2018

Development and Verification of Desktop Printed 3-Dimensional Guides for Angulation and Depth Controlled Conservative Endodontic Access

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Recommended Citation

Szczepanik, Bryce Ryszard, "Development and Verification of Desktop Printed 3-Dimensional Guides for Angulation and Depth Controlled Conservative Endodontic Access" (2018). *MUSC Theses and Dissertations*. 301.
https://medica-musc.researchcommons.org/theses/301

Development and Verification of Desktop Printed 3-Dimensional Guides for Angulation and Depth Controlled Conservative Endodontic Access

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A Thesis submitted to the faculty of the Medical University of South Carolina in partial fulfillment of the requirements for the degree of Master of Science in Dentistry in the College of Dental Medicine.

Department of Oral Rehabilitation

Division of Endodontics

2018

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Abstract:

BRYCE RYSZARD SZCZEPANIK. Development and Verification of Desktop Printed 3-Dimensional Guides for Angulation and Depth Controlled Conservative Endodontic Access. (Under the direction of HARMEET WALIA)

Introduction: Recent studies have shown that conservative endodontic cavities (CECs) have a higher mean load at fracture in molars and premolars compared to traditional access cavities, however, performing these CECs can be challenging for the practitioner. Microguided endodontic access is a reliable means of preserving dentin while gaining access to the pulp chamber. The aim of this study was to 1. Develop a protocol for designing angulation and depth controlled physical guides to perform endodontic access, and 2. To compare its ability to provide straight line access against a decoronated tooth, measuring angle of deflection of inserted files. **Materials and Methods:** With use of both Kodak Carestream 9000® CBCT scans and Planmeca PlanScan® intraoral scans of acrylic blocks containing extracted teeth, depth and angulation controlled guides were designed with the Planmeca Romexis implant planning software and printed with a Formlabs 2 3D printer. A total of 23 teeth (totaling 76 canals) were accessed using a #4 surgical length round bur with the guides in place. **Results:** Subjective analysis confirmed passive straight line access with a #6 C file through the CECs for all canals and CBCT images were captured. The imaging was repeated with files in the canal after the teeth were decoronated. Difference in angle of deflection of the files were measured between the 2 models, confirming the clinical finding of passive straight line access. The average file angle deviation was 1.98 ± 1.06° for all canals. No significant differences were seen between tooth types in each arch, nor between arches. File deviation ranged from 0.23° to 5.28°. **Conclusion:** A protocol was successfully developed to accurately and reproducibly create 3D printed guides for conservative fully-guided endodontic cavity preparation.

Introduction:

The ultimate goals of root canal therapy are asymptomatic function of the tooth, as well as radiographic healing of the periapical tissues. Successful root canal therapy is contingent upon adequate mechanical instrumentation and chemical disinfection the root canals, in addition to sealing the canal systems with a three-dimensional obturation material. Herbert Schilder provided objectives for mechanical shaping and properly sealing the cleaned canal system (1). The ability to properly perform these functions of root canal therapy are intimately associated with having proper access to the pulp chamber and canals. A traditionally ideal access preparation provides straight line access to the middle third of the root canal. In the past, this has always involved deroofing the entire pulp chamber which allowed the clinician to obtain proper access to the canal orifices and facilitated removal of debris and bacteria in pulpal horns (2). There has been a push in recent years, with the aid of the dental operating microscope, to perform minimally invasive endodontics with dentin conservation.

Minimally invasive endodontics, or MIE, is the concept of maintaining as much dentin as possible during the endodontic procedure. MIE is facilitated by using the dental operating microscope at high magnification. With the advent of ultrasonic tips, clinicians are now better able to preserve the structural integrity of the tooth, as hard to reach areas become accessible without the use of burs. While MIE focuses on dentin conservation during coronal access preparation, radicular apical preparation, and connection of the coronal to apical preparation (3), the focus of this paper will be primarily on minimally invasive endodontic access.

The American Association of Endodontists defines access cavity as “the opening prepared in a tooth to gain entrance to the root canal system for the purpose of cleaning, shaping, and obturating.”(4) With the advent of modern endodontics, the armamentarium has allowed clinicians to perform accesses which are smaller in nature, and may positively influence the long-term survivability of the tooth. These conservative modern molar accesses were first described by Clark and Khademi and focus on preserving soffits where the pulp horns of the chamber were once housed. The authors proclaim that not only is complete deroofing dangerous due to gouging of the chamber walls, but by removing the soffits, the tooth is invariably weakened prosthetically. In a 2010 article that appeared in the Dental Clinics of North America, it is made clear that “the authors believe that the current models of endodontic treatment do not lead to long-term success, and that the traditional approach to endodontic access is fundamentally flawed”. While many flaws are mentioned with the traditional technique of access, of significant importance is pericervicular dentin (PCD). PCD is dentin located near the alveolar crest of bone and is crucial to maintain during endodontic procedures. Outlined in the same paper is a critical zone of dentin which inhabits 4mm above the crestal bone, as well as 4mm below. It is imperative to maintain the dentin in this zone for proper ferrule and to decreasing risk of fracture.(5) Maintaining PCD has recently become a hot topic of discussion, but it is not a new concept. Reeh et. al. wrote of the critical role of PCD in the long term survivability of endodontically treated molars in 1989. (6)

Since Clark and Khademi outlined a more conservative approach for access, the trend has leaned towards even more conservation of dentin and enamel. After the inception of the CEC came the birth of the ultra-conservative “ninja” endodontic cavity (7). The “ninja” access is a push towards conserving even more critical pericervicular dentin. Another variation of conservative access design is an orifice-directed access cavity. This design focuses on using canal projections to the occlusal surface of the tooth to guide entry to the canal orifice. In some instances, a dual access preparation can be made to maintain a middle portion of the chamber to act as a truss (8). In engineering, a truss is a structure that "consists of two-force members only, where the members are organized so that the assemblage as a whole behaves as a single object". (9) Although a dentin/enamel truss has not been proven with research to be of importance, it is certainly not a detriment to the strength of the tooth. Dr. Pushpak Narayana, an advocate of the truss access, states that a properly designed orifice-directed access is a balance between dentin preservation and adequate access to the root canal system. He addresses the concern for an increased risk of file separation by saying, a “properly designed orifice-directed access cavity preparation eliminates sharp corners, the areas of highest risk from cyclic fatigue” and advocates the use of heat treated nickel-titanium instruments with controlled memory and smaller tapers and diameters (8).

