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Education

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Columbia University College of Dental Surgery, New York, NY

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Publications

Trattner BA, Barak Y, Tordik PA. Mucoepidermoid carcinoma mimicking a lesion of endodontic origin. J Endod. 2018;44:1303-07.

Presentations

Altered Root Morphology Resulting from Anomalous Branching of the Mandibular Canal
AAE Annual Session, Montreal, QC, Canada April 2018

Mucoepidermoid Carcinoma Mimicking a Lesion of Endodontic Origin
AAE Annual Session, Denver, CO April 2019

Honors

Scholarly Achievement and Excellence in Biology Award June 2009

Touro College Dean's List 2006-2009

Professional Experience

Kings Dentistry, Brooklyn, NY 2015-2016
General Dentist

Diagnosed, treatment planned, and provided comprehensive dental treatment, including endodontics, fixed and removable prosthodontics, operative dentistry, simple and surgical extractions, in a professional and caring manner.

Flawless Dental, Brooklyn, NY
General Dentist 2015-2016

Provided comprehensive dental treatment to a largely pediatric population. Treatments consisted of oral hygiene instruction, operative procedures, vital pulp therapy, and extractions.

Leadership Experience/Public Service

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ABSTRACT

Title of Thesis: Efficacy of Different File Systems in Removing Gutta-Percha Cones Coated with Nanoparticles and Bioceramic Root Canal Sealer

Yaakov Barak, Master of Science, 2019

Thesis Directed by: Dr. Frederico Martinho

Introduction: The purpose of this study is to compare the ability of the XP-3D (XP) Shaper (Brasseler USA, Savannah, GA), TRUShape 3D (TS) Conforming Files (Dentsply, Tulsa, OK), and Vortex Blue (VB, Dentsply) files to remove gutta-percha and BC Sealer (BCS, Brasseler USA, Savannah, GA) from root canals, and to compare the time necessary for retreatment.

Materials and Methods: 36 extracted single-rooted mandibular premolars were instrumented, and obturated with gutta-percha and BCS. The teeth were then retreated with either XP, TS, or VB. The teeth were sectioned and analyzed with a digital microscope at 35x and ImageJ software for the percentage of material on the canal walls.

Results: All groups removed obturation material to a similar extent. XP was significantly faster than TS or VB.

Conclusion: There is no significant difference in the ability of XP, TS, or VB in removing obturation material, however, retreatment with XP is significantly faster.

Efficacy of Different File Systems in Removing Gutta-Percha Cones Coated with Nanoparticles and Bioceramic Root Canal Sealer

by:
Yaakov Barak

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INTRODUCTION

A. Background

Non-surgical retreatment is often the treatment of choice after unsuccessful primary root canal therapy (1). Although primary root canal therapy has a relatively high success rate, with a range of 68-86% (2,3), failures occur for different reasons such as inadequate coronal seal (4,5), inadequate cleaning and shaping (6), poor obturation (4, 6, 7), iatrogenic errors such as perforations (8), persistent intraradicular, extraradicular infections, and true cysts (9).

A primary goal of non-surgical retreatment is the removal of all materials from the root canal system in order to allow for better contact of irrigants and/or intracanal dressings with the infected canal walls (10). Studies have shown, however, that current protocols do not usually result in complete removal of material from the root canal system (10, 22-24, 35, 40-42, 45-49, 51-51). Complete removal of material from the root canals constitutes a major challenge due to factors such as the irregular and complex shape of the root canal systems and limitations of traditional nickel-titanium (NiTi) files. These limitations include the tendency of NiTi instruments to machine a round area in canals that are often oval in shape (11), and the propensity of files to accentuate the preparation towards the outer wall of a curved apical canal and to underprepare the inner curve (12).

B. History of Nickel-Titanium Instruments in Endodontics

NiTi was first developed by William Buehler in 1963 for use in the U.S. space program, at the Naval Ordnance Laboratory in Silver Springs, Maryland, USA (13). It was adapted for use in dentistry by Andreasen and Hilleman in 1971, in order to develop a flexible orthodontic wire. This wire was found to have favorable properties, including low modulus of elasticity, shape-memory, and superflexibility (13). Walia et al developed the first endodontic files by machining NiTi arch wire blanks with a diameter of 0.02 inches (14). They demonstrated that these new files had significantly greater elastic flexibility than stainless steel files when analyzed during bending, clockwise torsion, and counterclockwise torsion. An additional finding was that the NiTi files had significantly greater resistance to torsion fracture than their stainless-steel counterparts (14).

At high temperatures NiTi exists in a stable, cubic lattice structure known as the austenite phase (15). When cooled, a martensitic transformation takes place resulting in an increase in ductility of the alloy. This process can be reversed by reheating the alloy to its original temperature. This ability for the alloy to return to its stable, austenitic form is termed "shape memory." This phase transformation can also occur as a result of stress. In contrast to most metals where an excess force results in a permanent deformation, with NiTi, a stress-induced martensitic transformation occurs. The plastic deformation that occurs in NiTi is recoverable as long as it is below a certain threshold (15).

