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Review Article

Application of Three Dimensional Printing in Endodontics

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Abstract

Aim: The purpose of this article is to discuss three-dimensional (3D) imaging technology and their recent advances in diagnostic techniques, thus providing a reference frame for the current construction of 3D printing technology.

Background: Recent advances in digital technology, such as 3D printing (3D) and haptic simulations, have helped to treat cases including maxillofacial, craniofacial, implants, orthognathic, endodontic, and periodontal treatment. In the event of intricate surgical treatment, endodontic models and 3D printed guides have been used to help the operator plan and treat the condition and it also helps to gain skill.

Conclusion: 3D-printed models play a positive role as an educational tool. This process is time-consuming and economical which is its limitations. Although the future size of advanced research in this field is enormous, it remains to be not fully exploited.

Clinical Significance: The knowledge of 3D printing in the field of dentistry is very important due to its wide range of applications for a wide range of dental skills. Its introduction at the institutional level with optional hands-on training will ensure its efficient use.

Key words: Additive manufacturing, Bioprinting, Education, Haptics, Models, Stereolithography, Three-dimensional printing

INTRODUCTION

Three-dimensional (3D) printing is a new technology in the field of dentistry. 3D printing began in the 1980s when Charles Hull invented a 3D object in 1983. He invented the first 3D printer that used the stereolithography process.[1] It is an incremental production method, which is a new invention over subtraction production method, where an object is cut from an item block.[2] This technical design also produces 3D models and helps to improve treatment rates for patients because they are less sensitive and more accurate. A variety of 3D dental imprints can be printed using methods such as selected laser sintering, stereolithography, fused deposition modeling, and laminated object manufacturing. 3D printing can be combined with oral scanning and computer-aided designing (CAD)/computer-aided manufacturing (CAM) design to produce crowns, bridges, stone models, and various orthodontic equipment. Improved success in dental implants with 3D printing has also been reported.

In endodontics, compared with conventional two-dimensional images, cone beam computed tomography (CBCT) improved the understanding and interpretation of complex structures. 3D printed objects are models and guides that are generated by automated processes and are based on the visual (computer-generated) rendering of compatible tissue and bone tissue. Haptic simulators are computer programs that create 3D virtual representations of the teeth and bone tissue by mimicking the potential challenges of various therapeutic procedures and providing real-time feedback using multiple sensors. Haptic simulators help improve skills in endodontic processes through the acquisition of psychomotor skills.[1]

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DESIGN AND PRODUCTION OF 3D-PRINTED OBJECTS

3D image data from CBCT scanners [Figure 1] are available in digital imaging and communications in medicine (DICOM) or related formats [Figure 2]. Volumetric data

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(DICOM format) from CBCT scanners are obtained by 3D visual editing programs that use special software to convert data into a standard tessellation language (STL) file format representing a 3D visual environment. Using special software, the CBCT and corresponding intra-oral/plaster model STL data sets are matched. A computer that produces a 3D image and then edits it with CAD or implant planning software to create a 3D printed object plan.The completed design is then digitally exported and sent to a 3D printer [Figure 3] for the appropriate printing process.[3] Available 3D-printing processes in creating 3D printed objects for dental applications include: -Stereolithography (SLG), digital light processing, multi-jet modeling, plaster-based 3D printing, selective laser sintering, fused deposition modeling, color jet printing, and digital light processing.

It works with many things such as acrylonitrile butadiene styrene and polylactic acid in addition to being used to describe stereolithography apparatus systems (SLG apparatus), the term stereolithography is used to describe 3D printing in general.[2]

Applications of 3D Printed Objects in Endodontics

Advantages of 3D printed materials in endodontic procedures, including the treatment of complex endodontic cases, for example, non-surgical endodontics, calcified canals, dilacerated roots, teeth with developmental abnormalities, and in surgical endodontics, teeth with apices close to critical anatomical structures, or covered under a thick cortical bone, which will expose patients to greater risk of procedural errors that may delay treatment outcomes. They develop appropriate treatment outcomes and promote the development of operator skills. The use of 3D printed models and guides for endodontics are: -

3D printed models

Plaster models have been used to serve as teaching tools for students and patients. However, the internal anatomical formation is not possible to simulate by plaster models; Printed 3D models and digital technologies can fulfill the same functions of plaster models and overcome limitations. In endodontics, 3D printed models can be used as a teaching aid for students to improve their understanding of dental anatomy, root and canal morphologies, and to simulate access to the cavity and to prepare the root canal. They help to plan treatment through advanced visualization and determination of important anatomical landmarks or pathosis such as internal and external root resorption.[1] The dental model is made up of a three-step process that will be translucent with the internal structures of the anatomical canal. These steps are: CBCT is used for data acquisition, image processing to visualize a model, and to do things with 3D printing. To achieve accurate and error-free access to the root directory, a custom guide jig is made.[4]

SLS is used to create easily accessible 3D printed models. The material is thermoplastic and has a very high melting point. Therefore, during treatment procedures, they can be handled safely when used for guidance or navigation.

