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3d Printing: A Futuristic Tool

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ABSTRACT:Three dimensional printing is a promising new technology in the field of conservative dentistry and endodontics. It is done by successively adding layers of material by additive manufacturing. It is a technology which can design and produce 3D models and is proving to improvise the standards of the treatment to the patients as it is less technique sensitive and more accurate and is proved to be a valuable adjunct. It is far better than sustractive manufacturing. Various methods like selective laser sintering (SLS), stereolithography, fused deposition modeling and laminated object manufacturing can be done. It has an optical scanner and a CAD/CAM to produce crowns, bridges, stone models and various orthodontic appliances.

KEYWORDS: Additive manufacturing, Stereolithography, Fused deposition modelling, Selective laser sintering.

I. INTRODUCTION

3D printing dates back to 1980s when Charles Hull printed a three dimensional object in 1983. Its use, that time, was limited to the fields of architecture, aeronautics andtelecommunications, by using stereo lithography. It was only later in 1990s that it attention was drawn to the medical specialists leading to more research to this emerging technology.

It basically makes use of CAD/CAM technique which comprises of three steps:

- Digital data acquisition using an intraoral scanner and/or a CBCT.
- Data processing and design within a software application.
- Manufacturing by milling or printing.

Three-dimensional (3D) printing can be precisely described as additive manufacturing (AM), rapid prototyping, layered manufacturing or solid-free form fabrication. It basically involves producing 3D sliced models which can be transferred into the 3D printer of compatible brand and type via USB, SD or Wi-Fi, which when goes through a 3D printer converts every slice into a 3D physical model[1] .

II. HOW IS IT DIFFERENT FROM CAD-CAM?

The former involves the subtraction manufacturing techniques and a huge amount of waste caused by milling of the 3D models.[2] .

The physical model representation is advantageous on many fronts like evaluation, case analysis, preclinical training all at table top.

Methods used for printing 3D models are:

- Stereo lithography
- Fused Deposition Modelling
- Multijet Printing
- Photopolymer Jetting
- ColorjetPrinting
- Digital Light Processing
- Selective laser sintering also known as selective laser melting
- Power binder printer

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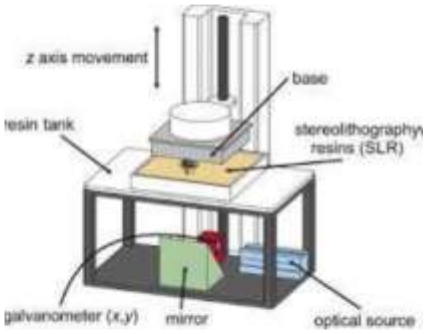
STEREOLITHOGRAPHYInvented by Charles Hull in the 1980's and is most popular rapid prototyping technology.

It is a form of additive manufacturing which converts liquid material (photosensitive monomer resin) into solid parts (polymer resin) using an ultraviolet light source through photo polymerization. Its use mostly is found in making of titanium implants in which the reaction takes place on surface and the materials used must be photo curable like acrylics, epoxies.

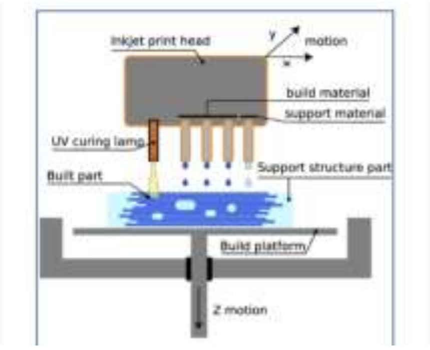
Kinetics can be controlled by the

- Power of the light source.
- The scanning speed.
- Chemistry and amount of the monomer and photo initiators.

The depth of polymerization can be controlled by adding UV absorbers to the resin.



FUSED DEPOSITION MODELLINGA simple model given by Schott C Rump object is built in a layered fashion by deposition of melted thermoplastic polycarbonate. It enables printing of simple and crude physical models without many complexities like printing of an edentulous mandible.



