2016

A Micro-Computed Tomographic Assessment of Dentin Removal Following Ultrasonically Activated Irrigation Comparing Stainless Steel and Nickel-Titanium Tips

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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 Master of Science in Dentistry in the College of Dental Medicine.

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2016

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ACKNOWLEDGEMENTS

I would first like to thank my thesis committee--Drs. Rohde, Assad, Bethea, and Levitan--for their invaluable advice and unwavering support not only during the preparation of this manuscript, but throughout my residency. I have learned so much from them and for that, I will be forever grateful.

Secondly, I would like to thank the MUSC Center for Oral Health Research laboratory manager, Johannes Aartun, for his instruction on use of the micro-CT scanner, data interpretation, and formatting images to create the figures used in this publication. His expert guidance was indispensable.

I would also like to thank Abigail Lauer for her help and support with the statistical analysis, as well as Vista™ Dental Products for donating the EndoUltra™ ultrasonic device, syringes, and irrigation solutions used for this project.

Finally, I would like to thank my biggest cheerleader, my loving husband Farooq.

The authors report no financial affiliations exist for this paper and deny any conflicts of interest related to this study. This project was supported by the L. Core, Center for Oral Health Research, Medical University of South Carolina funded by the National Institute of General Medical Sciences of the National Institutes of Health under award number P30GM103331 and the American Association of Endodontists Foundation (to VB).

ABSTRACT

VICTORIA JANE BALL. A Micro-Computed Tomographic Assessment of Dentin Removal Following Ultrasonically Activated Irrigation Comparing Stainless Steel and Nickel-Titanium Tips (Under the direction of DR. MARC LEVITAN).

<u>Introduction</u>: Ultrasonic irrigation is performed to disinfect and debride the canal space, yet little is known about the influence of ultrasonic tip selection and its impact on the surrounding structural components. The aim of this study was to quantitatively evaluate the amount of dentin removed following ultrasonic irrigation using the EndoUltra™ ultrasonic device. We compared this to a Satelec® Aceton® P5 Newtron® XS LED ultrasonic unit, commonly used in our postgraduate clinic at the Medical University of South Carolina.

<u>Methods:</u> Thirty mandibular premolars were standardized in length and instrumented to a size 35/04 taper. The teeth were then randomly divided into two groups (n = 15). <u>Group A:</u> 20/02 NSK Varios SS U files; <u>Group B:</u> 15/02 EndoUltra™ NiTi tips. Teeth were scanned following instrumentation using a micro-computed tomographic (micro-CT) device at an isotropic resolution of 16 µm. Ultrasonic irrigation was completed for both Groups using 6% sodium hypochlorite (NaOCl), 17% EDTA and 2% CHX, with 0.9% saline rinse following each irrigating solution. After final irrigation, the teeth were scanned a second time. Three-dimensional models were created to determine volumetric changes in dentin from pre- and post-irrigation scan comparisons. Statistical analysis of data was performed with a Wilcoxon signed-rank test, with significance set at $P < .05$.

Results: Removal of dentin was observed within both Groups. A statistically significant difference ($P < .01$) in the amount of dentin removed between Group A (Satelec® using a 20/02 SS U file) and Group B (EndoUltra™ 15/02 NiTi tip) following ultrasonic irrigation was observed.

Conclusions: Both groups exhibited dentin removal following ultrasonic activation. The EndoUltra™ manufacturer's claim that their activator tips do not engage or remove tooth structure was disproved.

Introduction

Importance of Endodontic Irrigation

In order for root canal treatment to be successful, vital and necrotic remnants of pulp tissue, microorganisms, and microbial toxins must be removed from the root canal system (1-4). This may be facilitated through chemomechanical debridement (5-7), however because of the complex nature of root canal anatomy (8-10) complete cleaning and shaping of the root canal system can be a challenge (11-20). Studies by Peters (21) and Paque (22) found that a significant part of the root canal wall is actually left untouched by contemporary instrumentation techniques. These uninstrumented areas may shelter tissue debris, microbes, and their by-products (8-10) which may result in persistent periradicular inflammation (23, 24). In order to clean beyond what is touched by root canal instrumentation alone, irrigation of the entire root canal system with antimicrobial solutions (25) is necessary to kill bacteria, disrupt the formation of biofilms, and dissolve remaining tissue remnants (26).

Syringe Irrigation

Before the advent of passive ultrasonic irrigation (PUI), conventional irrigation with syringes has been advocated as an efficient method of irrigant delivery (27). This technique involves dispensing of an irrigant into a canal through needles or cannulas of variable gauges, either passively or with agitation. The latter is achieved by moving the needle up and down the canal space. Some of these needles are designed to dispense the irrigating solution through their most distal ends, whereas others are designed to deliver an irrigant laterally through closed-ended, side-vented channels (28). The use of side-vented needles was proposed to improve the hydrodynamic activation of an irrigant and reduce the chance of apical extrusion (29).