PBP and epoxy resin infiltrate are used to produce 3D print that will be bone-like and suitable for use on osteotomies. These types can be used to mimic surgical procedures. During treatment in conditions such as intricate osteotomy areas, anatomical structures adjacent to abnormal root forms, this can improve the interaction of staff and ease of operation. Another important factor is the cost-effectiveness of those types of 3D printing. When printing models independently the cost can be reduced after the primary printer investigation. Commercially available models and frame models cost the same price but sextants used for real teeth are less expensive as they are printed blank - only with a small scaffold with a small resin.[3]

3D printed guides

When negotiating an apical canal or in finding canal orifices, common mistakes are most likely in cases of root canal obliteration and abnormalities in development. In such cases, difficulties exist. It is also difficult to accurately determine the site of osteotomy and the appropriate degree of root removal due to the proximity of critical anatomic structures, position of the tooth and location of root apices, the size of the cortical plates. To avoid these situations, 3D printed guides for orientation or surgery can also be helpful. The availability of CBCT information and implant planning software assisted in the development and implementation of 3D printed surgical guides.[1] Targeted access guides help to treat teeth with pulpal canal obliteration, malposition, or extensive restoration.[2]

Guided Non-surgical Endodontics

3D printed guides help in detecting canal orifices in teeth with high chances of procedural errors like root perforations. Pulp canal obliteration reportedly causes more perforations while attempts are made locating and negotiating the calcified canals.[2]

In the case of access preparation, and the average deviation was <0.7 mm and a threshold, which is the diameter of the drill plus the diameter of the main canal.[5] Slight deviations from the planned entry (0.12–0.34 mm at the end of the bur tip), and announced, with a mean angular deviation of <2°. These studies have shown that 3D-printed-access guides are a highly effective tool for the resolution of complex endodontic scenarios, due to the chemical and mechanical cleaning, and preservation of tooth structure.[6]

"Targeted endodontics," a modified approach to the preparation of extended access spaces, has been introduced for the purpose of dental treatment with pulp canal obliteration, malposition, or major rehabilitation.[7] CBCT scanning, visual scanning of intra-oral anatomy or plaster models were compared and CAD software was used to design the guides and select the depth of the burs to be used. The guides are teeth-supported by multiple units on either side for further stability. 3D printed printing guides are made using SLG or MJM and pre-installed, or CAD-CAM, with cylindrical steel tubes attached to the guide sleeves. The production of individual orientation guidelines for the entire canal area is required for teeth with multiple orifices or canal morphologies such as dens invaginatus.[1]

When processes were performed using a working microscope, the location and negotiation of calcified root canals are usually determined. However limited to such procedures, there will be a lot of tooth loss associated with the acquisition of the root canal. The access prepared by using targeted approach maintains as much tooth structure as possible. These small access preparations have greatly improved the resistance of the tooth to fracture. There were few limitations of this guided approach that include the need for a direct straight access to the apical area, limited access to the posterior teeth, and an increase in temperature. It increases the total duration of treatment with increasing costs, and small dental cracks may also result from the use of implant drills/dental burs when used in the tooth with root canal obliterations, but conservative access preparations and avoiding process errors outweighs this malignancy.[6]

Guided surgical endodontics

In surgical endodontics, 3D printed surgical guides were used where there is difficulty in determining the site of osteotomy and the degree of root removal in difficult cases, or in developing skills in the educational field. Endodontic microsurgery requires targeted osteotomy and root removal based on anatomic landmarks and X-ray or CBCT of preoperative measurements. In targeted surgical endodontics, the 3D-printed design of the surgical guide is completed using implant planning software loaded with the matching CBCTs and sets of test data. During treatment, the position of the guide arm on the cortical plate helps to identify the site of the osteotomy.[1] Under ideal conditions, the size of the osteotomy can be as small as 3 mm, which is also associated with reduced healing time, reduced postoperative pain, and improved outcomes. Using standard drills or piezoelectric tools to perform osteotomy, the shape of the guide sleeve should be maintained, thus limiting its size to 4 mm. Printed 3D templates can be used for the treatment of one or more roots with an internal or posterior location because radiographic DICOM and integrated scanning files are combined to form an individual and unique surgical template.[8]

