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Removal of Endodontic Fiber Posts Using Robot-Assisted Haptic Guidance: A Novel Approach

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Removal of Endodontic Fiber Posts using Robot-Assisted Haptic Guidance: A Novel Approach.

by

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ABSTRACT

Introduction: Fiber posts are frequently used for the restoration of endodontically treated teeth. Such posts are typically bonded to the tooth using a composite resin system. These posts often need to be removed during endodontic retreatment. While there are many techniques to remove fiber posts, most include drilling through the post itself which can be challenging and result in a perforation or excessive tooth structure being removed. Static and dynamic guided endodontic techniques have been proposed to safely remove fiber posts. Yomi (Neocis, Inc, Miami, FL) is a haptic robot guidance system has been FDA approved to assist in placing dental implants and may be able to be used for endodontic applications. This system combines the advantages of both static and dynamic guidance. The purpose of this study was to investigate the ability and efficiency of a robot-assisted haptic guidance system to remove bonded fiber posts in endodontically treated teeth. **Methods:** Forty-six natural extracted single-rooted maxillary anterior teeth with straight canals were selected and endodontically treated. Following obturation, a post space was created, and fiber posts placed and bonded with resin. The teeth were then mounted in acrylic blocks simulating a maxillary arch form. Preoperative CBCT volumes were acquired. The teeth were divided into 3 groups for fiber post removal. In Group 1 the fiber posts were removed by an endodontic resident using robot-assisted haptic guidance. In Group 2 the fiber posts were removed by an experienced endodontist using a freehand technique. In Group 3 the fiber posts were removed by the endodontic resident using a freehand technique. The volume of removed tooth structure was measured and time to remove the fiber posts recorded. Post-operative CBCT volumes were acquired. ITK-SNAP semiautomatic segmentation software was used to compare pre- and post-operative CBCT images for volumetric analysis in determining the amount of tooth structure removal. The data was statistically analyzed using independent samples t-tests, one-way ANOVA, and the Tukey post-hoc procedure. **Results:** All teeth were included for final analyses. The mean time to remove a post in Group 1 was 33.3 seconds, Group 2 was 446.2 seconds, and Group 3 was 607.2 seconds. There was a significant difference between each group regarding the time to remove the fiber post. The mean volume of tooth structure removed in Group 1 was 10.9 mm^3, Group 2 was 15.6 mm^3, and Group 3 was 24.3 mm^3. The difference in volume of tooth structure removed was significant between Group 1 and the two other groups. **Conclusions:** The removal of resin bonded fiber posts in single canal maxillary teeth is possible using a robot-assisted haptic guidance system. The robot guided system is more time efficient and results in less volume removed when removing fiber posts compared to freehand techniques. An experienced endodontist is more conservative in removing a fiber post than an endodontic resident when considering the amount of tooth structure removed.

KEY WORDS

Dynamic navigation; guided endodontics; haptic guidance; post removal; endodontics

INTRODUCTION

The objective of endodontic therapy is cure or prevent periradicular periodontitis and restore the treated tooth to its proper form and function within the mouth (1,2). This is accomplished by cleaning, shaping, and obturating the root canal system. Teeth with a definitive coronal restoration following root canal therapy have been shown to have significantly better periapical healing, thus this is considered the final step in the management of teeth undergoing root canal therapy (1,3). Such a restoration oftentimes will require a post for retention of a core buildup material. Posts can be classified into two main categories: prefabricated fiber posts and custom cast posts (1). Prefabricated fiber posts are typically bonded with resin cements. They have become the more popular choice in posts in recent times (4).

Primary root canal treatment is generally considered to have a high success rate (3). However, persistent or secondary infection is known to occur which would require retreatment of the root canal system (5). When retreatment is indicated, non-surgical root canal therapy may be the first choice if access to the canal system can be achieved (6). The placement of posts, specifically fiber bonded posts, can complicate re-access of the root canal apex. Due to the bond of the fiber post to the dentine, removal generally involves directly drilling through the post (7). Ultrasonic instrumentation has proved to be a successful technique when applied to metal post removal, however, risks including excess heat production and instrument separation limit its use for fiber post removal. Despite the many systems and techniques developed to remove fiber posts from endodontically treated teeth, post removal can be difficult or occasionally impossible (8). Potential complications of freehand (FH) post removal include root perforation, fracture, excess tooth structure removed leaving the tooth nonrestorable, excess heat and damage to the periodontium, and inability to remove the post (9). The ability to safely and predictably remove a fiber post would be an important factor in guiding clinical decision making and treatment planning.

