2019

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Recommended Citation

Christensen, Jordan Miles, "Straight-Line Access Accuracy in Posterior Teeth with a Dynamic Guidance System: A Comprehensive ex vivo Analysis" (2019). *MUSC Theses and Dissertations*. 203.
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Straight-line Access Accuracy in Posterior Teeth with a Dynamic Guidance System: A Comprehensive ex vivo Analysis

by

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A thesis submitted to the faculty of the Medical University of South Carolina in partial fulfillment of the requirement for the degree of Masters of Science in Dentistry in the College of Dental Medicine.

Department of Oral Rehabilitation, Division of Endodontics

July 25, 2019

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Abstract:

Introduction: Dynamic navigation has the ability to overcome many treatment limitations encountered when using static guides; however, its use for endodontic access is just beginning to be explored. The accuracy of new navigation systems needs to be further evaluated. The aim of this study is to evaluate angular deviations and position deviations of endodontic access preparations compared with the digital file plan, and the ability to provide straight-line access to the canal orifice as shown by the angle of deflection of inserted files. **Methods:** Thirty-two extracted human teeth were placed into two maxillary and two mandibular jaw models. Preoperative CBCT scans were uploaded into the X-Nav software, and access cavities were virtually planned. After access cavity preparation by two operators, postoperative CBCT scans were superimposed on the virtual plans. Accuracy was measured by calculating the angular deviations and position deviations of endodontic access preparations compared with the virtual plans, and the ability to provide straight-line access to the canal orifice as shown by the angle of deflection of inserted files. **Results:** All root canals were accessible after access preparation. Straight line access into canals was achieved with a low average file deviation angle of 5.19˚ ± 3.09˚. Relative to the preoperative access plan, the angular accuracy of drilled access using the tested device was 3.55˚ ± 1.87˚ for posterior teeth. Positional accuracy was 0.64mm ± 0.29mm measured at the coronal surface and 0.36mm ±

0.20mm measured at the cutting tip of the access bur. **Conclusions:** This study fills a gap in the current literature, showing that current technology in dynamic navigation enables very accurate and precise endodontic access cavities. Straight line access into canals was achieved with low average file deviation angle, and access cavity results that were accurate with the digitally planned access.

Introduction

The use of cone-beam computed tomography (CBCT) imaging for canal location and access planning in endodontics has increased significantly in recent years. With the ability to provide valuable anatomic detail, CBCT imaging allows for 3-dimensional treatment planning which enables more accurate and safe treatments [1].

CBCT imaging has not only allowed for improved ability to accurately plan free-hand endodontic access, but it has also enabled computer-assisted guidance systems to be developed. With the systems we see today, we can categorize them as either static or dynamic. Static systems use guides fabricated with computer-aided design/computer-aided manufacturing (CAD/CAM) based on the CBCT and 3D scans of the patient. Dynamic systems use the information from the CBCT alone to track the patient and surgical instruments; providing real-time feedback on positioning.

The use and accuracy of static guidance systems have been shown in implant placement for nearly 20 years. In 2001, Klein and Abrams suggested milled CT-based drilling guides as a solution to the common problem of poorly positioned implants being placed free-hand [2]. Just two years later, Sarment, et al., reported that the implants placed with 3D-printed surgical guides had significantly better placement accuracy than those placed without surgical guides [3]. Numerous studies since then have continued to confirm surgical guides as significantly more accurate than free-hand implant placement [4-6].

Static drill guides were first proposed for use in endodontics for guided periapical surgery [7]. Their adoption into the field has been slow, and it wasn't until Buchgreitz, et al., and Zehnder, et al., in 2016 showed the accuracy of using a CT-based static drill guide for endodontic access preparations that meaningful research on the topic was published [8-10]. Over the past few years, there have been numerous case studies and ex-vivo studies confirming the accuracy and benefits of utilizing CT-based static drill guides for endodontic access [11-16].

The literature for both implant placement and endodontic access using static guides clearly shows improved accuracy, but the complex workflow of available systems and their cost have prevented broader adoption [17].

Static guides have also been noted to have the following in-treatment limitations when being utilized for endodontic access:

1. Lack of inter-occlusal space for the guide and the drill, especially on posterior teeth
2. Inability to perform same-day treatment
3. Inability to alter treatment plan during the procedure, if needed
4. Metal guide rings are not designed for use with high-speed burs
5. Multiple drill guides needed when treating multi-canal teeth

With the significant improvements in computer processing and technological advances over the past 10 years, dynamic optically-driven guidance systems have become a reality. The accuracy and efficiency of these systems in use with implant placement has been shown to be similar to static guidance since 2010 [18-20].

Dynamic navigation has the ability to overcome all of the previously mentioned treatment limitations; however, its use for endodontic access is just beginning to be explored. Although there has been one ex vivo study [21], and a few case reports [22] of dynamic navigation being successfully used in endodontic access published; the accuracy of new navigation systems needs to be further evaluated.

The purpose of this study is to evaluate the accuracy of endodontic access preparations in dental models via the guidance of the X-Guide Surgical Navigation System (X-Nav Technologies, LLC, Lansdale, Pa). To the authors' knowledge, this is the first ex vivo study to evaluate the accuracy of endodontic access using a dynamic guidance system. The aim of this study is to evaluate angular deviations and position deviations of endodontic access preparations compared with the digital file plan, and the ability to provide straight-line access to the canal orifice as shown by the angle of deflection of inserted files.

