TITLE: OPTIMIZING A 3D ENDODONTIC STENT FOR ADHESIVE FIBER POST REMOVAL: IN VITRO EXPERIMENTAL STUDY

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ABSTRACT

Optimizing a 3d endodontic stent for adhesive fiber post removal: in vitro experimental study

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Background:

Aim: The aim of this study is to optimize the variables involved in the design and fabrication of 3D stent for fiber post removal to enhance it accuracy, efficacy and safety.

Material and methods: 3D stents were designed with 3D Slicer and Rhino software utilizing NextDent™ Model 2.0 or NextDent™ Surgical Guide (SG) materials. Four experiments were performed to determine the effect of 3D software and fabrication materials on hole size accuracy, hole shape characterization, enlargement margin, and wire deviation/deflection.

Results: 3D stents printed with NextDent™ Surgical guide (SG) fabrication material have larger hole sizes than the origin pre-determined size by +0.04-0.07 mm, while those made with NextDent™ Model 2.0 are smaller by -0.03–0.00 mm, regardless of the software used to design the stent. NextDent™ Model 2.0 has more staircase effects than NextDent™ SG. The required enlargement margin to allow a stainless steel round wire to fit into a matched pre-determined hole is +0.05-0.1mm. The deviation distance in 3D stents designed by 3D Slicer and printed by NextDent™ Model 2.0 decreased with stent thickness from 4mm to 8 or 12mm, regardless of hole size.

Conclusion: No matter the software or material used to design and print stents, the actual hole size is always different than the pre-determined hole. Always enlarge the hole radius by 0.5-1.0mm to allow a wire (or bur) to fit. Increasing stent height from 4mm to 8 or 12mm reduces wire deviation.

DEDICATION

This dissertation is dedicated:

This work is entirely dedicated to my kindhearted and adored mother, without whom this thesis paper would not have been possible. She is a constant source of inspiration for me.

At the same time, I want to express my gratitude to my loving friends, whose suggestions for this thesis paper were quite helpful.

This work is dedicated to my institution's mentors, who have helped me complete my dissertation with their consistent guidance. They not only provided me with academic knowledge, but they also provided me with wise guidance when I needed it most.

DECLARATION

I declare that all the content of the thesis is my own work. There is no conflict of interest with any other entity or organization.

Name: Fatemeh Fard

Signature:

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My research supervisor, Dr. Mohamed Jamal, deserves the greatest respect for his guidance, support, motivation, and encouragement during my research work. Without his insightful suggestions, worries, and encouragement, this paper would not have been completed. Dr. Mohammed Jamal has always provided me with outstanding guidance, assistance, and considerable advice.

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1. INTRODUCTION

Endodontically treated teeth with extensive loss of the coronal tooth structure might require reinforcement in the form of cast or prefabricated post and core system. With increased popularity of esthetic restorations, there have been increased interest in using fiber posts and composite cores due to their mechanical and esthetic properties(1). The recent generations of fiber posts have modulus of elasticity similar to that of human dentinal tissues(2).

Post-treatment endodontic diseases can develop due to persistent or re-introduced intra-radicular infection(3). In these cases, coronal disassembly and removal of root canal filling material are required to regain access to apex and re-clean and shape the root canal systems. Teeth that were restored with fiber post pose a challenge to clinicians. These posts adhere chemically to the root dentin, therefore and unlike metal post, it cannot be removed by breaking up the cement layer between the post and the root dentinal wall(4). Thus, clinicians need to drill through the fiber post to remove it and reach the apical area. Moreover, there is close resemble in color between fiber posts and root dentin. This might result in clinicians cause iatrogenic damage to the root dentin such as over-canal preparation that can weaken up root dentin or even root perforation(5, 6). Several techniques have been introduced to guide and facilitate fiber-post removal such as the use of ultrasonic tips, dental operative microscope and CBCT(7, 8).

However, even with the presence of these advanced techniques, several challenges still exist.

The concept of Guided Endodontics is raised recently for access and penetration the root canal system .

The guided endodontic procedure was first termed by Zehnder et al, who offered its use for teeth with calcified canal in pulp that is undergone root canal treatment(9). This concept uses CBCT prior to procedure and the planning a 3D printed stent to guide during penetration(9).

This procedure is very likely to lead to time saving and persevering the loss of a considerable amount of the surrounding dentine, which may result in root perforation or may weaken the tooth and predispose it to a vertical root fracture.

This project aimed to use and apply the concept of guided endodontics to design and develop a 3D stent to aid in removing fiber posts during endodontic retreatment procedures. This is in an effort to increase the accuracy of the procedure and reduce the potential iatrogenic. This investigated different types of software and the materials that are used to fabricate the stent in order to optimized the variable and increase the accuracy of the stent.

2. LITERATURE REVIEW

2.1 Goals of endodontic therapy

Endodontic treatment is aimed at either preventing apical periodontitis from developing or creating sufficient conditions for the healing of peri radicular tissues(10). This is done through removing the microorganism and bacterial biofilms from the root canal system, to eliminate the source of infection and inflammation, as described by Schilder in 1967(11). This is usually achieved by cleaning, shaping and filling the root canal system with 3-dimensional obturation material, that would act as a barrier between the root canal system and the surrounding tissues. Upon completion of the root canal treatment, a permanent restoration should be place to provide the required seal and prevent coronal leakage(12).

2.2 Rationale for endodontic retreatment

In modern dentistry, non-surgical root canal treatment has become a routine procedure.

However, not every treatment leads to optimal treatment healing for the long term. Given the high number of endodontic procedures performed, the very small rate of insufficient treatments leads to relatively many patients require retreatment. Undesirable endodontic therapy outcomes have been described as failures in the past(13). The concept of disease-treatment-healing is common in most patients. While failure implies no need to pursue treatment, apart from a negative term. The use of the term "Post endodontic treatment disease" is therefore recommended. as confusion will be reduced and communication between the dentist and the patient facilitated(3). After-treatment The primary cause of endodontic disease is the root canal infection. When previous treatment microorganisms survived. After therapy or invading the canal space(3).

2.2.1 Causes of post treatment disease

There are numerous causes for endodontic post-treatment diseases, which can be grouped into persistent intra or extra radicular infection or secondary (reintroduced) infection. Several procedural errors can lead to persistent intra or extra radicular infection such as poor cavity design, untreated canals, insufficient canals cleaning and sealing, ledges, perforations, separated instruments and root-filling material extensions. Coronal leakage, is the most common cause of secondary infection. For persistent Extra-radicular infection, it could be in a form of periapical cyst or foreign body reaction(13).

2.3 Restoration of endodontically treated teeth

Successful endodontic treatment of carious teeth with pulpal disease depends not only on sufficient endodontic therapy, but also on a coronal restoration(14). The restoration of the endodontically treated teeth is an area that is widely assessed in dental literature and discussed. In the last 20 years, significant changes have been made in the restoration of endodontically treated teeth(15). The survenance and success of the endodontic tooth will be affected by the quality of the coronal restoration. Endodontic treatment is generally believed to weaken up the tooth structure and to make it more prone to fracture than normal vital treatment teeth(16). Dentine were thought to be more weak and brittle because of loss of water and the loss of cross-linked collagen in endodontically treated teeth. Recent studies, however, dispute this(17). Huang et al. have compared dentin specimens' physical and mechanical properties. They found that neither dehydration nor endodontic therapy causes the physical or mechanical characteristics of dentin to degrade(16). A tooth that needs an endodontic treatment is often a tooth which has been severely restored and lost in a large volume of dental tissue. These teeth are usually more likely to fracture(15). Access preparations lead to increased deflections of the cusps during function and increase the possibility of cuspid fractures and microleaks(17).

2.3.1 Restoration type

The restoration type selected for the endodontically treated teeth is dependent on the available hard tooth structure. The remaining part of the tooth determines the tooth's fracture resistance and the retention of the restoration. The preservation of the tooth structure as much as possible is likely will improve the outcome(15). Several parameters define the ultimate decision regarding restoration choice. The type of tooth and position determined the exact choice of restoration type.

2.3.1.1 Anterior teeth

The restoration of the choice will be direct composite restoration in anterior teeth that are minimally to moderately destructive. For endodontic-treated anterior teeth that need to cover the whole labial surface of the tooth including the incisal edge and through proximal contacts, ceramic or composite resin veneers are often recommended. When an anterior endodontically treated tooth has to be crowned, metal ceramic crowns are often recommended. Compared to the metal-ceramic crown, all-ceramic crowns offer the dental clinician a superior esthetic result and often reduced tooth preparation(15).

2.3.1.2 Posterior teeth

The restoration of composite resin is seldom acceptable for posterior endodontically treated teeth as definitive long-term restorations. The material of choice for posterior teeth still consists of gold onlays or full coverage crowns, but that tends to be where esthetics are not a big concern. So in the area of esthetics The choice is for ceramic onlays/crowns. Full coverage metal-ceramic crowns on the posterior teeth is the most commonly placed restoration, especially if is a bridge abutments(15).

2.3.2 Indications for a post

The main purpose of a post is to retain a core with a large loss of coronal tooth structure(17). The placement of a post is typically suggested when restoring endodontically treated teeth, where the residual structure is not sufficient to support the core such as amalgam or composite core(15). A post and core may contribute to the prevention of coronal fracture if the remaining coronal tooth structure is thin after tooth preparation(18). Two major categories of posts exist: custom-made and pre-fabricated(14). Prefabricated posts are usually made in stainless steel, chromium alloy or titanium alloy. The fiber-reinforced polymer posts are also a newer type of prefabricated posts(14, 17). For many years, casted posts have been the standard and are still used by many clinicians. However due to extra number of appointments required and the extra laboratory fees, it became less popular. Moreover, it faces some limitation is restoration anterior esthetic areas. Therefore, prefabricated fiber posts became more popular in restoration teeth in esthetic zones(17).

2.3.3 Techniques of fiber post removal during nonsurgical endodontic retreatment

For teeth with Post-endodontic-treatment disease, post removal from root canal–treated teeth is frequently required(17). Fiber posts and composite cores have recently become more popular due to their mechanical and cosmetic features, which allow them to mix in with permanent restorations. Fiber posts have grown in popularity over the previous decade and are now the most commonly used forms of posts(18, 19). For the removal of the fiber posts, a number of devices and techniques have been described. These include ultrasonics, sonics, round burs, and specially designed burs kits. (8, 20, 21).

2.3.3.1 Iatrogenic errors in post-removal procedures

Post removal can be difficult for clinicians, and removing posts from root canals can be dangerous. This is mainly due to the color similarity between the root dentin and the tooth root dentin. Therefore, procedural errors such as unnecessary removal of sound root dentin, deviations from the root axis, microcracks, perforation, and root fracture are common iatrogenic mishaps. These errors can worsen the prognosis and jeopardize the success of the endodontic retreatment(20, 22, 23).

2.3.3.2 Techniques for preventing procedure errors

Clinicians can use the information obtained from a 3-D cone-beam computed tomography (CBCT) scans to reduce such errors. The development of a technology that allows practitioners to remove a fiber-post and retreat endodontic disease efficiently and conservatively is very desirable(24). The most current technologies introduced and hypothesized to overcome procedural errors that can occur during post-removal are the Guided Endodontic Stent and Dynamic Navigation System (DNS).

2.4 Guided endodontic

Guided Endodontic Procedures (GEP) have been introduced by Zehnder et al. to describe a method for treating teeth with calcified canals during root canal treatment(9, 25). This approach incorporates CBCT imaging before the procedure and the use of a 3D printed stent to guide penetration. In difficult cases where traditional radiographs do not provide enough information on the anatomy of the tooth and its surroundings, CBCT can be used(26). This 3D data can be combined with surface data from the teeth obtained with an intraoral scanner to create a treatment guide that can be designed and 3D printed(27).