Guided autotransplantation

In order to effectively maintain the transplanted tooth at place, preservation of the periodontal ligament (PDL) cells and the proper repair of the transplanted tooth at the recipient's site is mandatory. Extraoral communication and PDL trauma during the procedure affect the results.[9] In typical methods, the transplanted natural tooth has been used as a template. A series of appropriate attempts to adapt that tooth to the alveolar bone are required thereby significantly increasing the extra-oral time and significantly increasing the risk of injury to PDL.[10] The use of a computer-aided rapid prototyping was used to print duplicates of the tooth so that the manipulation of recipient bone areas were completed before extracting the teeth without damaging the PDL in repeated insertion and removal.[11,12] Depending on the local relationship of the tooth and the stage of root growth, CAD was used to select appropriate donor teeth. The sample teeth were modified to match the size of Hertwig's epithelial root sac and reduce apical papilla injury. Model teeth that are modified by the CAD system have been implanted in donor sites to create larger osteotomy sequence guides that allow for a more precise and effective surgical procedure. A total success rate of 80–91% while using rapid prototyping indicates the preparation of the recipient site before the placement of the transplanted tooth was successful.[10]

In Regenerative Dentistry

Pulp tissue regeneration

3D printing can be used to produce stem cells, pulp scaffolds, injectable calcium phosphates, growth factors, and genetic treatment in endodontics. To revive the pulp-dentin complex, several scaffolds were manufactured from calcium phosphate cement using 3D printing. Studies have shown that the use of 3D-printed polycaprolactone with plasma-rich platelet concentrated in dental pulpal cells has improved osteogenic *in vitro* activity. And almost identical tooth structures are produced using 3D printed polyepsilon-caprolactone and hydroxyapatite scaffolds.

Bio printing using cell ink-based bio-printers or spheroid micro-based systems that produce artificial "tissues" and have been shown to allow the setting of external *in vitro* 3D models. Thus, additive manufacturing technique has opened up access to stem cell therapeutics where it is possible to print the desired cells into a 3D complex that can be used in regeneration and transplantation. Reconstruction of pulp tissue structure is done by setting a layer of cells in a hydrogel. This helps to position the cells and thus to resemble the natural pulp tissue. This is achieved by the orderly formation of cells involving the placement of fibroblasts within core cells and odontoblastic periphery with a supporting network of vascular and neural cells.[13]

Dentin matrix regeneration

3D bio printing has evolved as a powerful technology to solve this huge need for regenerative dentistry. Bio printing allows direct placement of cellular scaffolds on demand, mounted on hydrogels, or free on scaffold support. Various 3D printing technologies such as micro extrusion, inkjet, magnetic levitation, and simple laser and lithography are used to create and extract cell bio-inks. The concept of using decellularized extracellular matrix as advanced bio-inks for 3D bio-printing has evolved, where the ideal bio-ink can also have natural molecules from the parent tissue. Bio-printing of bio-ink with a combination of hydrogel takes advantage of the natural functioning of the extracellular matrix and alginate printing. This bio-ink is called Alg-Dent. Alg-Dent retains sufficient soluble cues to enhance the differentiating capacity of bio-printed stem cells for dental regeneration systems.

The strength of hydrogel scaffolds is a key factor in determining the activity and proliferation of these pulp-like cells. When 1: 1 Alg-Dent hydrogels were used as a medium to culture SCAP cells, it showed an increase in survival rate by more than 90% of active cells. However, bio-inks for dental rejuvenation are not easy. 1: 1 and 1: 2 Alg-Dent hydrogel bioinks had the highest efficacy of both 2: 1 Alg-Dent and pure alginate hydrogels ($P < 0.0001$).