One disadvantage of conventional hand-held syringe needle irrigation is that the mechanical flushing action is relatively weak, making thorough canal debridement difficult (30-32). Another disadvantage of using conventional syringe needle irrigation is that when used, the irrigating solution is only delivered 1 mm deeper than the tip of the needle (33). This is disturbing because the needle tip is often located in the coronal third of a narrow canal or, at best, the middle third of a wide canal (34). The penetration depth of the irrigating solution and its ability to disinfect dentinal tubules are therefore limited and has been challenged (35-37).

Several studies (38-42) have shown that PUI is more effective than conventional syringe needle irrigation in removing pulpal tissue remnants and dentin debris. This might be due to the much higher velocity and volume of irrigant flow that are created in the canal during ultrasonic irrigation (43). It has been shown that large amounts of dentin debris remain in canal irregularities and oval-shaped canals after syringe irrigation (24, 31, 39, 44). During ultrasonic irrigation, oscillation of the file adjacent to canal irregularities might also have removed more debris from these hard-to-reach locations (43, 45). Several studies (46-52) have shown that when irrigating with a syringe, debridement properties of the solutions were adequate in the coronal two thirds of the canals but were less effective in the apical third (46).

Factors that have been shown to improve the efficacy of syringe needle irrigation include closer proximity of the irrigation needle to the apex (34, 48, 53), larger irrigation volume (54), and smaller-gauge irrigation needles (34). Smaller-gauge needles/cannulas might be chosen to achieve deeper and more efficient irrigant replacement and debridement (27, 34, 53). However, the closer the needle tip is positioned to the apical tissue, the greater is the chance of apical extrusion of the irrigant (33, 34). Slow irrigant delivery in combination with continuous hand movement will minimize NaOCl accidents. With careful use, the benefits of deep intracanal irrigation should outweigh its risks (55). Moreover, irrigant flow rate and the exchange of irrigant should also be considered as factors directly influencing fluid flow beyond the needle or cannula (56). However, it is difficult to standardize and control the fluid flow rate during syringe needle irrigation (56). Thus, it would be advantageous to develop new application systems that increase dentin tubular penetration depths. This ensures more thorough debridement of the prepared canals, while minimizing apical extrusion to eliminate the cytotoxic effects of canal irrigants such as NaOCl on the periapical tissues (57, 58). To achieve these goals, the use of ultrasonic irrigation systems is recommended (59, 60). Several studies have demonstrated enhanced root canal cleanliness as well as improved removal of the smear layer when using ultrasonic irrigation systems compared to conventional needle irrigation techniques (20, 38, 40, 44, 61-65).

Ultrasonic Irrigation

In 1957, Richman was the first to report the use of ultrasonics in endodontic treatment (66). Twenty-one years later, in 1976, Howard Martin et al discovered that the use of ultrasonically activated K-files could cut dentin and found that this application was useful in the preparation of root canals before obturation (67-69). Martin and Cunningham later coined the term “endosonics” which described the use of an ultrasonic and synergistic system of root canal instrumentation and disinfection (70). These ultrasonic devices were driven by magnetostriction or piezoelectricity, resulting in oscillation (25-40 kHz) of the inserted file which initiates acoustic microstreaming in the irrigation fluid (71). Initially, it was thought that ultrasonics allowed root canal preparation along with activated irrigation (70). However, it was shown that this dual use of ultrasonics resulted in unsatisfying preparation quality along with frequent zipping and straightening (72-84), and so it was recommended that acoustic streaming be the main mode of action of ultrasonics (85-90).

Ultrasonic energy works by producing multiple nodes and antinodes along the entire length of a vibrating tip. This mechanism of action serves to decrease the back and forth movement of the tip when a portion of the instrument, even if pre-curved, contacts dentin (91). There are two types of ultrasonic irrigation methods that have been described in the literature: one in which irrigation is combined with simultaneous ultrasonic instrumentation (UI) and another without simultaneous instrumentation, referred to as PUI (90, 92, 93). UI is described as intentionally bringing the file into contact with the root canal wall. This method has been shown to be less effective in removing pulp tissue and smear layer from the root canal wall compared to PUI (90, 93) due to a reduction in acoustic streaming and cavitation (90). Another disadvantage of UI is uncontrolled cutting of the root canal wall without effective cleaning. This is attributed to the fact that root canal anatomy is complex (94) making it unlikely that an instrument will come in contact with the entire root canal wall (95).

During PUI, the root canal system is filled with an irrigating solution and the ultrasonically oscillating file is placed into the canal to activate the solution. This is done after the root canal has been cleaned and shaped so that the ultrasonic file can move freely allowing the solution to penetrate easier into the apical portion of the root canal (92, 96, 97) resulting in more effective disinfection (74, 89, 90, 98-100). The cleaning ability of PUI involves the adequate removal of dentin debris, microorganisms and organic tissue from the root canal system (92). It also allows for active streaming of the irrigating solution to contact a greater surface area of the canal wall resulting in enhanced disinfection (20, 70, 89, 92, 100-102).