PHOTOPOLYMER JETTING

The basic structure of the machine includes nozzles through which the material is deposited in a layer by layer which later gets fused together which uses mostly biocompatible polymers, bioactive glass composites, Poly Methyl Methacrylate (PMMA).Building complex geometries usually necessitates the usage of a second extruder , for example, might extrude a water soluble support material.

It uses either a stationary platform and dynamic print head or a stationary print head and dynamic platform. Light sensitive polymer is jetted onto a build platform from an inkjet type print head and cured layer by layer on an incrementally descending platform.

Resolution of approximately 16 microns is given by this technology and it gives an easy access for making complex and fine detailed objects1.

Because of their digital precision, control, versatility, and benign effect on mammalian cells, this technology is already being applied to print simple 2D and 3D tissues and organs, also known as bio printing. Bio printing is used to create soft tissue scaffolds, 3-dimensional scaffolds, hydrogels, polymers. They can be used for implant guide drills and orthodontic brackets. The advantages are that it has a high finish and resolution but disadvantages like tenacious material and that it cannot be heat sterilized, cannot be less mentioned.

COLOURJET PRINTING

The Core™ material is spread in thin layers over the build platform with a roller. After each

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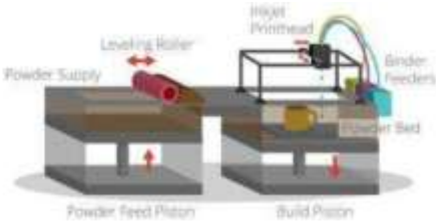
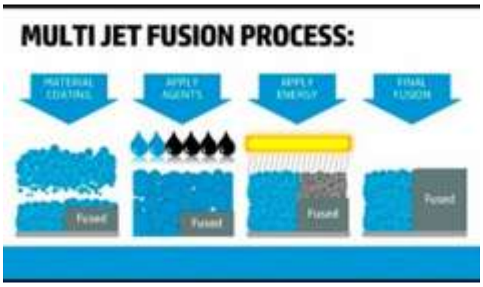
layer is spread, colour binder is selectively jetted from inkjet print heads over the core layer, which causes the core to solidify. The build platform lowers with every subsequent layer which is spread and printed, resulting in a full-colour three-dimensional model.



MULTIJET PRINTING

It has an inkjet printing process that uses piezo printhead technology to deposit either photo curable plastic resin or casting wax materials layer by layer.

Used for: to build parts, patterns and molds with fine feature detail to address a wide range of applications.

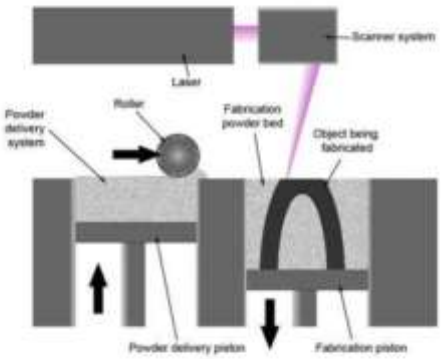


Advantages:

- Economical to own and operate
- Uses a separate, meltable or dissolvable support material to make postprocessing easier.
- Removing support material is virtually a hands-free operation
- Allows even the most delicate features and complex internal cavities to be thoroughly cleaned without damage.

SELECTIVE LASER SINTERING

A projector light source is used to cure the liquid resin in a layered fashion. The object is constructed on an elevating platform and the layer is created upside down. The polymer is layered pending the object is constructed and the residual liquid polymer is drained off.



A fine material powder is fused by scanning laser to build up structures incrementally. A new fine layer of material spreads uniformly over the surface as a powder bed drops down. It involves making of metallic frameworks by selective laser, melting in a layered manner that generates 3D pieces by strengthening selective and successive layers of powder material, one above the other, using heat generated by a computer controlled laser radiation.