The emerging availability and use of cone beam computed tomographic (CBCT) imaging in endodontics has benefited operators and patients greatly. This imaging has been particularly useful in diagnosis and treatment planning. In addition, CBCT has recently been used for guided endodontic procedures. The use of a static guide and dynamic navigation have recently been demonstrated as effective techniques in removing fiber posts (10, 11). Static guides are created using a preoperative cone beam computed tomographic (CBCT) image to virtually plan and manufacture a guide which fits the dentition and provides a path for the drill (11). This technique has been shown to reduce procedural errors. However, several limitations exist including space limitations in posterior areas or patients with limited opening, lack of visualization of the operative field, errors introduced during manufacturing, and no allowance for intraoperative procedural changes (10,11,12). The utilization of 3D dynamic navigation has been used recently in implant dentistry and introduced for endodontic applications. It has been shown to be useful in locating canals in calcified teeth, removal of fiber posts, and surgical access (11-20). This technology uses real-time 3D motion tracking which is based on the use of stereoscopic cameras and fiducial markers which enable the operator to follow a virtually planned trajectory in real-time (11,16,21). Several studies have confirmed its accuracy (13,20-24). Advantages include intraoperative procedural flexibility, reduced space limitations, and real-time visualization of the position and angulation of the drill (11). Limitations of dynamic navigation include cost, the need for a quality CBCT scan, fiducial marker movement, large cameras, planning errors, or inability to calibrate the drill, and the requirement that the operator look at a system display rather than directly visualizing the operative field (11).

Automation has become widespread across many industries, including healthcare. The degree of automation can range from manual (no automation) to complete automation (no human input) (25,26). Advances in technology and automation have led to the development and application of robotic systems in dentistry. Robots have been shown to improve certain aspects of dental procedures in reducing operating time, operator fatigue, and improving ergonomics, accuracy, efficiency, and reliability of procedures (27-30).

The Yomi Dental Robotic System was the first robotic device for dental surgery commercially available for use in the United States. It was created and marketed for use as an implant delivery system, aiming to combine the advantages of the physical restraint inherent to static guides and the flexibility of dynamic navigation (31). Prior to CBCT acquisition, an intraoral Edentulous Patient Splint is affixed to the patient's dentition using a vinyl polysiloxane material. This splint is used to attach fiducial markers to be captured within the scan. This apparatus is typically placed on contralateral to the surgical site as to not interfere with access during surgery. The image is uploaded to a software system where virtual 3D planning of implants is executed. Once the implant is planned, the robot provides physical guidance of the drill according to the plan. The robot will not restrain the operator if the placement of the drill is correct. However, if the drill deviates from the plan in any way, the robot-assistance will constrain the drill axis, providing resistance to movement in any direction or trajectory deviating from the plan. The operator feels the normal sensation of drilling during treatment. The plan can be modified at any time during the procedure. During the haptic guidance full visualization of and access to the surgical site for instrumentation and irrigation is provided (31). The advantages of this robot guided system include physical and visual guidance in real-time with haptic feedback ensuring the operator is following the virtual plan. The software allows for implants as small as 1 mm in diameter to be planned. This flexibility can allow for endodontic treatment planning as it applies to fiber post removal. The implant can be planned to simulate the size and general shape of fiber posts and superimposed over those posts in the CBCT scan.

Emerging digital protocols in dentistry show the potential for dynamic systems to enhance the benefits of static guidance. Endodontists may experience mental or physical fatigue following long procedures in ergonomically challenging positions, potentially leading to mistakes occurring (32). Robot guidance has the potential to improve efficiency and accuracy in such procedures. The accuracy of robot guidance may decrease the risk of iatrogenic errors, particularly in anatomical areas where critical structures exist such as the inferior alveolar canal and maxillary sinus. Endodontic procedures that could benefit from the streamlined digital planning and execution that robot assistance provides include endodontic microsurgery, calcified canal location, and removal of canal obstructions including resin bonded fiber posts.

To the best of the author's knowledge, there have been no studies investigating the use of robot guidance in endodontics. Therefore, the purpose of this study was to investigate the ability and efficiency of a robot-assisted haptic guidance system to remove bonded fiber posts in endodontically treated teeth in terms of volume of tooth structure removed and time required.

