A Comparative Study of Rotary Instrumentation of the Maxillary First Premolar Buccal Root Utilizing Cone Beam Computed Tomography

Stephan Zigo
Virginia Commonwealth University

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A Comparative Study of Rotary Instrumentation of the Maxillary First Premolar Buccal Root Utilizing Cone Beam Computed Tomography

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry at Virginia Commonwealth University.

by

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Abstract

A COMPARATIVE STUDY OF ROTARY INSTRUMENTATION OF THE MAXILLARY FIRST PREMOLAR BUCCAL ROOT UTILIZING CONE BEAM COMPUTED TOMOGRAPHY

By Stephan J. Zigo III, DDS

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry at Virginia Commonwealth University.

Virginia Commonwealth University, 2011.

Director: Karan J. Replogle, DDS, MS
Department Chair, Department of Endodontics

The study objective was to determine cementum-dentin wall thickness along the furcation groove in maxillary bifurcated first premolars after preparation with three successively larger, 0.04 tapered, nickel titanium rotary files. Pre-instrumentation and post-instrumentation imaging was accomplished utilizing Cone Beam Computed Tomography. All data was analyzed using an ANOVA.

Instrumentation resulted in a significant reduction in dentin-cementum wall thickness (p < .001). At mid-groove, predicted dentin-cementum wall thickness (95% CI) was equal to or less than the proposed standard (0.50 mm) for apical file sizes 30, 35, and 40 respectively. Instrumentation of the mid-groove in maxillary first premolars reduces dentin-cementum wall thickness to levels that may be insufficient to ensure tooth integrity.
Introduction

The primary purpose of non-surgical root canal therapy is to remove infected and necrotic pulpal remnants, eliminate microorganisms, and shape the root canal system in order to facilitate chemical debridement and placement of obturation materials. The goal of the clinician when performing endodontic therapy should be to preserve tooth and root structure, avoid inflicting iatrogenic damage, provide a complete chemo-mechanical debridement of the root canal system, and create a fluid tight seal with a biocompatible obturation material.

The structural integrity of the root canal system is impacted by the size and taper of the instruments used to shape the canal. Remaining residual dentin thickness (RDT) is considered a critical factor following canal preparation for both prosthetic restoration and long term prognosis of a tooth. A compromise in the remaining RDT may predispose the tooth to lateral or strip perforations (1-6) or root fracture. Caputo and Standlee have suggested that at least 1.0 mm of circumferential sound tooth structure is required to resist possible root fracture when a prosthetic post is required to restore a tooth (7).

Lim and Stock (6) attempted to establish a minimal RDT required for sustainment of root integrity during lateral condensation. They speculatively set 0.3 mm as the minimal remaining RDT at which condensation forces may exceed the resistance of the dentin and thus lead to perforation or fracture. Their study did not account for the
cementum layer present on roots and assumed the proposed 0.3 mm minimum was dentin alone.

McCann et al suggested that RDT is composed histologically of both the remaining dentin and intact cementum layers and should be referred to as dentin-cementum wall (DCW) thickness (8). They speculatively set 0.5 mm as the minimum DCW thickness required to prevent strip perforation or weakening of the mesial root in mandibular first molars following instrumentation.

The cementum layer is considered a part of the periodontal apparatus, but has been shown to provide structural support to the root in conjunction with dentin. Therefore, the cementum layer warrants inclusion as a part of the remaining root structure following instrumentation. For this reason, the purposed 0.5 mm DCW thickness minimum was chosen as the standard to which all instrumentation was compared in this study.

Numerous studies have evaluated the efficacy of various instruments for root canal preparation in simulated canals with simple and complex anatomy (9-13). The K3 (SybronEndo; Orange, CA) nickel titanium (NiTi) rotary file possess a slightly positive rake angle, wide radial lands, and a non-cutting tip which enables the file to plane the walls of the canal. Previous studies affirm K3 files remain relatively centered in the canal during instrumentation and subsequently reduced transportation and excessive dentin removal (14). Multiple studies have reported a superior shaping ability of NiTi rotary files which subsequently increased apical penetration of canal irrigants (13, 15-17).

