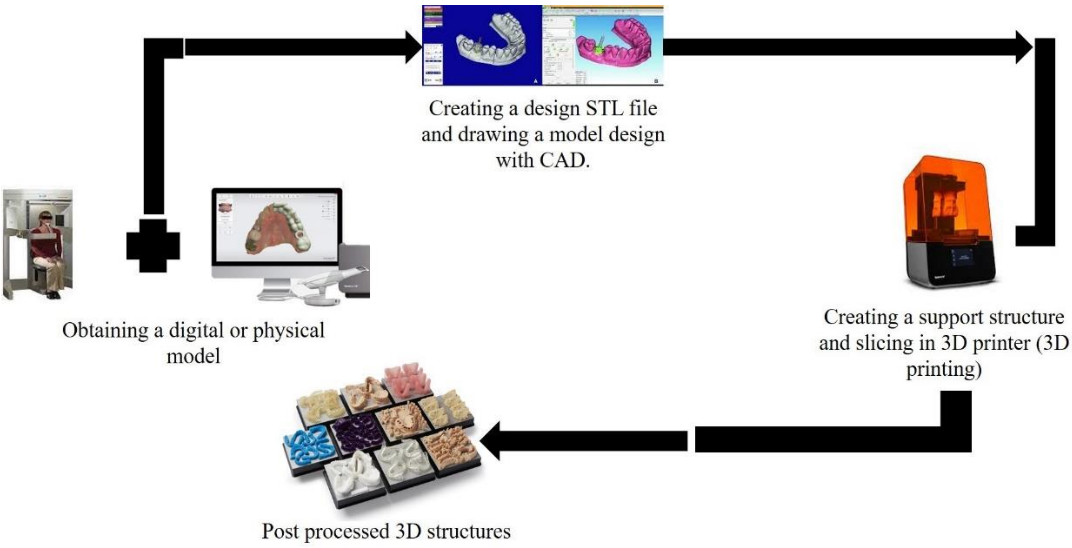

Figure 4: 3D Guide Planning and Designing [10]

B. The Surface Scan

All tooth surfaces and soft tissue surfaces should be recorded in detail. If an intraoral scanner is available, the patient's tooth arch can be scanned either immediately at the chairside or indirectly by scanning a model made from an impression. For the guide to be supported adequately, the scan must incorporate at least one dental arch quadrant.

C. Combining the CBCT scan and surface scan

The software needs to work with the CBCT scan program. Although many manufacturers claim that their open source system operates without issues, it is best to observe the systems in operation before making any investment.

The safest and easiest method is to have the surface scanner and CBCT scanner come from the same manufacturer, but this seldom happens because the surface scanner or CBCT scanner is frequently purchased for a different reason than guided endodontics.

For precision and fit of the guide, overlapping of CBCT data and surface scan is absolutely essential. During this stage, 3-6 points are highlighted on each scan file, and the software then automatically merges the two images.

The software allows you to merge the scans by displaying them side by side and placing markers on the appropriate spots. Analyze image superimposition for precise planning.

D. Designing of Endodontic Guide

- Tracing the Canal

For anterior teeth, where there is typically no curvature, it is simple to trace and select cases for guided endodontics. Guided access is only possible up to the first curve in canals featuring curves. The law of canal centrality should be applied during planning if the canal is not clear on the CBCT scan.

- Creating Virtual Drill Path

The following factors should be taken into consideration while designing the virtual drill path for the endodontic guide. The drill path should proceed from the tooth's incisal surface to a target site where it is assumed that a pulp space exists.

Different processes may be possible depending on the software, however the following general considerations must be made:

1. The target spot

2. The angle of the drill path in all dimensions

3. The drill’s diameter

E. The Target Spot

The target spot must be the area of the pulp canal space that is first visible. The axial view of the CBCT can be employed when the remaining root canal material is at the middle of the root's periphery. This is only relevant to teeth with a single root canal. It can be assumed that the root has more than one canal if the root's periphery exhibits concavities that indicate the presence of dividing structures. (Figure 5a)