MATERIALS AND METHODS

The study protocol was reviewed by local institutional review board (IRB) at the Medical University of South Carolina (MUSC), Charleston, SC and approved as IRB-exempt category, IRB number Pro00108923. Forty-five extracted human maxillary anterior teeth of similar size and shape were obtained from the oral rehabilitation department at the Medical University of South Carolina. The inclusion criteria included sound teeth with a single straight canal of at least 15 mm in length and a mature apex. Teeth with fractures, inadequate restorations, curved roots, or atypical root morphology were excluded. All teeth were sterilized using steam autoclave and kept in distilled water.

Specimen preparation

The teeth were accessed using a 4 round carbide bur in a high-speed handpiece using water irrigation. After access, a #10 K-file (Dentsply Sirona, Ballaigues, Switzerland) was used to establish patency. Working length was visually established under dental operating microscope (DOM) magnification (Global Surgical Corporation, St. Louis, MO) by viewing the file exit the foramen and subtracting 1 mm. The root canal preparation was completed using ProTaper Gold rotary files (Dentsply Sirona) according to manufacturer's recommendations. The canals were instrumented to a master file size F3 (ISO #30 with 0.09 variable taper). The canals were irrigated with 5.25% sodium hypochlorite (NaOCl) between files. The canals were sonically irrigated with EndoActivator (Dentsply Sirona) and 1 mL 17% EDTA for 1 minute. The canal was then flushed with 3 mL 5.25% NaOCl and final irrigation was completed with 5 mL sterile saline. The canals were dried using paper points (Dentsply Sirona) and obturated with a corresponding F3 gutta-percha point (Dentsply Sirona) and AH Plus sealer (Dentsply Sirona). The obturation was verified radiographically (XDR Radiology, Los Angeles, CA). A post space was created using System B (Kavo Kerr, Brea, CA) placed to approximately 10 mm from the CEJ leaving 4 mm of gutta-percha remaining in the apical portion of the canal. The post space was further prepared using a size #0.5 D.T. Light-Post Universal Drill (Bisco Dental, Schaumburg, Il). Remaining obturation material and debris was removed and cleaned using 70% isopropyl alcohol and the canals examined under DOM (Global). A tapered size #0.5 D.T. Light-Post with an apical diameter of 0.8 mm and coronal diameter of 1.25 mm was placed in the canal and a radiograph was taken to confirm full seating. The post was luted using RelyX Unicem 2 self-adhesive resin cement (3M ESPE, St. Paul, MN), and core buildup placed using Grandio Core Dual Cure nano-hybrid composite resin (Voco Dental, Cruxhaven, Germany) according to manufacturer's recommendations. The teeth were then mounted into anatomic maxillary anterior arch forms using Jet Acrylic (Patterson Dental, St. Paul, MN) and fixed on a typodont base. A preoperative limited field-of-view CBCT volume was acquired using Planmeca ProMax imaging (Planmeca, Helsinki, Finland) high resolution with a 0.075 mm^3 voxel size. The teeth were then divided into 3 groups: the robot guided group (n=16), the experienced freehand group (n=15), and the inexperienced freehand group (n=15). One tooth in each freehand group was damaged during transportation, and thus excluded from the study.

The Robot Guided Group

A preoperative single-arch CBCT volume was acquired using i-CAT Precise imaging (KAVO Dental Excellence, Biberach, Germany) high resolution with a 0.25 mm^3 voxel size. Prior to the scan, an intraoral Edentulous Patient Splint is affixed to dentition posterior to the surgical site. This splint provides a fixed location for the robot guided system kinematic tracking arm to attach and monitor typodont movement. A fiducial array is attached to the intraoral splint and must be captured in the scan for preoperative planning purposes. The Digital Imaging for Communication in Medicine (DICOM) data set was then uploaded and the software used to enter into the planning system. The drilling entry point, angle, depth, and trajectory needed to remove the fiber post were planned (Figure 1). The proprietary software is made for implant placement; the smallest diameter the implant size can be customized is 1 mm. This size corresponds closely to the size of the fiber post placed as well as the size #1 (0.8 mm diameter) Munce Discovery Bur (CJM Engineering, Ojai, CA) which was used using a slow-speed handpiece at 2000 rpm with water irrigation to remove the post (Figure 2). Drilling was stopped when the bur reached the end of the pre-planned path as signaled by the software.