It has been demonstrated that frequent and copious irrigation with sodium hypochlorite not only flushes debris from the canal lumen but also dissolves organic
tissue in areas instrumentation cannot reach (18-21). Likewise, the final apical size of the canal preparation has been shown to be instrumental in allowing irrigants to penetrate. Ram demonstrated that passive irrigation progresses apically only one millimeter from the needle tip (22). A number of studies have shown a decrease in bacterial count, increased efficacy of intracanal irrigants, and an inhibition of bacterial growth in canals instrumented with files greater than size #30 (12). Another study has recommended enlarging the apical third of canals to sizes greater than a #40 file to increase removal of debris and achieve better cleaning and shaping in the apical third of the root canal (11). Khademi et al found that the minimum apical size to allow irrigant penetration into the apical third of the canal was a size #30 file preparation (23).

Traditional endodontic research has focused more on the internal anatomy of teeth rather than their respective external anatomy. Many of these studies have examined the number of canals present, various shapes, canal diameter, direction or curvature, and location (23-26). The prevalence of bifurcated maxillary first premolars (MFPs) and the number of canals present has been well documented. Bifurcation of the roots has been reported to occur in 61% of all MFPs (26). Likewise, the prevalence of two canals has been reported to range from 89% to 91% (24, 26).

Past periodontal literature has acknowledged a direct relationship between external concavities and periodontal attachment loss in various teeth (27-29). Anatomic external variations exist in bifurcated MFPs.

Endodontic preparation of MFPs can present serious complications in the form of procedural accidents if the clinician is unaware of variable and complex anatomy these teeth may possess. Bifurcated MFPs often present with unique anatomical features which
require consideration when endodontically instrumenting or preparing a prosthetic post space. Few endodontic studies recognize a clinically significant anatomical groove in the buccal root. The groove was previously reported as a developmental depression (27), a buccal furcation groove (28), or a furcal cavity (29). Within the context of this study, the anatomical landmark will be referred to as a furcation groove.

The furcation groove is located on the lingual side of the buccal root and begins just apical to the level of the furcation before disappearing near the apex. The prevalence of the furcation groove in bifurcated MFPs has been reported to range from 62% to 100% (3, 27-29, 30-32). The deepest invagination of the groove begins at a mean distance of 1.18 mm from the furcation and extends to approximately 1.0 mm before the groove terminates (31). The mean distance from the furcation groove invagination to the inner canal wall has been reported to range from 0.81 mm to 1.14 mm (30, 31). The furcation groove travels a mean distance of 5.38 mm (32). Figure 1 provides an example of the furcation groove viewed under magnification with an operating microscope (PICO; Zeiss, Oberkochen, Germany) and stained with methylene blue dye (Vista-Blue; Vista Dental Products, Racine, WI).

The presence of a furcation groove may predispose MFPs to vertical root fractures (VRFs) or strip perforations during endodontic treatment or post space preparation. Fuss et al reported that root canal treatment and post placement are the major etiological factors of VRFs (1). This can be attributed to excessive removal of dentin and condensation force applied during obturation (32). Additionally, 56% of vertical root fractures (VRFs) have been reported to involve maxillary premolars (1-3, 5).
Special care and consideration should be given by the clinician when providing endodontic treatment to the buccal root of MFPs. Flaring of the canal walls with rotary instruments and post space preparation should remain as conservative as therapeutically possible in the buccal root. To date, no studies have measured DCW thickness along the furcation groove following NiTi rotary instrumentation.

Figure 1: A Bifurcated MFP Furcation Groove Stained with Methylene Blue Dye.

Periapical radiographs are considered standard of care in endodontic treatment (34). Two-dimensional (2D) radiographs are of significant value to the clinician but are limited in use when determining location of various anatomical features.

Bramante et al (35) described a method for comparing root canal anatomy before and after instrumentation utilizing a muffle. Teeth were embedded in a colorless acrylic resin block and transverse grooves were placed at levels in which the tooth would be sectioned for examination. The resin block was covered in a plaster muffle and sectioning of the aforementioned grooves was accomplished with a carburundum disc. The muffle functioned as a matrix to reposition each section in order to facilitate
instrumentation. This methodology was the standard in which all early comparative instrumentation studies were performed.