It has various applications in areas needing high fracture toughness and mechanical strength like metallic implants facilitating bone ingrowths and regeneration.

Advantages:
- Materials used can be autoclaved
- Printed objects have full mechanical functionality
- Use of lower cost materials in large volume.

Disadvantages:
- Powders are messy with increased inhalation risk
- Technology is expensive and requires of compressed air.

POWDER BINDER PRINTER

A modified inkjet head is used to print in this printing method. The liquid droplets are allowed to infiltrate a uniform and single layer of powder one after the other. With this, the powder bed drops incrementally, and a final model is ready. This model is built of many layers and a new fine layer of powder is swept over the surface. The un-infiltrated powder will itself support the model, and so no other support material is essential. A cyanoacrylate or epoxy resin can be infiltrated during post-processing procedures to improve the strength and surface hardness. These models are fragile, and their accuracy is limited; however, they are useful as study models or visual prototypes.

III. APPLICATIONS

The market is bound to evolve as this new technology proves its reliability in the upcoming era. With new formulations it has widely supported the following areas of dentistry.

- RECONSTRUCTION OF 3D MODELS

Reconstructed replica of the exact tooth not only enables the clinician for a superior observation and planning but also helps immensely in patient education, if required.

- TRAINING USING PRECLINICAL MODELS

The budding beginners are always taught to practice their skills on extracted tooth but unfortunately not all those teeth encircles all the possible anomalies that one could eventually get in a clinical scenario1.

The 3D printed tooth models can mimic teeth with internal, external resorption defects, open apices and those with pulp stones, dilacerations, dens in dente and many other anomalies which serve as more realistic anatomic structures, which in the development of endodontic skills by providing visual, acoustic and tactile proprioception and help in acquiring improved skills in minimal intervention during preclinical training .

- FABRICATION OF TOOTH RESTORATIONS

With lesser complexity and decreased technique sensitivity in restoring a complex restoration, this can be used to fabricate a restoration as under:
- Tooth preparation according to the cavity is done; it can be two or three surface preparations.
- Scanning of preparation and uploading the data on computer.
- Printing the filling with appropriate material of choice of restoration.
- Lastly, cementation of the prepared 3D filling into the scanned cavity with suitable adhesive material.

- FABRICATION OF A PRECISE WORKING PATH

A customized guide jig is fabricated to get a safe and precise working path to the root canal and follow up after few months can be done for complete healing of the periapical region1.

- GUIDED IMPLANT SURGERY

3D printed templates can give an edge of high accuracy for guided implant surgery when used as alternatives to laboratory manufactured templates. Surgical stent-like guides are designed that reproduces preplanned osteotomy site which can mitigate risk through avoiding encroachment upon neurovascular structures or adjacent teeth and also avoiding perforations and other errors at osteotomy sites[3,4].

- GUIDED ENDODONTICS

3D printed templates can be utilized to gain guided access to root canals and various in vitro research studies proved that accurate access cavity preparation up to apical third of the root could be obtained through 3D template guided Endodontic procedures. All this will pave way for lesser iatrogenic errors and minimally invasive endodontics which is the call for future endodontics. For eg: In a calcified canal, CAD software Digital impressions are merged with CBCT scans, this forms DICOM data which is then allowed to create STL file containing bony architecture for pulp canal obliterated teeth, these structures are sliced, and the sliced data is sent to the printer where the final printed guides are obtained[3,4,5].

- REPAIR OF BONY/SOFT TISSUE DEFECTS

Polyethylene oxide and polyethylene glycol dimethacrylate photopolymerisable hydrogels were used to fabricate scaffolds resulting in constructs that were comparable with soft tissues in terms of elasticity and high cell viability which was achieved along with high density constructs.

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• DENTAL PULP REGENERATION

By using the inkjet and 3 D reconstruction of various scaffolds the dental pulp tissue can be regenerated and tooth be revascularized. This is achieved by systematic positioning of cells that includes positioning of the odontoblastic cells at the periphery and fibroblasts within the core with a supportive network of vascular and neural cells. Research is focusing on in vivo creating a functional tissue like pulp.

