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Unlocking Precision: A Review of 3d Prinitng in Endodontic Practice

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ABSTRACT
The evolution of 3D printing technology in dentistry has greatly improved the educational experience for students and the quality of dental treatments. The use of 3D-printed guides has simplified the planning and implementation of both complex surgical and non-surgical endodontic treatments... These printed models effectively tackle critical issues in endodontics, such as accurately locating root canals, identifying osteotomy sites, preventing unwanted root perforations, aiding in auto-transplantation, and enhancing pre-surgical treatment planning. They also serve as important tools for education during preclinical training. This review focuses on the significance of 3D printing and its multiple uses in both teaching and managing endodontic processes.
Keywords: endodontics, 3D printing, CAD CAM, additive manufacturing, auto transplantation

I. INTRODUCTION

The advancements in 3D printing technology have brought substantial improvements to various dental applications. This progress has resulted from several benefits, such as enhanced accuracy, reduced chair time, the ability to create customized guides, better support for complex anatomical procedures, improved pre-surgical planning, decreased risk of iatrogenic injuries, cost efficiency for small-scale production, streamlined sharing of patient imaging data, and enriched educational opportunities.[1]The origins of Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM) can be traced back to the aerospace and automotive industries in the 1960s. The first dental application of CAD/CAM was introduced by Duret and Preston in 1991, focusing on fixed restorations made through subtractive manufacturing techniques.[2]Additive Manufacturing (AM) marks a significant shift from Subtractive Manufacturing (SM), as it builds models by gradually adding material rather than cutting from a solid block.[3,4]The terms AM and 3D printing are frequently used interchangeably in dental and medical contexts, although "3D printing" is the more commonly used term in practice. AM is particularly beneficial for creating complex designs, producing smaller models, minimizing material waste, offering a wider range of materials, and achieving cost savings compared to SM.[5,6]The production of 3D-printed items relies on automated processes and computer-generated scans of both hard and soft tissues.[7]Within dental specialties, 3D printing is mainly utilized in oral and maxillofacial surgery, orthodontics, and prosthodontics, but there is limited research focused on its applications in endodontics. This review aims to provide a concise overview of different additive manufacturing techniques, the need for 3D printing, and its specific applications in the field of endodontics.

II. DISCUSSION

3D printing, also known as additive manufacturing (AM), is a process that constructs objects by layering materials according to 3D model data.The design is developed with CAD software and subsequently sent to a 3D printer for production. This approach allows for extensive customization in producing intricate structures, including parts that may be difficult or even impossible to create through conventional manufacturing techniques Moreover, 3D printing reduces production costs, time, and material waste while fabricating intricate parts.[8]

Additive Manufacturing Techniques

AM TECHNIQUE	DESCRIPTION	MATERIALS	APPLICATIONS IN ENDODONTICS
FUSED DEPOSITION MODEING(FDM)	Melts and extrudes thermoplastic filament layer by layer.	PLA, ABS	Custom endodontic guides and models.
STEREOLITHOGRAPHY (SLA)	Uses a laser to cure liquid resin into solid layers.	Photopolymer resins	High- detail tooth models, surgical guides.

Selective Laser Sintering (SLS)	Fuses powdered material with a laser.	Nylon ceramics	Durable models for restorations.
Digital light processing (DLP)	Cures resin using a digital light projector.	Photopolymer resins	Detailed endodontic models and guides.

TABLE 1: VARIOUS ADDITIVE MANUFACTURING TECHNIQUES [9]

Stereolithography (SLA) is the earliest and most widely used 3D printing method. In this process, a photosensitive resin undergoes polymerization and hardens upon exposure to ultraviolet (UV) light, building the structure layer by layer. In contrast, Fused Deposition Modeling (FDM) melts the material and deposits it through a nozzle, where it subsequently solidifies. FDM is generally less precise but more cost-effective compared to other methods. Multijet Printing (MJP) employs a print head to deposit acrylic photopolymer and wax simultaneously, curing them with UV light. Although MJP offers high precision, it results in parts with lower strength. Polyjet printing involves jetted ultra-thin layers of photopolymer onto a build tray, with each layer cured by UV light, enabling immediate use without post-curing. Digital Light Processing (DLP) utilizes a projected 2D image onto a vat of liquid resin, hardening it layer by layer and is noted for its speed and surface quality. Colorjet printing disperses a binder onto powdered layers, while Selective Laser Sintering (SLS) uses a CO2 laser to selectively fuse powdered material, creating solid objects.[6]This article emphasizes the necessity of 3D printing in dentistry, its advantages over conventional techniques, its applications in endodontics, and possible directions for future research.

