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3D PRINTING IN ENDODONTICS – A NARRATIVE REVIEW

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ABSTRACT

The development of 3D printing in dentistry has positive impact on the student education and management of dental procedures. Complex surgical and non-surgical endodontic cases are easily planned and treated with the use of 3D-printed guides. 3D printed models help to overcome the challenges faced in endodontics which includes locating root canals, locating osteotomy perforation sites, undesirable root perforation, auto-transplantation, pre-surgical treatment planning, educational modeling in preclinical practices. This review explores the need for 3D printing and the applications of 3D printed objects in teaching and managing endodontic procedures.

KEYWORDS: 3D printing, Additive Manufacturing, Guided Endodontic Access, Auto transplantation, Educational models.

INTRODUCTION:

The evolution of 3D printing in dental applications has improved prominently. The advancement in 3D printing for dentistry emerges from its advantages like more accuracy, reduced chair time, the possibility of individualized guides, aids in anatomically challenging procedures, pre-surgical planning, reduced iatrogenic injury, savings on small-scale productions, ease in sharing patient image data, and educational upgrading.[1]

In 1960s, Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) were developed and first used by aerospace and automotive corporations. The first dental application of CAD/CAM was demonstrated by Duret and Preston in 1991 for the fabrication of fixed restorations using numerically controlled subtractive manufacturing (SM) miller.[2] Additive manufacturing (AM) is an innovation over Subtractive manufacturing (SM) as the models are fabricated using incremental deposition of material, whereas in SM, an object is cut from a block of material.[3,4] The term AM is used by the International Standards Organization and the American Society for Testing and Material. In dental and medical applications, the term '3D printing' is commonly used instead of the term 'Additive manufacturing'. AM is used in highly complex or intricate designs, suited for smaller models, reduced wastage of material, broader choice of materials and cost saving over SM. [5,6]

3D printed objects are manufactured through automated processes and based on computer-generated scanning of the hard and soft tissues. [7]

Among the dental specialities, applications of 3D printing is concentrated principally in oral and maxillofacial surgery, orthodontics, and prosthodontics, while there are very less publications in endodontics.[1] Thus the rationale behind this review is to provide a short overview on various additive manufacturing techniques, need for 3D printing, and various applications of 3D printing in Endodontics.

METHODS:

This review will include all studies which explain about 3D Printing, Need for it, its applications in the field of Endodontics. An online search was conducted using databases from PubMed, Scopus, Web Of Science and Google Scholar to find articles related to the same. This review included articles from 2011 to 2022.

RESULTS:

36 articles were included and analyzed for review.

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DISCUSSION:

The process of layering materials to make things from 3D model data is known as 3D printing (or additive manufacturing, or AM). Using CAD software, the component is created and then delivered to a 3D printer for printing. With 3D printing, component structures can be highly customised, and some components that cannot be created using some conventional production techniques may even be printed. Difficult parts can be fabricated with a significant reduction in fabrication costs, time, and spare materials.[8]

ADDITIVE MANUFACTURING TECHNIQUES:

The various additive manufacturing techniques is listed in Table 1.[9]

Various additive manufacturing techniques	Layer thickness
Stereolithography apparatus (SLA)	25-100 µm
Digital Light Processing (DLP)	25-100 µm
Fused Deposition Modelling (FDM)	178 or 254 µm
PolyJet and MultiJet (MJT)	up to 16 µm
ColorJet	50-100 µm
Selective Laser Sintering (SLS)	30-100 µm
Selective Laser Melting (SLM)	20-100 µm

TABLE 1: Various Additive Manufacturing Techniques

Stereolithography (SLA) is the earliest and most commonly employed manufacturing technique. With SLA system, the photosensitive monomer resin polymerize and solidifies on exposure to Ultraviolet light. In the serial curing process, a solid mass is formed building the object from bottom to top.[3,6] With Fused Deposition Modelling (FDM) printing, the material is melted and deposited through nozzle and then solidification occurs.[3,5,6] When compared with other manufacturing techniques FDM is generally less precise and less expensive.[6] With Multijet printing (MJP) simultaneous deposition of acrylic photopolymer and wax occurs using a print head, which is then cured by UV light. Among the manufacturing technique MJP has the highest precision but low strength. With Polyjet printing, photopolymer material is deposited by jetting in ultra-thin layers onto a build tray. Immediately after it is jetted, UV light is used to cure each photopolymer layer. The material is deposited drop on drop in Polyjet printing whereas it is deposited continuously in FDM. There is no post-curing needed in Polyjet printing and can be used immediately. With Digital Light Processing (DLP), a 2D image is projected into a vat of light-curable resin. It is a liquid based 3D printing technique. This technique has the best printing speed and surface finish. The Colorjet printing technique applies a binder to powder layers while selectively dispersing it using a print head. Using a CO2 laser beam, the Selective Laser Sintering (SLS) technique selectively fabricates models. SLS is a powder-based 3D printing method.[6]

This article aims to provide insight on the need for 3D printing, its advantage over the conventional methods and its applications in endodontics and to elucidate future pathway for research.