Materials and Methods

Study Design:

The design of this study consisted of two 2nd year endodontics residents planning virtual files to guide endodontic access to each canal on CBCT scans of jaw models; and then performing endodontic access preparations on the jaw models under guidance.

Dentoforms:

For this study 32 extracted human teeth (16 premolars, and 16 molars) (total of 70 canals) with minimal caries or restorative history were acquired in compliance with the Medical University of South Carolina Institutional Review Board. Teeth were encased at the apical extent in rope wax (Heraeus, South Bend IN), the crowns of the teeth were then seated into their proper arch position within a rubber model former mold (Buyamag, Carlsbad CA), and then the roots were encased in clear orthodontic acrylic resin (Dentsply Caulk, York PA) to create full arch custom dentoforms (Figures 1a and 1b).

Imaging:

Before a CBCT was acquired, a bite registration device with three fiducials (X-Clip, X-Nav Technologies, LLC) was placed on the arch just posterior to one of the second molars per the manufacturer’s instructions. The dentoforms were scanned with the Planmeca ProMax 3D Max cone-beam computed tomography (CBCT) machine at 80Kv, 10mA, and 150 micron slices. After the scanning was completed the x-clips were removed, labeled, and stored for use during treatment.

Virtual Endodontic File Design and Placement:

The DICOM data sets of each jaw model were exported from the Romexis software and uploaded into the X-Nav software. The software was used to define the arch and implant dimensional manipulation. Virtual endodontic files were custom created in the software by adjusting the diameter of the “implant” to 0.5mm, with lengths ranging from 7-14 mm to allow virtual placement with coronal termination of the file near the tooth’s occlusal surface. The X-Nav software currently allows for only a single implant to be placed associated with each tooth number, but you can plan multiple implants at each site by planning for adjacent teeth and dragging the implant to the desired site. This enables treatment planning of endodontic access for multi-canal teeth. For example, on tooth #30, the distal canal was #30, the mesiolingual canal was #31 and the mesiobuccal canal was number #32. The software allows for simultaneous visualization of multiple CBCT views (Axial, Sagittal, and Coronal) in order to properly orient the virtual implants into the coronal 1/3 of the canal and to allow straight vector access based upon the trajectory of the coronal aspect of each canal (Figures 2a and 2b).

Simulated Treatment Setting:

The teeth/dentoforms were hydrated in 0.9% normal saline for 24 hours. Typodont frames were screwed into the dentoforms, they were mounted on a post, and attached to the dental operatory chair (Figure 3). This set-up was done to simulate a clinical treatment scenario. The room was then set-up as normal for endodontic treatment (Figure 4). The X-

Guide machine was positioned in the corner of the operatory to ensure normal movement and positioning during treatment.

System Calibration and Treatment:

In order to provide dynamic guidance during treatment, the X-Guide tracks the motion of two dynamic reference frames (DRFs). One frame is attached to the patient via the X-clip bite registration device (patient tracker), and the other is attached to the surgical hand-piece (hand-piece tracker) (Figure 5). These reference frames must be calibrated before treatment per the onscreen manufacturer's instructions.

Following the manufacturer's instructions the overhead X-Guide cameras were in position to read the DRF's, placing the patient DRF, which is connected to the X-clip, onto the same location as when the CBCT scan was acquired, and holding the hand-piece DRF in the camera field of view as the bur is touched to the center of the sensor plate. The X-guide software walks you through the calibration in real time and notifies you when each calibration step has been completed.

The patient DRF calibration determines the relationship between the patient and the CT fiducials. Calibration of the hand-piece allows the system to determine the relationship between the hand-piece and the axis of the drill.

The hand piece and patient location are continuously triangulated by the tracking software to provide precise position and orientation during treatment. This information is fed to a multi-window video feed which gives live feedback as to the bur position, angulation, and depth during access.

Access drilling was completed by initially marking the enamel surface with a slow-speed bur under guidance, then perforating the enamel with a high-speed #4 round bur without guidance, and finally by drilling to depth using Munce discovery burs size #1 (0.8mm) (CJM Engineering Inc., Santa Barbara, CA) under guidance. The Munce burs were used in a latch fit 1:1 dental surgical electric hand-piece (W&H WS-56, Bürmoos, Austria), and drilling was done at 40,000 RPM. At the time of this study the X-guide system was not compatible with a high-speed hand-piece, and so this method was utilized to enable access through enamel.

Post-Operative Analysis:

After endodontic access, new CBCT images were captured. To determine the accuracy of our drilled accesses, the preoperative virtual access plan and a postoperative CBCT scan were superimposed (Figures 11a and 11b). In this process, using the X-Guide implant planning software, a trained engineer first identified the precise path of the drilled access in the postoperative CBCT scan. Next, the preoperative and postoperative CBCT scans were registered by aligning the sawbones structure in each scan via a rigid transformation. To generate the registration, polygonal meshes representing the outer sawbones surfaces were extracted from the pre- and postoperative CBCT scans via conventional iso-surface thresholding techniques. The meshes were then cleaned of any artifacts and aligned in the open-source MeshLab software suite. Using the rigid transform defined by the MeshLab registration, the virtual preoperative access path was projected onto the postoperative CBCT scan, where its position and orientation are compared with those of the drilled access.