Weller et al. first described the term PUI (93). The term “passive” was initially used to describe the “noncutting” action of the ultrasonically activated file. This term, “passive”, however, does not accurately describe the actual process because it is in fact an active process (92). Even though contact between the ultrasonic file and the root canal wall is not currently recommended during ultrasonic activation, unintentional contact may occur due to the complex anatomy of the root canal system (103). This unintentional contact of the file to the root canal wall can dampen the file motion and reduce its cleaning efficacy (87, 90) and may lead to uncontrolled removal of dentin (104) and result in the formation of a ledge or perforation (105, 106, 107).

In 2013, Boutsioukis et al conducted a study to measure the visualization of file-to-wall contact during ultrasonically activated irrigation in simulated canals. In this study, they found that not one of the thirty participants were able to avoid file-to-wall contact during 20 seconds of ultrasonic activation. Wall contact of the file during ultrasonic activation of irrigating solutions occurred in all cases studied (105). The authors concluded that although file-to-wall contact may be unintentional (108), its occurrence renders the term “Passive Ultrasonic Irrigation” incorrect. Passive implies no contact with the canal wall and their study found that file-to-wall contact was unavoidable. Therefore, the author’s proposed that the term “PUI” be substituted with “Ultrasonically Activated Irrigation (UAI)” to more appropriately describe this method of irrigant activation (105).

A Novel Ultrasonic Irrigation Device

Many ultrasonic products are available on the market with their manufacturers advertising that their products do not remove dentin or tooth structure (109, 110). In 2014 Vista™ Dental Products introduced EndoUltra™, the world’s first cordless, compact, battery operated piezo ultrasonic activation device. Oscillating at a frequency of 40 kHz (40,000 cycles/second) and utilizing a 15/02 or 25/04 nickel-titanium (NiTi) tip, the developers of the EndoUltra™ claim that their activator tips resonate down the entire length of the tip and will not engage or remove tooth structure (110).

Purpose of Study

The purpose of this study was to investigate the claim that the EndoUltra™ would not engage or remove tooth structure. This was done by quantitatively evaluating the amount of dentin removed following UAI with the EndoUltra™. We chose to compare the

EndoUltra™ to a Satelec® ultrasonic device, commonly used in our postgraduate clinic. To our knowledge, no prior studies have been reported using a micro-Computed Tomography (micro-CT) device to assess the amount of dentin removed following UAI comparing these two files. The null hypothesis were:

(1) The EndoUltra™, utilizing NiTi activator tips, would not remove tooth structure, as advertised by the manufacturer.

(2) There is no significant difference in the total volume of dentin removed when the EndoUltra™ device is compared to the Satelec® device.

Materials and Methods

Specimen Selection

The study was submitted and accepted (Pro00045023) by the Institutional Review Board (IRB) as well as approved by the ethics committee of the institution. A total of thirty extracted human de-identified permanent single-rooted mandibular premolars with straight root canals were selected for use in this study. The teeth were collected from the Medical University of South Carolina College of Dental Medicine pre-clinical laboratory, cleaned, sterilized and stored in a glass jar with Listerine® (Johnson & Johnson Consumer Inc, New Brunswick, NJ). The teeth were then selected from the glass jar and isolated into individual plastic containers containing sterile saline and assigned a number 1 through 30.

Randomization of Specimens

To control for bias, a 2-sided coin was flipped with the group assigned “heads” = Group A and “tails” = Group B. The specimens were consecutively divided until 15 specimens were assigned to a single group (n = 15), with the remainder completing the other group. To recap:

Group A – Satelec® with 20/02 NSK Varios SS U-file

Group B – EndoUltra™ with 15/02 NiTi tip

Access and Patency

A single operator performed all access cavities the same way on a bench top. Conventional access cavities were prepared using a #4 round carbide bur (Henry Schein, Melville, NY) and refined with an Endo-Z bur (Brasseler, Savannah, GA) using a high-speed hand piece with water. A dental operating microscope (Seiler Precision Microscope, St. Louis, MO) at a magnification of 12.5X was used to assist in locating canals. Patency was confirmed when a #8 stainless steel (SS) K-file (Henry Schein, Melville, NY) was visualized with the microscope exiting the apex.

Specimen Standardization & Working Length Determination

Using the microscope, the canal length was determined by placing a #10 SS K-file (Henry Schein, Melville, NY) into the canal until the tip of the file was flush with the root surface at the apical foramen. Specimens were decoronated to a standard length of 19.0 mm by removing excess crown structure with a 0816 diamond bur (Brasseler, Savannah, GA) perpendicularly to the tooth axis and creating a flat reference point on the crown. The working length (WL) was determined by subtracting 1.0 mm from the standardized length of 19.0 mm, making the WL 18.0 mm.