A recent study at the University of Toronto aimed to evaluate the dentin volume removed during conservative endodontic cavity preparation, and tested those teeth against both traditionally accessed and intact teeth to assess fracture resistance. It was found that mandibular molars and premolars had increased fracture resistance when prepared using CEC versus traditional endodontic access (TEC) (10). Plotino et. al. performed a similar study to compare fracture strength of root filled teeth that had been accessed with TEC, CEC, and an ultraconservative “ninja” endodontic cavity (NEC). The mean load at fracture was significantly lower for TEC compared to CEC and NEC, whereas no difference was noted between CEC and NEC.(7) While it cannot be disputed that the conservative endodontic cavity spares a significant amount of dentin, there are studies that show some sacrifice is also made. Krishan et. al. also assessed the impacts of CECs on the efficiency of canal instrumentation. The study examined incisors, premolars, and molars and the surfaces of untouched canal walls was analyzed using micro-CT scans. They found that the instrument effectiveness in distal canals of mandibular molars was significantly compromised in teeth accessed with CECs (10). A different study showed a benefit associated with CECs compared to TECs with relation to fracture resistance in maxillary molars. TECs did, however, show less canal transportation in palatal canals. Also, the ability to detect canals was enhanced with a TEC compared to a CEC (11). While there is some debate as to whether or not CECs should become the new standard, there is no argument that they are more easily performed when planning with a cone beam CT scan.

The cone beam computed tomography (CBCT) scan has become an integral part of diagnosis and treatment planning for the modern endodontist. The advantages of CBCT scans over periapical radiographs are overwhelming. CBCT has decreased anatomical noise and geometric distortion when compared to periapical (PA) radiographs. Studies have shown that it has a higher sensitivity than PAs and can detect periapical lesions that PAs cannot (12-14). CBCT scans can also be used to assess quality of obturation (15), diagnosis and treatment of resorptive defects (16), planning for surgical procedures (17), and can be helpful with trauma cases (18), to name a few additional applications. CBCT has long been used to guide clinicians in placing dental implants at the proper angulation and depth with a high degree of accuracy (19). A CBCT scan is merged with an intraoral scan, the implant is planned using computer software, and a guide is printed to the specifications provided by the operator. The clear benefit of the guided technique is the ability to remove operator error and provide complete depth and angulation control. It is with these principles that guided endodontic access has been performed both *ex vivo* and *in vivo* to evaluate its dependability.

There have been a handful of studies that aimed to evaluate the accuracy of the aforementioned technique for use in access cavity preparation (20-22). The investigators all found a low mean angle of deviation, as well as very low deviations between planned and prepared access cavities showing that fully-guided endodontic access is an accurate and operator-independent technique. In accordance with its accuracy and precision, the guided access simplifies locating a calcified canal while decreasing the operator’s anxiety and risk of iatrogenic misadventure. A case series published in 2016 gives a detailed account of 3D computer-aided root canal therapy from planning to completion on patients with calcified canal systems (van der Meer et. al). To the knowledge of the author, there has been no investigation into the use of 3D printed guides for fully-guided access on posterior teeth. It is likely that by using a 3D printed guide for endodontic access, one could conserve dentin while locating the canal system.

There is a void in the literature regarding guided access of posterior teeth. The aim of this study is to successfully develop a protocol to accurately and reproducibly create 3D printed guides for conservative orifice-directed fully-guided endodontic cavity preparation on both anterior and posterior teeth.

Materials and Methods:

Tooth Blocks:

For this study 42 extracted human teeth (having a total of 76 canals) with minimal caries or restorative history were selected in compliance with the MUSC IRB. Teeth were seated at the apical extent in rope wax, then the roots were encased in clear orthodontic acrylic resin to create blocks of three to five teeth (Figure 1). The tooth blocks were scanned with the Kodak Carestream 9000 CBCT at 80Kv, 10mA, and 76 micron slices (Figure 2). Optical surface scans were captured with the Planmeca (Helsinki, Finland) Planscan intraoral scanner. (Figure 3)

Virtual Endodontic File Design and Placement:

Optical “intraoral” scans were merged with the CBCT in the Planmeca Romexis 3D module. Virtual endodontic files were custom created in the implant module of the same software at 0.5mm diameter and length ranging from 10-18mm to allow virtual placement with termination of the file near the natural tooth surface (Figure 4). The files were placed into the coronal 1/3 to 1/2 of the canal or until a curvature was encountered. The files were placed with no consideration of conventional access, file emergence, or estimation of impinging tooth structure for instrumentation. Very simply, the straight virtual files were placed to allow straight vector access based upon the trajectory of the coronal aspect of the canals. For multirooted teeth, all canals were planned for if the canals were radiographically evident and independent. However, for maxillary molars, the MB2 canal was excluded as they could not be accurately assessed when the study was planned. Based upon the emergence position of the planned file, measurements were taken from the surface of the tooth to the pulp chamber, and from the surface of the tooth to the entrance of the canal. For each canal, ideal instrumentation depth was determined as a length from the tooth surface to approximately mid pulp chamber and rounded to a depth that can be measured clinically (to 0.5mm).