The FH Group

Two operators removed the fiber posts using a freehand technique. The experienced operator was a full-time endodontic faculty member with over 20 years of experience; the inexperienced operator was a second-year endodontic resident. Both operators used reviewed preoperative periapical radiographs (XDR Radiology) and limited FOV CBCT volumes (Planmeca) prior to post removal. Drilling through the fiber post was performed freehand under DOM (Global). Specific instrumentation methods and burs were at the discretion of the provider. A combination of carbide round burs, size #1 Munce Discovery Burs (CJM Engineering), size #0 UniCore Drill (Ultradent Products, Inc, South Jordan, UT) were used. The drilling was stopped when gutta-percha was visualized.

Data Collection and Statistical Analysis

Post-operative limited field-of-view CBCT volumes of all teeth were acquired using Planmeca ProMax imaging (Planmeca, Helsinki, Finland) high resolution with a 0.075 mm^3 voxel size. The DICOM data sets were uploaded to ITK-SNAP to measure the volume created by the drill path. ITK-SNAP is an open-source software application used to segment structures in 3D medical images. Efficiency was determined by the operation time in seconds. The time for each group was recorded from the start of drilling until the end of drilling.

FIGURE 1. Virtual 3D plan of removal of multiple fiber posts.

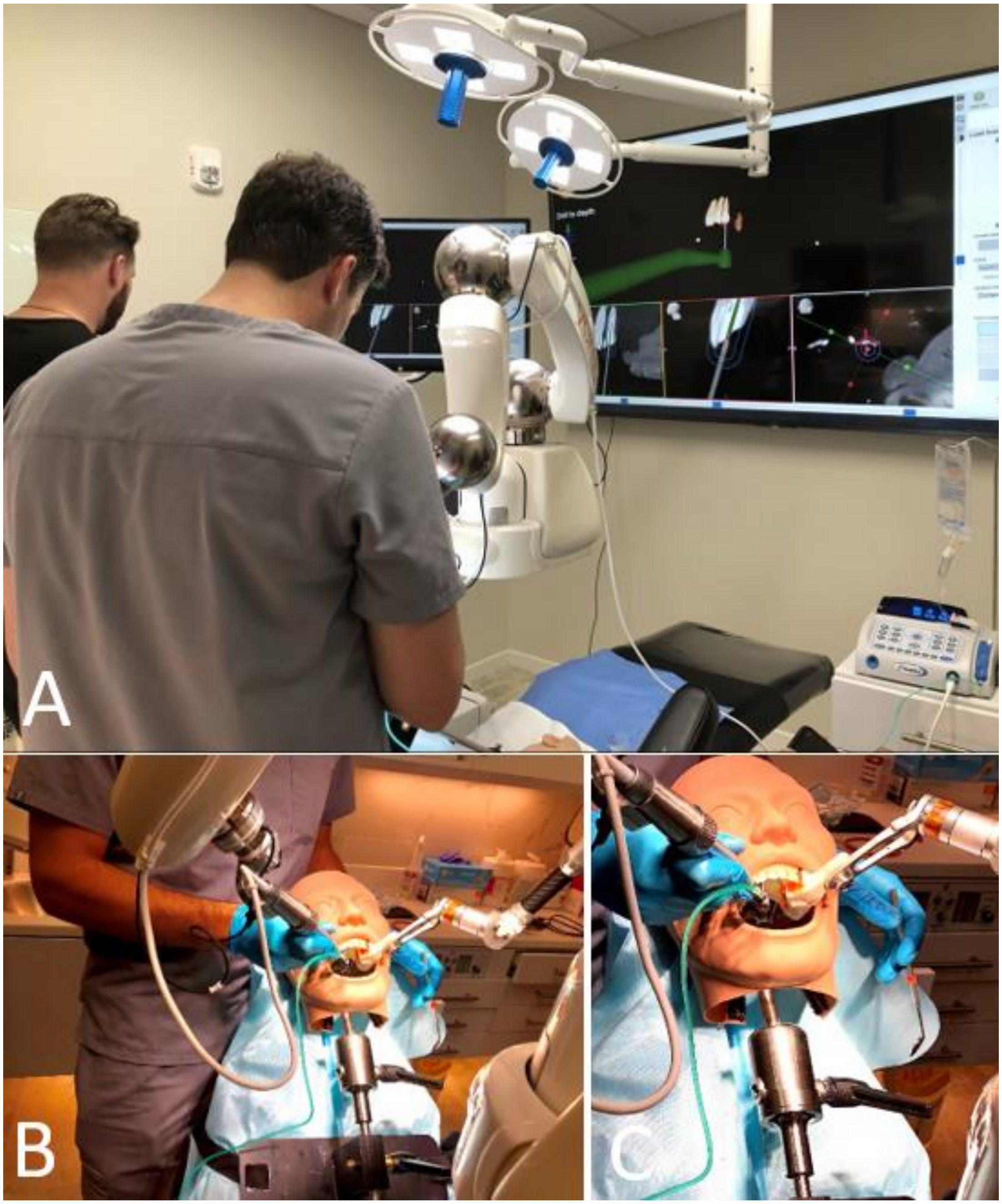

FIGURE 2. (A) Overview of robot guided procedure, note clinician is directly viewing operative field with system display being viewed by assistant. (B) Procedure from in front of patient, note the robot kinematic tracking arm in right side of image. (C) Close up of molded Edentulous Patient Splint with kinematic arm attachment in right side of image and drill in use.

RESULTS