CBCT provides a tool for diagnosis and treatment. In the field of oral implantology, CBCT is often used for three-dimensional planning, quantifying bone level, and visualizing anatomic features such as the mandibular nerve canal(28). Another application of CBCT is guided implant surgery, which uses templates to prepare the implant site and put the implant according to the design(29). CBCT allows for a non-invasive assessment of a tooth's morphology and internal obstructions, allowing a physician to plan treatment precisely. Endodontics has recently adapted 3D-printed surgical templates derived from dental implant design software, allowing for located and accessing calcified canals, auto transplanting, and endodontic microsurgery. These templates can now be created using 3D printing machines using matched 3D surface scans and CBCT data(25, 30).

The planning procedure for the design of the 3D guide normally includes the following steps: First, a high-resolution CBCT of the patient. Then, either directly with an intraoral scanner or indirectly by scanning the impression tray or plaster cast with an optical scanner, a digital intraoral impression of the patient's teeth is acquired. Then, using specialized image processing software, both scans (CBCT and intraoral) were surface registered(31). Several distinct software products were mentioned in the very minimal literature, including the following:

coDiagnostiX TM software, SIMPLANT® Computer-Guided Implant Treatment Software, and Blue sky plan software(25, 32, 33).

Then, using 3D design software, a template or guide is created based on the desired treatment pathway. Finally, the treatment guide is 3D printed or molded for utilization. As far as we know, the materials utilized in 3D printing are not well-defined or well-represented in the literature, with the exception of one article by Khorsandi et al 2021, which mentions polymers, metal-based materials, and ceramics(34).

2.4.1 guided endodontics' accuracy and limitations

The accuracy and the precision of 3D stent in dentistry and specifically in implant has been studied. However, in endodontic there are limited studies on the accuracy, safety and efficiency of the 3D printed guide/stent. This is a specifically important in endodontic as we are dealing with micro anatomical structure which require higher level of accuracy and precision, which can be translated to safety and reduction of iatrogenic errors.

To study the accuracy of a 3D printed model it is imported to define and determine the variables that may affected. The term 'accuracy' in 3D printing is used when both trueness and precision are met, according to ISO 5725-1:1994/Cor 1:1998. The trueness of a measurement method is indicated when a true value for a property can be envisioned. The need for precision stems from the reality that tests performed on supposedly equivalent materials under supposedly same settings may not necessarily produce the same results. The accuracy of a 3D-printed model is affected by the total errors that occur throughout the overall fabrication process, including model scanning imaging, image segmentation, STL file transition, STL post-processing, slicing of the STL file for 3D printing, 3D printing itself, and post-processing. All of these processes rely heavily on the software, the 3D printer, and, of course, the user(35). The accuracy of the guide, on the other hand, is affected by the manufacturing conditions. Material qualities (shrinkage and distortion), fabrication method (3-dimensional (3D) printing or milling), and equipment precision can all affect the final guide, resulting in inaccurate drilling. As mentioned previously there are limited studies in the precision of the 3D stent in endodontics. Therefore, studies are required to test the above mentioned variables the accuracy and precision of the 3D stent in endodontics before it widely used in clinic. So in order to determine the factors that require optimization a pilot experiment was conducted as follow:

Pilot experiment

A pilot experiment was conducted in-vitro to determine the factors that require optimization. The methodology of this pilot experiment is detailed in Appendix 1. Briefly, intact human premolars that were already indicated for extractions as part orthodontic treatment plan were collected. Then, they were mounted on silicon putty, had root canal treatment and finally restored with fiber post. CBCT were taken for these before the post removal procedure in order to generate digital data that will be used for the fabrication of the 3D stent and to be as a control to measure the volume of tooth structure loss.

The 3D stents were fabricated using 2 software, Rhino and 3D slicer. Holes that match the size of Mounce Bur size 2 were made virtually in these stent. Finally the stents were printed and fitted on the mounted teeth. The post removal procedure was done using the stent and compared to the conventional fiber post removal using bur and ultrasonic tip.

The result of the pilot experiment showed that removing the fiber posts using 3D printed stent was significantly faster and more conservative than the conventional method (Figure1). However the following were observed that can affect the safety and predictability of using such method in removing the fiber post using 3D stent:

1) The different software used to design the stent, produced 3D stents with holes sizes that differ from the predetermined one. It was difficult to determine the margin of error for each software from this pilot experiment.
2) The predetermined guide holes designed and produced by different software were different even if the same variables values were used in both software. The different between the 2 software was difficult to be determined through this pilot experiment.
3) The material used for stent fabrication also affected the guide hole size, even if the same software, variable values and printer were used
4) Although using a stent was faster and more conservative, however there was a deviation from the original pre-determined removal path. The reason of such deviation could be because of variability of the hole size to the bur size or due to the differences in height of the stent

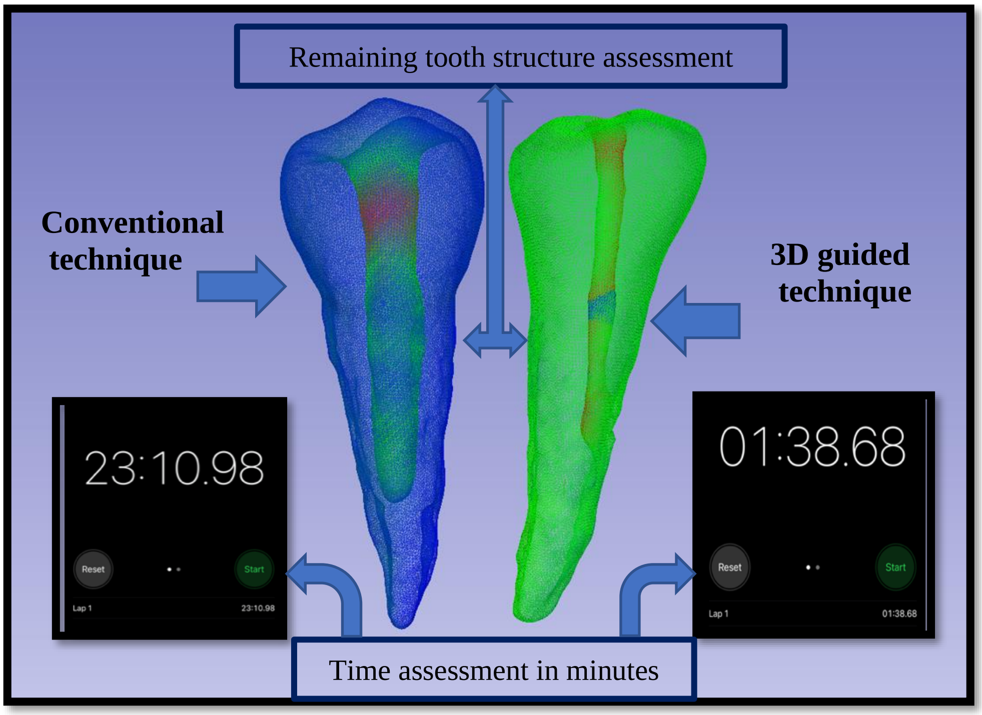


Figure1.Image illustration of the pilot experiment result

3. AIM OF THE STUDY

The aim of this study is to optimize the variables involved in the design and fabrication of 3D stent for fiber post removal to enhance it accuracy, efficacy and safety.

4. SPECIFIC OBJECTIVES

In order to achieve the aim of the study, the following objectives were formulated:

- Investigate the accuracy of different 3D software, specifically 3D-Slicer and Rhino in making pre-determined size hole in 3D stent.
- Investigate the effect of different 3D stent fabrication material on the hole size.
- Investigate the effect of the hole size and 3D stent height on bur deviation/deflection from the pre-determined course of insertion.

5. NULL HYPOTHESIS:

There is no significant difference between the software and materials

6. MATERIAL AND METHODS:

Experiment 1: Investigating the effect of the 3D software and fabrication materials on the accuracy of the hole sizes:

The aim of this experiment is to test the effect of the 3D software and fabrication material on the accuracy of the printed hole in comparison to the planned pre-determined hole diameter. To test such effect, 3D stents with different pre-determined holes were designed using 2 software, 3D Slicer (3D Slicer 4.11; Surgical Planning Laboratory, Harvard University, Boston, MA, USA), and Rhino (Rhino 3D V5 software , McNeel North America, Seattle, WA) were printed using either (NextDent™ Model 2.0, Vertex-Dental B.V., Soesterberg, The Netherlands)

or (NextDent™ SG, Vertex-Dental B.V., Soesterberg, The Netherlands) fabrication materials (Figure 2). Therefore, the stents were then grouped into.

- Group 1 (G1): 3D Slicer software/ NextDent Model 2.0 by 3D systems material.
- Group 2 (G2): Rhino software/ NextDent Model 2.0 by 3D systems material.
- Group 3 (G3): 3D Slicer software/ NextDent SG (Surgical Guide) by 3D systems material.
- Group 4 (G4): Rhino software/ NextDent SG (Surgical Guide) by 3D systems material.

In group G1 and G3, the stents were designed using 3D slicer software. Briefly, plain 3D stent model in Standard Tessellation Language (STL) format was imported into 3D slicer software. The dimensions of the stent was 30mm in length, 13mm in width and 5mm in height/thickness (Figure 3). The 3D model was converted into segment first. Then, using “Tube” tool, 4 cylindrical holes were created in the stent with the following radius 0.65, 0.7, 0.8 and 0.9mm (that correspond to 1.3, 1.4, 1.6 and 1.8mm in diameter). The segment was exported into printable STL format. The STL file was then imported into 3d printer (NextDent™ 5100, Vertex-Dental B.V., Soesterberg, The Netherlands) and printed using either NextDent Model 2.0 or NextDent SG fabrication material.

For group G2 and G4, the stent were designed using Rhino software. Briefly, plain 3D stent model in Standard Tessellation Language (STL) format was imported into Rhino software. The dimensions of the 3D model was exactly the same as in G1 and G3 (Figure 3). The 3D model was converted into segment first. Using "design" tool, four-round cylinder pilot hole that ran vertically through the 3D model were created with the following radius 0.65, 0.7, 0.8 and 0.9mm (that correspond to 1.3, 1.4, 1.6 and 1.8mm in diameter). The adjusted model was then saved and exported into printable STL format. The STL file was then imported into 3d printer (NextDent™ 5100, Vertex-Dental B.V., Soesterberg, The Netherlands) and printed using either NextDent Model 2.0 or NextDent SG fabrication material.

Measurements were made with a A Leica M205A Stereo-microscope (Leica Mikrosysteme Vertrieb GmbH, Wetzlar, Germany) to determine the diameters of the holes.

The experiment was carried out in triplicates in order to confirm the validity of the data. Therefore, there was a total of 12 holes per group and total of 48 holes for all group. This number of holes was chosen based on power calculation, this sample number has 80% power to detect a 25% change between groups in the variables being measured, that is hole diameter, assuming a standard deviation of 5 and alpha (type 1 error =0.05).