Three-dimensional (3D) radiographic images could potentially be of benefit when treatment planning or providing endodontic treatment. 3D image representation of changes in DCW thickness before and after instrumentation has been previously studied (38). The use of Cone Beam Computed Tomography (CBCT) continues to gain momentum in both non-surgical and surgical endodontic treatment planning (36-38). The CBCT provides a noninvasive evaluation method for both the external and internal morphology of a tooth (36-38). A characteristic of CBCT is its ability to measure both initial and post-instrumentation DCW thickness. This unique feature is important because it provides a reliable control (initial DCW thickness) against which each successively instrumented canal can be compared and analyzed.

Subsequent scans can be produced following canal preparations which provide an excellent way to examine the root canal in a nondestructive manner (37). The use of the CBCT appears superior to 2D radiographs because it affords a virtual in situ image. Likewise, physical cross-sectioning of the root is avoided which can invariably result in a loss of 0.4 mm or greater in each horizontal cut (8, 35). Subsequently, the loss of tooth structure may affect the accuracy of post-instrumentation data.

For the purpose of this study, a NewTom VG CBCT (QR SRL, an AFP Imaging Co., Elmsford, NY USA) was utilized at Virginia Commonwealth University School of Dentistry. Liedke et al found no statistical difference in diagnostic image quality when using either a 0.2 mm or 0.3 mm voxel size during CBCT imaging (39). The current NTT (New Tom Tomograph) imaging software offers two available voxel sizes (0.25
mm and 0.3 mm). In the current study, a 0.25 mm voxel size was chosen because it provided the best image quality during the pilot study.

Differentiation between the cementum and dentin layers is nearly impossible with both two-dimensional 2D and 3D radiography. Likewise, the NTT imaging software used in this study did not provide sufficient resolution to differentiate between the two layers. Inclusion of the cementum layer as part of the proposed DCW thickness (0.5 mm) appears clinically relevant when considering the aforementioned fact.

The purpose of this study was to determine DCW thickness on the lingual aspect of the buccal root in bifurcated MFPs after preparation with three successively larger, 0.04 tapered, NiTi rotary files utilizing CBCT and to relate the amount of remaining DCW thickness to the proposed 0.5 mm minimum standard.
Materials and Methods

Thirteen extracted human bifurcated MFPs were collected from various dental clinics and stored in 10% neutral buffered formalin. All teeth collected would have been disposed of accordingly, but were kept for the purpose of this study. Any remaining periodontal or gingival tissue remnants were removed by scaling the root surface. One tooth was consumed for a pilot study and was excluded. Two teeth were excluded because of the presence of more than one canal in the buccal root. The remaining ten teeth were examined for the presence of the buccal furcation groove utilizing an operating microscope.

The buccal cusp tip of each tooth was flattened to provide a stable reference point for working length (WL) determination. The initial WL of each tooth’s buccal root was pre-measured externally and recorded.

Each tooth was endodontically accessed with a #2 round bur (Henry Schein, Melville, NY) and an Endo Z bur (Dentsply, Tulsa Dental; Tulsa, OK) to ensure ideal straight line access. The principle canal orifices were identified with an operating microscope and an endodontic explorer (DG-16; Hu-Friedy, Chicago, IL). No instrumentation of the buccal canal was completed at this point.

Each tooth was mounted using a polyvinyl siloxane impression material (Genie:Sultan,Englewood,NJ) on a custom made polymethylmethacrylate resin mounting
jig with the access opening facing down. The 3.5 inch height of the mounting jig corresponded to the exposure field of the NewTom VG 9000 CBCT machine. This method of mounting allowed for precise repositioning with each subsequent CBCT scan. The exposure volume was set at 16.0 cm in diameter and 14.0 cm in height. The scan was set at 110 kV and 1-20 mA (pulsed mode), as recommended by the manufacturer.

Slice width was preset at a 0.25 mm slice thickness, which represents the smallest measureable width possible within the NTT imaging software. A preoperative series of tomographic images (voxel size was 0.25 X 0.25 X 0.25 mm interval) were obtained for each specimen. A desktop computer (Dell Inc., Round Rock, and TX USA) equipped with calibrated NTT software was used to measure both the pre-instrumentation and post-instrumentation images. The beginning and the end point of the scanning (on the z axis) were recorded to allow repeated scanning of the specimen at the same horizontal levels.