NEED FOR 3D PRINTING:

Prior to the development of technology, dentists were traditionally trained on mannequins, human cadavers, and animal models to gain practical experience. The drawbacks of this include limited supply, ethical considerations, lack of pathology, possible risk of cross-infection, high handling and storage costs. Since they can be produced more quickly, less expensive, and can be sterilised and used if the prosthesis needs to be implanted later, 3D-printed learning models serve as an excellent substitute.[10]

Other benefits of using 3D printed teeth in pre-clinical courses include standardisation, which frees students from having to deal with the morphological variations of natural teeth instead makes it easy for them to concentrate on learning the clinical procedure,[10] and improves the ability for students to practise procedures as many number of times as they like.[12] It is to be noted that dental students can confidently treat their patients the first time with less stress, when the techniques have been thoroughly taught in pre-clinical course.[13]

To better simulate hard and soft tissue and improve the tactile response, multiple materials can be added to different segments of the same model with the use of multi-material printing. Thus 3D-printed models support in the better diagnosis and treatment planning, to communicate the surgical stages to co-dentist allowing them to adjust the treatment plan appropriately, and explain the forthcoming surgical procedures to the patient. [10]

APPLICATIONS IN ENDODONTICS:

1. GUIDED ENDODONTIC ACCESS

Using 3D-printed guides for locating root canals has been shown to reduce the outcome differences between general dentists and endodontists regarding the number of calcified canals detected, the amount of structure loss, and the operating time. [14]

In 1989, Kvinnsland et al. discovered that obliteration of pulp canal is responsible for up to 75% of perforations that occur during the endeavour to locate calcified canals. Root canal access guides reduce the danger of perforation. They were also used to locate burs to otherwise difficult-to-reach canal sections.[2]

Streaking artifacts caused by radiopaque material can affect the diagnostic quality of CBCT images. However, artifacts do not affect the design of the 3D-printed guide. A 3D-printed guide for a molar with a PFM crown was created which successfully negotiated a previously missed mesiobuccal canal that was coronally calcified. Although the tooth was later extracted due to vertical root fracture, this case demonstrates that a 3D-printed guide can be a tool to effectively locate calcified canals despite the presence of a metal crown and root canal filling material. [15]

By providing both tooth structure preservation and chemo-mechanical debridement, 3D-printed access guides are an effective way to handle difficult endodontic situations. Targeted access guides may improve the efficacy of treatment for Malaligned teeth, teeth with pulp canal obliteration, or extensive restoration.[2]

2. AUTOTRANSPLANTATION

Autotransplantation of teeth has been used over a period of 60 years as a valuable method for replacing missing teeth in clinical practice.[16,17] A successful procedure is indicated by the support and retention of periodontal ligament (PDL) cells and proper integration of the donor tooth to recipient site.[18] Traditional techniques prepare the recipient site using the donor tooth as a template, frequently needing numerous "fitting" attempts with modifications need to be made to alveolar bone which prolongs extra-oral time and pose the risk of damaging the PDL.[19] According to the systematic review by Verweij et al. (2017b), usage of rapid prototyping in preparation of the recipient site before extracting the transplant tooth showed less than 1min of extra oral time with an overall success rate of 80-91%.[18] In comparison to the conventional tooth autotransplantation, the use of computer-aided design (CAD) in conjunction with 3D printing of the tooth models and surgical guides reduces the number of positioning trials with the donor tooth and shortens the time required to prepare the alveolar socket and the extra-alveolar time for the donor tooth.[20]