To analyze the ability of our access paths to enable straight-line access into each canal, we measured the deviation between estimated file path and true file emergence. This was done in each access cavity by placing a 0.08 k-file into each canal, and capturing additional CBCTs with the files in place. Only one file, per tooth, per image was utilized to reduce radiographic artifact. The crowns of each tooth was then sectioned away with a high-speed hand-piece under irrigation to the level of the CEJ. The files were then replaced, and CBCT images were taken one file, per tooth, per image just as before.

The DICOM data from the initial images taken with files in place were stitched with the images of the files in place after crown removal (Figures 12a and 12b). This allowed visualization of the two files superimposed, and enabled us to measure differences in angulation and position. 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 as the angle deviation.

The following deviation categories from the virtual plan were calculated for the access path:

- Angular Deviation (degrees): largest angle in 3D space between center axes of planned access path and actual access path.
- Coronal Deviation (mm): the difference in mesial/distal (y-axis) and buccal/lingual (x-axis) location of the access at the coronal surface.
- Apical Deviation (mm): the difference in mesial/distal (y-axis) and buccal/lingual (x-axis) location of the access at the apical extent of the access path.
- Drill Depth (mm): apical depth to which the drill was taken in order to facilitate straight-line access into the canal.
- File Angular Deviation (degrees): largest angle in 3D space between center axes of files in canals before and after decoronation.

Data and Statistical Analysis:

Each deviation category was then analyzed for significance in differences between maxillary and mandibular teeth, and between tooth types. For the comparison of maxillary to mandibular teeth, a Wilcoxon Rank Sum Test was used for the outcomes of Access Angular Deviation, Coronal Deviation, Apical Deviation and Drill Depth. A T-test was used for File Angular Deviation. P-values were found to be significant if they were less than 0.05. For the comparison of Tooth Type, an Analysis of Variance (ANOVA) model was used. All outcomes were log-transformed for normality except File Angular Deviation. All descriptives are presented on the normal scale. If the main effect was significant for Tooth Type, post-hoc comparisons were presented with a Tukey adjustment.

Results

Straight line access into canals was achieved with a low average file deviation angle of 5.19˚ ± 3.09˚. Relative to the preoperative access plan, the angular accuracy of drilled access using the tested device was 3.55˚ ± 1.87˚ for posterior teeth. Positional accuracy was 0.64mm ± 0.29mm measured at the coronal surface and 0.36mm ± 0.20mm measured at the cutting tip of the access bur.

When comparing maxillary and mandibular posterior teeth, the only variable that showed significance was the drill depth at a p-value = 0.0024. With the mandibular posterior teeth having significantly shorter drill depth.

Access Angular Deviation

		N	Mean	Median	Std Dev	5th Pctl	95th Pctl
Mand	**Posterior**	36	3.85	3.64	1.98	0.93	7.43
Max	**Posterior**	34	3.23	2.81	1.77	0.72	6.49

Coronal Deviation

		N	Mean	Median	Std Dev	5th Pctl	95th Pctl
Mand	**Posterior**	36	0.61	0.60	0.29	0.14	1.13
Max	**Posterior**	34	0.66	0.63	0.32	0.19	1.29

Cutting Tip Deviation

		N	Mean	Median	Std Dev	5th Pctl	95th Pctl

		N	Mean	Median	Std Dev	5th Pctl	95th Pctl
Mand	**Posterior**	36	0.37	0.34	0.22	0.08	0.78
Max	**Posterior**	34	0.34	0.31	0.17	0.10	0.68

Drill Depth

		N	Mean	Median	Std Dev	5th Pctl	95th Pctl
Mand	**Posterior**	36	8.74	8.45	1.81	6.50	12.60
Max	**Posterior**	34	9.96	10.00	1.27	8.00	12.00

File Angular Deviation

		N	Mean	Median	Std Dev	5th Pctl	95th Pctl
Mand	**Posterior**	36	5.09	4.44	2.96	0.21	10.45
Max	**Posterior**	34	5.30	5.05	3.23	0.02	10.64

Table 1. Measurements with respect to the differences between maxillary and mandibular teeth.

When comparing all tooth types, there was significance found in drill depth when comparing mandibular molars to maxillary molars (p-value = 0.0386) and maxillary premolars (p-value = 0.0058). With the mandibular molars having significantly shorter drill depths than the other two groups. For the file angular deviation, only the main effect of Tooth Type was significant.