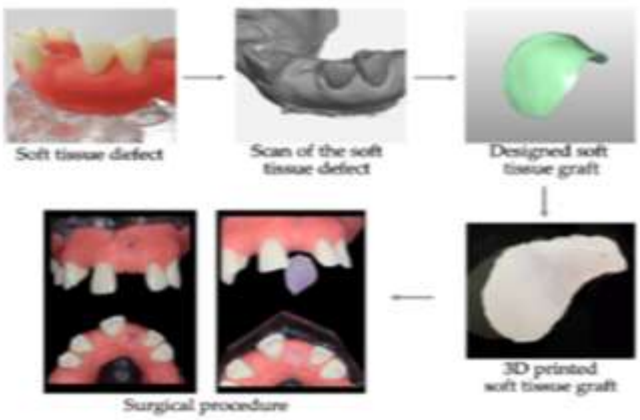
Auto transplantation using 3D printing increases the chances of the tooth-saving procedure. Computer-aided rapid prototyping (CARP) is used to print a replica of the tooth such that modification of recipient bone site is done before extraction without PDL damage from repeated insertion and removal. With this recipient, the tooth can be prepared for the crown, and a temporary crown can be placed immediately after placing the tooth in the desired tooth site. This method minimises extra oral time and chances of any error during auto transplantation[6,7].

• 3D RECONSTRUCTION OF ORAL TISSUES[8]

More than two decades ago, PDL-derived cells were used with the "cell sheet technology", i.e., cell detachment without enzymatic treatment for periodontal regeneration. Preclinical and clinical studies demonstrated periodontal regeneration with inserted PDL fibres and newly formed cementum in periodontal defects The major drawback of the cell-sheet approach was the compromised biomechanical stability and the demanding surgical technique. The improvements of the cell sheets' biomechanical properties included layering of several sheets, supporting the sheets with hydrogels, and adding ECM components to the thermo-responsive surface. With the development of additive manufacturing, a 3D-printed calcium phosphate (CaP)-coated PCL scaffold was combined with cell sheets from different human cell types resulting in significant periodontal attachment. The main idea is to incorporate as much inorganic and organic component to the scaffold so that it perfectly mimics the biological tissue

Hydrogels used for soft tissue regeneration can be either curable polymers, producing mechanically solid scaffolds upon solidification, or soft, injectable hydrogels. Both can be combined with cells; in the first case, cells are seeded after curing to avoid harsh printing/curing conditions; in the second, cells reside within the bioink during printing (bioprinting). A hybrid barrier membrane has been recently produced for guided tissue regeneration by 3D printing by combining gelatin (for cell adhesion), elastin (for membrane long-term stability and elasticity) and sodium hyaluronate (for cell-signaling), and cross-linked by 1-Ethyl-3-(3-dimethylaminopropyl) carbodiimide (EDC)

The membrane has small pores on one side and large pores on the other side to accommodate osteoblasts, fibroblasts, and keratinocytes population on the different sides. The in vitro analysis indicated biocompatibility, mechanical strength, degradation rates, as well as tensile modulus for easy surgical handling.



"Digital workflow" for soft tissue augmentation. The soft tissue defect is scanned (intraorally or from the imprint-derived cast); the ideal graft is designed and converted into an STL file. Upon 3D printing of a defect-tailored graft for optimal volume augmentation, the graft is surgically placed to fit the defect, and sutured.