Canal Instrumentation

A single operator instrumented all specimens the same way on bench top. Files were lubricated prior to insertion with ProLube® root canal conditioner (DENTSPLY Tulsa Dental Tulsa, OK) and passively enlarged using a watch-winding technique and alternating #8, 10, and 15 SS K-files (Henry Schein, Melville, NY) until the working length of 18.0 mm was reached. An Aseptico DTC AEU-25 torque controlled motor and a contra angle rotary hand piece with 8:1 reduction (DENTSPLY Tulsa Dental Specialties) was used for rotary instrumentation. The motor was set at 500 rpm and 300 g-cm torque. Coronal flaring was performed using 25/08 and 40/10 NiTi orifice shapers (Brasseler, Savannah, GA). Teeth were then instrumented in a crown-down manner to a size 35/04 taper using EndoSequence rotary files (DENTSPLY Tulsa Dental, Tulsa, OK). Throughout instrumentation, ProLube® was used as a lubricant and placed on hand and rotary files prior to their entry into the canal. Using a 30-gauge needle, all canals were irrigated with 6% NaOCl (Chlor-XTRA™ Vista Dental Products) to facilitate the removal of organic debris. Apical patency was maintained throughout instrumentation by reintroducing a #10 SS K-file into the canal after the use of each rotary.

When instrumentation was complete, all canals were flushed with 3 mL of sterile saline using a 30-gauge needle to remove any remaining debris. Specimens were returned to their individual compartment trays in preparation for micro-CT scanning (Scan 1).

Pre-Ultrasonically Activated Irrigation (Scan 1)

Following instrumentation, but prior to ultrasonic activation (Scan 1), each specimen was scanned using a micro-CT device (μCT 40; Scanco Medical AG, Brüttisellen, Switzerland) at 16 μm resolution (70 kVp, 114 μA, 8W).

Micro-Computed Tomography Scanning

The specimens were mounted in a 15 mm diameter sized tubes, each holding 3 specimens. The specimens were secured within the tube using packing foam to prevent any movement while being scanned. A small piece of foam was also placed between each specimen to prevent overlapping of the specimens in the Z-plane and to reduce noise. A diagram similar to Figure 1 was recorded in a log book to indicate how the specimens were stacked within the tube to ensure correct sample identification. Specimens were submersed in saline within the tube to prevent dehydration as well as allow for density calibration. The top of the tube was sealed with Parafilm® M (Bemis Company, Inc., Neenah, WI) to prevent evaporation of saline during scanning (Figure 1). A low resolution two-dimensional radiograph, referred to as a scout view, was taken prior to the three-dimensional micro-CT scan to ensure correct placement of the specimens within the tube. The scout view also allowed the ability to individually identify the specimens within the tube by labeling them (Figure 2). If the specimens were positioned correctly on the scout view then the micro-CT scan was performed. To achieve a 16 µm voxel size, samples were placed in a 15 mm diameter tube which held up to 3 specimens at one time. Each specimen took 57 minutes to scan, therefore to scan the entire 15 mm tube with 3 specimens, took 171 minutes. After the specimens were scanned, each sample was carefully placed back into their individual compartment trays containing sterile saline.

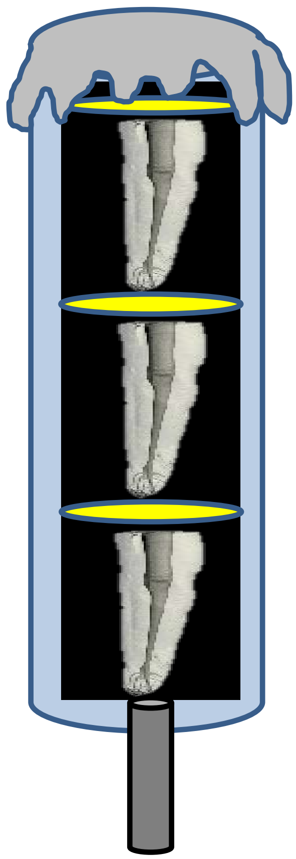

Figure 1. Specimens mounted in tube secured with packing foam (represented by black space around the specimens). A small piece of foam (represented by the yellow oval) was placed between each specimen to prevent overlapping. Saline was placed in the tube and the top was sealed with Parafilm® M (represented by the gray cover on top of the tube) to prevent evaporation of the saline during scanning.

