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Research Paper

3D printing: Beginning of the new era in Endodontics

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ABSTRACT: *In the field of dentistry 3D printing is entrenching itself as an advancing forefront. Additive manufacturing, or 3D printing, is becoming a viable alternative to subtractive manufacturing, or milling in the field of computer-aided manufacturing. Material research for use in additive manufacturing is ongoing, and a wide range of materials are being used or developed for use in dentistry. Digital technology and 3D printing have significantly elevated the rate of success in the field of endodontics using custom-made 3D surgical guides thus improving the quality and accuracy of dental treatment. Educational programs that use 3D printed models encourage students and trainees to improve their dental expertise. This article aims to review the various 3D printing techniques, materials for fabricating models, and applications in endodontics.*
KEYWORDS: *Substractive manufacturing, additive manufacturing, guided endodontics.*

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I. INTRODUCTION

The current world is developing so fast that it is quite difficult for anyone to keep pace with it. Technology has steadily and slowly paved its way into dentistry and it is one such branch that keeps on changing with time as the world is developing and dentistry loves to deal with new materials and technologies and digitalization in dentistry is all we are looking for future.[1]

The development of Digital OPG (Orthopantomogram), RVG (Radiovisuography), CBCT (cone beam computed tomography), digital impression machines, and in-office CAD-CAM milling machines have made accurate treatment planning and other tasks easier than they were before the arrival of technology. 3D printing is the most recent innovation in dentistry. It is a rapidly evolving technology that has received universal acceptance in dentistry and is considered a disruptive technology that has the potential to transform the way products are manufactured.[2]

Unlike traditional 2D printing, 3D printing produces multiple layers on top of each other to create a three-dimensional model layer by layer.[3] It was started in the 1980s when Charles Hull printed a three-dimensional object in 1983. He then developed the world's first stereolithography-based 3D printer.[4]

All over the world, the use of 3D printing in endodontics is increasing rapidly such as 3D printed models, surgical and nonsurgical guides that are produced through automated processes and are based on virtual (computer-generated) depiction of the dentition and associated skeletal tissues. The automated processes involve 3D printers, which utilize various 3D printing techniques to fabricate objects.[5]

II. 3D PRINTING TECHNOLOGY

- Stereolithography,
- Fused deposition modeling,
- Selective electron beam melting
- Selective laser sintering,
- Photopolymer jetting,
- Digital light processing,

- Powder binder printing.

STEREOLITHOGRAPHY [SLA]

Charles W. Hull in 1986 first of all coined the term “stereolithography”. It's a process for printing thin layers of UV curable materials one on top of the other to create solid objects.[6] It is the oldest and most typically used methodology of 3D printing in dentistry.[7]

Principle

- Conversion of photosensitive monomer resin into a polymer and solidifies once exposed to UV light.
- The system uses a scanning laser, and the exposure path of the UV laser is directed onto the surface of the light-sensitive resin, resulting in 3D printing of each layer.[8]

Uses

Fabrication of temporary restorations, temporary and permanent crowns and bridges, surgical guides, dental model replicas, and templates.[9]

FUSED DEPOSITION MODELLING [FDM]

Fused deposition modeling (FDM) was developed by Scott Crump within the late 1980s and was commercialized in 1990. It is referred to as Fused deposition modeling however the non-proprietary term is “fused filament fabrication” (FFF). After stereolithography, this technique has become the second most commonly used 3D printing technique.

Uses

- Printing of temporary crown and bridges.[9]

SELECTIVE ELECTRON BEAM MELTING [SEBM]

SEBM is a method of additive manufacturing that produces metal pieces that are closer to the shape of the net. The process involves the manufacturing of parts by melting metal powder layer by layer using an electron beam in a high vacuum.[6] Instead of a laser, an electron beam is used as the power source in this procedure.

Uses

For the production of customized implants and the ability to manufacture highly porous structures, this technology has a wide range of applications in orthopedics and maxillofacial surgery.