Access Angular Deviation (degrees)

		N	Mean	Median	Std Dev	5th Pctl	95th Pctl
Mand	**Molar**	27	4.03	3.64	2.06	0.93	7.43
	Premolar	9	3.30	3.88	1.72	1.08	5.29
Max	**Molar**	25	3.35	3.14	1.93	0.72	6.49
	Premolar	9	2.92	2.57	1.28	1.71	5.09

Coronal Deviation (mm)

		N	Mean	Median	Std Dev	5th Pctl	95th Pctl
Mand	**Molar**	27	0.57	0.53	0.29	0.14	1.05
	Premolar	9	0.74	0.71	0.24	0.30	1.13
Max	**Molar**	25	0.70	0.64	0.35	0.21	1.29

		N	Mean	Median	Std Dev	5th Pctl	95th Pctl
	Premolar	9	0.56	0.55	0.21	0.17	0.82

Angular Deviation (mm)

		N	Mean	Median	Std Dev	5th Pctl	95th Pctl
Mand	**Molar**	27	0.36	0.33	0.24	0.08	0.78
	Premolar	9	0.40	0.43	0.17	0.08	0.67
Max	**Molar**	25	0.33	0.31	0.17	0.10	0.68
	Premolar	9	0.37	0.44	0.18	0.15	0.58

Drill Depth (mm)

		N	Mean	Median	Std Dev	5th Pctl	95th Pctl
Mand	**Molar**	27	8.50	8.40	1.55	6.50	11.70
	Premolar	9	9.48	8.50	2.41	7.00	14.00
Max	**Molar**	25	9.73	9.50	1.34	8.00	11.50
	Premolar	9	10.61	10.00	0.77	10.00	12.00

File Angular Deviation (degrees)

		N	Mean	Median	Std Dev	5th Pctl	95th Pctl
Mand	**Molar**	27	5.58	5.93	3.13	1.02	10.45
	Premolar	9	3.61	3.59	1.80	0.21	6.34
Max	**Molar**	25	5.92	5.67	3.33	0.37	10.64
	Premolar	9	3.59	4.10	2.28	0.01	6.75

Table 2. Measurements with respect to both tooth type and arch location.

When comparing molars and premolars, the only variable that showed significance was the file angular deviation at a p-value = 0.0289. With the premolars having significantly less file angular deviation.

Access Angular Deviation

Tooth type	N	Mean	Median	Std Dev	5th Pctl	95th Pctl
Molar	52	3.70	3.49	2.01	0.72	7.43
Premolar	18	3.11	2.90	1.49	1.08	5.29

Coronal Deviation

Tooth type	N	Mean	Median	Std Dev	5th Pctl	95th Pctl
Molar	52	0.63	0.60	0.32	0.19	1.29
Premolar	18	0.65	0.68	0.24	0.17	1.13

Cutting Tip Deviation

Tooth type	N	Mean	Median	Std Dev	5th Pctl	95th Pctl

Tooth type	**N**	**Mean**	**Median**	**Std Dev**	**5th Pctl**	**95th Pctl**
Molar	52	0.34	0.31	0.21	0.08	0.68
Premolar	18	0.39	0.44	0.17	0.08	0.67

Drill Depth

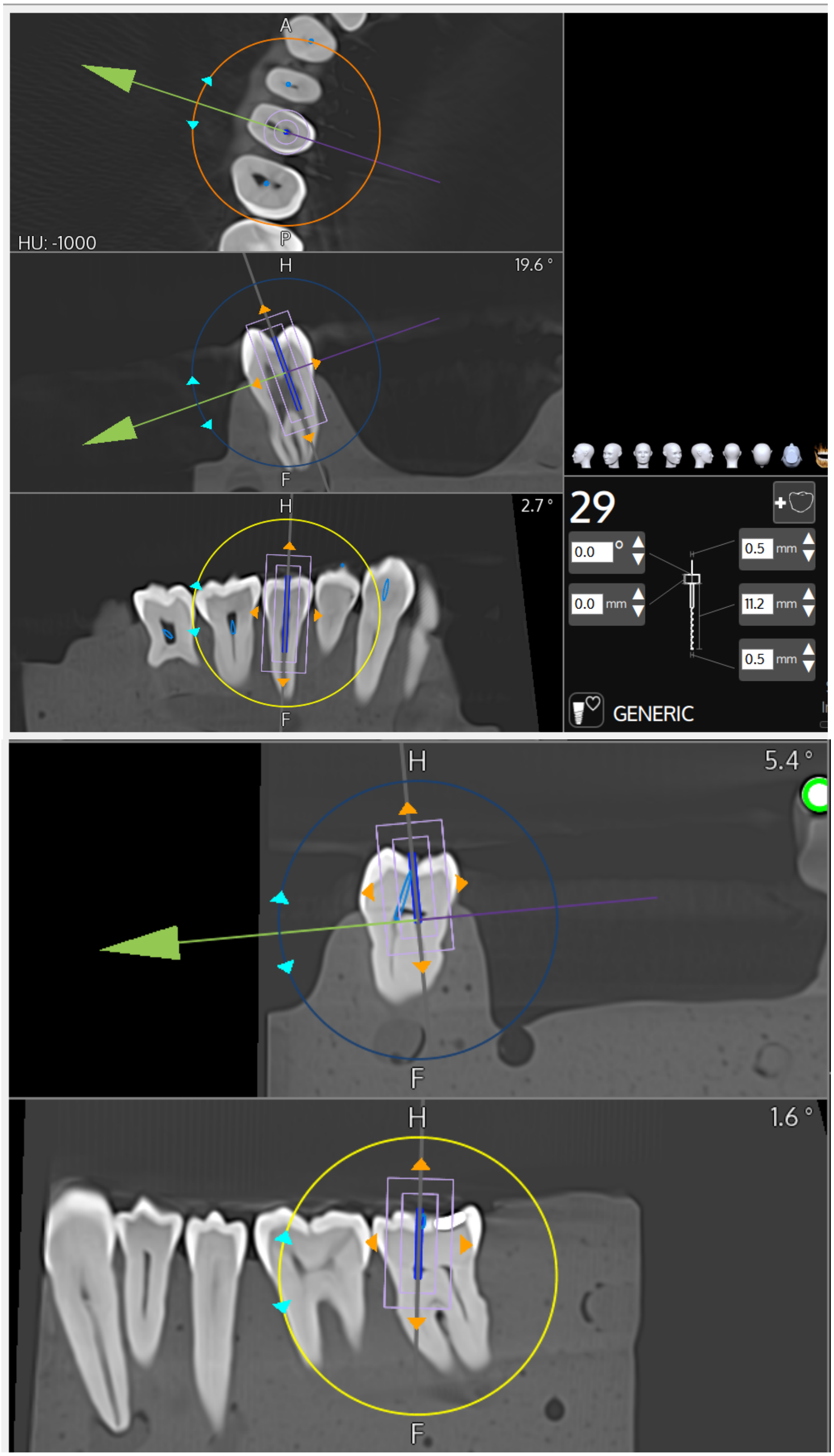
Tooth type	**N**	**Mean**	**Median**	**Std Dev**	**5th Pctl**	**95th Pctl**
Molar	52	9.09	8.80	1.57	6.50	11.70
Premolar	18	10.04	10.00	1.83	7.00	14.00