DCW thickness was measured within the axial plane at three specified locations (slice levels) along the furcation groove for each respective tooth. Figure 2 illustrates an example of each point or slice level measured along the furcation groove in a sagittal plane. The first slice (Point A) was measured at 0.5 mm apical to the coronal initiation point of the furcation groove. The third slice (Point C) was measured at 0.5 mm coronal to the termination of the furcation groove. The second slice (Point B) was measured at the median slice number between the first and third slice numbers respectively.

Upon completion of the pre-operative scan, the buccal canal of each tooth was explored for patency using a size 8 K-file (Dentsply Maillefer; Ballaigues, Switzerland). A pre-operative WL was verified with a periapical radiograph (Dexis; Henry Schein, Melville, NY) utilizing a size 15 K-file. The corrected WL was determined as the
radiographic WL minus 0.5 mm. The apical terminus of each tooth was examined with an operating microscope to ensure the integrity of the minor constriction and to adjust any file that appeared overextended. Canal irrigation was achieved with 5.25% sodium hypochlorite (NaOCL 5.25%) during instrumentation and delivered into the canal by a 10cc 30-gauge needle (Monoject; Sherwood Medical, St. Louis, MO).

![Figure 2: An Artist’s Sketch of a MFP Buccal Root in a Sagittal Plane Orientation.](image)

Instrumentation was initiated with a Gates Glidden #3 drill (Henry Schein, Melville, NY) into the most coronal 1.0 mm of the canal to remove any cervical dentin constriction. A glide path was established to WL with a size 20 K-file before instrumentation was initiated with K3 NiTi rotary files. A patency file (#10 K-file) was
used along with a copious irrigation (2 mL) regiment of 5.25% NaOCL after each successive hand and rotary file used.

Each tooth was instrumented to WL utilizing a crown down preparation technique. Individual NiTi rotary files were limited to five uses or until plastic deformation was noticed under an operating microscope.

All teeth were initially instrumented to an apical size 0.04/#30 and repositioned into their respective holder for imaging. A series of CBCT images were obtained at the same resolution and horizontal intervals as the pre-instrumentation images. Both pre-instrumentation and post-instrumentation images were retrieved for comparison.

The aforementioned process permitted repeatable measurements between each imaging series. The exact process of instrumentation, repositioning, and imaging were completed for both apical size 0.04/#35 and 0.04/#40.

DCW thickness was measured between the deepest aspect of the furcation groove (i.e. concave aspect of the “C” in cross section, respectively) and the corresponding outer lingual wall of the canal. Figure 3 further depicts the method in which measurement of the DCW was completed utilizing the NTT software. In Figure 3, two horizontal lines are drawn parallel to each other and separated by a perpendicular line. The first horizontal line is drawn on tangent with the deepest invagination point of the furcation groove. The second horizontal line is drawn on a tangent with the innermost lingual portion of the canal wall. The perpendicular line connects both horizontal lines and represents the DCW present. All measurements were recorded in the axial plane in order to provide a repeatable horizontal measurement at the specified slice level. This
measurement technique is consistent with other morphometric studies in which DCW width measures were obtained (8).

DCW thickness was modeled using a repeated-measures mixed-model analysis of variance. The four levels of instrumentation (pre-instrumentation, 0.04/#30, 0.04/#35, and 0.04/#40), the three tomographic slices, and the NTT slice measurement were used in the ANOVA model. All analyses were performed using SAS PROC MIXED software (version 9.2, SAS Institute, Inc., Cary, NC). The 95% confidence interval on the mean residual DCW thickness was compared to the proposed 0.5 mm minimum.

![Figure 3: Illustration of Calibrated Measurement Technique in an Axial Plane View.](image)
Results

The measured NTT slice location for each of the ten teeth is shown in Table 1. The repeated-measures mixed-model ANOVA indicated that the NTT slice location was not significant after all factors had been accounted for (p = 0.12). The interaction test for slice number and instrumentation indicated that the effect of instrumentation was different depending upon the slice number (p = 0.0032).