Endodontic Access Guide Design and Fabrication:

After virtual file positioning, the access guides were created using the Romexis implant guide design module. Parameters were set: guide thickness 2mm, guide tube length 7mm, gap to tube 1.5 mm, and tube internal diameter 1.45mm. Stereolithography (.stl) format computer files of the designed guides were exported to the Formlabs (Somerville, MA, USA) Preform software and supports were added for printing with careful attention to add the supports only to the external surface of the guide, and with no supports terminating within the guide tubes. The guides were printed with dental model resin (RS-F2-DMBE-02, Formlabs) with the Formabs 2 3D printer. Support removal and processing of the guides was done per Formlab’s instructions.

Endodontic Access Instrumentation:

Guides were fully seated on the tooth blocks after 24 hour hydration of the teeth/blocks in 0.9% normal saline. Access preparation drilling was completed with #4 surgical length round carbide burs, using a fresh bur for each canal. The burs were placed into friction grip high-speed dental operative electric handpieces (NSK) and seated at the appropriate depth as measured with an endodontic file based upon the ideal instrumentation depth noted in the file design section of the methods. Drilling was done at 150,000 RPM under irrigation with a single forward motion to depth until the head of the handpiece met resistance at the guide tube.

Post-operative analysis:

After endodontic access, the guides were removed and CBCT images were captured. Each access hole was evaluated for passive canal access using a 0.6 C-file, and additional CBCTs were captured with the files in place at a maximum of one file, per tooth, per image to reduce radiographic artifact. In an effort to determine the accuracy of our anticipated path of access, and to determine the difference between that path, and the natural path of the physical endodontic file placed to length in the canal, a protocol was developed to measure the deviation between estimated file path and true file emergence. To do this the clinical crowns of the teeth were sectioned away with a high-speed handpiece under irrigation to the level of the CEJ. The files were replaced and once again, CBCT images were taken. The DICOM data from the initial images taken with files in place were merged with the images of the files in place with the crowns missing. The two files were then able to be seen superimposed and the differences in angulation and position could be measured. Variation was measured from the first perceivable point of the vertex (point prior to separation) and rays were marked on the same side of the files to yield an angulation. For each canal, the files were observed circumferentially and the direction of greatest variation was recorded between the files.

Data and Statistical Analysis:

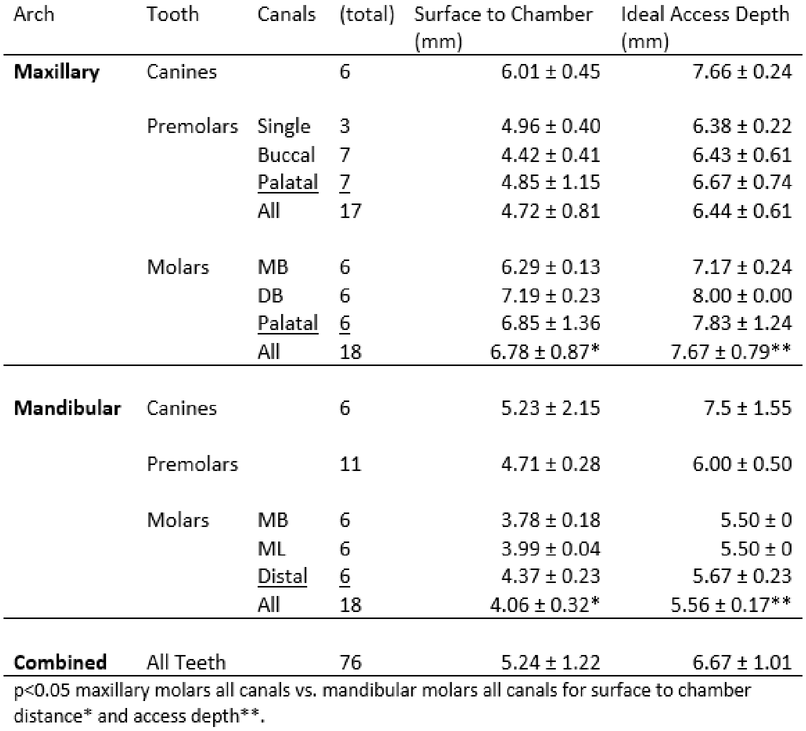
Data are reported as mean ± standard deviation. For the statistical analysis, *t-test* or one-way ANOVA were used where appropriate to compare population means. An alpha value of 0.05 was defined as the limit for significance.

Results:

After access drilling, endodontic C-files were placed into the access holes and were directed passively to the canal entrance for every canal. Therefore, 100% success and accuracy from the standpoint of direct clinical canal access was attained. In 3 cases the bur removed tooth structure at or around the canal entrance. In these instances no perforations were noted and access to the canal was not impeded. It was noted on multiple occasions that the surgical burs used for access slipped inside the friction grip of the high-speed handpiece, changing the depth of the bur. There is speculation that this may account for the error noted in the 3 cases.

For the teeth randomly selected for this study, surface to chamber and surface to mid-chamber (ideal drilling depth) lengths were measured. No significant differences were seen between canines, premolars, and molars comparing teeth within each arch. A significant difference was measured when averaging all canals for mandibular versus maxillary molars for distance and access depth. The average distance from the enamel surface to the pulp chamber for all teeth was 5.25 ± 1.22mm and the average drilling access depth was 6.67 ± 1.02mm (table 1).