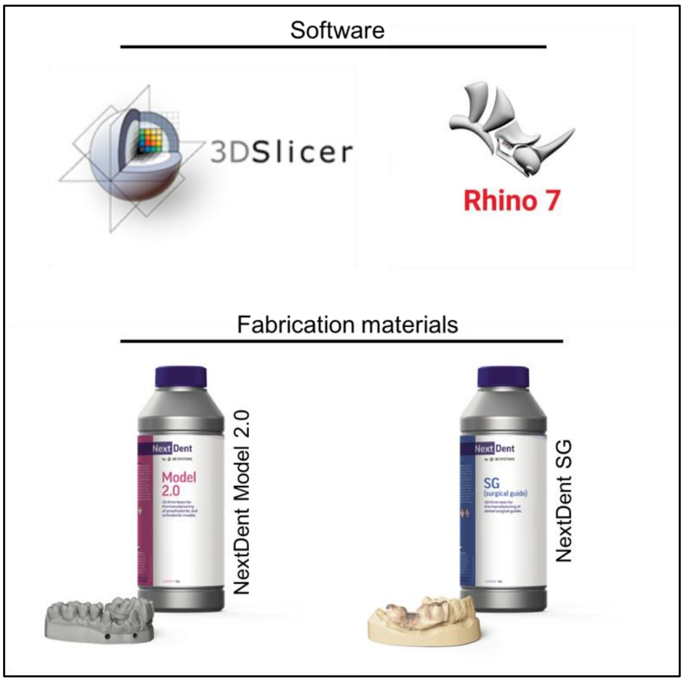


Figure 2. Image illustrating the different software and material used in the study.

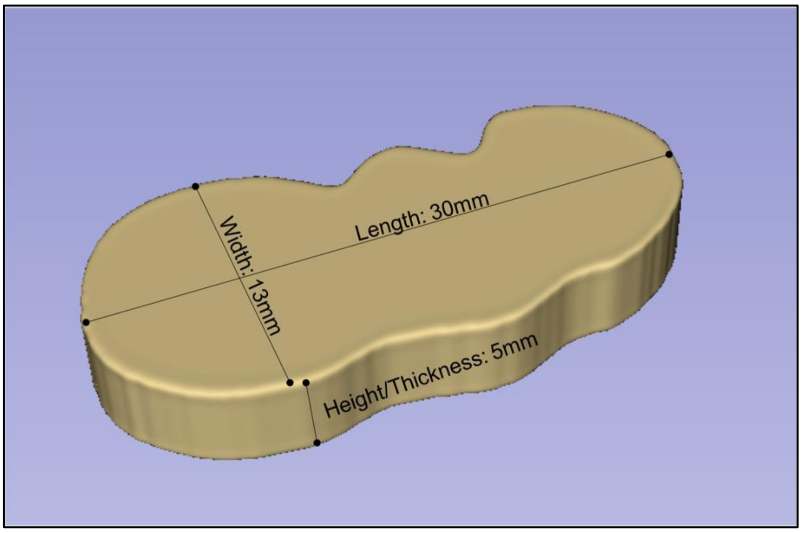


Figure 3. Image of the stent demonstrating the dimension in mm for the length, width and height.

Experiment 2: Hole shape characterization

The aim of this experiment is to describe and characterize the hole shape in regard to the presence or absence of staircase effect. Usually, many printers print objects in layers, and staircase effect occur when the layers become distinctly visible on the objects' surfaces, giving the perception of a staircase (Figure 4). Such effect can affect the roundness and actual diameter of the hole in comparison to the planned pre-determined hole. It can reduce the area of a round hole in a range of 6 to 7% (Figure 4).

In this experiment, stents with the holes that were made in the previous experiment were examined under a stereomicroscope. Each hole was examined and scored as "1" if the staircase effect present or scored as "2" if the staircase is absent. The experiment was carried out in triplicates in order to confirm the validity of the data (3 models from each group, total of 12 holes per group, and a total of 12 models and 48 holes for all groups).

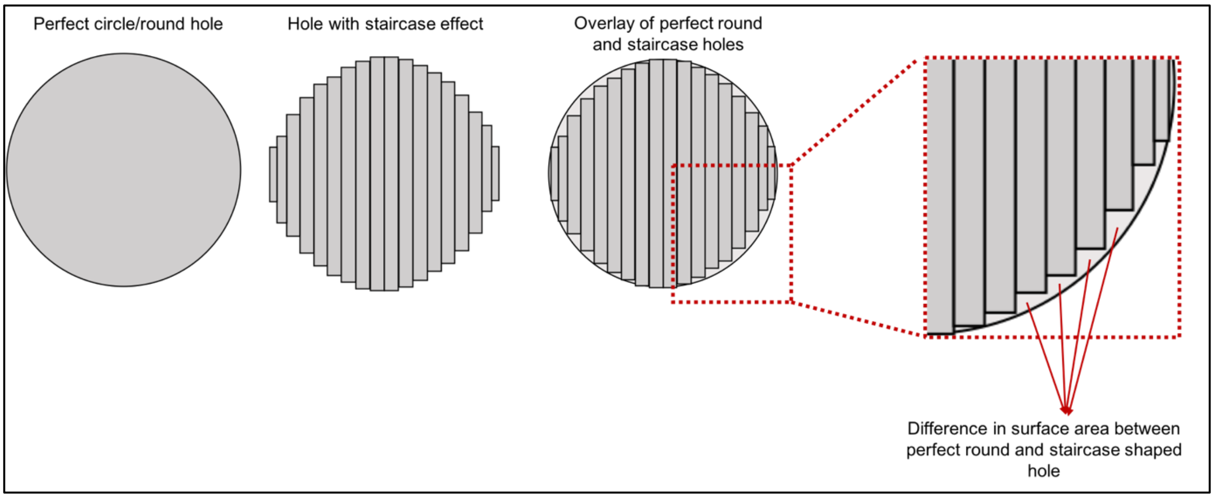


Figure 4. Image illustrating the difference between a perfect round hole and a hole with staircase effect.

Experiment 3: Determining the enlargement margin

The aim of this experiment is to determine the enlargement margin required to allow stainless-steel wires of different diameters to be inserted in holes with matching pre-determined diameter. Another aim is to determine the level of insertion and type of fitness.

First, stents of 6mm in thickness and with holes of different diameter were designed using two different software (3D Slicer and Rhino) and printed using either NextDent Model 2.0 or NextDent SG fabrication materials, similar to experiment 1. Stents were grouped into:

- Group 1 (G1): 3D Slicer software/ NextDent Model 2.0 by 3D systems material.
- Group 2 (G2): Rhino software/ NextDent Model 2.0 by 3D systems material.
- Group 3 (G3): 3D Slicer software/ NextDent SG (Surgical Guide) by 3D systems material.
- Group 4 (G4): Rhino software/ NextDent SG (Surgical Guide) by 3D systems material.

In each group, 3 stents were made with six holes with following radius: 0.4, 0.45, 0.5, 0.55, 0.6 and 0.65 mm. Therefore, there was a total of 18 holes per group.

Second, four stainless steel orthodontic wires with round cross section and diameter of 0.8, 0.9, 1, and 1.2 mm (0.4, 0.45, 0.5 and 0.6mm in radius) were fitted in each hole by two blinded examiners. Each examiner gave the following score to determine the level of insertion and type of fitness:

- Score 1 (No fit): The wire cannot fit into the hole.
- Score 2 (Partial fit): The wire can fit tightly into the hole, but it can’t go through and through.
- Score 3 (Tight fit): The wire fit tightly into the hole and can go through and through.

- Score 4 (Loose Fit): The wire fir loosely into the hole and can go through and through

To ensure the reproducibility and reliability of the data, the 2 examiners were trained and calibrated before conducting the experiment. Furthermore, the data was subjected to Kappa interrater reliability test, and the Altman's scale was used for interpretation. Moreover, the list of each examiner was compared with the other and the differences were resolved after joint discussion. Additionally, all wires were measured with a digital calibre to ensure that the given diameter is accurate.

Experiment 4: Investigating the effect of hole size and stent thickness on wire deviation/deflection.

The aim of this pilot experiment is to investigate the effect of the hole size and stent thickness (height) on bur deviation/deflection from the pre-determined course of insertion.

Here the stents were designed by 2 software (3D Slicer and Rhino) and printed using either NextDent Model 2.0 fabrication materials, similar to experiment 1. Stents were grouped into:

- Group 1 (G1): 3D Slicer software/ NextDent Model 2.0 by 3D systems material.
- Group 2 (G2): Rhino software/ NextDent Model 2.0 by 3D systems material.

In each group, 9 stents were made, 3 with 4mm, 8mm and 12 mm thickness. In G1, 3 holes were made in each stent with the following radius 0.65, 0.7 and 0.75mm, which represent an increase of 0.15, 0.2 and 0.25mm respectively in comparison to the wire to be used which is 1mm in diameter (0.5mm in radius).

In G2, 3 holes were made in each stent with the following radius 0.6, 0.65 and 0.7mm, which represent an increase of 0.1, 0.15 and 0.2mm respectively in comparison to the wire to be used which is 1mm in diameter (0.5mm in radius).

Then a stainless-steel orthodontic wire with round cross section and a diameter of 1mm (0.5mm radius) was inserted in each hole.

A maximum deflection was applied at one end of the wire, and an image was taken at the other end using a stereomicroscope to measure the deflection or deviation angle to the line that is perpendicular to the stent. (Figure 5).

Furthermore the deviation distance at 15mm was calculated using the following formula: Distance at 15mm is =15/TAN(RADIANS(90-Angle)).

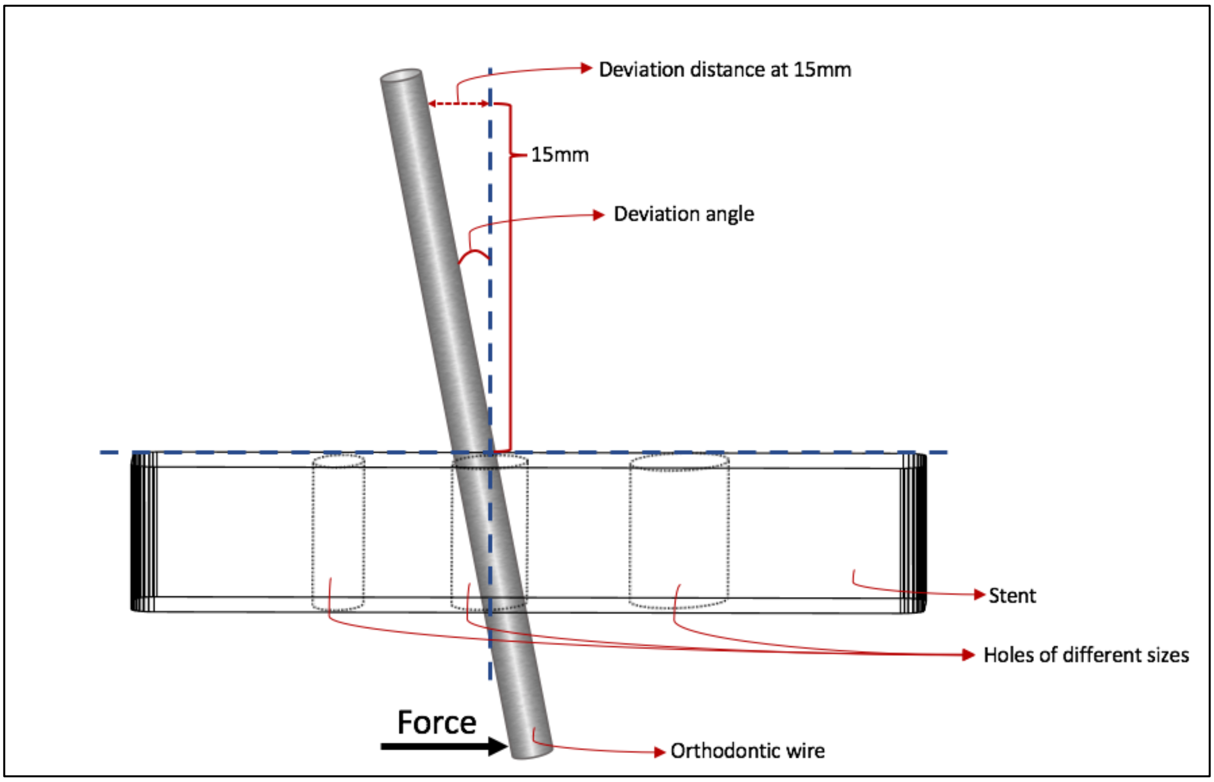


Figure 5. Image illustrating measurement procedure of the deviation angle and distance.