An NTT slice number represents a 0.25 mm thick axial (horizontal) slice along the furcation groove in each respective tooth. At Point A, all NTT slice numbers were measured at 0.5 mm apical to the origin of the furcation groove. At Point C, all NTT slice numbers were measured at 0.5 mm coronal to the termination of the furcation groove. The difference between the mean NTT slice number at Point A and the mean NTT slice number at Point C was 13.4. The mean groove length was determined by multiplying the difference in Point A and Point C slice numbers (13.4) by the axial slice thickness (0.25 mm) and adding the sum (1.0 mm) of the origination and termination points. The mean groove length in the current study was 4.35 mm.

The predicted DCW thickness at all three points before and after instrumentation is shown in Table 2. At Point A, the mean pre-width DCW thickness is 0.73 mm. The corresponding 95% Confidence Interval (CI) indicates a 95% confidence that the DCW pre-width thickness will range between 0.64 mm and 0.83 mm respectively. Instrumentation with a 0.04/#30 rotary file reduces the pre-width DCW thickness by a
mean of 0.12 mm. Subsequently, this changed the corresponding 95% CI range. It is now, post-instrumentation, predicted to range between 0.52 mm and 0.71 mm.

Instrumentation with a 0.04/#35 rotary file reduces DCW thickness by a mean of 0.20 mm. Subsequently this changed the 95% CI range. It is now, post-instrumentation, predicted to range between 0.44 mm and 0.63 mm. Instrumentation with a 0.04/#40 rotary file reduces DCW thickness by a mean of 0.29 mm. Subsequently this changed the 95% CI range. It is now, post-instrumentation, predicted to range between 0.35 mm and 0.54 mm.

Table 1: NTT Slice Number of Each Respective Point

<table>
<thead>
<tr>
<th>Tooth #</th>
<th>Specified Location (NTT Slice #)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Point A</td>
</tr>
<tr>
<td>1</td>
<td>101</td>
</tr>
<tr>
<td>2</td>
<td>92</td>
</tr>
<tr>
<td>3</td>
<td>76</td>
</tr>
<tr>
<td>4</td>
<td>87</td>
</tr>
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<td>5</td>
<td>90</td>
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<td>6</td>
<td>94</td>
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<tr>
<td>7</td>
<td>80</td>
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<td>8</td>
<td>76</td>
</tr>
<tr>
<td>9</td>
<td>76</td>
</tr>
<tr>
<td>10</td>
<td>93</td>
</tr>
<tr>
<td>Mean</td>
<td>86.5</td>
</tr>
</tbody>
</table>

At Point B, the mean pre-width DCW thickness is 0.63 mm with a 95% CI range between 0.50 mm and 0.76 mm. Instrumentation with a 0.04/#30 rotary file, reduces DCW thickness by a mean of 0.13 mm and changes the 95% CI range (0.37 mm to 0.63 mm). Instrumentation with a 0.04/#35 rotary file reduces DCW thickness by a mean of 0.24 mm and changes the 95% CI range (0.26 mm to 0.52 mm). Instrumentation with a
0.04/#40 rotary file reduces DCW thickness by a mean of 0.33 mm and changes the 95% CI range (0.17 mm to 0.43 mm).

At Point C, the mean pre-width DCW thickness is 0.70 mm with a 95% CI range between 0.61 mm and 0.79 mm. Instrumentation with a 0.04/#30 rotary file, reduces DCW thickness by a mean of 0.08 mm and changes the 95% CI range (0.53 mm to 0.71 mm). Instrumentation with a 0.04/#35 rotary file reduces DCW thickness by a mean of 0.16 mm and changes the 95% CI range (0.45 mm to 0.63 mm). Instrumentation with a 0.04/#40 rotary file reduces DCW thickness by a mean of 0.19 mm and changes the 95% CI range (0.42 mm to 0.60 mm).