File Angular Deviation

Tooth type	**N**	**Mean**	**Median**	**Std Dev**	**5th Pctl**	**95th Pctl**
Molar	52	5.74	5.80	3.20	0.37	10.64
Premolar	18	3.60	3.74	2.00	0.01	6.75

Table 3. Measurements with respect to tooth type alone.

Figures 1a. Front view and 1b. Side view of teeth mounted into custom acrylic dentoform.



Figures 2a. Premolar and 2b. Molar virtual planning of access drill paths in X-nav software.

Figure 3. Dentoform mounted to operatory chair and patient DRF in place.

Figure 4. Operatory set-up for treatment

Figure 5. X-Guide sensor plate and dynamic reference frames used for system calibration and tracking. From left to right: bur sensor plate, handpiece DRF, and patient DRF.

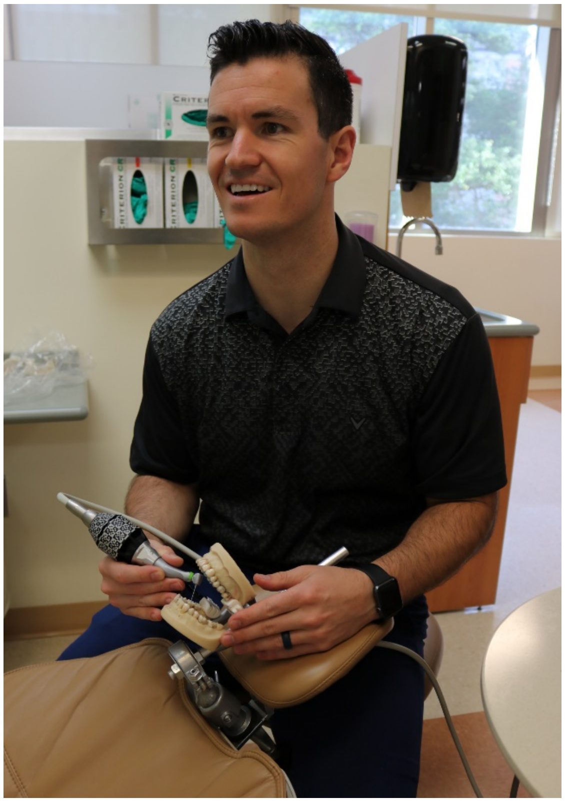


Figure 6. Operator positioning during treatment with focus on the X-Guide monitor to guide access.

Figure 7. View of X-Guide monitor during dynamic navigation.

Figures 8a. Occlusal view and 8b. Facial view of dentoform arch after all canals accessed.

Figure 9. Occlusal surfaces of three teeth with access preparation completed.