SELECTIVE LASER SINTERING [SLS]

Selective laser sintering is defined as “sintering the individual layers of an object, which means that a laser fuses the individual material particles on the surface. Thus, only a partial melting process occurs”. The terms "laser sintering" and "laser melting" are used interchangeably. The distinction between Selective laser sintering (SLS) and Selective laser melting (SLM) is that SLS uses powdered materials while SLM uses liquid materials; also, each new layer in SLS is sintered whereas in SLM it is melted plastics, metals, and ceramic materials are all part of the material spectrum (Figure 4). These techniques are primarily utilized in dentistry for metallic materials.[7] It considers the printing of basic anatomical models with little complexity, such as an edentulous jaw. [1]

PHOTOPOLYMER JETTING (PPJ)

A print head with many linear nozzles builds up the object in layers. The concept is very similar to that of a traditional inkjet printer. For photopolymer jetting, a liquid photo monomer is employed instead of ink drops.[7] This process may be used to print a range of materials, including resins, casting waxes, silicone rubber, and materials with complex geometry and exquisite details. It gives a resolution of about 16μ.[8]

USES

- The printed goods can be used as crowns or models for anatomical studies.
- Implant drill guides can be manufactured more quickly and at a lower cost, with higher quality.[9]

DIGITAL LIGHT PROCESSING (DLP)

DLP was invented by Larry Hornbeck (Texas Instruments) in 1987.[10] DLP technology is a relatively new technology for which realization stereolithographic printing devices are used and it is a projection-based SLA technique named digital light processing (DLP) is the second technique that is commonly used.[11]

Process

- The build platform may be ascending or descending depending on the position of the UV source.
- Next layers will be formed on their previous layers.

POWDER BINDER JETTING (PBJ)

Binder jetting is a variation of the photopolymer jetting process in which a liquid binding agent is selectively deposited to join powder particles.

Process

- The binder jetting technology uses a jet chemical binder onto the spread powder to form the layer.
- The constructing platform drops after each layer, and a blade applies a fresh coating of powder at the level of a Z layer.

- If metal and glass powders are used, the object can then be subjected to a sintering process in which the adhesive is burned out.[7]

Uses

Produce casting patterns, the printing of study casts or prototypes.[9]

III. 3D PRINTING MATERIALS

Unlike substractive manufacturing, 3D printing in dentistry needs high-quality materials that meet consistent specifications to build consistent high-quality products. However, 3D printing technology can produce fully functional parts from a variety of materials such as ceramics, metals, polymers, and their combinations in the form of hybrids, composites, and functionally graded materials (FGM).[12]

POLYMERS

This includes a wide variety of substances such as thermoplastic, polylactic acid (PLA), acrylonitrile butadiene styrene polymer (ABS), wax and photoinitiated resins, etc. Additive manufacturing printers such as fused deposition modeling (FDM) printers use polymers as a raw material for building programmed structures.[13] Most of the 3D printers available nowadays at the dentist‟s disposal today accommodate a wide range of polymeric substances which are used in the fabrication of dental implants, crowns and bridges, and other 3D tissue structures.[14]

Based on the chemical reaction, the following classes of polymers can be classified:

(a) Vinyl polymers

Vinyl polymers are extensively used for dental 3D printing that involves sintering (e.g: SLS) or photopolymerization (e.g: SLA) Although vinyl polymers are biocompatible but the majority of them are not biodegradable making them unfavoured material for many medical applications, but not dentistry, since degradation is not desirable for long-term use, such as in dental implants. Polyvinyl alcohol (PVAL) is the most commonly used polymer in dentistry because of its tunable properties.

Polymethyl methacrylate (PMMA) is the most favorable material for printing denture base materials owing to the ease of its processing, low cost, lightweight, stability in the oral environment as well as aesthetic properties.[9]

(a) Styrene Polymer

Polystyrene (PS) and acrylonitrile-butadiene-styrene (ABS) are two styrene polymers often used in dental 3D printing.

PolyStyrene is transparent with a brilliant surface and very good electrical and dielectric properties, as well as mechanical properties and ease of fabrication, making it a good candidate for dental applications.[10]

Acrylonitrile-butadiene-styrene (ABS), is a thermoplastic polymer that inherits its superior properties from its monomers: acrylonitrile, butadiene, and styrene. Each of the monomers contributes to the quality of ABS. Therefore, ABS owes its heat tolerance, high impact strength, and rigidity to acrylonitrile, butadiene, and styrene respectively.[9]

(b) Polyesters

Polyester refers to a group of thermoplastic polymers that contains ester functional groups in the main chain. They are polymerized via polycondensation by the removal of water molecules.