There were 46 teeth prepared for the study. Tables 1 and 2 show the descriptive statistics for the two dependent variables of interest, by operator. Group 1 is the robot guided procedure performed by a second-year endodontics resident, Group 2 is an experienced endodontics faculty member with over 20 years of experience performing the procedure freehand, and Group 3 is a second-year endodontics performing freehand.

The first set of analyses assess whether time and volume differ significantly between the same operator (second-year endodontics resident) using different methods: the robot guided approach versus the freehand approach. Independent samples t-tests were used to test differences. The results for time indicate that the robot guided approach was faster than the freehand approach, with a difference in means of nearly 574 seconds, t = -8.91, p <0.0001. The volume removed was also lower for the robot guided approach than freehand, with a difference in means of 15 mm^3, t = -9.60, p <0.0001. To summarize, for the same operator, the robot guided approach performed better on both outcomes of interest.

TABLE 1. Mean time (seconds) to remove fiber post. Group 1: resident robot guided, Group 2: experienced FH, Group 3: resident FH

Group	N	Mean	Median	Std Dev	Minimum	Maximum	Range
1	16	33.3	28.0	21.5	15.0	97.0	82.0
2	15	446.2	383.0	214.2	220.0	964.0	744.0
3	15	607.2	598.0	248.5	216.0	1081.0	865.0

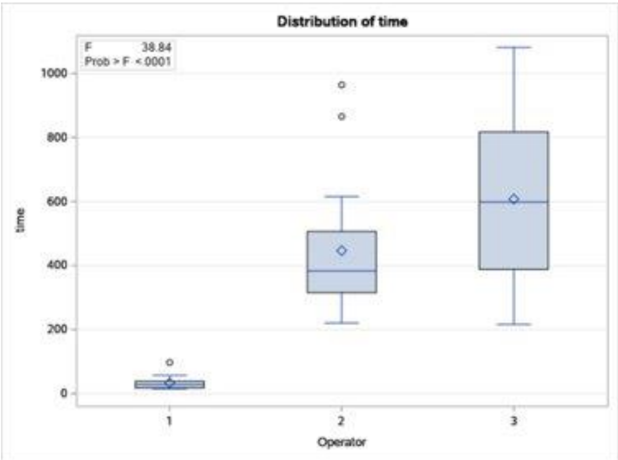

FIGURE 3. Mean time (seconds) to remove fiber post. Group 1: resident robot guided, Group 2: experienced FH, Group 3: resident FH

In the next set of analyses, we introduce an experienced endodontist to perform the freehand approach. We use one-way Analysis of Variance (ANOVA) to assess whether there are any differences in time and volume removed between the robot guided approach performed by a second-year resident, a freehand approach performed by a second-year resident, and a freehand approach performed by the experienced endodontist.