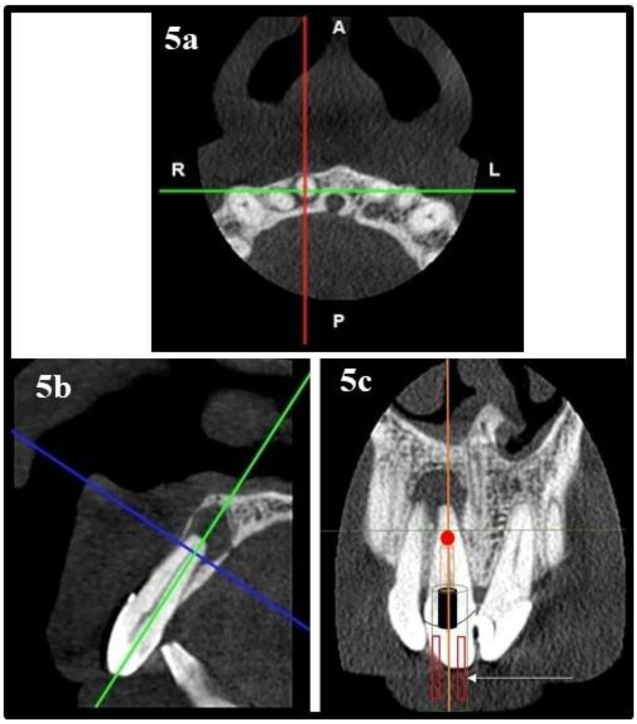

Figure 5: Designing of Endodontic Guide- a) Axial view of the CBCT; b)Tracing the Canal; c) Creating Virtual Drill Path [10]

F. The Angle of the Drill Path

The ideal virtual route angle ensures that the drilling path from the target point to the entrance point, stays in the root's axis and that the drilling reaches the root canal space, preferably short of the target site. Even if it turns out that it is essential to drill beyond the target point because the canal cannot be explored, the drill will remain in the root's axis and lessen the chance of perforations. A drill path frequently interferes with the incisal edge when it is placed in the axis of an incisor, causing unnecessary damage to the tooth. In these circumstances, tilting the virtual drill path can be used to alter the drill path's angle. More caution is required, though, so make sure not to drill through the target spot. (Figure 5b &5c)

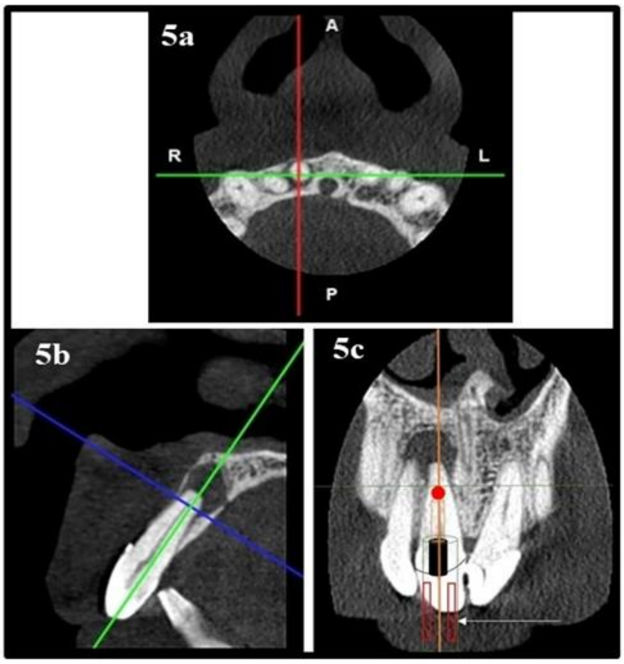

Figure 5: Designing of Endodontic Guide- a) Axial view of the CBCT; b)Tracing the Canal; c) Creating Virtual Drill Path [10]

The Diameter of the Drill

The drill's diameter needs to be large enough to prevent it from bending while it's being used. On the other hand, there is a maximum drill size, based on the size of the tooth and the amount of dental substance that is remaining, mostly because the drill hole will weaken the tooth. To make sure that the diameter can be used in the tooth, the majority of software providers give customers the option to rotate a slice view along the axis of the virtual drill path. By doing this, it is possible to make sure that the drill path leaves enough dentin, especially at the curvatures of the root.

For non-surgical endodontic therapy, a drill diameter of 1.00 mm or less is advised. We can utilise those dimensions to make the guide over the tooth's surface once the aforementioned parameters have been set. (Figure 6)

Sleeve Selection		
A virtual sleeve is added to the scan after the target, the angle, and the bur diameter are chosen.		
Sleeve Insert Type Sleeve inserts are available in two different kinds: o Hand-hold sleeve inserts (drill key) o Drill-hold sleeve inserts (guide sleeve)- Recommended		
Three essential parameters should be taken into consideration when choosing the sleeves:		
Inner Diameter of the Sleeve Recommended inner diameter should be 0.1 mm larger diameter than the diameter of the bur.	Outer Diameter of the Sleeve It should be minimum 0.1 mm larger than inner diameter for stability.	Height of the Sleeve Recommended sleeve height for endodontic treatment should be 5–7 mm.
Additional Considerations for Endoguide Planning:		
Offset of the Guide (0.15mm) • Adjust the offset to set the clearance between guide and the patient's contact surface. This affects the fit of the guide	Wall thickness (3.5mm) • Adjust the wall thickness of the guide. This affects the stability of the manufactured	Connector Thickness • Use large connectors This affects the overall stability automatically connected parts of the manufactured guide