To determine the deviation between the planned straight vector canal access and seated endodontic file position, scans of files placed in the accessed canals and scans of the files placed in the same canals, to the same depth, but with the clinical crown removed were overlaid. This also served as an indirect measurement of access accuracy. Average file angle deviation was 1.98 ± 1.06° for all canals. No significant differences were seen between tooth types in each arch, nor between arches. File deviation ranged from 0.23° to 5.28°. In addition, a full breakdown of ideal access depth and surface to chamber roof can be visualized in Table 1.



Arch	Tooth	Canals	(total)	Surface to Chamber (mm)	Ideal Access Depth (mm)
Maxillary	Canines		6	6.01 ± 0.45	7.66 ± 0.24
	Premolars	Single	3	4.96 ± 0.40	6.38 ± 0.22
		Buccal	7	4.42 ± 0.41	6.43 ± 0.61
		Palatal	7	4.85 ± 1.15	6.67 ± 0.74
		All	17	4.72 ± 0.81	6.44 ± 0.61
	Molars	MB	6	6.29 ± 0.13	7.17 ± 0.24
		DB	6	7.19 ± 0.23	8.00 ± 0.00
		Palatal	6	6.85 ± 1.36	7.83 ± 1.24
		All	18	6.78 ± 0.87*	7.67 ± 0.79**
Mandibular	Canines		6	5.23 ± 2.15	7.5 ± 1.55
	Premolars		11	4.71 ± 0.28	6.00 ± 0.50
	Molars	MB	6	3.78 ± 0.18	5.50 ± 0
		ML	6	3.99 ± 0.04	5.50 ± 0
		Distal	6	4.37 ± 0.23	5.67 ± 0.23
		All	18	4.06 ± 0.32*	5.56 ± 0.17**
Combined	All Teeth		76	5.24 ± 1.22	6.67 ± 1.01

$p<0.05$ maxillary molars all canals vs. mandibular molars all canals for surface to chamber distance* and access depth**.

Table 1. Measurements with deviation for surface to chamber and ideal access depth in mm for all tooth types tested.

Figure 1. Tooth block mounted in acrylic.

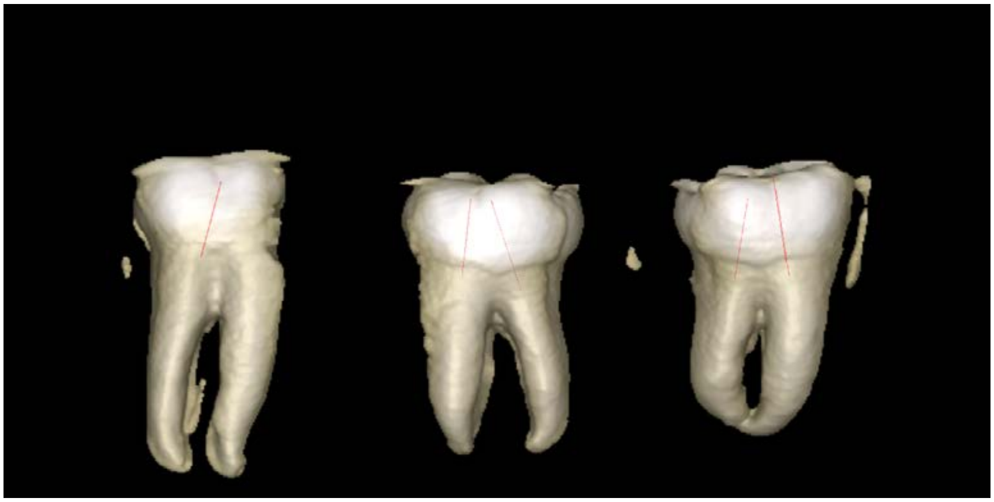


Figure 2. CBCT scan as viewed in Planmeca Romexis 3D model software.

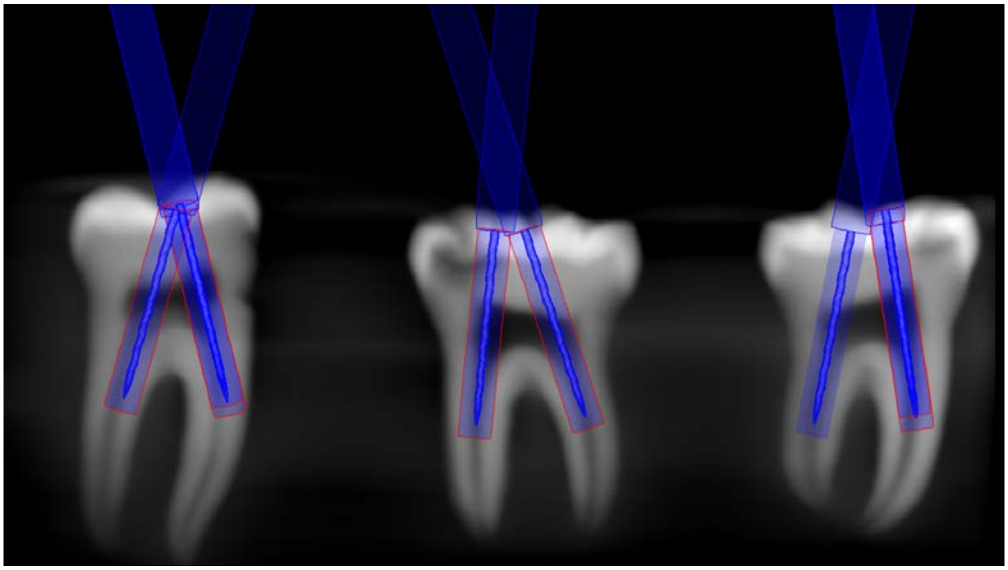


Figure 3. Virtual planning of access guide.