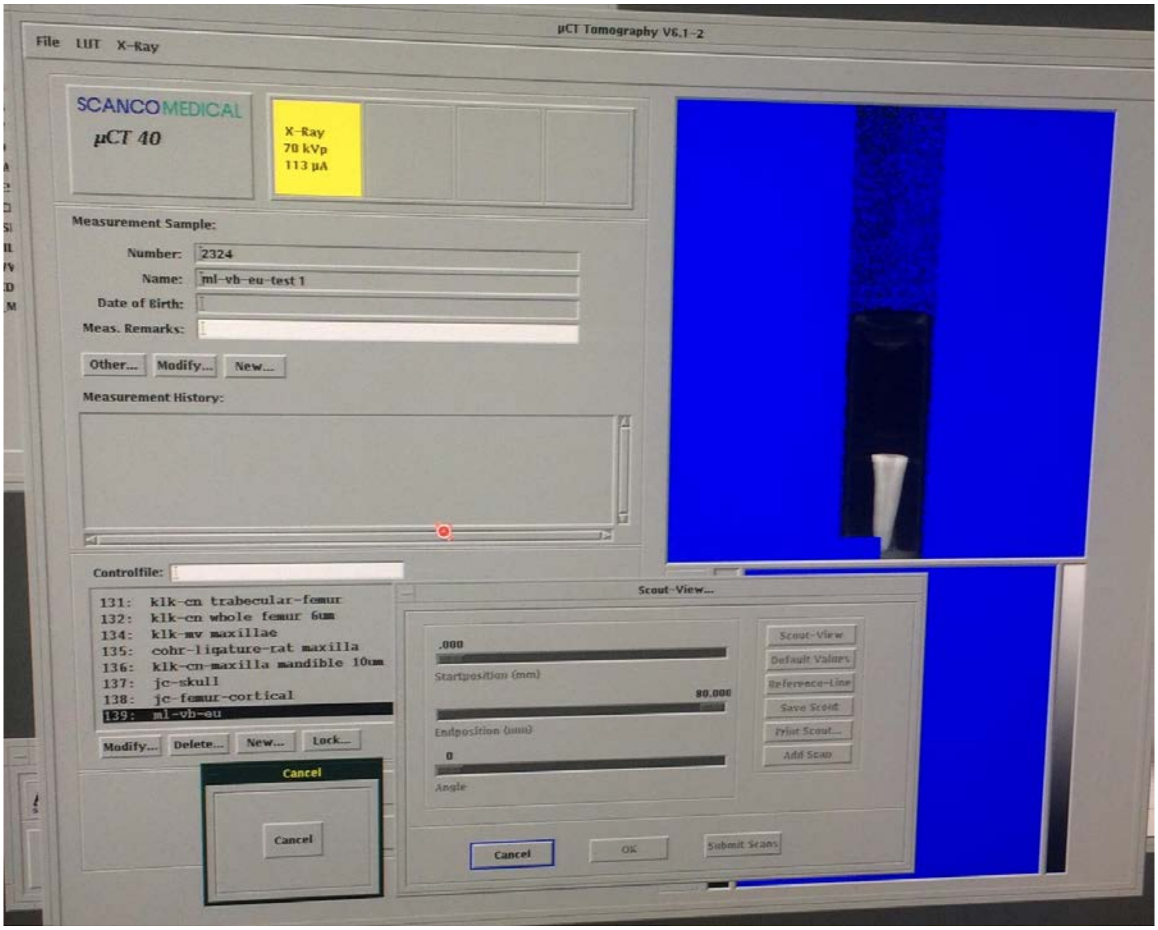

Figure 2. A scout view of the specimens was taken prior to the three-dimensional micro-CT scan to ensure correct placement within the tube.

Figure 3. A 33 mm size 20/02 taper SS NSK Varios U file secured to an NSK Varios E12 95 degree angle holder.

Group A

Following the pre-UAI (Scan 1), all specimens had a final rinse using the following irrigation sequence: 2 mL of 6% NaOCl (Chlor-XTRA™ Vista Dental Products, Racine, WI) delivered 3 times over a 20 s period, 2 mL of 17% EDTA (Vista Dental Products, Racine, WI) delivered 3 times over a 20 s period, 2 mL of 2% CHX (CHX-Plus™ Vista Dental Products, Racine, WI) delivered 1 time over a 20 s period, rinsing with 3 mL of sterile saline between each solution. Ultrasonic activation of irrigating solutions described in the final rinse protocol previously mentioned was performed in Group A using a 33 mm size 20/02 taper SS NSK Varios U file (NSK America Corp, Schaumburg, IL, USA) secured to a NSK Varios E12 95 degree angle holder (NSK America Corp, Schaumburg, IL, USA) (Figure 3) that was then attached to the Satelec® Aceton® P5 Newtron® XS LED ultrasonic unit (Satelec Aceton Group, Merignac, France) and operated at a power setting of 10 in accordance with the manufacturer's recommendations (111). A rubber stop was used to indicate insertion depth of the file and placed 3 mm short of the WL, at a length of 15 mm. The file was held steady, as close to the longitudinal axis of the root canal as possible. A new file was used after every 4 root canals.

Figure 4. A 21 mm size 15/02 taper EndoUltra™ NiTi activator tip.

Group B

The same final rinse protocol described in Group A was performed in Group B, however UAI was performed in Group B using a 21 mm size 15/02 taper NiTi activator tip (Figure 4) attached to the EndoUltra™ ultrasonic device operating at a frequency of 40,000 Hz. A rubber stop was used to indicate insertion depth of the activator tip and placed at the same distance previously described in Group A, at 15 mm. The NiTi activator tips were replaced after every 20 canals in accordance with the manufacturer's recommendations (112).

Post-Ultrasonically Activated Irrigation (Scan 2)

All specimens were scanned again following ultrasonic activation, post-ultrasonically activated irrigation or post-UAI (Scan 2) using the same protocol as described previously.