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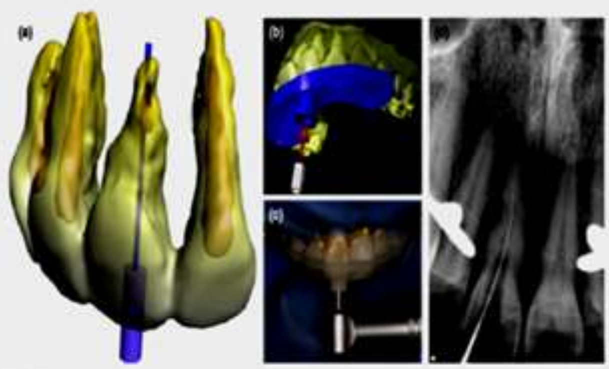
Table 1. 3D Printing modalities

3D Printer	Materials	Applications	Advantages	Disadvantages
Stereolithography (SLA)	Photopolymerising Resins, Acrylics & Epoxies.	Dental models, surgical Guides, orthodontic retainer and aligners, crowns and bridges.	High accuracy, Good surface finish, high mechanical strength, rapid fabrication.	High cost, cannot be heat sterilized, Limited shelf life, skin irritation by resin contact or inhalation.
Fused Deposition Modelling	Thermoplastic polymers like Polylactic acid, Polycarbonate, Polyether Ether Ketone, Poly Methyl Methacrylate, Bioactive glass Composites	Bone tissue Engineering, Craniofacial Defects, Maxillofacial Prosthetics (prototyping anatomical parts)	Most low cost 3D printer.	Limited materials – only thermoplastic materials can be used. Limited shape complexity. FDM requires support structures to be removed.
Selective Laser sintering	Polymer Powder such as Alumide, Polyamide, rubber like polyurethane, Metal alloys like titanium, Co Cr, stainless steel.	Metal crown copings, metal or resin partial denture framework, Cutting drilling guides.	High fracture toughness and mechanical strength. Polymeric metals can be autoclaved, metallic materials can be recycled.	High cost, significant infrastructure required, messy powders with inhalation risk. Explosive Risk.
Powder Binder Printers	Plaster of paris, Pigmented water	Study models, Visual prototypes.	Low cost, relatively fast process, materials used are safe, they can print coloured 3D objects.	Low resolution, Limited Accuracy, Less strength, Difficult to heat sterilize.
Bioprinting	Alginate, fibrin, collagen, PLGA (poly lactic co-glycolic acid), tricalcium phosphate, chitosan, Hyaluron	It creates structure with living cells, Hard and soft tissue scaffolds, 3-dimensional hydrogels, ceramics and hydrogels.	It can be operated at room temperature. They do not require thermoplastic materials.	Distortion of cellular structure and loss of cellular viability.

IV. STUDIES DONE ON 3D PRINTING[9]



van der Meer et al. Guided Endodontic Access (a) Planning of a directional guide. A cylinder is used to depict the direction of the drill necessary to locate the root canal system. Other cylinders are automatically aligned with the directional cylinder. Those cylinders are used for the design of the directional guide. (b) The final directional guide design. After the rapid prototyping of the guide a metal tube is placed in the corresponding hole. The metal tube has an inner diameter that is slightly larger than the bur used during the location of the root canal system. (c) The directional guide in place, whilst a bur is used to gain access to the canal system. As can be seen, the direction of the bur is not exactly parallel to the long axis of the tooth during preparation. This coincides with the 3D planning. (d) Working length radiograph after the root canal system had been located with the aid of a directional guide. Reprinted from Journal of Dentistry, Vol 45, Wicher J. van der Meer, Arjan Vissink, Yuan Ling Ng, Kishor Gulabivala. 3D Computer aided treatment planning in endodontics, Pages No. 67-72, Copyright (2016), with permission from Elsevier.

Above image shows a study by van der meer et al showing guided endodontic access.

Similarly, case reports describing the use of 3D printed guides to access an obliterated maxillary incisor (Krastl et al. 2016), a mandibular molar (Shi et al. 2017), type V dens evaginatus (Mena-_Alvarez et al. 2017) and obliterated mandibular incisors (Connert et al. 2018) support the clinical utility of the technique.