7. RESULTS

Experiment 1: Investigating the effect of the 3D software and fabrication materials on the accuracy of the hole sizes:

Overall, the actual hole radius in printed stents made by different fabrication materials and designed by different software was always different from the pre-determined planned hole radius. This difference or margin of error was in either positive or negative value.

Specifically, in G1 group the mean radius of the actual hole for 0.65, 0.7, 0.8 and 0.9mm holes were 0.638, 0.694, 0.820, 0.899mm respectively (Figure 6). Therefore, the radius of the actual holes in this group were smaller than the pre-determined holes with a margin of error of 0.0 to -0.03mm. While in group G2 the mean radius of the actual hole for 0.65, 0.7, 0.8 and 0.9mm holes were 0.637, 0.684, 0.733, 0.870mm respectively (Figure 7). Therefore, the radius of the actual holes in this group were smaller than the pre-determined holes with a margin of error of 0.0 to -0.02mm. In G3 the mean radius of the actual hole for 0.65, 0.7, 0.8 and 0.9mm holes were 0.665, 0.746, 0.812, 0.925mm respectively (Figure 8).. Therefore, the radius of the actual holes in this group were larger than the pre-determined hole with a margin of error of +0.04 and +0.07mm. While in G4 the mean radius of the actual hole for 0.65, 0.7, 0.8 and 0.9mm holes were 0.660, 0.699, 0.806, 0.913 respectively (Figure 9). Therefore, the radius of the actual holes in this group were larger than the pre-determined hole with a margin of error of +0.05 mm.

Our results showed that there was no significant difference in the margin of errors between groups G1 and G2 as well as G2 and G4 ($P=0.9905$ and $P=0.6917$ respectively). However, there was significant difference in the margin of error between groups G1 and G3 as well as G2 and G4 ($P<0.0001$ for both) (Figure 10). These results indicate that the software used to design the stent has no significant effect on the margin of error, while the material used to fabricate the material has a significant effect on the margin of error.

When we tested the effect of the pre-determined hole radius on the margin of error of the actual printed hole radius, the results showed that there was no statistical difference in margin of error between the pre-determined hole sizes within each group.

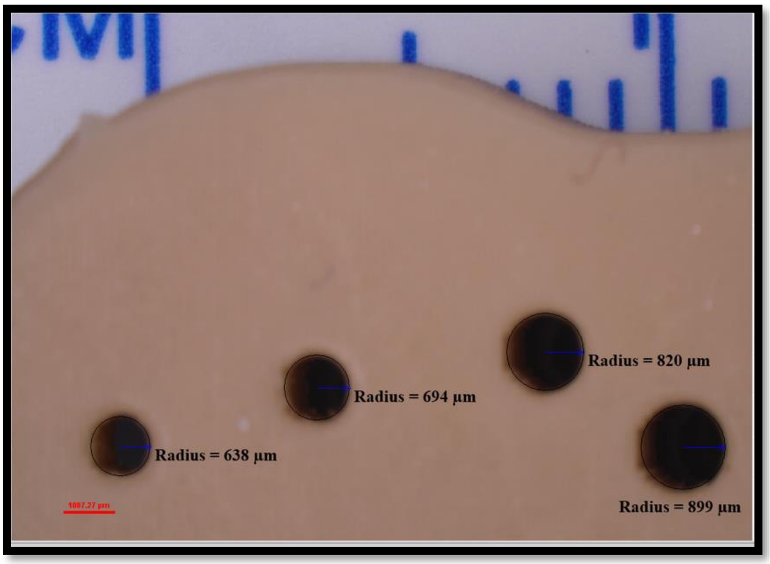


Figure 6. Stereomicroscopic picture of the 3D stent made by 3D Slicer software/ Model 2.0

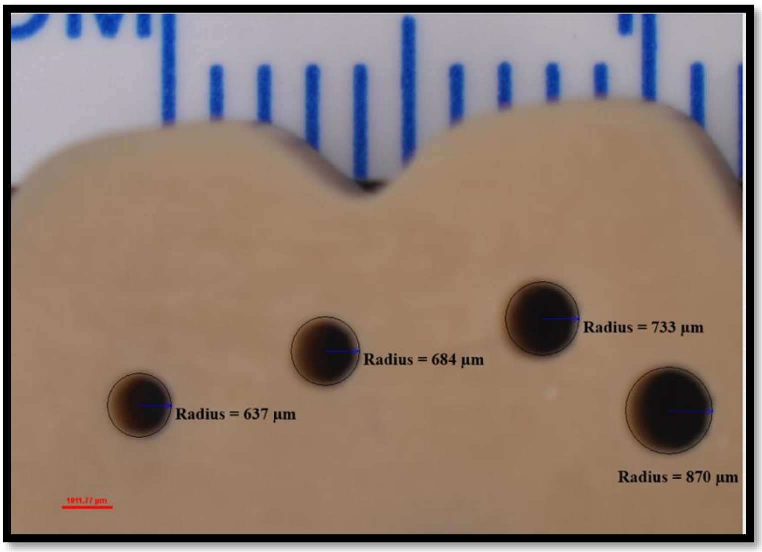


Figure 7. Stereomicroscopic picture of the 3D stent made by Rhino software/Model 2.0

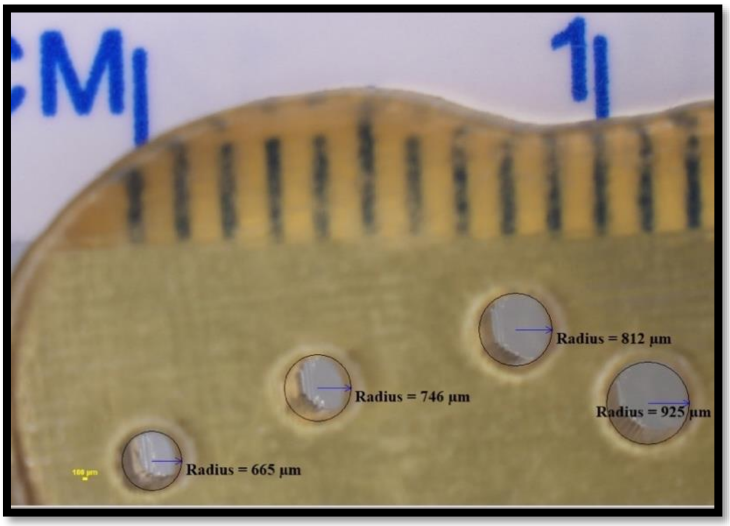


Figure 8. Stereomicroscopic picture of the 3D stent made by 3D Slicer software/ Surgical Guide

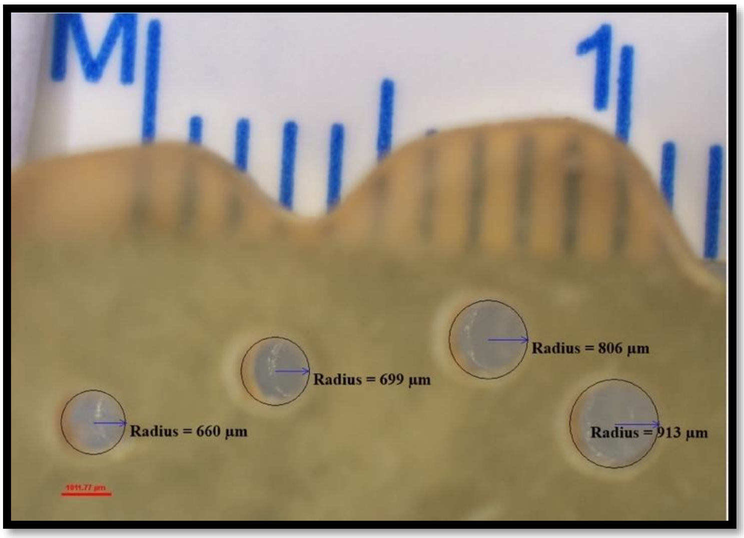


Figure 9. Stereomicroscopic picture of the 3D stent made by Rhino software/ Surgical Guide

Pre-determined hole sizes / Actual hole sizes (Groups)	0.65mm	0.7mm	0.8mm	0.9mm
Group 1 (G1): 3D Slicer software/ Model 2.0	0.638mm	0.694mm	0.820mm	0.899mm
Group 2 (G2): Rhino software/ Model 2.0	0.637mm	0.684mm	0.733mm	0.870mm
Group 3 (G3): 3D Slicer software/ SG (Surgical Guide)	0.665mm	0.746mm	0.812mm	0.925mm
Group 4 (G4): Rhino software/ SG (Surgical Guide)	0.660mm	0.699mm	0.806mm	0.913mm

Table 1. Demonstrate the comparison between the predetermined hole radius size and the actual hole radius size measurement

	0.65	0.7	0.8	0.9
3D Slicer / Model 2.0	-0.03	-0.02	0.00	0.00
3D Slicer / SG	0.06	0.07	0.04	0.06
Rhino / Model 2.0	-0.01	0.00	-0.02	-0.01
Rhino / SG	0.05	0.05	0.05	0.05

Table 2. Actual hole radius differences from the pre-determined hole radius to the actual hole radius. Number are in mm and represent radius.