Micro-Computed Tomography Analysis

All scans were evaluated using the μCT Scanco Evaluation software V6.1-2 (Scanco Medical AG, Brüttisellen, Switzerland). Specifically, the canal space was manually contoured for each individual premolar for both pre- and post- UAI scans. Segmentation values were set equally for all specimens, which allowed accurate delineation of any residual soft tissue from dentin. Canal volumes from preliminary scans were subsequently subtracted from post-UAI scans to determine volumetric changes in dentin (Figure 5).

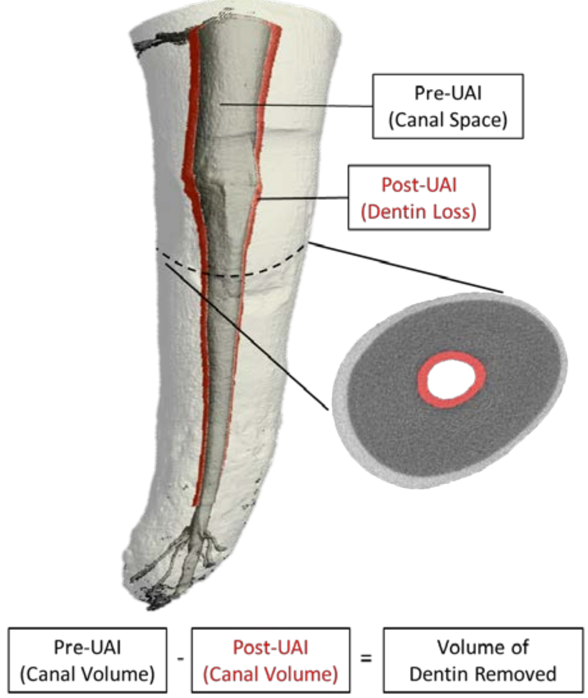

Figure 5. Representation of pre- and post-UAI micro-CT analysis of the canal space. The change (Δ) in canal space volume from post- and pre-scans was representative of dentin removal.

Results

The present study sought to determine the validity of the manufacturer's claim that performing ultrasonic irrigation with the EndoUltra™ NiTi activator tips would not engage or remove tooth structure. Contrary to the manufacturer's claim, post- UAI scans demonstrated lower dentin volumes compared to pre-UAI scans, rejecting the first null hypothesis.

To determine the translational relevance of the EndoUltra™, we chose to compare the amount of dentin removed to the Satelec®. A statistically significant difference ($P < .01$) in the amount of dentin removed, based on volumetric changes in dentin from pre- and post-UAI scans, was observed in Group A (Satelec® with a 20/02 SS U file) compared to Group B (EndoUltra™ 15/02 NiTi tip), rejecting the second null hypothesis.

An overview of the results is depicted in Table 1 and Figures 6 & 7. The results (Table 1) revealed that 68% (0.74/0.44) more dentin was removed in Group A (Satelec® with a 20/02 SS U file) compared with Group B (EndoUltra™ 15/02 NiTi tip).

A nonparametric Wilcoxon signed-rank test with the level of significance set at $P < .05$ (95% CI) was performed rather than a paired Student's *t*-test as a result of non-normally distributed data. A post-hoc power analysis revealed that based on our results in Table 1, we were sufficiently powered (> 99%) with an n =15 per group and a α level of 0.05.

	Pre-UAI	Post-UAI	Δ = Dentin
Group	Canal Volume (mm^3)	Canal Volume (mm^3)	Removed (mm^3)
A (20/02 SS)	29.5 ± 2.1	30.6 ± 2.0	0.74 ± 0.07
B (15/02 NiTi)	34.8 ± 1.5	33.4 ± 1.5	0.44 ± 0.07

Table 1. The change in volume from post- and pre-UAI μCT scans. Data expressed as mean ± SEM.