3. TARGETED EMS (ENDODONTIC MICROSURGERY)

When precise control over the depth, diameter, and angulation of the root-end resection and osteotomy is required, targeted EMS is advantageous. Comparing freehand osteotomy to more precise 3D surgical guide (3DSG) osteotomy in vitro, the latter caused 3-mm initial perforation errors 22% of the time.[21] Ackerman et al. discovered that implementing a 3D-printed guide, instead of the "freehand" method considerably increased the chances of a clinically successful apicoectomy access.[22]
It is possible to shorten the surgical phase and save time, but preoperative preparation calls for specialised knowledge, instruments, and software for combining files and printing 3DSGs. Polymer-based computer-aided manufacturing applications are steadily increasing, and affordable benchtop printers are now available.[23] Even while it may seem like a lengthy process to plan 3D-printed apicoectomy guides, particularly given the challenging learning curve of software, the actual treatment time in the chair is much shorter than with a non-guided technique. The possibility of tooth retention may make the extra costs for CBCT and the 3D-printed guide justifiable by reducing iatrogenic errors.[22]

4. EDUCATIONAL MODELS & CLINICAL SIMULATION

Ex vivo studies and pre-clinical training still typically use natural teeth as the standard. They have a number of benefits, such as hardness, morphology, colour, texture, and radiodensity of natural tissue, but they also have a number of disadvantages, including difficulty in collection, potential for cross-infection, storage, and ethical issues.[9] These constraints might all be solved by 3D-printed teeth that mimic natural teeth in their features.[23,24,25,26] Steps of root canal treatment starting from access opening and working length determination till root canal filling can all be practiced on teeth that were created via 3D printing. [27] To print ceramic models for endodontic lab exercises, Robberecht et al. (2017) created a material which is radiopaque, porous, hydroxyapatite-based and has hardness equivalent to dentine. [28] Prior to treating the

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actual case, Kfir et al. (2013) used a tooth replica to preoperatively replicate perfect access opening, instrumentation, and obturation in a difficult type 3 dens invaginatus scenario.[29]

The digital file is simple to store, reproduce, and exchange electronically.[30] Models can be produced using various colours, transparencies, textures, and/or mechanical properties appropriate for sterilisation or simulation, depending on the 3D printing technology employed. To help distinguish between different tissue types, these 3D printed models can also be stained during the post-processing step or can have distinct colours and textures added during manufacturing.[31]

Tchorz et al. (2015) evaluated the impact of students practising on artificial teeth versus human teeth that had been extracted on the standard of the First root canal procedure performed on patients. Artificial teeth are appropriate for endodontic education, as they were unable to differentiate between the two groups. [32]

As a result, 3D models can be utilised as a teaching tool to help students better comprehend the morphologies of teeth, roots, and canals as well as to replicate access cavity and root canal treatment. For standardised, unbiased skill assessments as well as to track students' skill development individually, 3D printed models can be employed.[7]

FUTURE ENDODONTICS - 4D PRINTING:

The term "4D printing" describes the addition of the fourth dimension to three-dimensional printing and its control. With this sort of additive manufacturing, we can manage the fourth dimension while making any part, component, or machine. 4D printing is the technique of self-folding materials over time in response to variations in temperature and humidity.[33,34,35] The idea behind 4D printing is to produce 3D printed objects that have the ability to spontaneously alter their shape in reaction to heat or moisture changes of the oral environment.

4D printing involves two steps - First, the material is processed under 3D printing. Second, the material is programmed to convert to another shape when exposed to certain stimuli in self-folding pattern. Advantages include 4D restorative materials are capable of moving towards the periphery thereby avoiding microleakage and overhanging of the margin, can be used in inaccessible areas, reduced chair time, and eliminate use of dental adhesives as 4D printed material relies on mechanical adhesion.[36]

While 3D printing is used in many different sectors, the complexity of materials is increasing, which presents chances for technical advancements. Adaptive materials are used in 4D printing to create products that can be constructed, flexible, or adapt to changing conditions.Future developments in this technology will offer exceptional chances to address the different difficulties in dentistry. [36]

CONCLUSION:

3D printing is a better educational tool for dental practitioners and students. Teaching and managing endodontic procedures may be advantageous due to recent developments in 3D printing and virtual planning, as well as the necessity to enhance skills in order to improve patient wellbeing and treatment success. The outcomes of guided endodontic procedures are techniques with highly predictable favourable outcomes, reduced iatrogenic damage, and reduced chair time. There are several drawbacks like cost, lack of expertise in the speciality, diverse product availability with little clinical testing. With further research and progress, limitations can be conquered. The dental research, therapeutic, and educational sectors have a tremendous of scope for change owing to 3D printing.

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