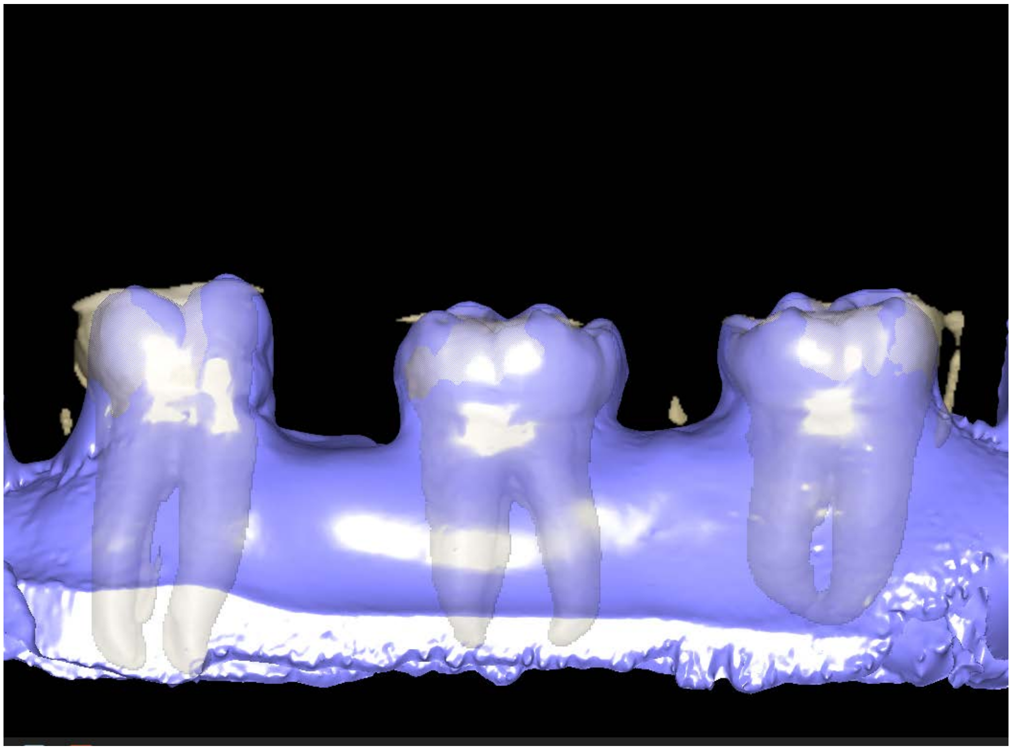


Figure 4. CBCT and intra-oral scans virtually merged.

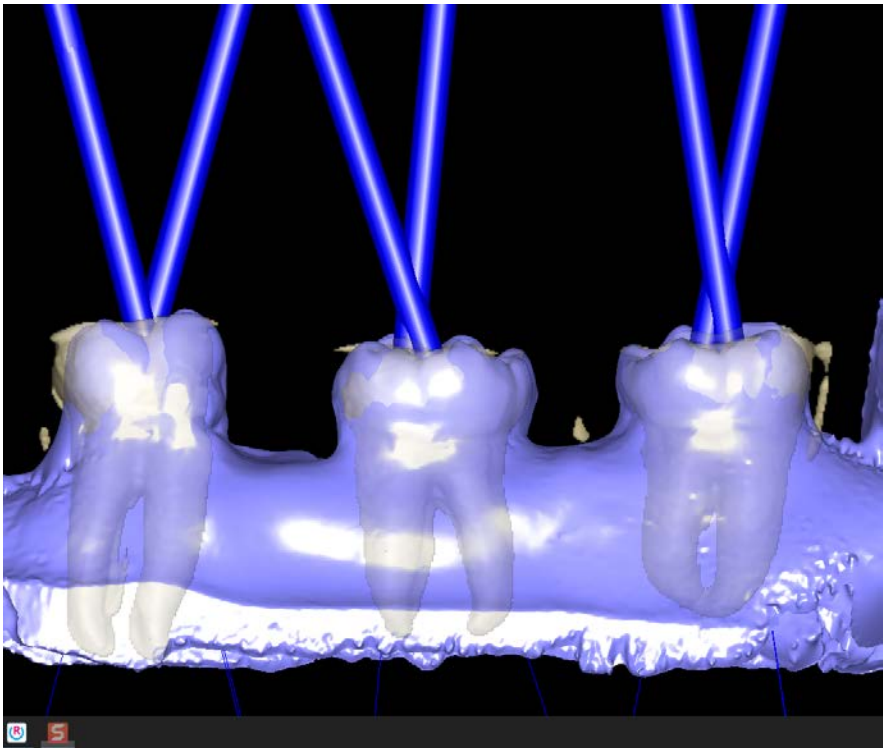


Figure 5. Path of planned access trajectory.

Figure 6. Virtually planned guide.