Alginate proteins and dentin matrix are an important components of dentin-derived ECM hybrid cell-laden hydrogel bio-inks. They show high print and cell survival in a variety of concentrations. In addition, these hybrid hydrogels can be combined with acid-soluble dentin molecules, which improve the odontogenic differentiation of SCAPs. All of these elements of the novel bio-inks provide the ability to accurately control the local presentation of signals and the interaction of heterotypic cells to optimize the pulp dentin complex. Therefore, these biomaterials may represent an important tool in the regeneration of craniofacial and dental appplications.[14]

SIMULATION OF INTERNAL ROOT CANAL MORPHOLOGY

The formation of a visible dental model means producing the external structure of the teeth. Internal root structures visualization were helpful for patients with atypical root morphology, areas of root resorption sites. A new experiment was developed in which a dental model was developed through image processing, visual modeling, and 3D printing. In 3D printing, flexible resin material is used not only to visualize the root canal but also to improve the tactile sensitivity involved. In short, the DICOM file from the CBCT images was categorized by a multi-layered design process to obtain a limited working environment. Using 3D slicer the separated DICOM file was converted into a SLG (STL) system. In the STL file, there will be no representation of any internal dental structures, and it only describes the surface of the object.

The dental model is almost divided into two pieces, each representing an internal hole as the outer surface of each part. The STL files of these pieces were eventually merged to represent the STL dental file containing the details of the internal structures. The STL file was then printed with a high resolution printer. Clear acrylic photopolymers are used as a 3D printing materials. To explore and foresee the root canal, a red water-based dye is injected through the apical foramen of the fabricated model.

The access was carefully prepared with the direct access found in the visual model. A jig for reproducing this path in the real tooth is made using a round bur and a composite resin. The durability of the custom jig was confirmed by placement on the pre-made stone model. On subsequent patient visits, a custom jig was applied on the crown of the tooth, and a preparation point that would be directed to the root canal was shown accessed using a long shank round bur# 2 where the tip has been coated with methylene blue dye.[4]

EDUCATIONAL MODEL AND CLINICAL SIMULATION

Dental education has historically relied on extracted teeth, human cadavers, resin blocks, or resin teeth for pre-workout exercises. Dental prototypes are used to mimic with benefits over-extracted teeth.

Additive manufacturing plays a major role in endodontic training and education. There is this growing trend in various dental institutions around the world to replace the typhodont teeth with 3D-printed tooth anatomies, based on computer-tomographic images of extracted natural teeth with a higher anatomical root canal structure.[16] 3D-printed models and computer software such as haptic simulators help build endodontic skills by providing visual, acoustical, and tactile power to the user.

Critical structures such as nerves or blood vessels or large cortical bones covering the roots often lead to systemic errors where such models can serve as a blessing in preparation for a physician for severe conditions.[3] 3D printing function is a visible aid to the patients in the acceptance of their treatment procedures. Acceptance of the treatment by a patient not only allows for more patient-centered programs but also reduces the patient's anxiety level, which is important during the treatment provided. In this way, 3D printed models can directly affect the patient's motivation levels and indirectly help keep the patient calm during the procedure.[16]

HAPTIC SIMULATOR AND ITS OPERATION

Virtual simulation systems actually produce visual and auditory simulation and allow for powerful interactions with specialized systems, such as haptic devices. Haptics describes the science of the concept of touch and its interaction with the virtual environment. Haptic simulators mimic the sensory tactile sensation by using real robotic response systems capable of creating vibrations and combat forces. Most haptic devices provide six degrees of free space (DOF) for location but three for DOF for forced response, which limits the existing limit.

The combination of haptic technology with virtual reality and integration with 3D imaging data in dentistry has led to the emergence of haptic dental simulators that can create virtual oral anatomy and facilitate the simulation (3D visualization) of dental procedures with real-time visual, tactile and audio response. Therefore, these devices are mainly used in dental education for 3D visual planning. The software relies on simultaneous operation and interaction between two processes - graphics rendering and haptics. The graphics rendering process is responsible for the stereo view of the 3D visual environment. The Haptics delivery process monitors the location of the haptic stylus, detects collisions with the physical environment, and calculates the reaction forces that should be used by the robotic method. Benefits of haptic simulators include strengthening of educational teaching, acquisition of psychomotor skills, ergonomic chair-side positioning, the ability to access various pathological conditions by modifying data sets, self-assessment. However, commercial devices are expensive, use a limited range of materials and do not mimic soft tissues accurately. In addition, research into the authenticity provided by these dental procedures resources is lacking.[1]

APPLICATION OF HAPTIC SIMULATOR IN ENDODONTICS

Haptic simulators are useful in teaching endodontic treatment. Haptic simulators should provide a realistic imitation of non-surgical and surgical procedures, as well as a proper armamentarium, as well as anatomical complexity considerations. Haptic simulators can be useful as a teaching tool for endodontic processes that include access to the root canal, osteotomies, and root transplantation.