The three most popular polyesters are polycarbonate (PC), polycaprolactone (PCL), and polylactic acid (PLA)

Polycarbonates are used extensively in dentistry to produce orthodontic brackets, denture bases, and prefabricated provisional crowns. They have been used experimentally as a based composite printed by FDM. [9]

Polycaprolactone (PCL) is synthesized via ring-opening polymerization of ε-caprolactone monomers in the presence of a catalyst such as stannous octanoate.

Due to its great impact resistance and non-toxic surface finish, polylactic acid (PLA) is rather more environmentally friendly and appropriate for use in the oral cavity, albeit as a provisional material, than ABS.

METAL-BASED MATERIALS

Metal is another common material used in dentistry. Its popularity has been further viewed in the field of 3D printing as well, mainly in the use of selective laser sintering (SLS).[15]

Metals are vastly employed in fabricating biocompatible products, especially when resistance to corrosion and wear is required. Biocompatibility and mechanical properties are also key considerations when selecting metal for biomedical applications.

Despite many types of metallic materials available, only a few of them are biologically compatible with the human body and can be used for long-term applications such as:

- Stainless steel alloys
- Titanium and its alloys
- Cobalt-based alloys
- Aluminium-based alloys[9]

CERAMICS

Nowadays Ceramics represent another common material to produce 3d printed objects by using 3D printing approaches in dental practice especially in the field of prosthetic dentistry.[15]

Ceramics are highly biocompatible and possess strong mechanical properties, excellent wear resistance, and superior aesthetics compared with titanium or CoCr alloys. Due to their excellent biocompatibility, ceramic materials are recommended as the material of choice from dental restorations and implants to bone grafting materials.

For the creation of ceramic structures for use as tissue scaffolds or dental ceramic prosthesis, additive techniques like SLA and SLS have been employed, in which specific ceramic powder or pre-sintered ceramics are targeted to generate strong bonding.[15]

APPLICATIONS

ENDODONTICS

3D printing has carved a prolific niche in the endodontic discipline as well [16] (Anderson et al 2018). In endodontics, the paradigm change from manual to digital workflow has resulted in unrivaled simplification of procedure, greater precision and accuracy, improved patient comfort, a breakthrough in regenerative endodontics, and the advancement of operator abilities through training and education.3D printing serves as a solution for endodontic challenges; some of which include

- Guided access preparation
- Autotransplantation[17] (Kim et al 2016)
- Accurately locating the osteotomy perforation sites, pre-surgical planning[16] (Anderson et al 2018).
- Educational models and
- Stent guides[18] (Dawood et al 2017).

Manufacture of complex file structures for endodontic filing

Complex cross-sectional areas, such as the honeycomb cell, can now be manufactured using additive manufacturing technology. A hybrid design of endodontic instrument that can shapes the root canal apically, so as to allow the irrigants to clean the canal thoroughly apically and provide a shape for obturation, while allowing it to expand and collapse in the mid root and coronal aspects to allow the endodontic instrument to adapt to natural root anatomy. It emphasizes how 3D printing allows for the production of real and complicated structures. Another way of using 3D printing technology is to allow for the support structures internally.[19]

3D PRINTED GUIDES

Non-surgical endodontics can be accomplished for teeth where the pulp space has not been significantly reduced or altered, allowing for easier location of canal orifices and canal entrance negotiation.

Similarly, performing surgical endodontics on anterior teeth, where lesions may have penetrated the cortical plate, is less difficult, enables the easier location of osteotomy sites. It might also be difficult to precisely determine the osteotomy site and the correct level of root ablation due to the proximity of essential anatomical structures, the thickness of cortical plates, tooth location, and orientation of root apices,

3D printed directional or surgical guides, based on concepts similar to guided implant surgery, may be effective in overcoming these challenges and optimizing outcomes for complex endodontic situations. 3D printed guides, based on the design and fabrication principles for guided implant surgery, have been adapted for use in guided non-surgical and surgical endodontic procedures.[20]

GUIDED NON SURGICAL ENDODONTICS

Directional guides that are 3D printed can be useful for locating canals during non-surgical endodontic treatment where there is a high probability of procedural errors, including root perforation, which can severely compromise treatment outcomes.