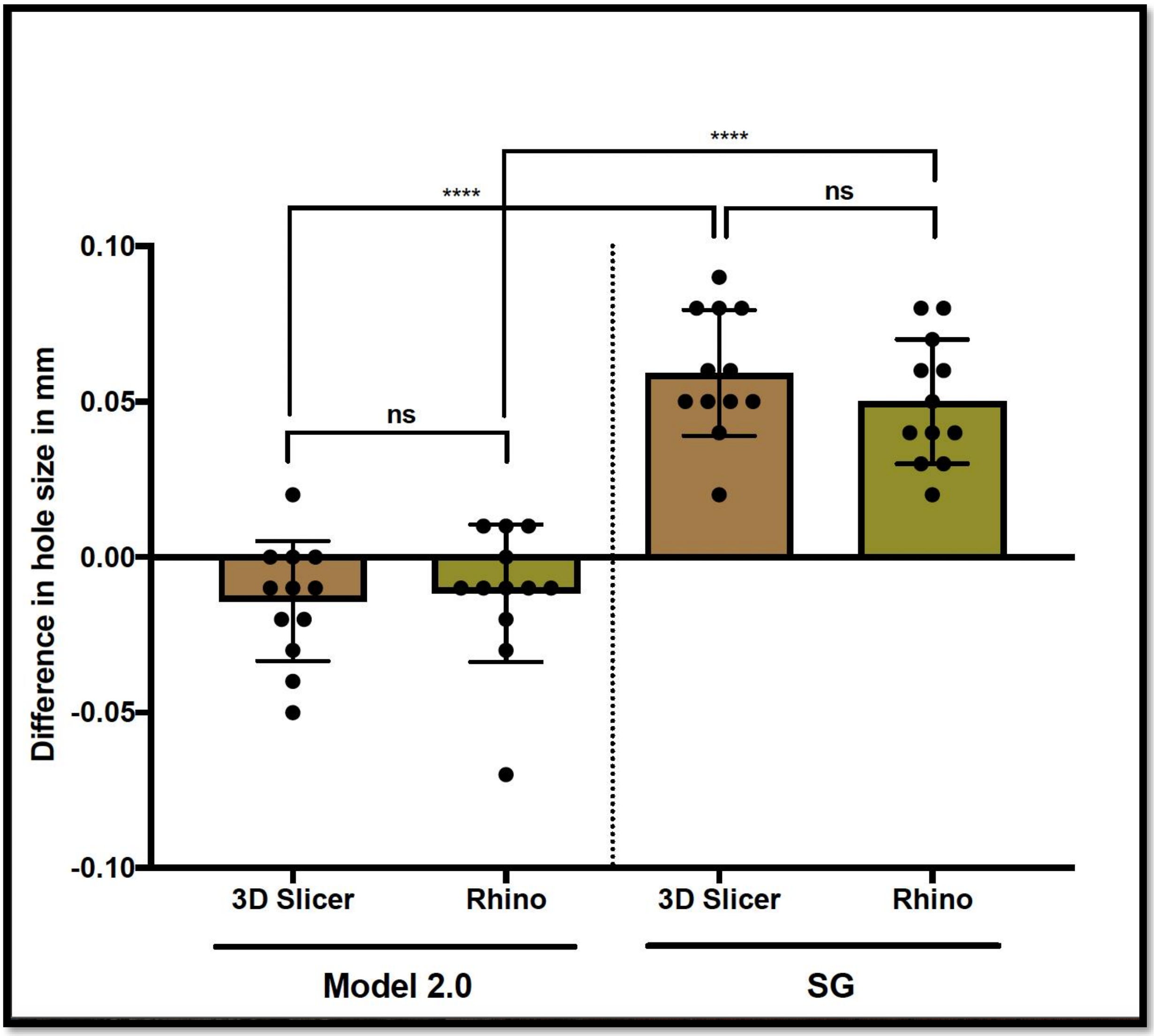
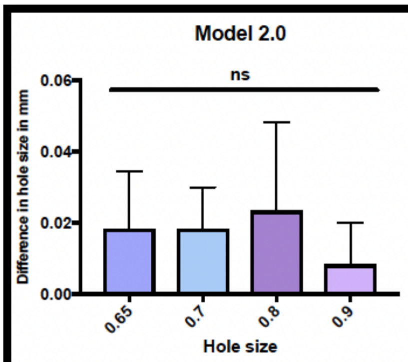
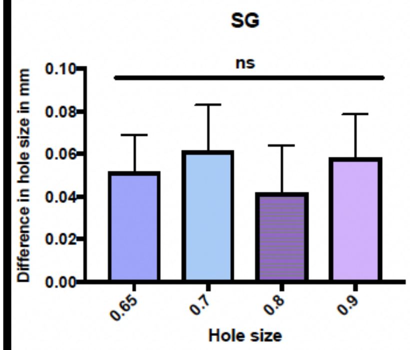


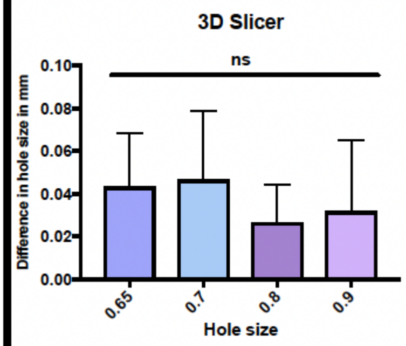
Figure 10. Bar chart represents the One-way ANOVA comparison data of the difference in actual hole radius size between the materials and the software.



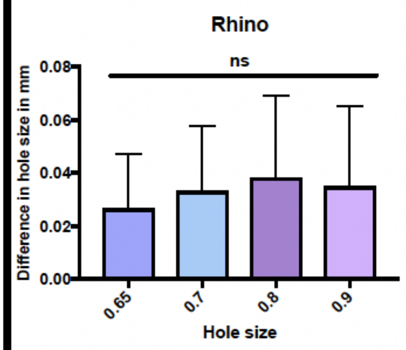
Tukey's multiple comparisons test	Significant?	Adjusted P Value
0.65 vs. 0.7	No	>0.9999
0.65 vs. 0.8	No	0.9559
0.65 vs. 0.9	No	0.7407
0.7 vs. 0.8	No	0.9559
0.7 vs. 0.9	No	0.7407
0.8 vs. 0.9	No	0.4404



Tukey's multiple comparisons test	Significant?	Adjusted P Value
0.65 vs. 0.7	No	0.8307
0.65 vs. 0.8	No	0.8307
0.65 vs. 0.9	No	0.9411
0.7 vs. 0.8	No	0.3511
0.7 vs. 0.9	No	0.9919
0.8 vs. 0.9	No	0.5054



Tukey's multiple comparisons test	Significant?	Adjusted P Value
0.65 vs. 0.7	No	0.9967
0.65 vs. 0.8	No	0.7299
0.65 vs. 0.9	No	0.8854
0.7 vs. 0.8	No	0.6067
0.7 vs. 0.9	No	0.7873
0.8 vs. 0.9	No	0.9892



Tukey's multiple comparisons test	Significant?	Adjusted P Value
0.65 vs. 0.7	No	0.9723
0.65 vs. 0.8	No	0.8732
0.65 vs. 0.9	No	0.9482
0.7 vs. 0.8	No	0.9879
0.7 vs. 0.9	No	0.9995
0.8 vs. 0.9	No	0.9963

Figure 11. Bar charts represent the distribution of a comparisons test between all different hole radius sizes

Experiment 2: Hole shape characterization.

The results showed that the staircase effect was present in 83% and 11.1% of the holes made in stents printed with NextDent Model 2.0 and NextDent SG materials respectively (regardless of the software used). Moreover, the staircase effect was present in 38.8% and 44.3% of the holes made in stents designed by 3D Slicer and Rhino respectively (regardless of the material used).

The contingency statistical analysis showed that the staircase effect is significantly more likely to present in holes made in stents printed by NextDent Model 2.0 than those printed by NextDent SG (P <0.0001, Fisher's exact test). While, there was no significant correlation between the presence of staircase effect and the type of the software used to design the stent (P >0.9999, Fisher's exact test).

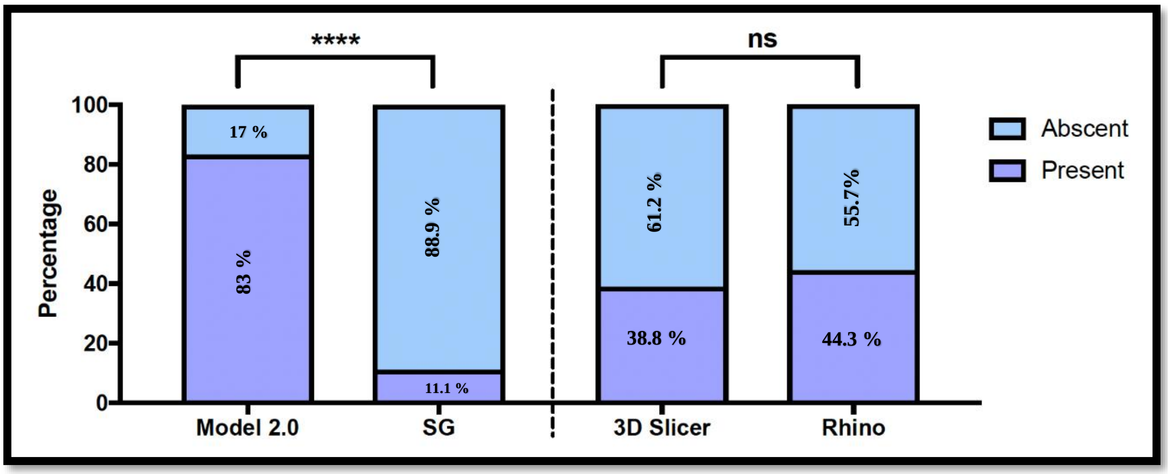


Figure 12. Bar charts represent the distribution of staircase effect results

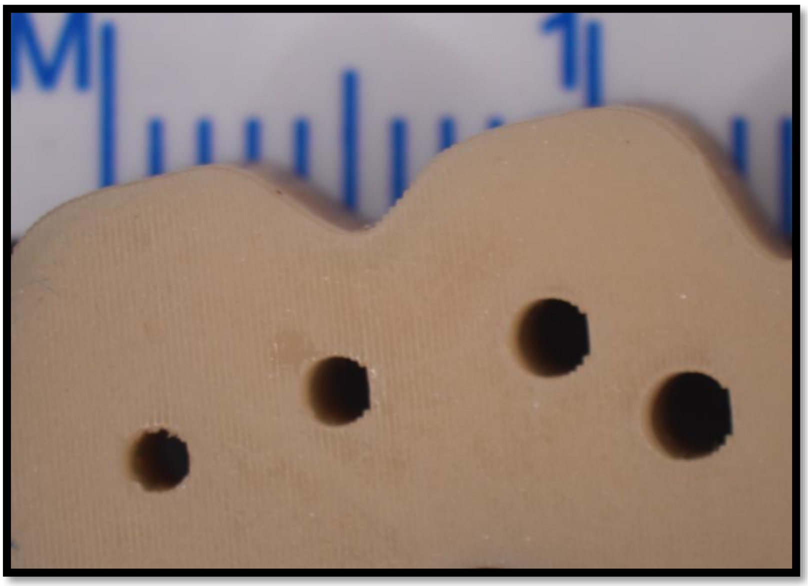


Figure 13. Staircase effect image

Experiment 3: Determining the enlargement margin.

The Kappa interrater reliability score was 0.83, which indicate a very good agreement among the examiners based on the Altman's kappa benchmark scale.

To give an overall idea of the ability of a wire to fit into a hole with matched diameter/size, the data from the 2 examiners were pooled and scored as “no fit” if it gets score 1 and as “fit” if it get score 2, 3 and 4. In group G1 90% of the wires scored “no fit” when it was inserted into a matched hole size, while 75% and 100% of the wires scored “fit” when it was inserted into a holes with pre-determined hole size that are larger by 0.05 and 0.1 mm respectively. In group G2 58% of the wires scored “no fit” when it was inserted into a matched hole size, while 100% of the wires scored “fit” when it was inserted into a hole with pre-determined hole size that are larger by 0.05 and 0.1 mm. In group G3 75% of the wires scored “no fit” when it was inserted into a matched hole size, while 92% and 100% of the wires scored “fit” when it was inserted into a hole with pre-determined hole size that are larger by 0.05 and 0.1 mm respectively. In group G2 42% of the wires scored “no fit” when it was inserted into a matched hole size, while

100% of the wires scored “fit” when it was inserted into a hole with pre-determined hole size that are larger by 0.05 and 0.1 mm.

The overall conclusion is that most wires scored “no fit” if it was inserted in hole with matched diameter. On the other hand, most wires scored “fit” if it was inserted in a hole with pre-determined hole radius larger by 0.05-0.1mm.