Table 2: Predicted DCW Thickness for each Instrumentation Size and Point

<table>
<thead>
<tr>
<th>Instrumentation</th>
<th>DCW Thickness</th>
<th>95% CI</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Predicted</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Point A (86.5 NTT Slice #)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre Width</td>
<td>0.73</td>
<td>0.635</td>
<td>0.825</td>
</tr>
<tr>
<td>.04/#30</td>
<td>0.61</td>
<td>0.515</td>
<td>0.705</td>
</tr>
<tr>
<td>.04/#35</td>
<td>0.53</td>
<td>0.435</td>
<td>0.625</td>
</tr>
<tr>
<td>.04/#40</td>
<td>0.44</td>
<td>0.345</td>
<td>0.535</td>
</tr>
<tr>
<td><strong>Point B (93.4 NTT Slice #)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre Width</td>
<td>0.63</td>
<td>0.499</td>
<td>0.761</td>
</tr>
<tr>
<td>.04/#30</td>
<td>0.50</td>
<td>0.369</td>
<td>0.631</td>
</tr>
<tr>
<td>.04/#35</td>
<td>0.39</td>
<td>0.259</td>
<td>0.521</td>
</tr>
<tr>
<td>.04/#40</td>
<td>0.30</td>
<td>0.169</td>
<td>0.431</td>
</tr>
<tr>
<td><strong>Point C (99.9 NTT Slice #)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre Width</td>
<td>0.70</td>
<td>0.608</td>
<td>0.792</td>
</tr>
<tr>
<td>.04/#30</td>
<td>0.62</td>
<td>0.528</td>
<td>0.712</td>
</tr>
<tr>
<td>.04/#35</td>
<td>0.54</td>
<td>0.448</td>
<td>0.632</td>
</tr>
<tr>
<td>.04/#40</td>
<td>0.51</td>
<td>0.418</td>
<td>0.602</td>
</tr>
</tbody>
</table>
Figure 4 illustrates with line drawings the DCW thickness at all three points as a function of instrumentation at the 95% CI. The blue line represents Point A, the red line represents Point B, and the green line represents Point C. Point A remained above the recommended 0.5 mm DCW thickness after instrumentation except when file size 0.04/#40 was used. Point C never fell below the recommended 0.5 mm DCW thickness with any file size used. The 95% CI for Point A in the Figure 4, indicates a 95% confidence that the mean DCW thickness will remain above 0.5 mm regardless of the increase in instrument size. Even in the case of the 0.04/#40 instrumentation, the 95% CI of between 0.34 mm and 0.54 mm included the 0.5 mm minimum. Similarly with Point C, 0.04/#40 instrumentation results in a 95% CI between 0.42 mm and 0.60 mm.

On the other hand, at Point B the mean predicted DCW thickness fell below the 0.5 mm minimum. For the 0.04/#35 instrumentation, the mean predicted DCW thickness was 0.39 mm. The 95% CI ranged between 0.26 mm and 0.52 mm, which does include the 0.5 mm minimum. For the 0.04/#40 instrumentation, the mean predicted DCW thickness was 0.30 mm and the 95% CI ranged between 0.169 mm and 0.43 mm. The 95% CI upper bound of 0.43 mm fell below the 0.5 mm minimum.

Instrumentation resulted in a significant reduction in the DCW thickness (p < .001). At mid-groove (Point B), the predicted DCW thickness (95% CI) was 0.5 mm, 0.39 mm, and 0.30 mm for file sizes 30, 35, and 40 respectively. The predicted DCW thickness was equal to or less than the proposed adequate standard (0.5 mm).
Figure 4: Predicted DCW Thickness for each Instrumentation and Point
Discussion

In this study, an evaluation of the DCW thickness along the furcation groove in the buccal root of bifurcated MFPs was performed before and after NiTi rotary instrumentation utilizing CBCT imaging. No previous studies had attempted to assess the quantity of dentin removed during endodontic preparation of the buccal root relative to the furcation groove and compare it to the proposed minimum 0.5 mm DCW thickness.

The 0.5 mm DCW thickness purposed by McCann et al is in contrast to the 0.3 mm RDT purposed by Lim and Stock. The obvious 0.2 mm difference between both purposed minimal standards is attributed to the inclusion of the cementum layer. A previous microscopic study of root apices within two different groups (young group = ages 18 to 25 years and an older group = ages 55 years and older) revealed a difference in cementum deposition as a factor of age (40). The observed 0.2-0.3 mm difference among the two groups indicates that cementum deposition occurs throughout life. Although there are no studies which measure the lateral cementum layer of root apices, it is prudent to assume cementum deposition also occurs in this aspect of the root. Therefore, within the scope of this study the 0.5 mm minimal DCW thickness proved to be a reasonable choice as it included the cementum layer.