NiTi has become popular in endodontic instrumentation because of its favorable properties including greater flexibility and decreased working time as compared to stainless-steel instruments (16). In recent years, manufacturers have used many different techniques to improve the properties of these file including micromilling, electropolishing, heat treatment (pre- or post-manufacture), and twisting (13). Advances in file design and metallurgy have led to the production of novel file systems that can contract and expand to conform to the natural root canal anatomy. Two examples are the XP-3D (XP) Shaper (Brasseler USA, Savannah, GA) and the TRUShape 3D (TS) Conforming Files (Dentsply, Tulsa, OK).

XP (Fig. 1) is a single-file system with a flexible core that allows the file to adapt to the canal shape. It is an ISO #30 with a taper of 1 degree but its design allows it to adapt to canals ranging from a #30 to #90 and a taper of .02 to .08.

Figure 1: XP-Shaper file

TS are a series of multiplanar S-shaped files that are designed to conform to the irregularities of the root canal system and to better contact the walls during shaping. The S-shape of the file is meant to create an "envelope of motion" which conforms to unconstrained spaces larger than the nominal size of the file, while maintaining the integrity of constrained spaces (17).

Figure 2: TruShape3D files

Vortex Blue (VB) rotary files (Dentsply, Tulsa, OK) undergo a proprietary manufacturing process which gives them their characteristic blue color, representing the titanium oxide layer. This process results in a file with increased flexibility and reduced shape memory (18).

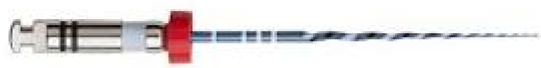


Figure 3: Vortex Blue file

C. Comparison Studies

Because of variations in root canal morphology and the limitations of rotary instruments, current protocols can leave 60-80% of the canal walls untouched during instrumentation with traditional rotary instruments (19). However, when comparing XP to VB in a micro-CT study, the XP groups left significantly less untouched walls (39%) than VB (59%) (20). When XP and TS were compared, there was no significant difference in the amount of unprepared surface area, when analyzed with micro-CT (21).

When XP-shaper was compared to two other single-file rotary systems (Hyflex EDM and WaveOne Gold) for their efficacy in removing root canal filling material during endodontic retreatment, XP-shaper was shown to be more effective than Hyflex EDM but similar to WaveOne Gold (22).

Due to their unique design, TS has been hypothesized to remove more debris than traditional files. In a study by Niemi et al (23), TS removed more filling material than VB only when using a contracted endodontic cavity access design but not when a traditional access design was used. De Siqueira Zuolo et al (24) showed no difference in removal of materials from canals obturated with gutta-percha and BC Sealer (BCS) using either TS or Reciproc files.

A study by Machado et al (25) compared XP, TS, and the Self-Adjusting File (SAF), and showed no significant differences between the groups in the amount of removed filling material during retreatment, as measured by micro-CT. An additional finding was that complete removal of material was achieved in 70% of specimens in the XP group, 55% for SAF, and 30% for TS (25).

D. Properties of EndoSequence BC Sealer

EndoSequence BC Sealer (BCS, Brasseler USA, Savannah, GA) has been introduced as a calcium silicate-based sealer with several desirable properties. These include biocompatibility (26), antibacterial properties (27), hydrophilicity, lack of shrinkage (28), and stimulation of hydroxyapatite formation upon setting (29). They are designed to be used with EndoSequence BC points (Brasseler USA, Savannah, GA) gutta-percha cones (GP) which are impregnated with nanoparticles of BC Sealer. Because of their coating, they are designed to bond to BC Sealer, which in turn bonds to the canal walls, ostensibly creating a “monoblock” (30).

BCS has been shown to be less soluble than AH Plus in commonly used solvents such as chloroform (31). Because of this limitation, the ability for mechanical instruments to contact more of the canal walls becomes increasingly important. As previously mentioned, XP has been shown to contact a larger portion of the canal wall than traditional files (20), and XP and TS appear to be similar in their effectiveness (25). Thus, XP and

TS could presumably be more effective than traditional files (ie. VB) in removing GP and BCS from the root canal system.

E. Specific Aims

1. To compare the ability of the TS, XP, and VB files to remove gutta-percha coated with nanoparticles and BCS from root canals.
2. To compare the time necessary for retreatment using these file systems.
3. To compare the incidence of file separation during instrumentation.

F. Hypotheses

The null hypotheses of this study are:

(1) There is no significant difference in the amount of remaining debris after retreatment with either XP, TS, or VB files in the coronal, middle or apical thirds. Additionally, there is no difference when analyzing the entire root length in total.

(2) There is no significant difference in the retreatment time when using XP, TS, or VB.

(3) There is no difference in the incidence of file separation when retreating using XP, TS, or VB files

The specific research hypotheses of this study are:

(1) Instrumentation with XP or TS files results in canals with less residual debris than with VB files in the coronal, middle and apical thirds. In

addition, when analyzing the entire root length, instrumentation with XP or TS results in canals with less residual debris than with VB.