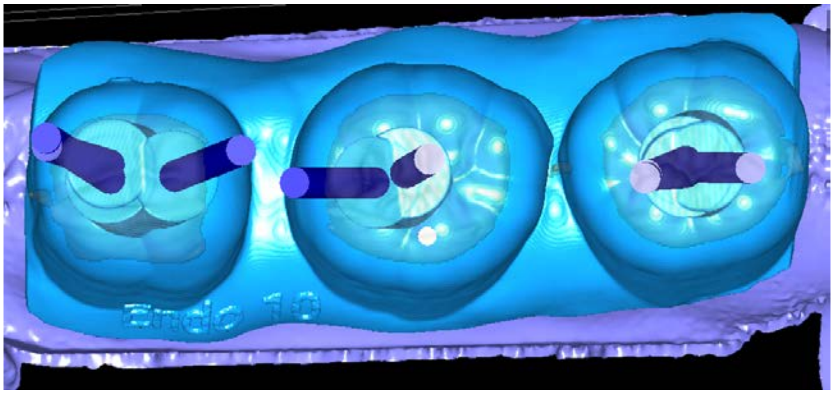
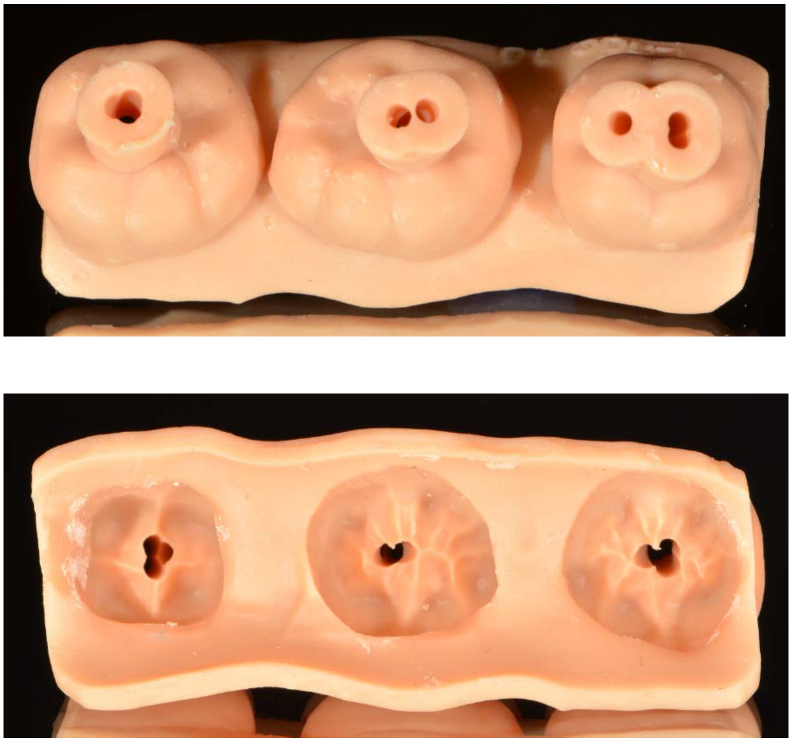


Figure 7. Occlusal view of virtually planned guide.



Figures 8A. Cameo surface of 3D-printed guide and 8B. Intaglio surface of 3D-printed guide.

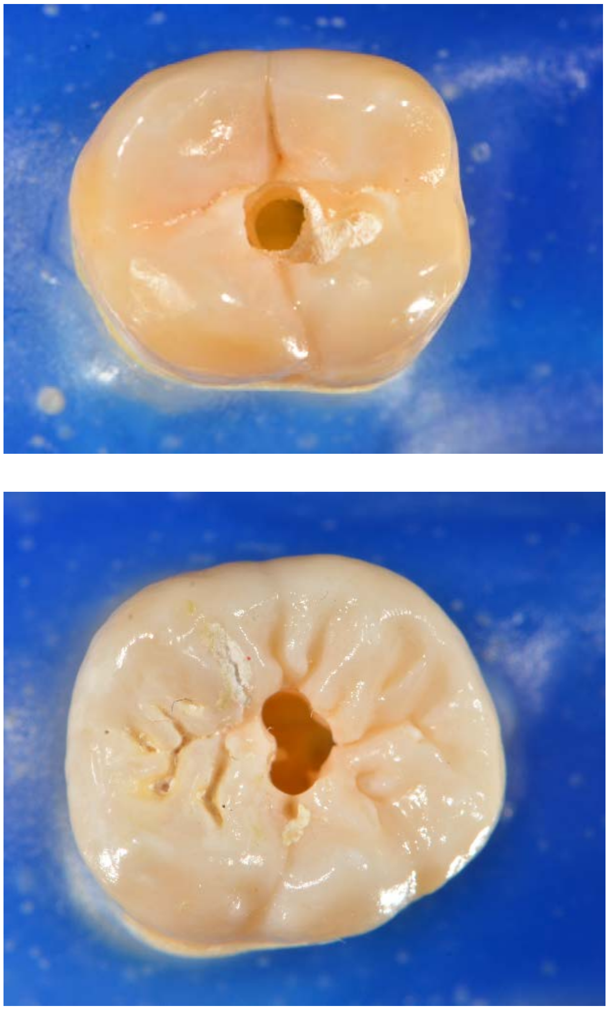


Figure 9. Occlusal surface of two molars with access preparation completed.

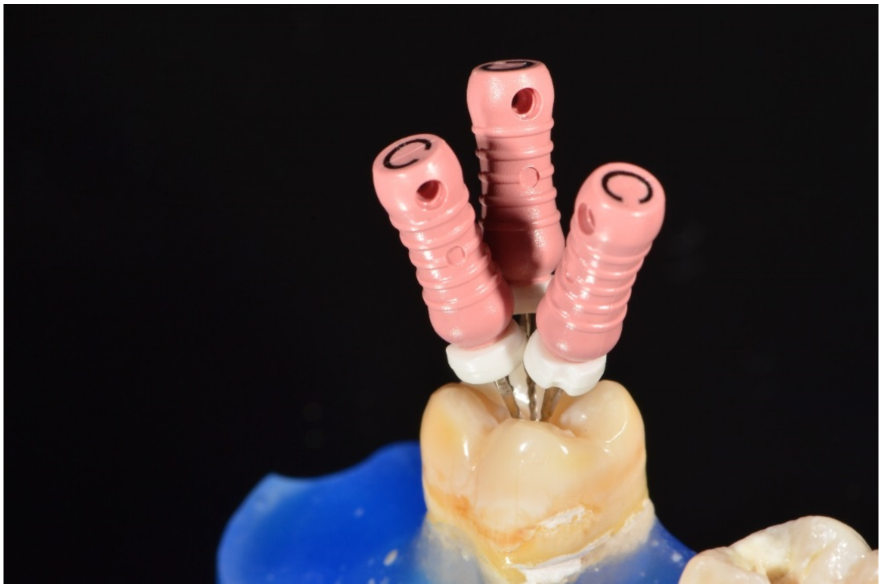


Figure 10. Files in all three canals of a mandibular molar.