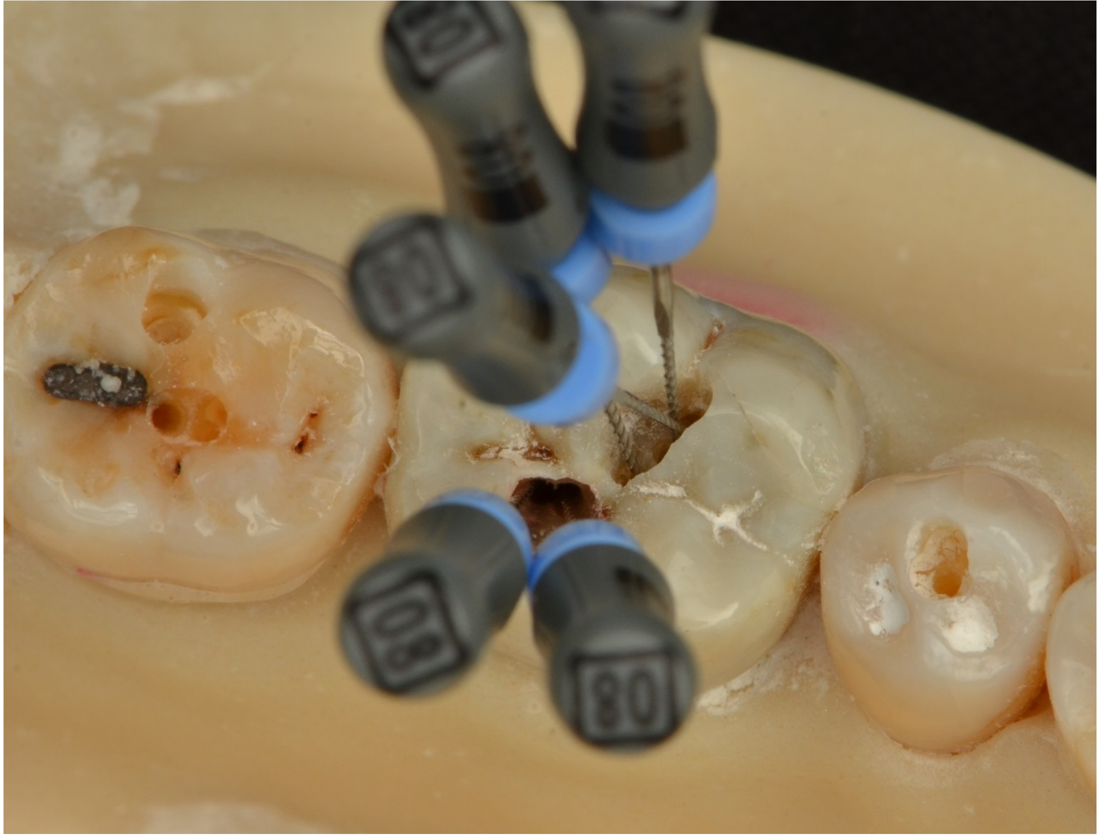
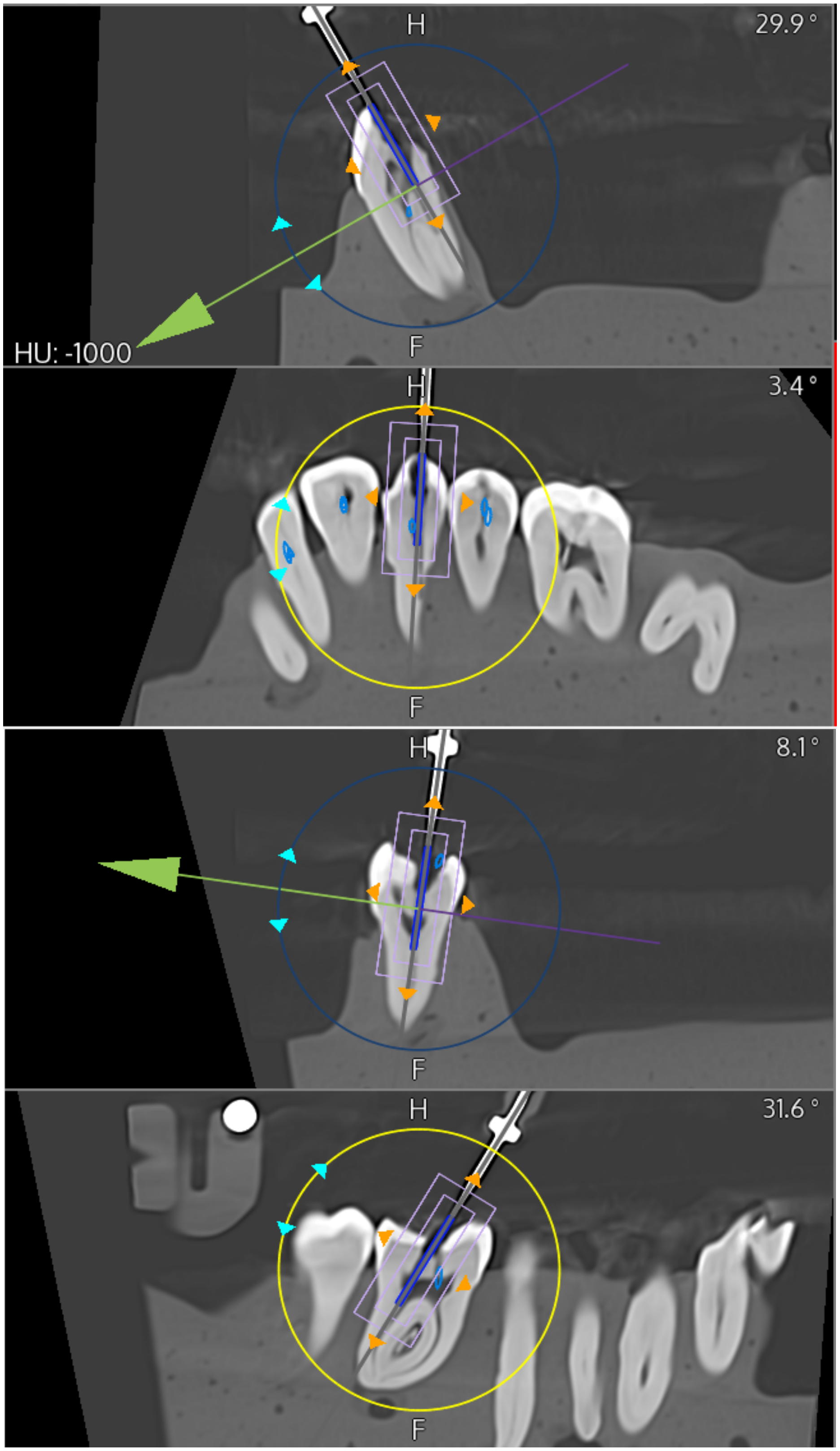