(2) Retreatment using XP is faster than with TS or VB.

2. Materials and Methods

Extracted single-rooted human mandibular premolars were obtained from an oral surgery practice and stored in .01% thymol. Teeth with multiple canals, pulp canal obliteration, immature apices, previous endodontic treatment, or apical curvatures greater than 20 degrees were excluded. Teeth were radiographed bucco-lingually and mesio-distally to confirm that they met the criteria. A digital caliper was used to measure 16mm from the root apex, at which point the tooth was sectioned horizontally, leaving a standardized length of 16mm for all samples. All treatment was performed by a single operator (YB).

A. Primary Endodontic Treatment

Working length was established at 15mm. After glide-path preparation with #10 and #15 Flexofiles (Dentsply Maillefer, Tulsa, OK), VB files with a 0.04 taper were used at 500 RPM, in a crown-down manner, until working length was achieved as follows: 40.04, 35.04, 30.04, 25.04. All canals were prepared to a master apical size of 40.04. A total of 5 mL 5.25% NaOCl (Clorox, Oakland, CA) was used to irrigate between file sizes as well as after completion of instrumentation.

After drying the canal with paper points, a 40.04 gutta-percha cone (GP) was coated with EndoSequence BC Sealer and placed in the canal to the working length. A System B plugger at 250 degrees Celsius was used to sear off the coronal GP. The teeth were stored in an incubator at 37 degrees Celsius with 100% humidity for one week, to allow for setting of the sealer.

B. Experimental Groups

A random number generator (random.org) was used to randomly assign each specimen to one of three groups of 12 teeth each for retreatment technique: XP Shaper (XP), TruShape 3D (TS), Vortex Blue (VB).

C. Non-Surgical Retreatment

For all groups, a #2 gates-glidden drill (Dentsply Maillefer, Tulsa, OK) was taken 3mm into the canal at 900 RPM. 3 drops of chloroform (Sultan Healthcare, York, PA) were placed in the access and a 25.04 VB file was taken to the WL (15mm). If needed, a #10 C-file (Dentsply Maillefer, Tulsa, OK) was used to reach the WL after which the 25.04 VB file was advanced. Patency was then checked and verified with a #10 C-file.

All teeth were kept in the incubator until immediately before they were to be instrumented. The teeth were held with gauze in a water bath at 37 degrees Celsius during instrumentation. The retreatment time for the following instrumentation sequence was measured using a stop-watch.

For the XP group, an XP Shaper instrument was used for 20 in-and-out strokes at the working length. For the TS group, the canals were instrumented to working length in the following sequence: 20.06V, 25.06V 30.06V, 40.06V, at 300 RPM. For consistency, the VB group was instrumented in the same sequence as TS, as follows: 20.06, 25.06, 30.06, 40.06, at 500 RPM.

In all groups, the canals were irrigated with a total of 5 mL of 5.25% NaOCl between each file change and at the end of treatment. The final rinse consisted of 1 mL of 17% EDTA for one minute, followed by irrigation with 5 mL 5.25% NaOCl. Finally, the canals were dried with paper points.

D. Specimen Preparation and Image Scoring

A longitudinal groove was prepared on the buccal and lingual surface of each root using a 0.4mm width diamond-coated wafering disk (IsoMet, Manassas, VA) in an IsoMet Low Speed Precision Cutter (IsoMet, Manassas, VA). Care was taken to avoid entering the canal space when preparing the grooves. A chisel was then used to separate the two sides of the root. Both sides of the cut samples were photographed with a digital microscope at 35x magnification (Hirox KH-7700, MXG-2500REZ, Tokyo, Japan). Using ImageJ software (National Institutes of Health, Bethesda, MD), a color threshold was utilized to select obturation material on the basis of hue, saturation, and brightness. The amount of residual filling material was represented in pixels. The surface area of the canal wall was also calculated in pixels. The number of pixels representing the filling material from both sides of the root were added together to represent the amount of filling material. This number was divided by the total surface area of the two sides of the root, to calculate the percentage of remaining filling material.

Each root was divided into three parts of 5.3 mm each and scoring was done for each part of the root canal (coronal third, middle third, apical third), as well as for the entire root canal length. Representative images of the canal thirds (coronal, middle, apical) for each experimental group, both prior to and after thresholding, are shown in the appendix.

E. Statistical Analysis:

A sample size of 12 per group was selected based on the results of previous studies (10, 12).

Data was analyzed using one-way analysis of variance (ANOVA) for each canal segment (coronal, middle, apical) and for the total length of the canal to determine differences between the groups and pairwise comparisons were done using a post hoc Tukey's honestly significant difference (HSD) test. Homogeneity of variance was checked because of unequal sample size between groups. Data for retreatment time was also analyzed using ANOVA and pairwise comparisons were done using HSD. Data for incidence of file separation was reported using descriptive statistics. Significance was set at $p \leq .05$.