TABLE 2. Volume (mm^3) of tooth structure removed during post removal. Group 1: resident robot guided, Group 2: experienced FH, Group 3: resident FH

Group	N	Mean	Median	Std Dev	Minimum	Maximum	Range
1	16	10.9	10.8	0.9	9.9	12.8	2.9
2	15	15.7	15.6	2.3	12.0	19.7	7.7
3	15	26.0	24.3	6.0	19.5	38.8	19.3

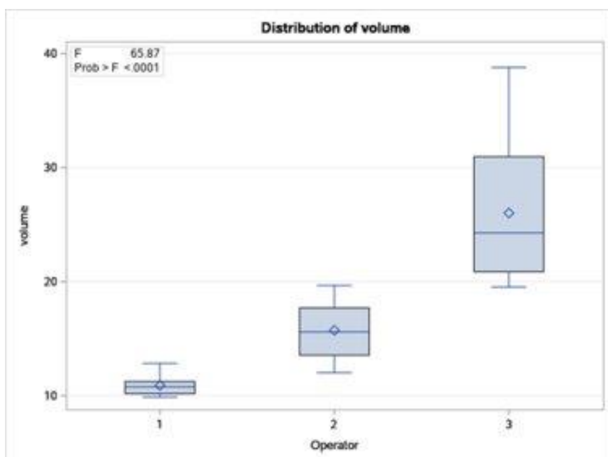

FIGURE 4. Volume (mm^3) of tooth structure removed during post removal. Group 1: resident robot guided, Group 2: experienced FH, Group 3: resident FH

The results of the one-way ANOVA for time indicate that there is a difference in the means between at least two of the operators, F=38.84, $p < 0.0001$. The Tukey post-hoc procedure compares each pair of operators to determine where the differences lie. These results show that there is a significant difference between the robot guided approach and the experienced endodontics faculty, and between the robot guided approach and the second-year endodontics resident (Table 3). In other words, the mean for the robot guided approach was lower than the mean for the experienced endodontist (difference between means = 412.89 seconds), $p = 0.05$. Likewise, the mean for the robot guided approach was lower than the mean for the second-year endodontics resident (difference between the means =573.89 seconds), $p = 0.05$. The mean for the experienced endodontist FH was not significantly lower than the mean for the second-year resident FH (difference between the means =173.7 seconds), $p > 0.05$.

These results for time suggest that the robot guided approach takes less time than a freehand approach, regardless of the experience level of the endodontist performing the procedure.

TABLE 3. Tukey HSD Pairwise Comparisons, time

Group Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
3 - 2	161.00	-5.30	327.30	
3 - 1	573.89	410.21	737.57	***
2 - 1	412.89	249.21	576.57	***

Comparisons significant at the 0.05 level are indicated by ***

Turning to the analysis of the volume of tooth removed, the results of the one-way ANOVA indicate that there was a significant difference in volume removed between at least two of the operators F = 65.87, $p<0.0001$. The Tukey HSD post-hoc test results (Table 4) indicate that there is a significant difference (p = 0.05) between the robot guided procedure and the endodontic resident, and between the experienced endodontist and the resident but not between the robot guided procedure and the experienced endodontic operator.

The difference in volume of tooth removed was 15.1 mm^3 less in the procedure using the robot guided technology than for the procedure performed by the endodontic resident ($p = 0.05$), 10.3 mm^3 less for the experienced endodontist compared to the endodontic resident ($p = 0.05$), and 4.8 mm^3 less for the robot guided approach compared to the experienced endodontist ($p = 0.05$).

TABLE 4. Tukey HSD Pairwise Comparisons, volume

Group Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
3 - 2	10.285	6.981	13.588	***
3 - 1	15.108	11.857	18.360	***
2 - 1	4.824	1.573	8.075	***

Comparisons significant at the 0.05 level are indicated by ***

DISCUSSION

Fiber posts may need to be removed from endodontically treated and restored teeth in cases of treatment failure or fracture. This study investigated a novel approach to fiber post removal. The study shows the robot guidance system can remove a bonded fiber post from a previously endodontically treated tooth. The study also attempts to compare the robot guided system to the commonly used freehand methodology to that of an experienced operator.

To the best of the author's knowledge, no study has investigated the use of a robot guidance system for use in endodontic procedures. Previous studies have shown that dynamic navigation systems are accurate and efficient in removing fiber posts from root canal treated teeth (11). This study included post-operative analysis of global and angular deviation of the procedure. The current study did not include this analysis; therefore, the accuracy of the robot guided system could not be compared. The dynamic navigation system investigated previously investigate shares many treatment planning and operative features with the robot guided system. However, the system differs in that it applies haptic guidance and allows for direct visualization of the operative field during the procedure. These features have the potential to decrease the risk of iatrogenic error, particularly in critical anatomic areas such as cervical radicular dentin, during fiber post removal.