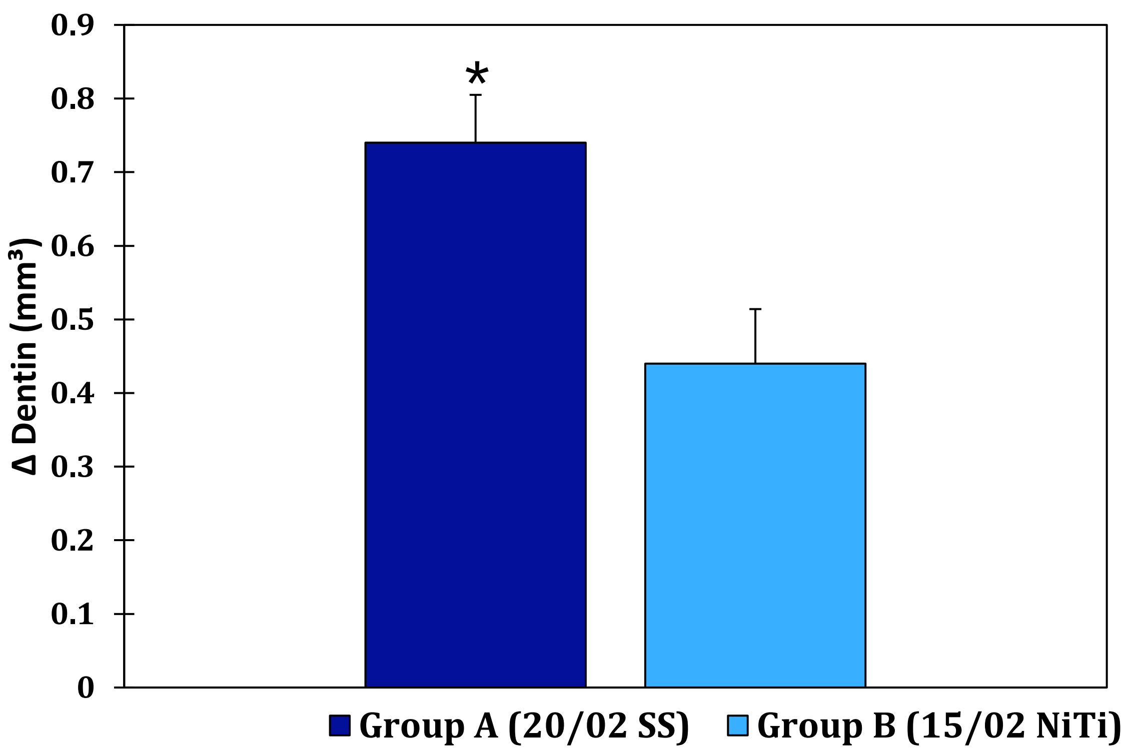

Figure 6. micro-CT scans showed greater change in canal volume in Group A (20/02 SS) compared to Group B (15/02 NiTi), indicating a greater amount of dentin was removed. * denotes $P < .05$

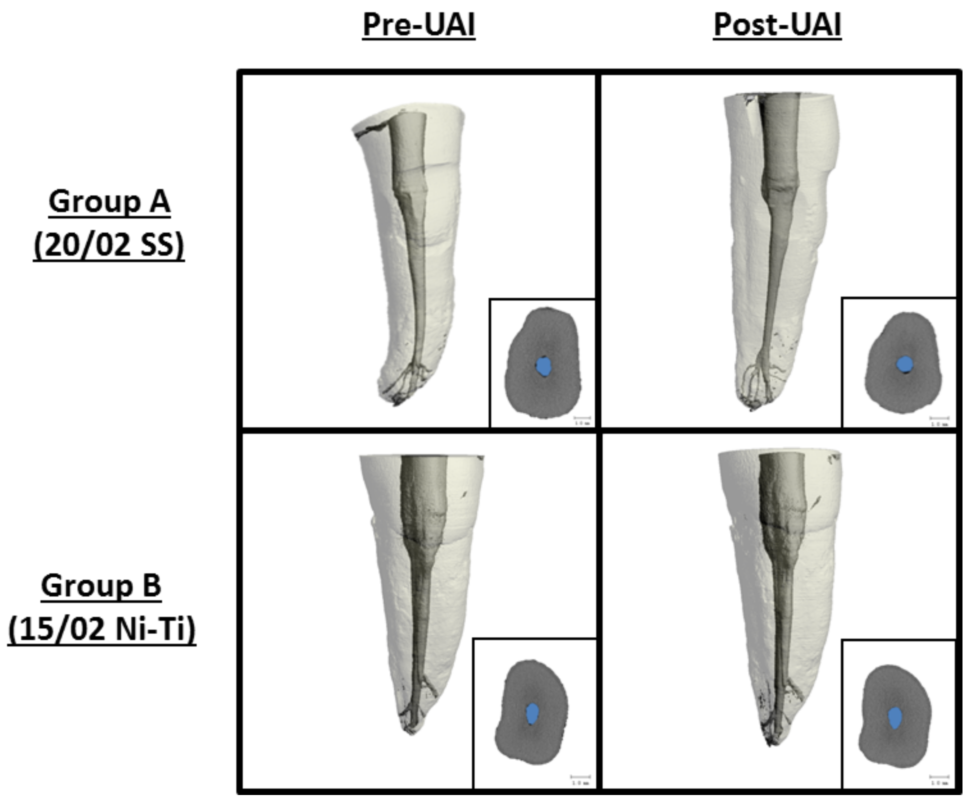

Figure 7. Three-dimensional representations of pre- and post-UAI micro-CT scans showing increased volume of canal space indicating dentin removal.

Discussion & Conclusions

In summary, both types of ultrasonic files used in this study removed dentin after ultrasonic activation. Although minimal, the EndoUltra™ ultrasonic device utilizing the NiTi activator tips did remove tooth structure, contrary to the manufacturer's claim.