3. Results

A. Percentage of Remaining Filling Material

Twelve teeth were included in each group for a total of thirty-six teeth. Of these, one specimen from the VB group was lost during sectioning and was excluded from the microscopic analysis. In the XP group, the apical segment of two specimens and the coronal segment of one were excluded due to damage during sectioning. In the TS group, two middle segments were excluded for the same reason. One apical segment from the VB group was also damaged and excluded.

The percentage of remaining filling material on the canal wall for all groups is shown in Table 1. There was no significant difference in the percentage of remaining filling material between the groups at any canal segment (coronal, middle, apical) or for the total canal length. Although there were slight differences in the sample size between groups for some of the analyses, homogeneity of variance was not significant, thus allowing the use of ANOVA for detecting differences. When examining the total area of the root, there was a trend showing less remaining root filling material in the XP group than in the TS or VB groups ($p > .05$, $p = .097$). This trend was also seen in the coronal third ($p > .05$, $p = .119$). In the middle third, the XP and TS groups were similar and trended towards less filling material than VB ($p > .05$, $p = .167$). In the apical third the largest difference in the means was between TS and VB, although this difference was not statistically significant ($p > .05$, $p = .369$). No sample in any group was found to be completely free of root filling material. Overall, the means were highest for all groups in the coronal third, next highest in the middle third, and lowest in the apical third.

Table 1: Mean (SD) Percentage of Residual Filling Material on Canal Wall								
	XP		TS		VB		F Value	p Value
	Mean	n	Mean	n	Mean	n		
Coronal	**36.99** (16.46)	11	**49.82** (11.66)	12	**48.09** (17.92)	11	2.279	.119
Middle	**21.47** (15.44)	12	**24.53** (19.66)	10	**35.48** (18.69)	11	1.903	.167
Apical	**17.37** (13.47)	10	**13.58** (11.94)	12	**23.24** (21.07)	10	1.031	.369
Total	**30.41** (14.39)	12	**39.98** (11.26)	12	**42.12** (14.65)	11	2.507	.097

B. Retreatment Time

The mean instrumentation time for each group is shown in Table 2. The mean instrumentation time for XP was 29.4 seconds, which was significantly lower than TS (91.4 seconds) or VB (82.4 seconds). The post-hoc HSD test revealed no significant difference in the instrumentation time between the TS and VB groups.

Table 2: Mean (SD) of Instrumentation Time by Group (in seconds)			
XP	TS	VB	p Value
29.4^{a} (10)	**91.4**^{b} (14)	**82.4**^{b} (12)	0.005

Different superscript letters indicate statistically significant differences ($p \leq .05$)

C. Patency

Patency, as defined by the ability to advance a #10-C file through the apical foramen, was achieved in all teeth during the primary treatment phase of the study. Additionally, during retreatment, patency was achieved in all teeth except for one in the XP group, for a total percentage of 97%.

D. File Separation

No hand or rotary instruments were fractured during the initial treatment phase of this study. In the retreatment phase, a 10-C file and a 25.04 VB file were fractured while attempting to achieve patency, prior to division into experimental groups. In addition, one file from the XP group was fractured after it was accidentally taken past the apical foramen.

4. Discussion

A. Comparison to Previous Work

The present study found no statistically significant differences in the percentage of remaining filling material at any level of the canal or when analyzing the entire canal length. When examining the entire canal length, we found an overall trend showing less remaining filling material in the XP group than in the TS or VB groups. Our study is in moderate agreement with Azim et al (22) who used cone beam computed tomography (CBCT) with a voxel size of 0.125 mm to evaluate the amount of remaining root canal filling material after retreatment with one of three single-file rotary systems. They found that XP was the most effective file in removing filling material, compared to Hyflex EDM and WaveOne Gold, which is in agreement with our study. The difference between XP and EDM was not statistically significant (p = .092), but XP was significantly better than WaveOne Gold. Our study did not show a significant difference between XP and TS or VB. One possible explanation may be that TS or VB are more effective than WaveOne Gold. If WaveOne Gold was used as one of the experimental groups in this study, we might have shown a significant difference. An additional difference between our studies is the method of measuring the amount of remaining debris. In our study, direct visualization with a digital microscope at 35x magnification was used. In contrast, Azim et al (41) used CBCT with a 0.125mm voxel size. A major limitation of CBCT is its poor resolution. Use of a more sensitive imaging modality such as digital microscopy can detect a greater amount of residual filling material and can result in different findings. Perhaps a more important difference between these two studies is the independent variable that was being measured. Azim et al (41) measured the amount of filling material remaining as a percentage of the original volume of filling material. In the present study, we measured the amount of root canal wall surface area that was covered with filling material, regardless of the volume of filling material that was originally present in the root canal. To illustrate, even if one file was considerably more effective than another in removing filling material from the center of the root canal, this difference would not be detected if the material was not completely removed from the root canal wall.