Previous studies have shown that an experienced operator takes significantly less time to remove a fiber post than an inexperienced operator using a freehand technique (16). This study did not find the same statistical significance in time when comparing experienced to inexperienced operators but should note a trend toward agreement. Also, it should be noted that the time measured was only "chairside." There was significant time spent in the preoperative planning stages with the robot guided system. Planning included intraoral placement of the fiducial markers, preoperative CBCT scan and transfer of DICOM file to the software, and implant planning to simulate the post placement for drill path trajectory and depth. The statistically significant difference in time between groups translates to clinical significance. The freehand group times to remove the post may account for over 20% of the total time needed to complete a retreatment procedure. Therefore, a significant reduction of this portion of the procedure would be significant clinically.

It has been stated that robot systems used in dentistry are complex and require expertise for their proper operation and function. There may be a significant difference in treatment outcomes depending on the experience of the provider with the new technology. Meticulous preoperative planning, data input, and implementation is required for positive outcomes (32). Prior to engaging in the study, the resident was proficient at using a different dynamic guidance system which utilized many of the same fundamental skills and participated in a hands-on demonstration with an experienced operator of the robot guided system. Technicians were available for technical planning and instruction throughout the procedure. However, this support was in no way a substitution for adequate training and experience.

Another limitation of the study includes the mechanical limitations of the electric motor and handpiece that were used with the Munce bur to remove the post. An implant motor with a maximum limit of 2000 rpm was used. This is 5-10% of the speed typically used to remove a fiber post and may have limited the cutting efficiency of the bur and increased heat production during the procedure. Also, the diameter of the bur used with the robot guided group was smaller than the diameter of the cervical portion of the fiber post. While the Munce bur was able to penetrate and remove the center of the fiber post, remnants of the post were likely remaining in the middle and cervical areas of the tooth. The technique described with the robot guided group created a space that would best be used as a pilot hole for a post removal bur which would completely remove the fiber post in all portions of the root.

Statistical limitations of this study include the relatively small sample size and the lack of multiple operators. Future studies can build on this work by increasing the sample size and recruiting more operators with varying levels of experience to conduct both the freehand and robot-assisted techniques.

A complication that can arise when removing a post is excess tooth structure removed which could compromise the integrity of the tooth, thus affecting the restorative prognosis. The results not only show the robot guided system to be superior, but also highlight the difference in freehand technique between experienced and inexperienced operators. To provide context, the volume of the post placed in each tooth was approximately 8.5 mm^3. The robot guided system on average removed 18% more volume than absolutely required to take out the post; the experienced operator removed 84% more volume; the inexperienced provider removed 206% more volume than required. Robot guidance, therefore, may minimize the disparity between varying levels of experience.

CONCLUSIONS

A robot-assisted haptic guidance system can remove bonded fiber posts from human single-rooted endodontically treated teeth with straight canals. This system is more time efficient and results in less volume of tooth removed when removing fiber posts compared to freehand techniques. An experienced endodontist removes less tooth structure when removing a fiber post than an endodontic resident.

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APPENDIX

Overall data:

Cast	Tooth I.D. #	Volume (mm^3)	Time (seconds)
TR1	5	14.77	220
	6	13.31	360
	7	19.35	265
	8	14.66	315
TR2	9	16.35	445
	10	14.8	964
	11	19.66	325
	12	15.74	615
TR3	13	12.01	410
	14	16.04	295
	15	13.55	383
TR4	1	13.44	865
	2	18.98	340
	3	12.69	385
	4	15.59	506
Robot1	1	9.96	55
	2	11.3	97
	3	10.96	40
	4	12.3	16
Robot2	5	11.2	34
	6	10.8	37
	7	10.76	21
	8	12.03	28
Robot3	9	10.42	57
	10	9.98	33
	11	10.68	28
	12	11.02	17
Robot4	13	10.34	20
	14	9.88	15
	15	12.83	18
	16	10.03	17
JD1	1	30.96	421
	2	31.76	897
	3	25.18	817
	4	19.52	685
JD2	5	23.52	388
	6	25.92	609
	7	24.27	559

	8	19.69	1081
JD3	9	20.82	925
	10	27.04	720
	11	20.87	598
JD4	12	26.37	507
	13	32.78	216
	14	23.38	387
	15	22.13	298