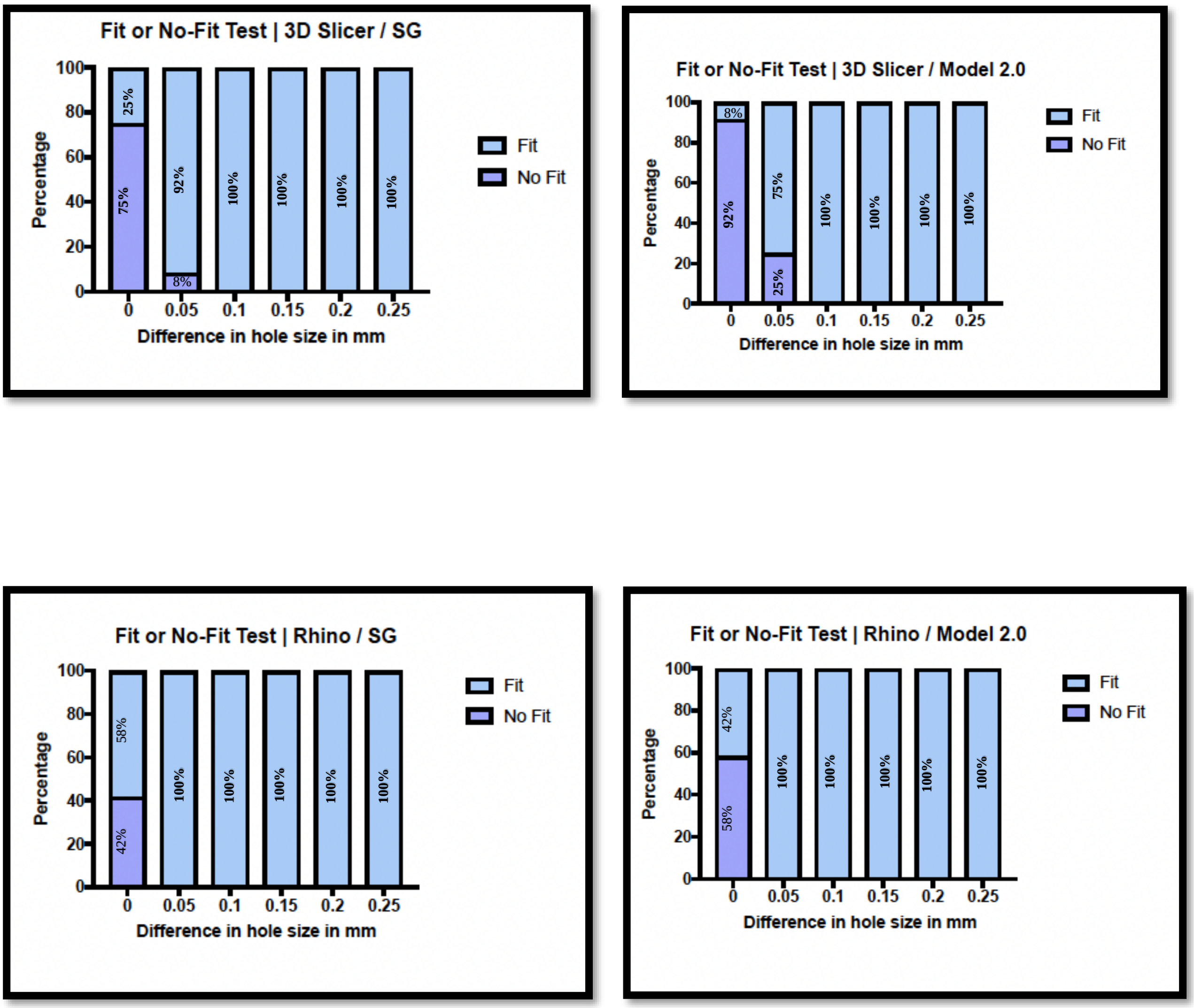


Figure 14. bar charts explain the hole size analysis

To determine the type of fit, the scoring data by the 2 examiners were analyzed without pooling. In group G1, 92% of the wires scored “1” (no fit) when they were inserted in a matched pre-determined hole. When the pre-determined hole size is larger by 0.05mm, 50%, 25% and 25% of the wires scored “2” (partially fit), “1” (no fit), and “3” (Tight fit) respectively. When the predetermined hole size is larger by 0.1mm, 78 % of the wires scored “3” (tight fit), and 22 % scored “2” (partially fit). Furthermore, when the predetermined hole size was larger by 0.15, 0.20, and 0.25mm, 100% of the wires scored “4” loose fit.

In group G2, 58% of the wires scored “1” (no fit) and 42% scored “2” (partial fit) when they were inserted in a matched pre-determined hole. When the pre-determined hole size is larger by 0.05mm, 33% and 67% of the wires scored “2” (partial fit), and “3” (tight fit) respectively. When the predetermined hole size is larger by 0.1mm, 11% of the wires scored “3” (tight fit), while 89% scored “4” (loose fit”. Furthermore, when the predetermined hole size was larger by 0.15, 0.20, and 0.25mm, 100% of the wires scored “4” (loose fit).

In group G3, 75% of the wires scored “1” (no fit) and 25% scored “2” (partial fit) when they were inserted in a matched pre-determined hole. When the pre-determined hole size is larger by 0.05mm, 83.3%, 8.3% and 8.3% of the wires scored “2” (partial fit), “1” (no fit), and “3” (tight fit) respectively. When the predetermined hole size is larger by 0.1mm, 100% of the wires scored “3” (tight fit). Furthermore, when the predetermined hole size was larger by 0.15, 0.20, and 0.25mm, 100% of the wires scored “4” loose fit.

In group G4, 42% of the wires scored “1” (no fit) and 58% scored “2” (partial fit) when they were inserted in a matched pre-determined hole. When the pre-determined hole size is larger by 0.05mm, 75%, and 25% of the wires scored “3” (tight fit) and “4” (loose fit) respectively. When the predetermined hole size is larger by 0.1, 0.15, 0.2 and 0.25mm, 100% of the wires scored “4” (loose fit).

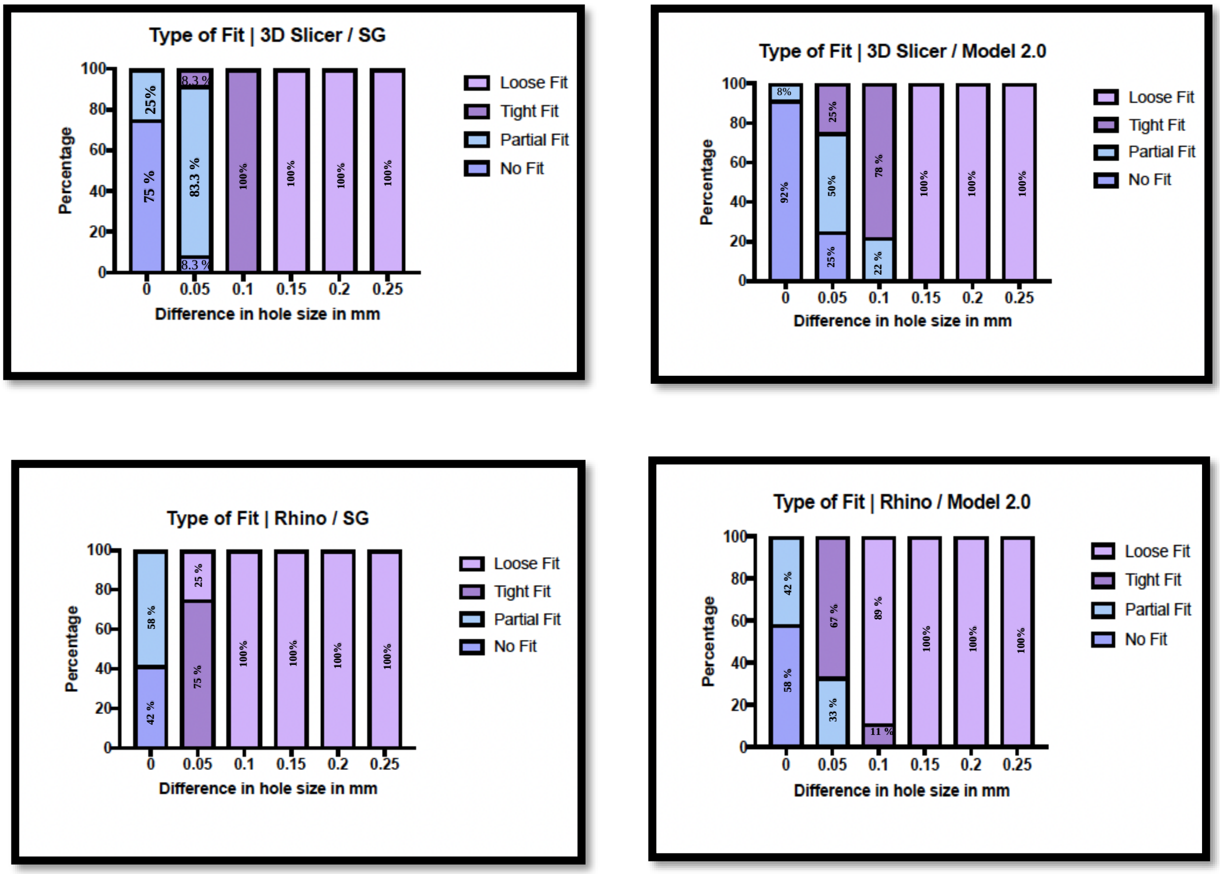


Figure 15. bar charts explain the Type of Fit analysis

Figure 16. Image shows the experiment 2 material

Figure 17. Image represents the orthodontic wires

Figure 18. Image represents the digital caliber

Fleiss' Generalized Kappa		
Number of Raters:		2
Number of Items:		288
Number of Rating Categories:		4
	p_a	0.82986111

Table 3. Interrater reliability: the kappa statistic

Altman's Kappa Benchmark Scale	
Kappa Statistic	Strength of Agreement
< 0.20	Poor
0.21 to 0.40	Fair
0.41 to 0.60	Moderate
0.61 to 0.80	Good
0.81 to 1.00	Very Good

Table 4. Altman's kappa Benchmark Scale

Experiment 4: Investigating the effect of hole size and stent thickness on wire deviation/deflection.

In group G1, the results showed that the mean deviation angle of the wire inserted in a hole larger by 0.15mm in radius is 3.3°, 3.3° and 0.4° in stents that are of 4mm, 8mm and 12mm in thickness respectively. While the mean deviation angle for wire inserted in a hole larger by 0.2 in radius is 5.3°, 3.3° and 1.3° in stents that are of 4mm, 8mm and 12mm in thickness respectively. Whereas the mean deviation angle for wire inserted in a hole larger by 0.25 in radius is 9°, 6.3° and 2° in stents that are of 4mm, 8mm and 12mm in thickness respectively. In regard to the deviation distance at 15mm, the mean deviation distance of the wire inserted in a hole larger by 0.15mm in radius is 0.83, 0.86 and 0.13mm in stents that are of 4mm, 8mm and 12mm in thickness respectively. While the mean deviation distance of the wire inserted in a hole larger by 0.2mm in radius is 1.4, 0.86 and 0.36mm in stents that are of 4mm, 8mm and 12mm in thickness respectively. Whereas the mean deviation distance of the wire inserted in a hole larger by 0.25mm in radius is 2.4, 1.6 and 0.53mm in stents that are of 4mm, 8mm and 12mm in thickness respectively.

In group G2, the results showed that the mean deviation angle of the wire inserted in a hole larger by 0.1mm in radius is 4.3°, 1.6° and 2.3° in stents that are of 4mm, 8mm and 12mm in thickness respectively. While the mean deviation angle for wire inserted in a hole larger by 0.15 in radius is 3.6°, 2.3° and 3° in stents that are of 4mm, 8mm and 12mm in thickness respectively. Whereas the mean deviation angle for wire inserted in a hole larger by 0.2 in radius is 7.6°, 4° and 4° in stents that are of 4mm, 8mm and 12mm in thickness respectively. In regard to the deviation distance at 15mm, the mean deviation distance of the wire inserted in a hole larger by 0.1mm in radius is 1.4, 0.43 and 0.6mm in stents that are of 4mm, 8mm and 12mm in thickness respectively. While the mean deviation distance of the wire inserted in a hole larger by 0.15mm in radius is 0.93, 0.6 and 0.7mm in stents that are of 4mm, 8mm and

12mm in thickness respectively. Whereas the mean deviation distance of the wire inserted in a hole larger by 0.2mm in radius is 2, 1 and 1mm in stents that are of 4mm, 8mm and 12mm in thickness respectively.