Our finding that XP and TS were not significantly different in their effectiveness in removing root filling material is consistent with the findings of Machado et al (25). In their study, the amount of removed filling material using XP, TS, or the Self-Adjusting File was measured by comparing pre-operative and post-operative micro-CT scans. No significant difference was found between any of the groups.

We found no statistically significant difference in retreatment efficacy when using TS or VB. This finding agrees with that of Niemi et al (23) who found that after retreatment with TS or VB through a traditional endodontic access, there were no statistically significant differences in the percentage of remaining obturation materials. Similarly, in comparing TS to Reciproc, De Siqueira Zuolo et al (24) found no statistically significant difference in the percentage of remaining filling material.

In our study, patency was achieved in 97% of samples during the retreatment phase. Similarly, Kim et al (32) and Agrafioti et al (33) both found that patency was achieved in every specimen when retreating canals obturated with gutta-percha and BCS. In the study by Agrafioti et al (33), patency was achieved despite the fact that in one group the gutta-percha was intentionally filled 2 mm short of the working length. In contrast, Hess et al (34) found that when using BCS and the gutta-percha was intentionally filled 2 mm short of the working length, patency was only achieved in 30% of the specimens. The differences between the studies may relate to the differences in the tooth type used. Agrafioti et al (33) used single-rooted teeth which are usually wider and straighter, whereas Hess et al (34) used mesiobuccal roots of mesial canals which are more likely to be curved. Oltra et al (31) found that use of chloroform was an important determinant of whether patency could be achieved in teeth obturated using BCS. When chloroform was used patency was achieved in 93% of specimens, however when chloroform was not used, patency was achieved in only 14% of specimens. These findings seem to imply that chloroform is somewhat effective in dissolving BCS.

B. Discussion of the Findings

Although no statistically significant differences in the percentage of remaining root canal filling material were found between the groups in our study, when looking at the means there was a difference of 11% or more between the XP and VB groups at the coronal and middle segments, and for the total canal. This level of difference would appear to be clinically important. The lack of statistical significance can be attributed to the large standard deviation in all groups. There are multiple factors that may have contributed to the wide variability in the scores. For example, when sectioning the teeth, we used an IsoMet Low Speed Precision Cutter to ensure a straight and consistent groove. However, the limitation of this method is the inability to cut directly in the center of curved canals. This resulted in some samples missing a portion or all of the canal space, which could have altered the results of the study.

Additionally, we used ImageJ software to analyze the amount of remaining filling material in proportion to the surface area of the canal wall. Although this is an improvement over methods using a grading scale (35), there are several limitations to our method of analysis which could account for the large standard deviations we found. Firstly, the canal space had to be manually outlined using a freehand selection tool. In a few instances, the exact areas of the canal space were not obvious and had to be approximated. More importantly, when using a color threshold to select root filling material, ranges of hue, brightness, and saturation have to be manually adjusted for each sample, to select the filling material only and exclude the canal wall. However, the ability of the software to differentiate filling material from canal wall is affected by numerous factors including lighting, shadows, hue, brightness, and saturation. Selecting the correct thresholding level is often a delicate balance between selecting all the filling material and minimizing the amount of background selected.

None of the root canals were completely free of filling material after instrumentation. This finding is consistent with the majority of studies on retreatment efficacy, which have shown that no retreatment protocol is completely effective in removing obturating material (10, 22-24, 35, 40-42, 45-49, 51-51).

Instrumentation for all experimental groups was done in a water bath set to 37 degrees Celsius since XP exhibits a phase transformation from martensitic to austenitic at temperatures greater than 35 degrees Celsius (36). Additionally, several studies have shown that the mechanical properties of NiTi rotary files are altered by temperature (37-39).

The mean percentages for remaining filling material were highest for all groups in the coronal third, next highest in the middle third, and lowest in the apical third. This is most likely due to the root morphology of single-rooted mandibular premolars. These teeth tend to have a canal diameter in the coronal third which is larger than the diameter of the rotary files used. Since no brushing motion was used in our study, it could be expected that a significant amount of sealer would remain on the walls. Additionally, when the teeth were divided into thirds (coronal, middle, apical), they were divided evenly into segments of 5.3 mm because it was often difficult to identify the location of the pulp chamber floor. Thus, the results of the coronal third group often included not only the canal but the pulp chamber, resulting in a high amount of residual filling material. Finally, in a clinical situation the presence of residual material in the coronal third is less of a concern than in the middle or apical thirds. This is because the coronal third is readily accessible and visible. If residual sealer is identified other techniques can be used to remove it such as a brushing motion, use of solvents, or use of hand instruments, among others.