The mean pre-width DCW thickness at all three specified points (A, B, & C) did not exceed 0.73 mm and was smallest in the mid-groove at Point B (0.63 mm). When an average of the mean pre-width DCW thickness at all three points (A, B, & C) is
calculated, the mean DCW thickness of the entire groove is 0.69 mm. In a previous morphological study by Tames et al, the mean DCW thickness of the entire furcation groove was reported to be 0.81 mm with the thinnest area located in the mid-groove area (30). The 0.12 mm difference between both studies appears to be insignificant. Likewise, both studies confirm that the thinnest initial DCW thickness occurs in the middle aspect of the furcation groove.

Katz et al reported initial DCW thickness in the coronal and mid-groove aspect to be the thinnest (41). Their findings were 0.99 mm in the coronal aspect and 0.78 mm in the mid-groove respectively. When compared to the mean pre-width DCW thickness at Point A (0.73 mm) and at Point B (0.63 mm) in the current study, there appears to be close similarities between both studies.

As would be expected, reduction of the DCW thickness occurs throughout the entire canal with instrumentation. The relationship between the initial DCW thickness and the increase in file size is inversely proportional. That is, as the apical size and taper of the NiTi rotary file increases, the DCW thickness decreases.

Two enlightening observations were made from this study. The first was the relatively small amount of predicted residual DCW thickness remaining in the mid-groove (Point B) after NiTi rotary instrumentation was completed with both the #35/0.04 (0.39 mm) and the #40/0.04 (0.30 mm) files. Both files reduced the mid-groove predicted DCW thickness below the proposed 0.5 mm recommendation.

Additionally, a relatively small amount of predicted residual DCW thickness was also observed in the coronal portion (Point A) of the groove after NiTi rotary
instrumentation with a #40/0.04 file. This resulted in a predicted DCW thickness of 0.44 mm which is below the proposed 0.5 mm recommendation.

These results are in agreement with the findings of a previous study by Katz et al in which DCW reduction was greatest in the coronal and mid-groove areas along the furcation groove in bifurcated MFPs (41). However, each study incorporated Gates Glidden drills for coronal flaring in a different manner. The current study introduced a #3 Gates Glidden drill into the coronal portion of the canal to a depth no greater than 1.0 mm to remove the cervical dentin constriction. Within the aforementioned study, Gates Glidden drills (sizes 2 and 3) were introduced into the canal in a crown down manner to a depth of 2.0-3.0 mm (41). This may explain the overall significant loss of DCW thickness noted in the coronal third in the previous study opposed to the current study in which only one file size (0.04/#40) was found to significantly reduce coronal DCW thickness. This is a clinically relevant point since many practitioners use both size 2 and 3 Gates Glidden Drills to at least a depth of 2-3 mm. If both drills would have been used in a like manner within the current study, a predicted DCW thickness below the recommended 0.5 mm minimum would have occurred.

A discrepancy appears between the reported NTT slice numbers for each specified point and each respective tooth. All measurements were recorded within the axial plane and each slice number represents a 0.25 slice width. The difference in NTT slice numbers can be attributed to the morphological variation of each respective tooth. Morphological factors that should be considered are the difference in coronal-apical height of the tooth, the length of the furcation groove, and the level of the bifurcation between the buccal and lingual roots. Deutsch et al reported a cusp to furcation height of
11.55 mm with a standard deviation (SD) of 1.12 mm (42) and a chamber floor to furcation height of 1.85 mm ± 0.85 mm SD. Discrepancy in NTT slice numbers, therefore, did not impact the study results.

Tamse et al reported the mean length of bifurcated MFPs as 21.0 mm with a 1.56 mm SD (30). Additionally, in respect to furcation groove length, Tamse et al reported a mean groove length of 5.38 mm. The current study found the mean groove length to be 4.35 mm (30). The variation between the two studies could be attributed to the difference in sample size.