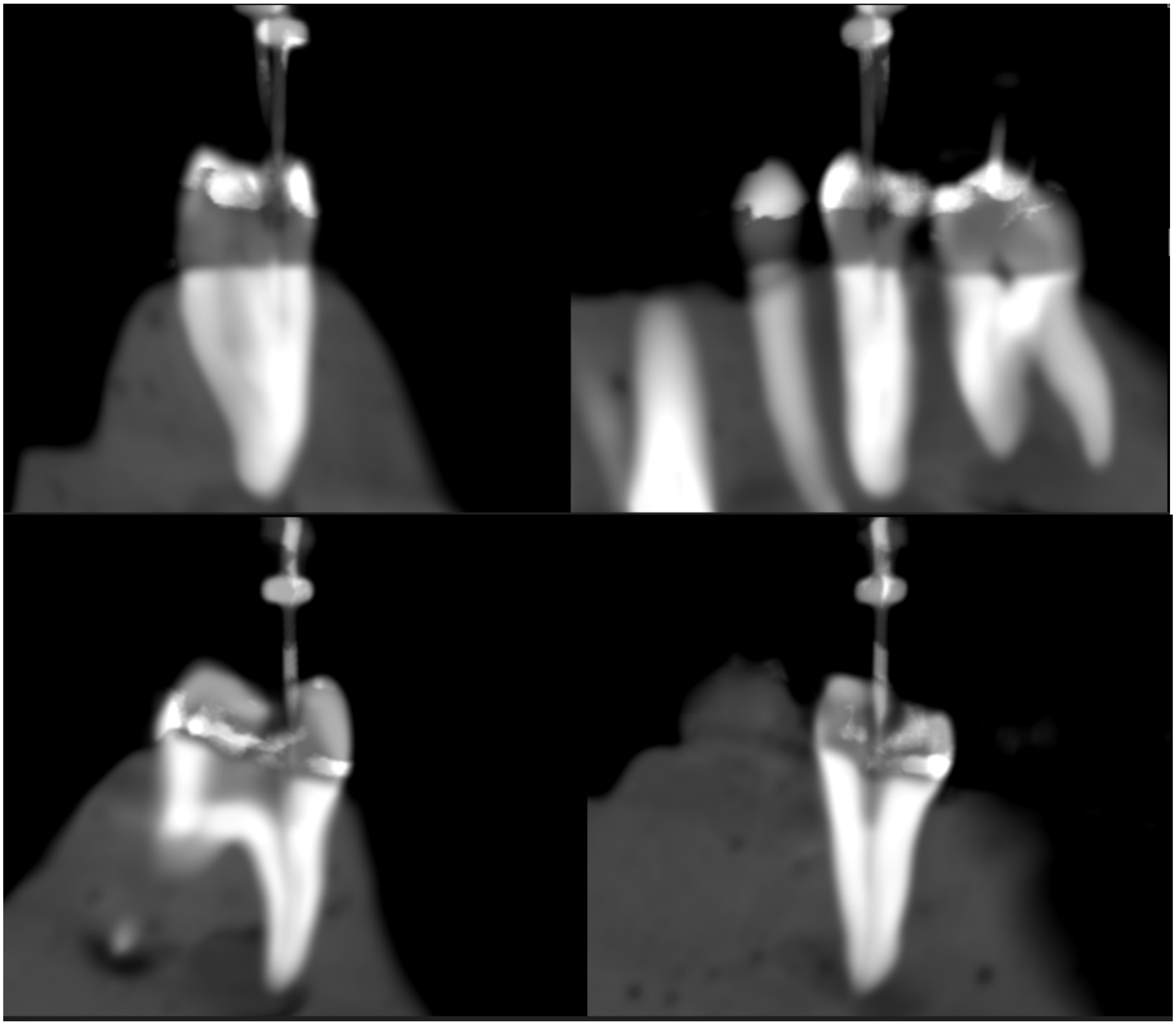