Figure 6: Sleeve Selection [10]

Inspection Window

To assess the tooth's surface, it is helpful to add a custom inspection window. A guide's fit should be checked for accuracy. The heat produced by drilling can also be dissipated with the use of an inspection window. It also enables the use of additional coolant from that surface, if necessary. An improperly extended inspection window could cause the guide to weaken.

Endoguide planning is commonly done using a variety of programmes and platforms, including coDiagnostiX®, 2Ingis system, AIS Acteon, DDS pro, etc. (10)

III. Guided non-surgical endodontics

Guided non-surgical endodontics offers several advantages over traditional root canal procedures. It is less invasive, reduces the risk of post-operative pain and swelling, and can be completed in a shorter amount of time.

With the aid of 3D printed guides, the treatment of teeth with pulp canal obliteration and developmental anomalies affecting root canal systems is made safer, quicker, and more efficient. Endoguides may also be utilized as teaching aids for postgraduate students doing non-surgical root canal therapy, where there are considerable risks of mishaps, including root perforation, that may impair treatment outcomes. (12) A novel method for treating a posterior tooth with canal calcification and periapical lesion was reported in a case report by Xilin Shi et al. (13) A digitally printed template was used to help locate the root canal precisely because there was a chance of perforation during the treatment. The patient was not symptomatic and the periradicular radiolucency was decreasing in size after 6 months.

Using a guided endodontic approach and three-dimensional printed surgical stents, Afzal Ali et al. (2019) described a conservative endodontic treatment procedure for the management of teeth with Type II Dens Invaginatus. Without endangering the health of the main pulpal tissue, this technique provided a precise and minimally invasive approach in the conservative treatment of Dens Invaginatus. (14)

More research is needed to determine their precision and the frequency of dentinal cracks associated with the use of depth-calibrated dental burs and implant drills. The clinical feasibility of alternative treatment plans that call for access to the apical canal, such as the construction of staging platforms for the retrieval of broken instruments and the negotiating the obstructions/ledges in the teeth, must also be determined through research. (12)

IV. Guided surgical endodontics

Guided surgical endodontics offers several benefits over traditional endodontic surgery, including increased accuracy, reduced invasiveness, and improved patient outcomes. Here are some of the uses of guided surgical endodontics:

1. Apical surgery: Guided surgical endodontics is particularly useful in performing apical surgery or apicoectomy. The surgical guide helps the endodontist to accurately access the root tip, remove the infected tissue, and seal the end of the root with a filling material.

2. Resorption treatment: Guided surgical endodontics can also be used to treat external root resorption. The surgical guide helps the endodontist to precisely locate the area of resorption and remove it with minimal damage to the surrounding tissues.

3. Perforation repair: In cases where there is a perforation in the tooth, guided surgical endodontics can be used to accurately locate the perforation site and repair it using specialized techniques.

4. Fracture treatment: Guided surgical endodontics can also be used in cases where the tooth has suffered a fracture. The surgical guide helps the endodontist to precisely locate the fracture and perform the necessary repair. (15)

In a recent case report, Strbac et al. described the treatment planning and use of 3D printed surgical guides to perform predetermined osteotomies and root end surgeries for obturated posterior teeth with periapical lesions. (16)

Following flap elevation and retraction, osteotomies and root-end surgeries were carried out with piezoelectric instruments under the guidance of 3D printed surgical guides that were directed by the teeth and bone. (15)

In a case report from 2020, Mark Antal et al. described a root end surgery that was digitally designed using a static guide and customised trephine burs. It was possible to plan the root end removal in a simulated setting and produce 3D printed static surgical templates to make the procedure easier. A persistent periapical lesion was effectively treated. (17)

V. Conclusion

In conclusion, 3D printing offers several benefits to endodontics, such as the production of customized endodontic instruments, dental implants, and surgical guides. By leveraging the power of 3D printing, dentists and endodontic specialists can provide highly efficient, precise, and less invasive treatment for patients. 3D printing technology provides quick manufacturing solutions, allowing for personalized treatment to optimize endodontic success.

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