In ex vivo investigations of accuracy, Buchgreitz et al. (2016), Zehnder et al. (2016) and Connert et al. (2017) assessed stent guided access preparations by superimposing a post-access CBCT upon a pre-operative designed access. Buchgreitz et al. (2016) found the mean deviation of the access cavities to be lower than the 0.7-mm threshold defined by the radius of the bur plus the radius of the root canal. Zehnder et al. (2016) and Conner et al. (2017) also found small deviations from the

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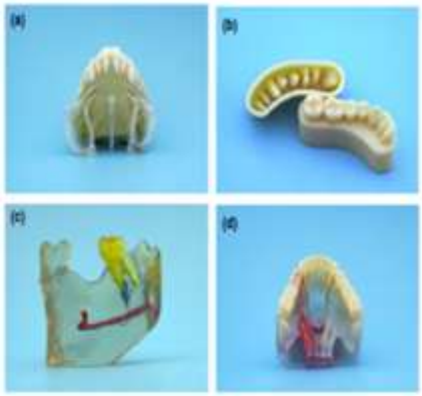
intended access (0.12–0.34 mm at the tip of the bur) and a mean angular deviation of less than 2°. These investigations suggest that 3D printed access guides represent an efficient and safe means of addressing challenging endodontic scenarios, enabling both chemo mechanical debridement and conservation of tooth structure.

Above image shows auto transplantation done using 3D printing using CARP.

In a case report, Strbac et al. (2016) described the autotransplantation of immature premolars in a maxillary incisor avulsion scenario using a completely digital workflow. The authors used CAD to select the appropriate donor teeth based on dimensions and stage of root development. Prototype teeth were modified to accommodate the dimensions of Hertwig's epithelial root sheath and to minimize damage to the apical papilla. The CAD modified prototype teeth were virtually auto-transplanted into the donor sites to create successively larger osteotomy guides that allowed for a more precise and efficient surgical phase. In a proof of concept, Anssari Moin et al. (2016) used CAD to print custom surgical instruments accommodating the transplanted tooth, achieving an apical deviation of less than 1 mm from the planned final tooth position in a human mandible. A systematic review by Verweij et al. (2017b) found an overall success rate of 80–91% when rapid prototyping was applied attributing success to preparation of the recipient site prior to extraction of the transplanted tooth, in some cases enabling an extra-oral time of less than 1 min. In a multi-disciplinary case, successful autotransplantation of tooth 21 to the site of tooth 9 was made possible by CARP. Future studies may further clarify the outcomes impact of CARP.



Endodontics Residency 3D printing applications: (a) Surgical model used for pre-surgical treatment planning and simulation. (b) Instructional models. (c) Large-scale model of periapical lesion adjacent to mandibular canal. (d) Regenerative endodontics model with open apices and ports for simulated apical haemorrhage.

Above image shows 3D printed models for evaluation of different clinical scenarios

- Since 2013, FLM is suitable for processing high performance polymers from the group of polyaryletherketone (PAEK). PAEKs are semi-crystalline linear aromatic thermoplastics, whereby the number of ether and ketone bindings provides different variants, such as polyetherketoneketone (PEKK) and polyetheretherketone (PEEK), which have slightly different mechanical and thermal properties. In dentistry, PEEK is commonly used as it has outstanding properties, such as excellent biocompatibility, non-cytotoxic and bio-inert behaviour, favourable mechanical properties, radio translucency, bone-like Young's modulus of 3–4 GPa and low plaque affinity and chemical stability which all accounts for the overall credibility of this material.

Prechtel in his in vitro study was to investigate fracture load, fracture types, and impact of chewing simulation of human molars restored with 3D printed indirect polyetheretherketone (PEEK) inlays and compare these with milled indirect PEEK inlays, direct resin composite fillings, and sound teeth

All 3D printed and milled indirect PEEK inlays as well as the direct resin composite fillings presented a higher fracture load than the expected physiological and maximum chewing forces.

Clinical relevance 3D printing of inlays out of PEEK via FLM provided promising results in mechanics, but improvements in terms of precision and esthetics will be required to be practicable in vivo to represent an alternative dental material[10].