Figure 10. Files in all five canals of a mandibular molar.



Figures 11a. Premolar and 11b. Molar Post-operative access angulation assessment using superimposed CBCT scans.



Figures 12a. Premolar and 12b. Molar superimposed CBCT scans in the sagittal and coronal views of files in place with and without crown present.

Discussion

Challenging access preparations due to calcification, angulation, or unique anatomy are an everyday occurrence in an endodontic practice. It is not uncommon to have to sacrifice more tooth structure than desired in order to locate canals. Not to mention the additional treatment time needed, and stress produced in these situations.

Although static guidance for endodontic access has been used for quite some time and has been shown to be very accurate, it is still not commonly utilized. This is especially true in multi-canal posterior teeth where there have traditionally been numerous limitations with the utilization of static guides. Despite the significant trend in digital and 3D applications, the likely reason we have not seen any degree of success with multi-canal teeth prior is the complexity of the guide design [17]. As stated previously, there are numerous treatment limitations when using static guides for endodontic access.

To our knowledge there is only one study, currently unpublished, utilizing static guidance that has shown the ability to overcome multiple of these limitations. However, treatment plan flexibility and the capability to perform same-day treatment are still an obstacle.

The aim of this study was to evaluate angular deviations and position deviations of endodontic access preparations compared with the digital file plan, and the ability to provide straight-line access to the canal orifice as shown by the angle of deflection of inserted files. Straight line access into canals was achieved with a low average file deviation angle of 5.19˚ ± 3.09˚. Relative to the preoperative access plan, the angular accuracy of drilled access using the tested device was 3.55˚ ± 1.87˚. Positional accuracy was 0.64mm ± 0.29mm measured at the coronal surface and 0.36mm ± 0.20mm measured at the cutting tip of the access bur. In endodontics, where every half millimeter counts, the accuracy of these values represents the positive effect on treatment outcome that dynamic guidance could provide.

Our results show that utilizing dynamic navigation for endodontic access provides similar results to those shown previously in studies using static guides. The technology used in this study and the process for its use may seem complicated at first; however, it is actually very intuitive and easy to learn. Both of the doctors performing access preparations were completely new to the system. Prior to beginning the study, each doctor planned and completed endodontic accesses on just two canals to familiarize themselves with the technology. Despite the lack of training and experience with the navigation software, the results were very precise and accurate. 100% success and accuracy from the standpoint of direct clinical canal access was attained. Even difficult cases such as late splitting Vertucci type V canal configurations in mandibular premolars, and middle mesial canals in mandibular molars were planned and executed successfully. The results of this study show that there is great application for this type of device in clinical practice. Once the software is learned after a couple cases, the planning stage of treatment could be realistically accomplished in 10-20 minutes. The ability to perform guided endodontic access that can be planned and executed in the same treatment visit is very beneficial.

There were two main limitations we saw with this technology. The first is that currently it can only be used with a slow-speed hand-piece. This means that you have to perforate the enamel with a different high-speed hand-piece, as we did, before you begin your navigation. If it were possible to use it with a high-speed hand-piece your access could be done under navigation from start to finish, making for a much more efficient and probably more accurate coronal access.

The second limitation was seen during the planning stages. You are only able to place one implant per tooth site. If you are wanting to plan multiple canal accesses on a multi-canaled tooth then you have to drag implants from different tooth sites over to the tooth you are working on. Ultimately this process works if you are only planning to treat one tooth in the quadrant; however, it makes things a little more confusing and messy to view in the software. A change in the X-Nav software could be made that allows for multiple implants, which can then be individually labeled, to be planned at a single tooth site. This would enable the clinician to produce a very organized plan for each tooth regardless of the number of canals being treated. Both of these changes would make the planning and treatment processes much more efficient. It is the authors' understanding that both of these updates are soon to be available.

Another area of this study to be addressed is seen in the results. Although the file angular deviation is very low for all posterior teeth, there is significantly more deviation seen with the molars (5.74˚ ± 3.20˚) than with the premolars (3.60˚ ± 2.00˚). A strong contributing factor to this was likely the size of the canal orifices in the teeth used in the study. Some of the molars used had large ovoid palatal or distal canals. These large canals made it nearly impossible to not have higher deviation once the tooth was decoronated. These canals did consistently have higher deviation. It is the authors' opinion that without these canals factoring into the statistics, the results for the molar teeth would have been in-line with the results seen with the premolar teeth.

When looking at the ability dynamic navigation provides to produce such constricted endodontic access cavities, we must also mention the inherent difficulty that would result when attempting to debride and disinfect the pulp space. This has been shown recently by Neelakantan, et al. in a 2018 study. The group evaluated whether or not there was any difference in the ability to debride the pulp chamber, canals, and isthmuses on mesial roots of mandibular molars when working with a DDC (orifice-directed dentin conservation) access or a TEC (traditional endodontic cavity). Their results showed that while the remaining pulp tissue in the canals was not significantly different between the groups, there was significantly more remaining pulp tissue in the chambers of teeth treated using a DDC compared to the TEC [23]. New technology in irrigation, such as the GentleWave by Sonendo, have been shown to have the ability to clean inaccessible or un-instrumented areas better than conventional irrigation protocols [24-26]. These technologies look to be promising; however, further independent research is needed to validate these claims. It is also worth noting that a larger access cavity than what was demonstrated in this study is still necessary to accommodate these devices.

Conclusion

This study fills a gap in the current literature, showing that current technology in dynamic navigation enables very accurate and precise endodontic access cavities. Straight line access into canals was achieved with low average file deviation angle, and access cavity results that were accurate with the digitally planned access. Relative to the preoperative access plan, the angular accuracy of drilled access using the tested device was 3.55˚ ± 1.87˚ for posterior teeth. Positional accuracy was 0.64mm ± 0.29mm measured at the coronal surface and 0.36mm ± 0.20mm measured at the cutting tip of the access bur. Future studies evaluating dynamic navigation access in calcified teeth, and directly comparing dynamic navigation to freehand access are recommended.

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