When analyzing the amount of remaining root canal filling material after retreatment, several methods have been used, including micro-CT (25, 40-41), CBCT (22, 42), conventional radiography (43-45), root decalcification and clearing (46), scanning electron microscopy (SEM) (47), and stereomicroscopy (48-49). Advantages and limitations of each method are listed in Table 3. In our study, digital microscopy was used to analyze the percentage of residual filling material. The most significant limitation of this method is the need to section the teeth, which may result in loss of filling material from the canal. Additionally, it is difficult to section directly through the center of the canal, which may result in incomplete visualization of some or all of the root canal space. Despite these limitations, this method has significant advantages including the ability to directly visualize the root canal walls, quickly and easily capture images, and manipulate image characteristics directly through the microscope prior to image capture.

Table 3: Advantages and Disadvantages of Different Methods of Analyzing Remaining Root-filling Material		
Method	**Advantages**	**Disadvantages**
Micro-CT	1. High resolution relative to CBCT 2. 3D visualization 3. No destruction of specimen 4. Can compare differences between filling material before and after instrumentation	1. Lack of direct visualization 2. Unable to distinguish between gutta percha, sealer and debris 3. Significant time required for volume acquisition
CBCT	1. No destruction of specimen 2. Can compare differences between filling material before and after instrumentation	1. Low resolution 2. Lack of direct visualization 3. Cannot distinguish between gutta percha, sealer and debris 4. Artifacts (ie. beam hardening, streak artifacts)
Conventional Radiography	1. No destruction of specimen 2. Can compare differences between filling material before and after instrumentation	1. Two-dimensional representation of three-dimensional object 2. Magnification and distortion errors 3. Lack of direct visualization 4. Cannot distinguish between gutta percha, sealer and debris 5. Lacks sensitivity to detect all filling material (45)
Decalcification/ Clearing	1. No destruction of specimen 2. Filling material clearly visible from apex to orifice (54) 3. Can be viewed three-dimensionally	1. Lack of direct visualization
SEM	1. Allows for direct visualization 2. Can distinguish sealer from gutta percha 3. Allows for high magnification and ability to visualize dentinal tubules	1. Requires destruction of specimen 2. Cannot compare differences in material before and after instrumentation 3. More time required to acquire images than stereo- or digital microscopy
Stereomicroscopy	1. Allows for direct visualization 2. Can distinguish sealer from gutta percha 3. Image capture is immediate	1. Requires destruction of specimen 2. Cannot compare differences in material before and after instrumentation
Digital Microscopy	1. Allows for direct visualization 2. Can distinguish sealer from gutta percha 3. Ability to directly capture images to digital picture format 4. Ability to manipulate image characteristics (ie. contrast, brightness, lighting, etc.) 5. Image capture is immediate	1. Requires destruction of specimen 2. Cannot compare differences in material before and after instrumentation

BCS was used in our study due to its recent popularity, however concerns have been raised about the ability to retreat this sealer compared to traditional sealers (50). Although this concern is validated by several studies, others show no difference. When comparing retreatment of teeth obturated using either BCS or Pulp Canal Sealer, De Siqueira Zuolo et al showed a greater amount of remaining filling material in the BCS group (24). Similarly, Uzunoglu et al found more remaining filling material after retreating teeth obturated with GP and BCS than those in which AH-26 sealer was used (51). Oltra et al found that when chloroform was used, more residual root canal filling material was found in teeth obturated with BCS than in those with AH Plus sealer (31). In contrast, Kim et al showed no significant difference in the amount of remaining debris whether AH Plus or BCS were used (32). Ersev et al studied the effectiveness of ProTaper Universal in retreating teeth obturated with a single cone of gutta percha and either Hybrid Root SEAL, EndoSequence BC Sealer or AH Plus. They found that all three sealers were removed to a similar extent (52). When analyzing the number of open dentinal tubules after retreatment using scanning electron microscopy (SEM), Simsek et al found no significant difference between teeth obturated using BCS, MM Seal, or AH Plus (47). Suk et al used rotary instrumentation followed by photon-initiated photoacoustic streaming to remove filling material from teeth obturated with gutta-percha and either BCS, MTA Fillapex, and AH Plus sealers. Micro-CT analysis revealed a greater reduction in filling materials from the MTA Fillapex group but no difference between the BCS and AH Plus sealer group (53). Although there is no consensus regarding the ability to remove BCS as compared to other sealers, many studies do show that BCS is more difficult to remove. Therefore, it would seem beneficial to use rotary files that can potentially contact more of the canal space, such as XP and TS. Thus, we were interested to study how XP and TS would compare with each other and with VB in their ability to remove GP and BCS.

C. Limitations

Limitations of this study include the necessity to section the roots, which could result in disruption and distortion of the canal filling material as well as possible damage to the roots. Additionally, there are inherent inaccuracies when using imaging software to detect residual filling material, as discussed above. Another limitation may be the sample size. Although our post-hoc analysis showed that the sample size was adequate, in light of the large standard deviation values increasing the sample size may result in a statistically significant finding.

D. Direction for Future Studies

Future studies should test the differences between XP, TS, and VB in curved as well as narrower canals. Additionally, the efficacy of these files should be compared using micro-CT analysis in order to validate the results of this study. Studies testing these file systems using traditional sealers, such as AH Plus, would shed light on whether our findings may be a result of the use of BCS.