Although optimal standardization would entail using ultrasonic files of equivalent tip size and taper for both groups, the EndoUltra™ NiTi activator tips exist in only two sizes, 15/02 and 25/04. The 20/02 SS U file is the standard U file used when performing ultrasonic irrigation at the Medical University of South Carolina Postgraduate Endodontics Clinic and thus was readily available and of interest to the author. Given the size and taper of this SS U file, the EndoUltra™ 15/02 activator tip was the closer comparison of the two choices.

A micro-CT scan of the specimens prior to instrumentation (pre-instrumentation scan) was not performed in this study. The sensitivity of the micro-CT operating at a tube voltage of 70 kVp and tube current of 114 μA has sufficient resolution to distinguish between bone and soft tissue or debris, independent of a pre-instrumentation scan (Figure 8). Therefore we do not believe our measurements were significantly affected.

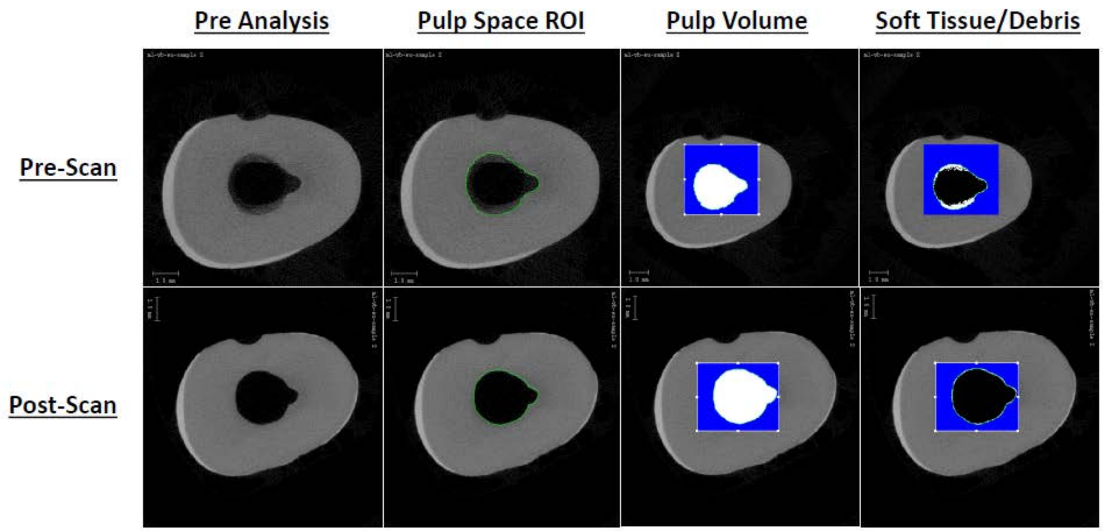

Figure 8. The sensitivity of the micro-CT will allow us to segment out any residual soft tissue or debris left over after instrumentation. Given the sensitivity and well-defined dentin layer, accounting for soft tissue or debris from pre- to post- scans is feasible independent of a pre- instrumentation scan.

We used thirty single, straight-rooted mandibular premolars in this study, assuming that they all have similar initial canal volume. Although there is a chance that one group would have a larger initial average canal volume, the randomization should nullify this potential confounder. However, the authors acknowledge that randomization following instrumentation would more strongly counter any chance for bias, as opposed to randomizing them prior.

One could question if the measured amounts of dentin removed in this study translate to a clinical setting. This study was conducted under optimal visibility and access, which can be considered as a "best-case scenario" (113). Orientation of the files and their depth within the canals were ideal and carefully controlled. However, this is not always possible in a clinical setting. We believe our measurements are the minimum amount of dentin removed using these devices and that there could be more dentin removed in a clinical setting.

The results of this study, as well as the results from a recent study conducted by Boutsioukis et al, both disproved manufacturer's claims and showed that dentin was removed after performing ultrasonic irrigation (113). Therefore, it is noteworthy to mention that ultrasonic activation should not be regarded as a "passive" procedure because in fact, dentin is removed when specimens are evaluated using a micro-CT (113).

The manufacturers of the EndoUltra™ claim that their NiTi activator tips possess "noncutting" edges and a blunt tip designed specifically to prevent damage to dentin when performing ultrasonic irrigation (110). The results of this study showed that although the removal of dentin was slight, the EndoUltra™ 15/02 NiTi activator tip did remove dentin, contrary to the manufacturer's claims (110).

This research could be expanded by measuring the difference in dentin removed using the EndoUltra™ 25/04 NiTi tip compared to its' smaller 15/02 NiTi tip. Another study could measure the difference in dentin removed comparing the EndoUltra™ 25/04 NiTi tip and a 20/02 or 25/02 SS U file. All of these studies could be replicated in both straight and curved root canals.

Another interesting study would be to compare an IrriSafe™ file versus an EndoUltra™ activator tip. Both manufacturers (109, 110) claimed their products did not remove tooth structure or damage root canal walls. Our study showed that the EndoUltra™ in fact does remove dentin and a study by Boutsioukis et al showed that the IrriSafe™ file also removed dentin (113). Future research is needed to determine if the difference in dentin removed by these files is clinically relevant.

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