- Ishak[11] in his study on a 52-year-old female patient who was diagnosed with chronic periapical periodontitis associated with severely calcified lower central incisors. Radiographic examination revealed no visible root canal in the coronal-third of the root. Virtual implant software was used to visualize the surgical access into the sclerosed root canals. After locating the canals, the guide was removed, and the teeth were treated under a rubber dam. The guided approach allows predictable, efficient endodontic treatment of teeth presenting calcified canals, with minimal removal of sound dentine and less risk of root perforations.

(A) Image showing severe tissue loss due to severe bruxism. (B) Initial pre-op X-Ray.

Panoramic And Sagittal Axis Showing Virtual Drill Preparation with Axis Tilt.

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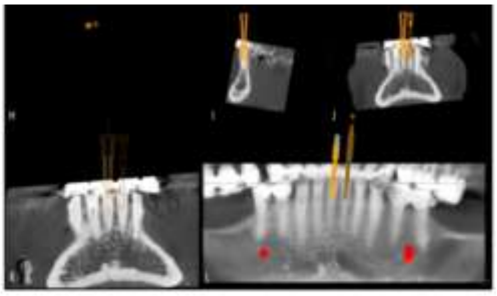
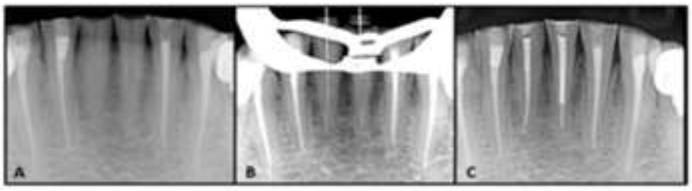


(A) Endodontic guide positioning. (B) Testing stability and adaptation. (C) Drilling through the endodontic guide and sleeve; drill of 0.75 mm diameter (FFDM Pneumonat, Bourges, France).



(A) Pre-operative X ray after micro-guided drilling. (B) Working length determination. (C) Post obturation and filling.

Connert et al[12] in his study to compare the endodontic access cavities in teeth with calcified root canals prepared with the conventional technique and a guided endodontics approach regarding the detection of root canals, substance loss, and treatment duration. Six identical sets of upper and lower jaw models were produced with 3-dimensional–printed incisors that had simulated calcified root canals the mean substance loss of the conventional access and the guided access was 49.9 mm3 and 9.8 mm3 respectively. The treatment lasted 21.8 minutes for the conventional technique and 11.3 minutes for guided endodontics indicating that guided endodontics allows a more predictable and expeditious location and negotiation of calcified root canals with significantly less substance loss.

CONCLUSION

In summary, 3D printing is a versatile additive manufacturing technology offering vast patterning possibilities, precise manufacturing, and abundant choices of biomaterials for a cost-effective patient-tailored end construct. 3D printing technology has already been largely employed and being found successful in numerous biomedical applications to make tissues, organs, and medical devices, as well as to provide surgical planning aids and educational models. Continuous expansion and adaptation of 3D printers' abilities, combined with reduced costs, increased speed, and use of a broader range of printable materials will bring this technology to the forefront of biomedical applications, as we get new insights to this revolution every day. New challenges, needs, and achievements can be envisioned in the field of bio printing as more researchers with different backgrounds and research questions employ 3D printers. In dentistry, particularly for soft tissue regeneration, application of the "digital workflow" to achieve a perfect-fit patient-tailored graft according to the defect, with an adjusted inner architecture and outer shape to maximize tissue mimicry, will result in functional as well as aesthetically pleasing tissue restoration, which will surely benefit the patient and clinician in the long run. Its utility in treatment planning and analysis of treatment outcomes improvises the quality of treatment provided by the dentist to the patient enhancing the patient satisfaction and clinician fulfilment in meeting those demands. Further research in this would revolutionize digital dentistry and contribute to overall benefit in patient care and clinician efficiency.

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