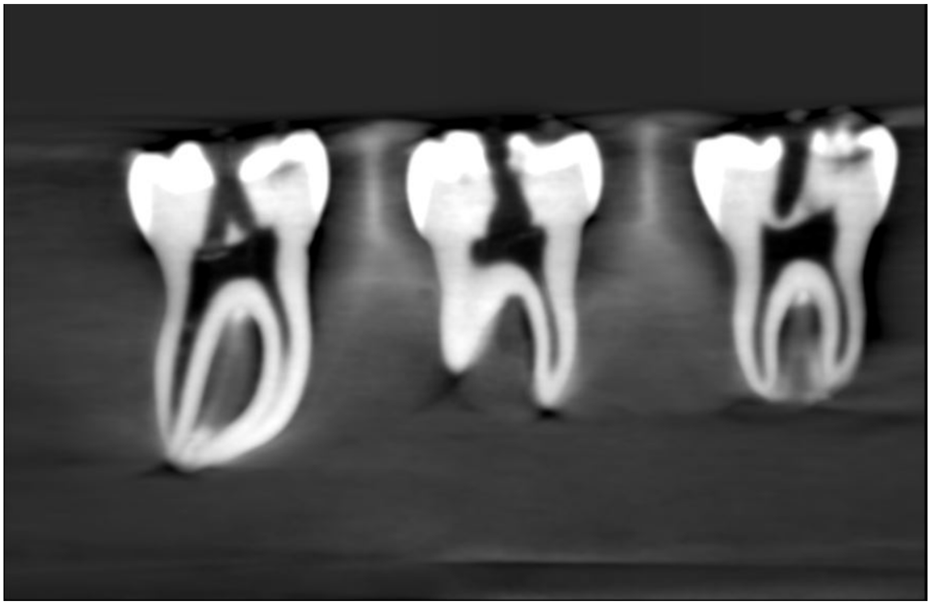


Figure 11. CBCT scan of accessed molars with crowns intact.

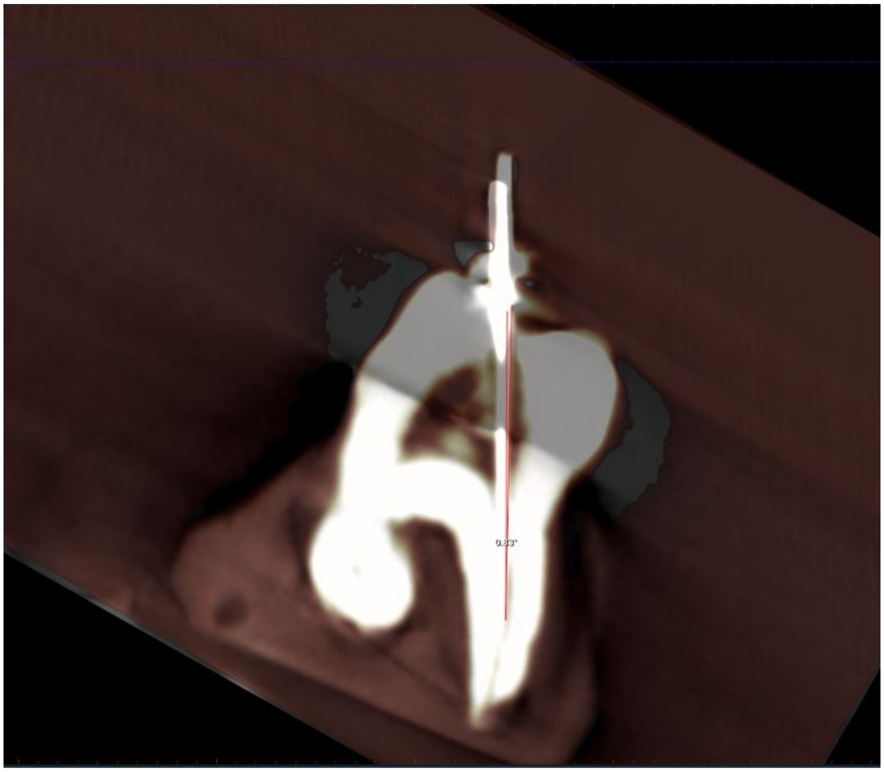


Figure 12. Overlapped CBCT scans in the sagittal view of file in place in both tooth with and without crown present.