5. Conclusion

Within the limitations of this *in vitro* study, XP-Shaper, TRUShape 3D, and Vortex Blue rotary files are similar in their effectiveness in removing root filling material from root canals obturated with gutta-percha and EndoSequence BC Sealer. Retreatment with XP-Shaper is significantly faster than with TRUShape 3D or Vortex Blue.

APPENDIX

Representative Images of Coronal, Middle, and Apical Thirds by Group

A. XP Group

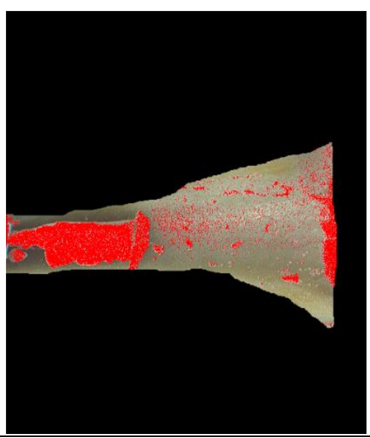
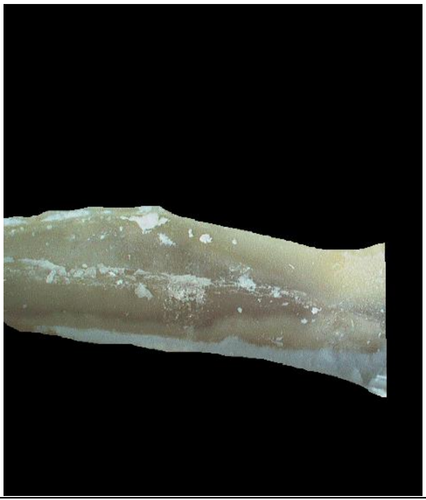
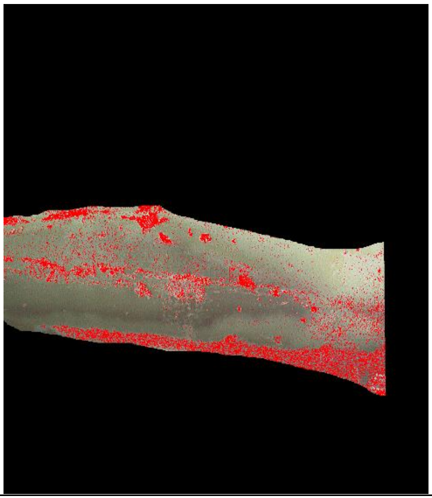
Figure 1: Coronal third section	
Figure 2: Root canal selection	
Figure 3: Root-filling selection	

Figure 4: Middle third section	
Figure 5: Root canal selection	
Figure 6: Root-filling selection	

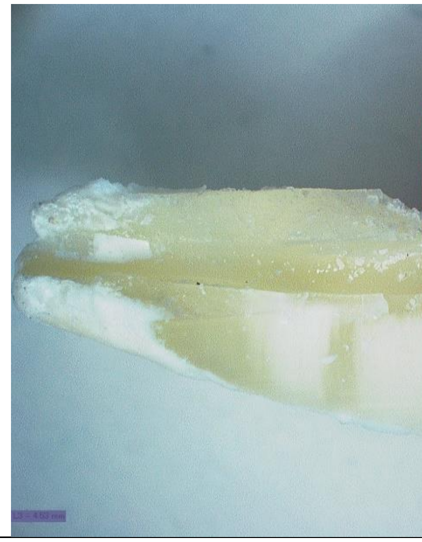


Figure 7: Apical third section

Figure 8: Root canal selection

Figure 9: Root-filling selection

B. TS Group

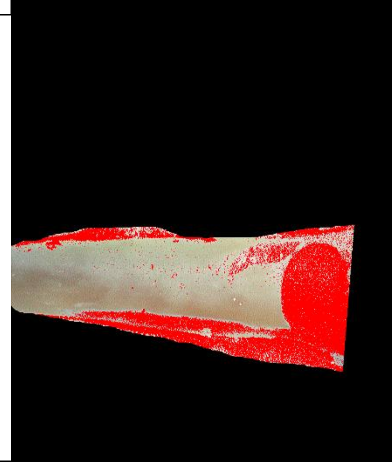
Figure 13: Coronal third section	
Figure 14: Root canal selection	
Figure 15: Root-filling selection	