The statistical analysis showed that in G1, the deviation distance reduced significantly with increase in the stent thickness (from 4mm to 8mm, from 4mm to 12mm and from 8mm to 12mm (P<0.001)), regardless of the hole of size. Except when the hole was larger by 0.15mm in radius, there was no statical significant difference when the thickness increase from 4mm to 8mm. However, in G2, the results varied a lot. There was no statistical significance in the deviation distance between stents of 8mm and 12mm in thickness, regardless of the hole size. Moreover, there was no statistical significance in the deviation distance between stents of 4mm and 8mm in thickness, as well as between 4mm and 12mm when the hole size was larger by 0.15mm. Statistical significance in the deviation distance was only detected between stents of 4mm and 8mm in thickness as well as between 4mm and 12mm, when the hole size was larger by either 0.1 or 0.2mm (P<0.001)

Groups	Deviation	Hole = > 0.1mm		Hole = > 0.15mm		Hole = > 0.2mm		Hole = > 0.25mm	
		Deviation Angle °	Deviation distance at 15mm	Deviation Angle °	Deviation distance at 15mm	Deviation Angle °	Deviation distance at 15mm	Deviation Angle °	Deviation distance at 15mm
(G1) 3D Slicer/ Model 2.0	4mm			3.3°	0.83mm	5.3°	1.4mm	9°	2.4mm
	8mm			3.3°	0.86mm	3.3°	0.86mm	6.3°	1.6mm
	12mm			0.4°	0.13mm	1.3°	0.36mm	2°	0.53mm
(G2) Rhino/ Model 2.0	4mm	4.3°	1.4mm	3.6°	0.93mm	7.6°	2mm		
	8mm	1.6°	0.43mm	2.3°	0.6mm	4°	1mm		
	12mm	2.3°	0.6mm	3°	0.7mm	4°	1mm		

Table 5. Mean of deviation distance at 15mm[mm] and the deviation angle[°]

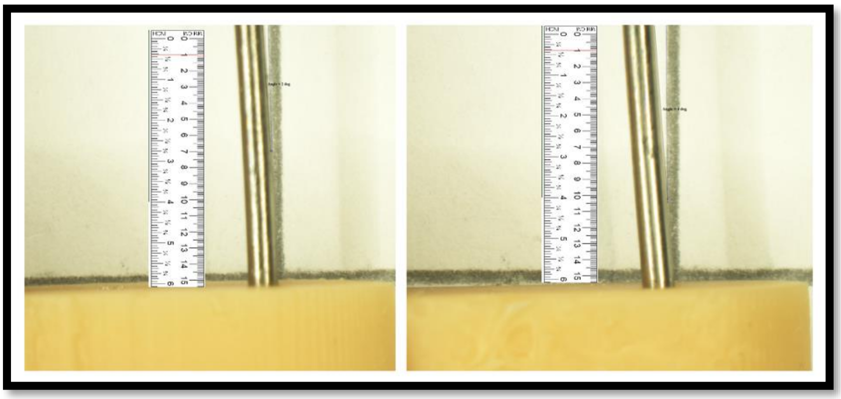


Figure 19. Stereomicroscopic picture represents experiment 4

8. DISCUSSION

This study investigated the effect of different variables on the accuracy of 3D printed stents designed by different software and printed by different material with aim to develop a model for fiber post removal. Such a model is aim to be developed after the encouraging results of several pre-clinical studies, in which the precision of guided access cavity preparation appears to be acceptable, It showed Using "Guided Endodontics," helped all calcified root canals to be accessible using a size 10 K-File(9), which is an accurate, fast, and operator-independent tool for accessing root canals(36), as well as a valuable tool for negotiating partial or complete pulp canal obliteration(37).

Although guided endodontics has previously been discussed(25, 27, 37, 38), pre-clinical studies have indicated that the technique is very accurate when comparing the drilled path to the planned treatment without being impacted by the operator's experience. Additionally, using a treatment guide may lessen the amount of time spent in the chair, This unique concept could aid clinicians throughout treatments by preventing unneeded tissue removal, reducing complications, and so improving treatment prognosis(25, 36). This is consistent with the findings of our pilot study, which showed that guided endodontic in the form of using a stent to remove a fiber post was faster and more conservative than traditional methods. The results of the pilot study demonstrate that the 3D printed stent approach presented here is a quick and simple method for removing adhesive fiber posts from root canals. These preliminary results was supported by other similar studies(33, 39, 40).

However, there were some degrees of deviation observed in our pilot study, which could be due to the use of different materials and software. In order to use the 3D guide in a safe way, it is important to check the accuracy and precision of these two variables. In endodontics, where we work with very small diameters, even the smallest deviation can cause errors like ledges, zipping, and perforations.

Therefore, this study aimed to investigate the effect of these variables on accuracy, efficiency and safety of the 3D stent for fiber post removal. To our knowledge, there are no studies so far that investigated the accuracy of a predetermined hole size by using two distinct materials and two different software programs in the same experiment.

In this study our findings revealed that there is always a difference between the pre-determined hole diameter that was used in the software and actual hole diameter on the printed stent and this was affected by the type of the fabrication material. Specifically, those stent that were made by SG was always larger than the original pre-determined hole radius by +0.04-0.07 mm while those made by Model 2.0 were smaller by -0.03-0.00 mm. Our findings are consistent with Son's study, in which he found that there is a margin of ±0.3mm error in the actual guide hole diameter when compared to the original pre-determined hole diameter. He suggest that new methods should be developed to printed a precise guided hole for dental implant surgical guide fabricated with 3D printing technology(35).

We then hypothesized that such a difference might be affected by the original pre-determined hole diameter in which planning for larger pre-determined hole diameter can result in printed hole with lower margin of error. However, our results showed that there is no significant effect of the pre-determined hole diameter on the margin of error. This was the case regardless of the software or the material used to design and print the stent. This finding indicates that planning for small hole as small as 0.8mm can still lead to as accurate as 1.4mm. This is very significant in the endodontic field, as most of the instruments and files are very small in diameter, therefore, there is a potential to print small guide hole to allow micro endodontic instruments such as access burs, endodontic manual and rotary files.

As discussed previously that Model 2.0 material producesd a hole size that is 0.0-0.03 mm in radius smaller than the pre-determined hole size, while on the other hand, the SG material, produced a hole size that is 0.04-0.07mm larger than the pre-determined hole size. One possible explanation is the staircase effect that is significantly more present in stent printed with Model 2.0 material than the SG. Our results revealed that the staircase effect was evident in 83.1% and 11.1% of the holes made in stents printed with NextDent Model 2.0 and NextDent SG materials, respectively (regardless of the software used).As discussed previously the staircase effect can reduce the hole diameter by 6-7%, therefore, the smaller hole diameter in stents printed with Model 2.0 could be related to its association with the staircase effect. This was in accordance with a study conducted by Dana, M., and colleagues (2017). They examined the precision of 3D-printed holes, discovering their geometric accuracy was not perfect; for example, a flat surface is created at the bottom of the holes, and in some cases, sagging, burning, or cavities are created on the upper side. This is referred to as the "staircase effect," and it arises from the fact that 3D printing technology works on the idea of building items up layer by layer, rather than all at once. Printed cylindrical cylinders with a horizontal axis are the most noticeable examples of this problem. Because of this, a part with a smooth, continuous surface that was formed by a very complicated curve can't be made(41).   This can be further supported with the fact we have used NextDentTM 5100 3D printer that works with digital light processing (DLP) technology that is associated with the staircase effect. Unkovskiy et al discovered while researching "Stereolithography vs. Direct Light Processing." that the SLA-printed bases had less of a staircase effect than the DLP bases in all orientation groups. Because of the intrinsic process-related differences between these two vat polymerization processes, this may be a contributing factor. In this case, even if the layers are arranged so that they are perpendicular to the intaglio surface, the light projection of the square-shaped 2D pixel patterns through the mirror device, which makes up each individual pixel pattern in the image, can still create the staircase effect(42).

Another possible explanation is the possibility that NextDent SG material have a more shrinkage rate while setting than the Model 2.0, which can result in larger hole diameter. However, so far we did not find any study supporting such assumption and further investigation are required in this regard.

The general conclusion for enlargement margin is that the majority of wires scored "no fit" when placed into a hole the same diameter as the wire. When placed into a hole with a pre-determined hole radius larger than 0.05-0.1mm, most wires scored "fit," which is consistent with the findings of the son's research study, which he conducted on a similar subject. 3D printing of the surgical guides with guide hole sizes of 5.0 mm (original size) and 5.2 mm (+0.2 mm) in diameter was used to fabricate the surgical guides for the patient. Inserting an implant surgical guide drill into the hole of the surgical guide with guide hole sizes ranging from 5.0 mm to 5.2 mm in diameter will allow you to determine the size of the hole. This is what they discovered. The entry of the drill was impossible at 5.0 mm, but it was doable at 5.2 mm(35).

To summarize the findings, if we are going to use the 3D Slicer software/Model 2.0 material, because this material always shows a smaller hole size than the actual predetermined size, we will need to increase the actual radius size by 0.1, and if we are going to use the 3Dslicer software/Surgical Guide material, we will need to increase the actual radius size by 0.05, but as already prescribed, the actual measured size of this material always gives a bigger size than the actual predetermined, so in fact, we will increase by 0.1. Furthermore, if we intend to use Rhino software/Model 2.0 material, we must increase the size by 0.1. Finally, if we intend to use Rhino software/Surgical guide material, we must increase the size by 0.05, and again, we will increase it by 0.1.

Another aim of the project is to study the deviation of the bur from the pre-determined insertion course that was noticed in our pilot experiment. Such deviation, even if slight can generate serious iatrogenic errors such as ledges, zipping, and perforations in the field of endodontics, where we operate with very small diameters. We have hypothesized that by increasing the thickness (height) of the stent can reduce the deviation. Therefore, we have conducted an experiment in which we tested the effect of thickness on the deviation. Our results revealed that G1, the deviation distance reduced significantly with increase in the stent thickness (from 4mm to 8mm, from 4mm to 12mm and from 8mm to 12mm), regardless of the hole of size. Except when the hole was larger by 0.15mm in radius, there was no statical significant difference when the thickness increase from 4mm to 8mm. However, in G2, the results varied a lot. There was no statistical significance in the deviation distance between stents of 8mm and 12mm in thickness, regardless of the hole size. Moreover, there was no statistical significance in the deviation distance between stents of 4mm and 8mm in thickness, as well as between 4mm and 12mm when the hole size was larger by 0.15mm. Statistical significance in the deviation distance was only detected between stents of 4mm and 8mm in thickness as well as between 4mm and 12mm, when the hole size was larger by either 0.1 or 0.2mm. Choi et al. (2004) discovered that lengthening the drill guiding channel can minimize angular deviation values during dental implant insertion, which is in some ways consistent with our findings. Also of note, he pointed out that the deviation, measured in degrees, at a channel length of 9.0 mm was much smaller than the deviation, measured in degrees, at a channel length of 6.0mm(43). In 2009, Park et al. came to the conclusion that a 4-millimeter-high precision surgical guide could be utilized for implant placement with accuracy comparable to that of guides with heights of 6 mm or 8 mm, and that this was feasible(44). This leads us to the conclusion that additional research is required in this area as well.