Guided endodontic access

Endodontic access to calcified root canals is a challenging task.[21] Pulp canal calcification (PCC), that can also be called pulp canal obliteration or calcific metamorphosis, is defined by the accumulation of calcified tissue along the canal walls which makes root canal space become partially or completely obliterated[22] leading to technical failures including alterations in the geometry of root canal and substantial loss of dental hard tissue, which may weaken a tooth considerably or result in root perforation. To avoid such complications, a novel guided approach for the fabrication of apically extended access cavities was developed that is "Guided endodontics".[21]

The computerized planning technique and directed guide resulted in simplified complex root canal treatment in obliterated teeth while also lowering the chances of iatrogenic root damage from severe dentine destruction and root perforation

GUIDED SURGICAL ENDODONTICS

Surgical guides that are 3D printed can be used in surgical endodontics where defining the osteotomy site and level of root resection in complex situations is difficult, as well as for skill development in an educational context.[22]

Like other guided treatments, guided surgical endodontics relies on rigorous treatment planning, which includes finalizing the design of the 3D printed surgical guide and employing implant planning software with matched CBCT and optical scan data sets. The guide sleeves were positioned above the cortical plate that helps in locating the site for the osteotomy during treatment.

The osteotomy is performed with depth calibrated drills or piezoelectric instruments that ensure parallelism with the guide sleeve, as a result, its size is limited to 4 mm elevation and retraction., osteotomies, and root-end resections were performed using piezoelectric instruments directed by the teeth- and bone-supported 3D printed surgical guides.[20]

AUTOTRANSPLANTATION

Autotransplantation is a relatively longstanding technique with a well-recognized application for replacing congenitally missing teeth lost due to trauma.[23]

Appropriate adaptation of the transplanted tooth to the recipient site and the preservation of PDL cells are required for successful autotransplantation. Traditional procedures employ the transplanted tooth as a template for preparing the recipient site, which sometimes necessitates numerous fitting efforts with some alterations in alveolar bone, resulting in increased extra-oral time and the possibility of PDL damage.

3D printing can be useful in this as the image of a tooth can be scanned before extraction and the recipient tooth can be modified accordingly and placed in the extraction socket. The recipient tooth can be prepared for a crown and a temporary crown can be placed immediately after placing the tooth in desired site. This minimizes the chances of errors during autotransplantation.

Strbac *et al*. in 2016[24] revealed how to use a fully digital approach to autotransplant immature premolars in a maxillary central and lateral incisor avulsion case. CAD was used by the researchers to choose the ideal donor teeth that are based on their root development stage and dimension. To accommodate the proportions of Hertwig's epithelial root sheath (HERS) and prevent injury to the cells of apical papilla modifications were done in prototype teeth. To construct gradually big osteotomy guides, prototype teeth that were digitally modified using CAD were auto-transplanted into the donor sites, allowing for a rapid and more accurate surgical phase.

EDUCATIONAL MODEL AND CLINICAL SIMULATIONS

For preclinical exercises, dental education historically utilized extracted teeth, human cadavers, plaster models, resin blocks, or commercially accessible resin teeth. Extracted teeth provide a clinical simulation that is semi-realistic, although teeth with ideal features are not always available due to the need for decontamination, preservation, and storage, which can degrade properties. Teeth with open apex should have frequently been made by root-end manipulation for regenerative endodontic simulations. The utilization of human cadavers has been used for root canal therapy simulation exercises, but their usage has been limited due to cost, availability, and storage issues.[16]

Nowadays there has been an increasing trend in dental schools across the world towards replacing extracted typodont teeth with 3D-printed tooth models,[25] use of 3D printing enable the creation of tooth models with realistic anatomical root canal structures by using CT Images, thereby providing dental students an opportunity to deal with realistic procedures, rather than the usage of ideal typodont teeth.[4]

3D PRINTED DENTAL PULP REGENERATION

3D cell printing techniques can be utilized for replacing pulp tissue. The structure of the pulp tissue can be recreated by using an inkjet device by dispensing layers of cells that are suspended in the hydrogel. This helps in the placement of cells with precision and this mimics the natural pulp tissue of the too. This is achieved by a systematic arrangement of cells that comprises odontoblastic cells at the periphery and fibroblasts within the center with a network of blood and brain cells. Research is focusing on in vivo creating a functional tissue-like pulp.[4]

IV. CONCLUSION

The technology of 3D printing has revolutionized dentistry and has the potential of serving as an educational tool by creating the most accurate models thus providing extended learning opportunities for dental students. In dental practice, the ultimate goal is to provide patients with the most technologically sophisticated dental treatment with the highest level of accuracy and the least amount of discomfort possible. With the development of 3D printing technologies, there are possible benefits for educating and managing guided non-surgical and surgical endodontic procedures for dental students.

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