Figure 16: Middle third section

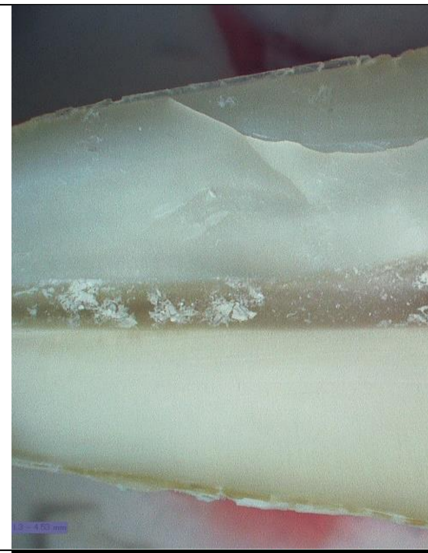


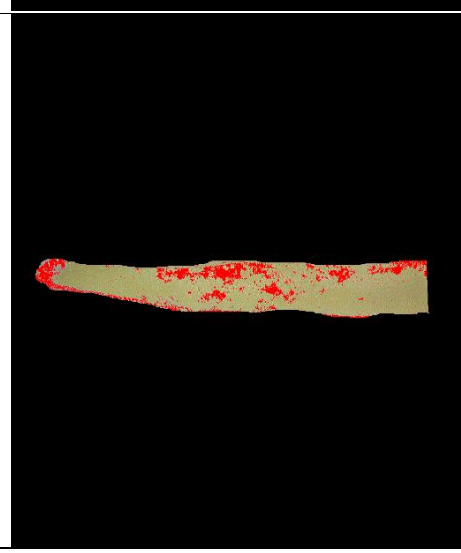
Figure 17: Root canal selection

Figure 18: Root-filling selection

Figure 19: Apical third section

Figure 20: Root canal selection

Figure 21: Root-filling selection



C. VB Group

Figure 22: Coronal third section

Figure 23: Root canal selection

Figure 24: Root-filling selection

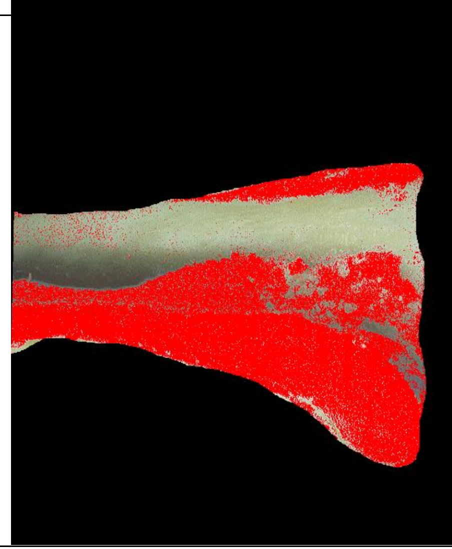
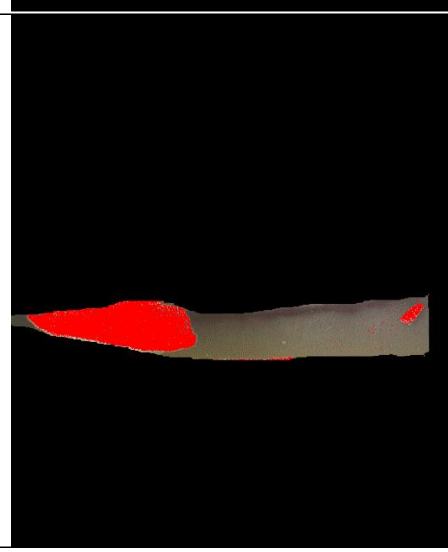


Figure 25: Middle third section	
Figure 26: Root canal selection	
Figure 27. Root-filling selection	

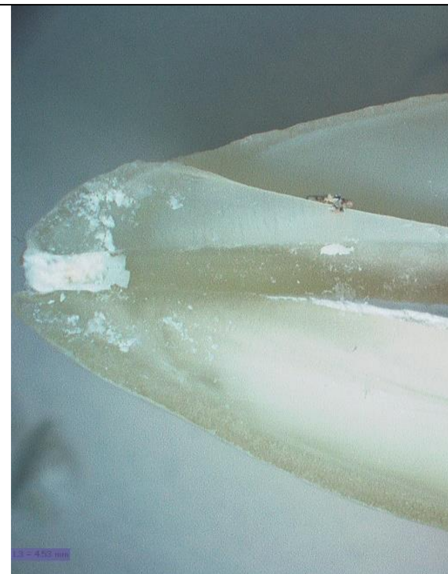


Figure 28: Apical third section

Figure 29: Root canal selection

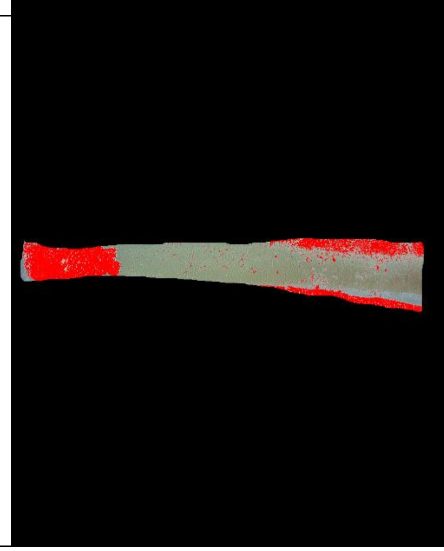


Figure 30: Root-filling selection

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