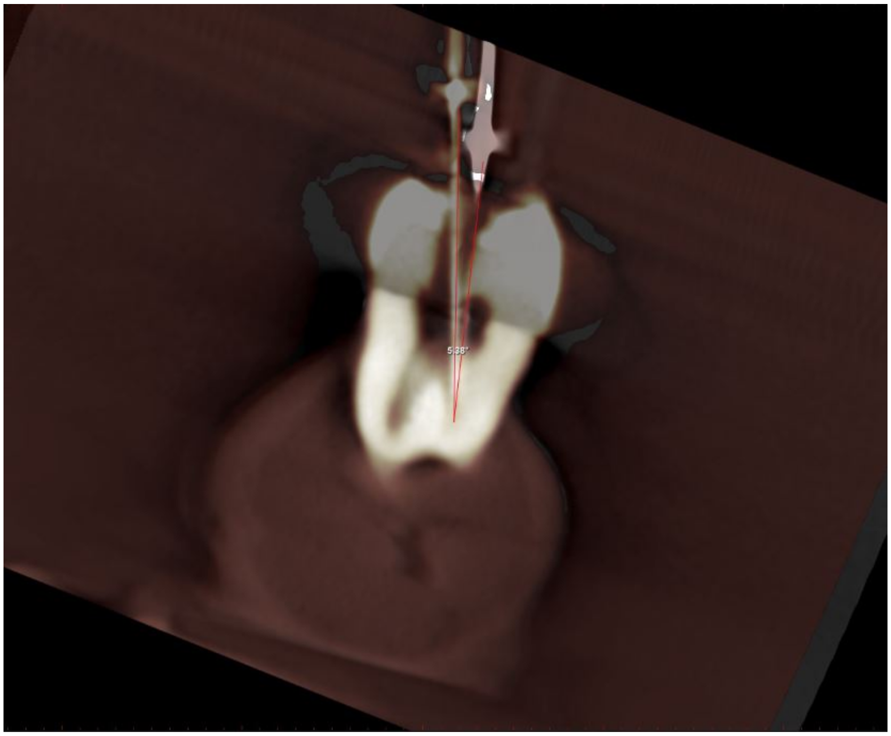


Figure 13. Overlapped CBCT scans in coronal view of file in place in both tooth with and without crown present.

Discussion:

The aim of this study was to 1. Develop a protocol for designing angulation and depth controlled physical guides to perform orifice-directed endodontic access, and 2. To compare its ability to provide straight line access to the orifice against a decoronated tooth, measuring angle of deflection of inserted files. The researchers were able to successfully develop a protocol for the planning process that allowed the operator to gain straight line access to the canal orifices with a high amount of accuracy.

This protocol could be very useful to the endodontic practitioner in clinical practice. Endodontists are faced with challenging access preparations due to calcification, pulp canal obliteration, and angulation on a daily basis. Many times when these challenges arise, excessive tooth structure is removed in order to locate the canals. These clinical scenarios become even more demanding when the tooth to be treated is a molar. Previous studies have identified protocols to perform guided endodontic access on anterior teeth, but the current study was novel in its focus on posterior teeth. With CBCT becoming standard armamentarium for the endodontic practitioner, as well as the decreasing cost of 3D printers and intraoral scanners, there is a lot of promise in the use of this protocol in the clinical setting.

While the current protocol was determined to be successful, there were limitations noted during the process that would need further study. One such limitation is that the current protocol for development of a guide was performed only on teeth with a large pulp chamber present. The access was only taken as far apically as the CEJ leaving a large margin of error on the accuracy of the depth control component of the guides. Future research would need to be completed to ensure that the current protocol could be utilized for teeth with calcified chambers and canals. Another possible limitation of the current guide design is the interocclusal space that would be needed in clinical practice. Much like the restrictions associated with guides used during implant placement in posterior sites, the patient’s ability to open to the extent needed to provide space for the guide and surgical length bur would likely come into play. This possible problem could be combatted by creating a thinner guide or by using a bur that has a shorter shank, both of which were not investigated.

During the initial brainstorming process, it was decided to use a surgical length #4 round bur for access as this allowed us to build depth control into the guide. In order for the bur to be fully-guided, it must have a head diameter smaller than the shank diameter must be used. For this reason a #4 size surgical length round bur was utilized. With a diameter of 1.4mm, the #4 round bur would remove an excessive amount of tooth structure if used for troughing into the root body of the tooth. In this case a smaller bur size would be advantageous for dentin conservation. Also, the implementation of water-coolant to the spinning bur would need to be addressed. The intimate fit of the shank to the guide did not allow water to penetrate to the cutting surface to cool the tooth. This could be problematic in a clinical setting as the heat generated could damage the PDL. The protocol could be further improved with the implementation of metal sleeves placed in the guide. In order for the bur to be fully-guided during the procedure, the shank was in intimate contact with the guide. The guide was 3D printed using acrylic material which is susceptible to distortion and damage from the metal bur rotating as extremely high RPMs. Metal guide sleeves could be placed in the guide to help eliminate the chance for misadventure.

It became apparent that debriding and disinfecting the pulp chamber would be problematic once the CECs were completed for this research project. The teeth were immersed in 5.25% sodium hypochlorite for 12 hours prior to photography and pulp chamber tissue could still be visualized. The difficulty in cleaning the remaining pulp tissue (RPT) was verified with an investigation by Neelakantan et. al. in a 2018 study. The group’s study examined if a specific type of CEC (orifice-directed dentin conservation -- DDC) access was able to debride the pulp chamber, canals, and isthmi on mesial roots of mandibular molars similar to TECs. They found that the RPT in the chamber was significantly higher in the DDC compared to the traditional endodontic cavity, while the RPT in the canals was not different amongst the groups (23). Promising tools such as GentleWave by Sonendo have been developed and shown to be able to clean these previously inaccessible areas better than conventional irrigation protocols (24-26).

Conclusion:

The current study filled an important gap in the literature and proved that with current technology clinicians are able to perform accesses that deviate from what is considered normal with a high degree of accuracy. It is important to clarify that the results of this study are not advocating for any particular type of access cavity. The ultra-conservative orifice-directed access was chosen as it has the smallest room for error and maintains the maximum amount of dentin. This protocol could be utilized for a variety of different access designs. The clinical decision making will ultimately be left to the clinician, but this study shows the possibilities are limitless with current technology. The proposed protocol demonstrated both a low average file deviation angle, as well as accurate depth control during guided access to the chamber.

The future directions of research should focus on the utilization of the proposed protocol for access of calcified posterior teeth, introducing and experimenting with different types of burs, and ability to adequately irrigate the tooth while accessing to prevent overheating.

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