However, only access preparations, osteotomies, and root end resections were possible with commercially available haptic simulators. They are VirTeaSy Dental (HRV, Laval cedex, France) and Simodont® Dental Trainer.[1] In conclusion, the identification of appropriate variables that can reflect the extent of expertise and/or acquisition of skills is essential to the development of goal-scoring processes that lead to the establishment of sound educational frameworks.[17]

DISCUSSION

3D printing offers an alternative device for "extracting" CAD dental software; making it possible to make complex objects and objects with a variety of synthetic materials. With this new technology comes a new opportunity; the challenge we face is not to look at 3D printing as a new tool to do what we have been doing, but to look at it as a technology that will allow us to be creative, develop new things and guess new, less invasive and less expensive procedures for our patients.[18]

Accuracy of 3D printers is defined by 2 specifications: XY adjustment and layer size. XY Adjustment has been the most common specification used to describe quality or print details and is similar to pixel size; the smallest movement that a laser printer can make within a horizontal layer. Layer thickness or Z height refers the surface finish of a part, the implication being that lower layer heights improve surface finish. Layer thickness is affected by frame type and printer settings. There is no gold standard for testing 3D printers. The typical size of the CBCT used in endodontic applications can be as small as 0.076–0.6 mm, much smaller than the recommended 1 mm 3D printing limit. Many endodontic applications for 3D printing to date have been modified from implant planning software. After nearly two decades of 3D printing, the first certified biocompatible-based resin, NextDent SG was launched in 2016. Printed 3D bioscaffolds containing Mineral Trioxide Aggregate and Bio dentine have improved the differentiation of human dental cells for osteogenesis *in vitro* models. Additional studies exploring innovations could increase the use of 3D printing in regenerative endodontics, targeted tissue regeneration, and wound healing. Given the accuracy of this 3D printing method, little discrepancy can be expected between editing and

Figure 1: Computerized tomography scan machine

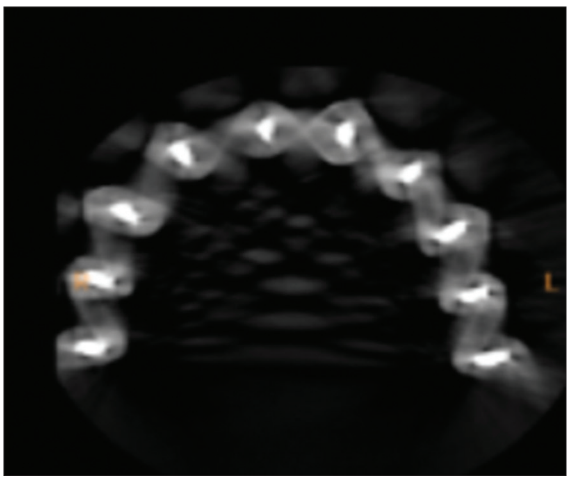

Figure 2: Cone beam computed tomography data acquisition in digital imaging and communications in medicine format

Figure 3: 3D printer

execution. One reason for this is a system error, namely, a summary of all existing errors in various categories, accumulating in the end result. In the data acquisition phase, CBCT database resolution should be considered even if CBCT can be considered very accurate. Since the voxel size is 0.3 mm, the accuracy of the whole system is unlikely to exceed 0.3 mm.[18] The digital design method and the rapid prototyping of endodontic guides allow for reliable and predictable planning of operations in root system.[19]

CONCLUSION

The endodontic literature for 3D printing is limited to case reports and pre-clinical studies. Endodontic applications for stent-guided EMS, rapid prototyping of anomalous teeth, autotransplantation, and educational modeling are documented within the literature. In the future, widespread use of 3D printing technology in endodontics will be possible as further research and development occur. With continuous improvements in 3D imaging, 3D printing, and 3D virtual planning, combined with the need for skill development, to optimize treatment outcomes and to improve patient comfort, there are potential benefits for teaching and management of non-surgical and surgical endodontic procedures using these technologies. Further research on the various applications of 3D printed models, 3D printed guides, and haptic simulators in endodontics is required.

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