Limitation: Additional in vitro or clinical investigations are required to verify the improvement of the accuracy of the printed 3D Stent with the current findings, which is a limitation. Furthermore, we did not employ the intraoral scanner because our goal was to reduce the amount of time spent in the clinic as well as the expense.

9. CONCLUSIONS

Based on the results of this study, the following conclusions can be drawn:

1. Stent made by NextDent SG material is larger than the original pre-determined size by 0.04-0.07 mm while those made by Model 2.0 were smaller by -0.03 – 0.00 mm.
2. Staircase effects are much more likely to present when NextDent Model 2.0 than when NextDent SG is used to make holes in stents.
3. The usage of an enlargement margin of 0.05-0.1mm can result in the majority of wires being graded as "fit."
4. In 3Dslicer/model 2.0, the deviation distance decreased significantly with an increase in stent thickness, regardless of the size of the hole.When the hole size was increased by 0.1 or 0.2mm in Rhino/model 2.0, only a statistically significant difference in the deviation distance was found between stents of 4mm and 8mm in thickness, as well as between 4mm and 12mm in thickness.

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11.APPENDICES

Pilot experiment:

To determine the variables that will affect the fabrication of the 3D stent, a pilot experiments and trials on extracted teeth was designed and conducted as the following:

Sample collection:

The required institutional review board (IRB) from MBRU has been obtained before collecting teeth from Dubai Dental Hospital (DDH). All teeth were deidentified before collecting them for this project.

Teeth were selected according to the following inclusion and exclusion criteria:

Inclusion criteria:

- Single rooted premolar with single canal.
- Intact apices
- No previous endodontic treatment
- Root length of at least 14 mm as measured from the apex to the labial cemento-enamel junction.

Exclusion criteria:

- Extensive restoration
- Crown or root facture
- Resorption or calcified root canal
- Open apices

Furthermore, radiographs were taken for all samples to exclude all teeth with more than single canal and to choose teeth with mean degree of canal curvature root of <20 according to Schneider method(11). Moreover, clinic examination under the microscope will be conducted to exclude any fractured teeth.

Experimental procedures

Teeth mounting:

Selected teeth were mounted in silicon putty that is shaped in a way to resemble human arch. Two premolars were mounted on each side of the silicon putty and in between 2 molars (distal to the premolars) and 2 anterior teeth (mesial to the premolar). This setting has been made to replicate the clinical situation and reduce the number of the CBCT scans to be taken.

Figure 16. Image shows the silicon model of the teeth arrangement

Root canal procedure:

All root canal preparations for all teeth were standardized and performed in the same way and by the same operator. To determine the working length (WL), K-file # 10 was inserted into the canal and the file viewed under a dental operating microscope at x25 magnification, until the file is just visible at the apical foramen. The length measured was 0.5 shorter than the apical foramen.

All teeth were cleaned and shaped with the Protaper Universal System according to the manufacturer's recommendations and several in-vivo and in-vitro studies(45, 46). Briefly, after determining WL, patency, and glide path, they were achieved using K-files # 10 and 15. Then ProTaper Universal rotary files were introduced to WL, starting with S1 and finishing with the

F2 rotary file. During cleaning and shaping, teeth are irrigated with 2.5% NaOCl using a 30g side-vented needle. After cleaning and shaping is completed, after drying the canal with paper points, a master cone of adequate size is used. Obturation is completed using warm vertical compaction using the "Element Obturation System." After endodontic treatment is completed, a Cavit provisional restoration is placed in the access opening.

Post placement procedure:

To ensure standardization, the post-placement protocol is performed by the same operator for all teeth. The provisional restoration was removed with a no. 4 round bur, and the canal was prepared following the manufacturer's instructions for RelyXTM Fiber Post 3D Glass Fiber Post from 3M (white 1.10, yellow 1.30, red 1.60, and blue 1.90 mm in diameter based on the corresponded size of the canal). These posts have a tapered structure to match the canal itself, following the same geometry. For both groups, posts were cleaned with alcohol, root dentin was etched with 37% phosphoric acid for 15 s, rinsed with water for 30 s, and dried with absorbent paper points. Adhesive systems were applied with RelyX TM Unicem System 2 automix self-adhesive resin cement according to the manufacturers' instructions. After preparation of the root dentin, the resin cement is mixed following the manufacturer's recommendations and placed with the endo tip and a lentulo spiral drill into the canal. Finally, the post is inserted into the canal and light-cured for 40 s through the fiber posts. After placement of the post, phosphoric etch is placed on all residual tooth structure around the post. It is then rinsed, dried, and Universal Adhesive is applied to the post and all adjacent remaining tooth structure, and then light-cured for 10 seconds. The coronal portion is reconstructed with composite resin using an automatrix retainer less matrix system.

Post removal procedures:

After completing the cleaning and shaping, obturation, and post placement procedures, teeth were randomly distributed into 1) the conventional post-removal technique group and 2) the guided technique.

Conventional post removal technique:

The core material, along with the fiber poster (above the canal orifice), was removed using a tapered diamond bur in a high speed hand piece. After removal of the core material, the coronal part of the fiber post was removed using a size #2 Mounce bur. The middle and apical thirds of the post were removed using a size 3 ultrasonic tip. This process continues till the apical Gutta percha can be seen. This procedure was conducted on all teeth in this group by the same operator and under the microscope.

Post removal with 3D guided stent:

3D stent fabrication with Rhino 3D V5 Software :

A CBCT scan was obtained to plan the removal of the fiber-post. The CBCT images were loaded into Dolphin 3D software in order to determine and trace an ideal fiber post and canal pathway, as well as obtain a 3D image of the cast. After that, each tooth's 3D picture is converted into Standard Tessellation Language format. The STL file is imported into the Rhino 3D V5 program for the purpose of creating a stent "guide." In the lab, the virtual guide was exported as an STL file and sent there. There, it was made in 3D on a 3D printer with two different materials (Surgical Guide and Model 2.0).

Figure 17. Illustration of the Dolphin 3D software

3D stent fabrication with 3D Slicer Software :

A CBCT scan was obtained to plan the removal of the fiber-post. The CBCT images were loaded into the 3D slicer in order to determine and trace an ideal fiber post and canal pathway. In the lab, the virtual guide was exported as an STL file and sent there. There, it was made in 3D on a 3D printer with two different materials (Surgical Guide and Model 2.0).

CBCT :

Our research models were scanned four times with a cone beam computed tomography (CBCT) scanner: once before the RCT, once after the RCT was completed, once after post placement, and once after post removal.

Outcome assessment:

The time it took to remove the fiber post was recorded using the timer feature of a digital watch. The recording began when the Mounce bur was attached to the hand piece and ended when the apical gutta-percha first appeared in the canal, which was when the fiber post was successfully removed. When it came to this particular experiment, the recording protocol was performed in both techniques.

After the post is removed, the volume of the root canal space is measured to evaluate how much tooth structure has been preserved. The volume is calculated with the help of the Amira software, which has segmentation and volume statistic functions.

Ethical considerations

This study was carried out in strict accordance with the principles of the "Declaration of Helsinki," Good Clinical Practice (GCP), and the rules and regulations of the United Arab Emirates and the Dubai Health Care City (DHCC). The ethical approval was obtained from the research and ethics review committee of Hamdan Bin Mohammed College of Dental Medicine.

Results:

When it comes to the overall evaluation, the average time consumed in removing the fiber post and exposing the GP differed significantly between the conventional techniques (ultrasonic and burs) and the 3D guided stent technique, with the conventional technique taking approximately 23 minutes and the 3D guided stent technique taking approximately 2 minutes in all cases, respectively.

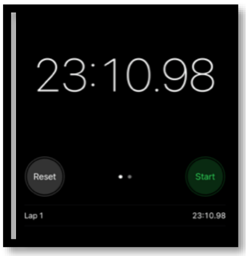

Figure 18.Image shows the time assessment in a conventional technique

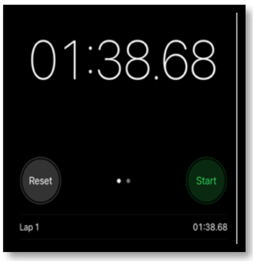

Figure 19.Image shows the time assessment in a 3D guided technique

According to the results of the study, a significant difference was seen between traditional and 3D guided procedures in terms of the amount of tooth structure retained, as determined by comparing the volume of root canal space before and after the post-removal process. The distinction is readily demonstrated by the volumetric segmentation of the data. It was also obvious that there were some deviations to some degree. As a result, we identified two main variables in this study that needed to be optimized: the software and materials, as well as the bur alignment, which is a measurement of deviation from the standard. Overall, the findings varied according to whether we employed the same or different software or different materials.

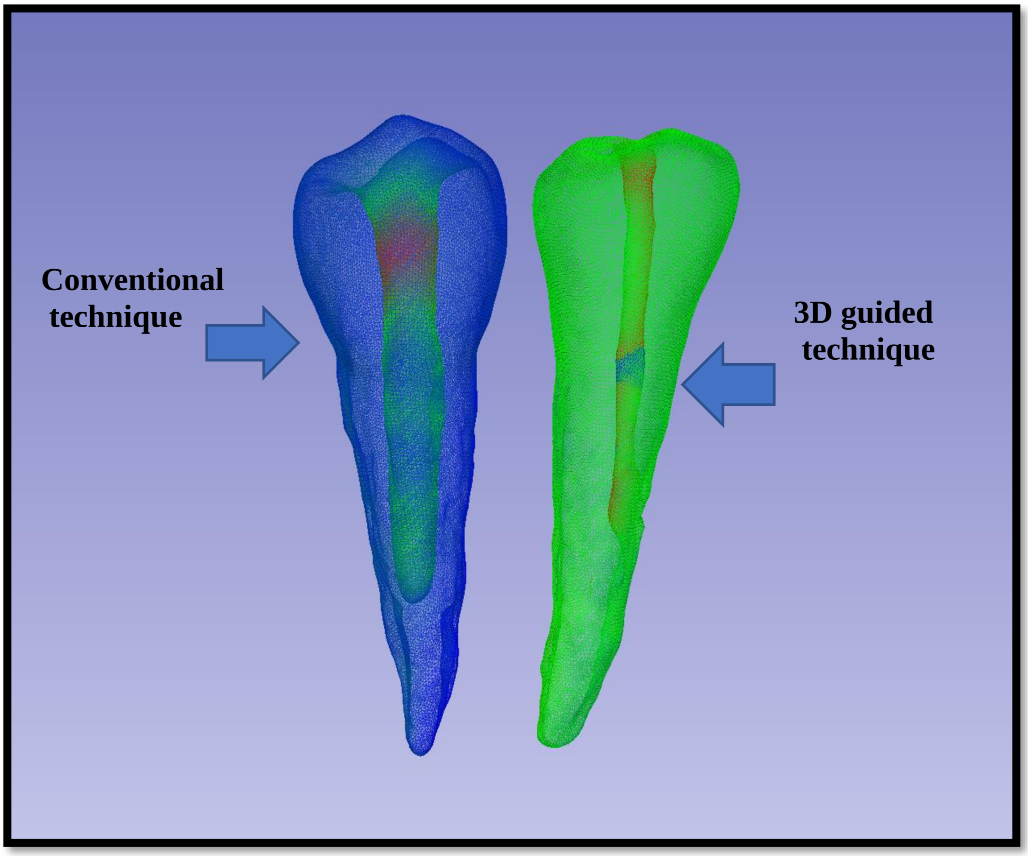

Figure 20.Illustration of volume measurements in both techniques