Need for 3D Printing

1. Customized Guides for Complex Cases: In procedures such as apicoectomy or when accessing calcified canals, 3D-printed guides provide precise direction for instruments, improving accuracy and minimizing the likelihood of errors.[11]
2. 3D Printed Tooth Models: By leveraging CBCT scans, endodontists can produce models that accurately reflect patients' teeth, including their intricate root canal anatomy. This enhances pre-operative planning, particularly in challenging cases featuring complex root structures.[10]
3. Pre-Surgical Planning: Before conducting surgeries like periapical procedures, 3D-printed models allow endodontists to visualize the anatomical layout, facilitating an understanding of proximity to vital structures and ensuring minimal invasiveness during surgery.[12]
4. Educational and Training Tools: 3D-printed tooth models can serve as training resources, allowing practitioners to practice on realistic models that mimic various complexities, thereby simulating actual clinical cases.[13]
5. Post-Treatment Appliances: For cases requiring follow-up care after endodontic procedures, 3D printing can produce tailored posts or appliances, ensuring a better fit and improved durability.

Applications in Endodontics

1. **Guided Endodontic Access**:The use of 3D-printed guides for locating root canals has been shown to reduce discrepancies in treatment outcomes between general dentists and endodontists. These guides assist in identifying calcified canals, minimize unnecessary tooth structure removal, and shorten the overall operating time.[14]A study by Kvinnsland et al. in 1989 revealed that up to 75% of perforations during root canal treatments occur due to challenges in locating calcified canals. By employing root canal access guides, the risk of perforation is notably diminished. These guides are also effective in directing burs to difficult-to-reach canal sections.[2] While radiopaque artifacts can compromise the diagnostic quality of CBCT images, they do not affect the design of 3D-printed guides. One notable case involved a 3D-printed guide designed for a molar with a porcelain-fused-to-metal crown, successfully locating a previously missed coronally calcified mesiobuccal canal. Although the tooth was ultimately extracted due to a vertical root fracture, this case underscores the effectiveness of 3D-printed guides in identifying calcified canals, even in the presence of metal crowns and prior treatments.[15]By promoting both the preservation of tooth structure and effective chemo-mechanical debridement, 3D-printed access guides represent a valuable resource for managing complex endodontic cases, particularly for misaligned teeth, those with pulp canal obliteration, or extensive restorations.[2]
2. **Autotransplantation of Teeth**: Autotransplantation has been a significant method for replacing missing teeth for over six decades.[16,17]The success of this procedure relies on the retention of periodontal ligament (PDL) cells and effective integration of the donor tooth at the recipient site.[18]Traditional techniques often involve using the donor tooth to prepare the

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recipient site, which can require multiple fitting attempts and modifications to the alveolar bone, increasing the time the tooth is outside the mouth and heightening the risk of PDL damage.[19]A systematic review by Verweij et al. in 2017 indicated that utilizing rapid prototyping for preparing the recipient site before tooth extraction resulted in less than one minute of extraoral time and a success rate ranging from 80% to 91%.[18]The use of CAD and 3D printing for creating tooth models and surgical guides streamlines the process, minimizing the number of positioning trials and preparation time needed for the alveolar socket.[20]

3. **Targeted Endodontic Microsurgery (EMS)**: In scenarios requiring precise control over depth, diameter, and angulation of root-end resections and osteotomies, targeted EMS offers distinct advantages. In a comparison between freehand osteotomies and those performed using 3D surgical guides, the latter demonstrated a 22% incidence of initial perforation errors at the 3 mm level.[21]Research by Ackerman et al. indicated that using 3D-printed guides significantly increased the likelihood of successful access during apicoectomy procedures compared to freehand methods.[22]While the surgical phase can be shortened, the preoperative phase necessitates specialized knowledge, equipment, and software for merging files and producing 3D surgical guides. The rising use of polymer-based computer-aided manufacturing, with affordable benchtop printers now accessible, is promising.[23]Although planning for 3D-printed apicoectomy guides may seem time-consuming, particularly due to the learning curve associated with the software, the actual chairside treatment time is significantly reduced when compared to non-guided techniques. The potential for tooth preservation justifies the additional time invested in planning.[22]

4.**Educational Models & Clinical Simulation**: 3D-printed models are being more widely adopted for training, providing benefits compared to traditional approaches, such as using extracted teeth.[23,24,25,26]Natural teeth can present challenges due to variations in structure, availability, and ethical considerations, as well as issues related to the difficulty of accurately simulating clinical scenarios.[31]3D-printed models can address these challenges, allowing educators to create replicas tailored to specific instructional goals.[27,32]They can replicate various anatomical complexities, giving students and practitioners realistic opportunities to practice techniques in a controlled environment.[28,29,30]

Future Endodontics: 4D Printing

The concept of 4D printing may usher in a new era of advancements in dentistry, characterized by materials that respond to external stimuli such as heat, moisture, or pH changes.[33,34,35]These smart materials can adapt to environmental conditions, enhancing the restorative capabilities of dental materials. Their integration into clinical practice could lead to improved outcomes for patients, as well as more effective management of complex dental procedures.[36]

III. CONCLUSION

As the landscape of dental education continues to evolve, the role of 3D printing has become increasingly vital for both students and practitioners. Its integration into endodontic training and procedures not only enhances skill development but also significantly improves patient care outcomes. While there are challenges associated with the costs and the need for technical expertise in 3D printing, ongoing research and development efforts have the potential to further enhance the integration of this technology into dental practice, ultimately improving standards of care across the field. The promising future of 3D printing in dentistry will likely lead to advancements that elevate the quality of endodontic treatments and educational methodologies.

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