Fracture resistance decreases proportionally relative to the amount of dentin removed during endodontic treatment and prosthetic post placement. At least 1mm of sound dentin is required along all aspects of the root for the entire length of the post (7, 25). Studies have indicated a greater fracture occurrence in areas of the root that are anatomically thinnest (1-2, 7, 25). The relevance of remaining DCW thickness after root canal therapy and post preparation is equally important. A direct relationship exists between the remaining DCW thickness and the strength of the root. Preservation of sound dentin is of utmost importance.

Previous morphology studies have demonstrated a high prevalence of thin roots in bifurcated MFPs (4, 30-31, 33, 41). The mean pre-width measurement at Point A was 0.73 mm, at Point B was 0.63 mm and at Point C was 0.70 mm respectively. When one considers the amount of potential dentin removal from endodontic therapy alone, post space preparation would in all likelihood create a strip perforation or significantly decrease the ability of the tooth to withstand lateral forces. The findings in the current
study appear consistent with previous studies which contraindicate post placement in the buccal root of bifurcated MFPs (4, 7, 25, and 41).

The three sizes of NiTi 0.04 taper rotary files (ISO # 30, 35 and 40) used in this experiment provided adequate apical enlargement and sufficient taper to ensure apical penetration of irrigants. In the current study, the mean predicted DCW thickness pre-width never exceeded 0.73 mm at any of the three specified Points (A, B, or C). Therefore canal enlargement in the buccal root should be kept as minimal as therapeutically possible to ensure maximum remaining DCW thickness. Ultrasonic activated irrigation in conjunction with mechanical cleaning and shaping can provide a substantial adjunct to ensure removal of bacteria and debris from the canal.

It seems reasonable that if 0.06 taper NiTi rotary files of the same apical diameter had been tested in this study, an increased risk of a strip perforation at mid-root (Point B) would have occurred because of the resultant decrease in predicted DCW thickness with smaller diameter 0.04 NiTi rotary files. NiTi 0.06 taper rotary files would have decreased the predicted DCW thickness at Point B even further and may have resulted in a significant decrease at Point A or even Point C. Replication of this study using 0.06 taper NiTi rotary instruments is likely to show a decrease in DCW thickness at Point A (coronal aspect) that may result in a strip perforation or compromise root integrity. However, the authors did not find it necessary to include 0.06 taper NiTi files in the current study and conclude that 0.06 taper NiTi rotary files should not be used in the buccal root of bifurcated MFPs.

The authors recognize that micro-computed tomography (μCT) could have provided better image quality which potentially may have increased the accuracy of the
data collected (37, 38). µCT is specifically designed for *in vitro* imaging of extracted teeth which limits their use to lab based studies. An advantage of µCT technology in comparison to conventional CBCT technology is its ability to superimpose pre-instrumentation and post-instrumentation images of a canal. This three dimensional feature is especially useful when comparing dentin removal relative to an area which poses an anatomical risk such as the furcation groove in MFPs. The significant cost of µCT restricts their use.

In conclusion, the following observations have been made. Post placement in the buccal root of MFPs is contraindicated because of inadequate initial DCW thickness before endodontic therapy is initiated. The buccal root in MFPs appears to be at risk for a potential perforation when increasing NiTi instrumentation above a size #30/0.04. The mid-groove region of the furcation groove appears most susceptible for a potential lateral strip perforation or compromise in remaining DCW thickness below the proposed 0.5 mm minimum.
References


### Appendix

Table 3: Raw Data Collection

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Average 0.63 0.5 0.39 0.3
Median 0.5 0.5 0.4 0.3
Figure 5: Picture of Custom Mounting Jig
Vita

Dr. Stephan Joseph Zigo III was born on March 2, 1971 in Silver Springs, Maryland. He is currently a citizen of the United States of America. Dr. Zigo received a Bachelor of Science in Biology from East Central University (Oklahoma) in 1996 followed by a Doctor of Dental Surgery from the University of Oklahoma, College of Dentistry in 2001. Dr. Zigo entered active duty in the United States Army following graduation and completed a one year Advanced Education in General Dentistry residency in 2002. While on active duty, Dr. Zigo was deployed to Iraq in support of Operation Iraqi Freedom I and served as a forward team dental officer providing dental care to ground combat forces. Following his discharge from active duty in 2004, Dr. Zigo practiced general dentistry for five years prior to enrolling in the Advanced Specialty Program in Endodontics at Virginia Commonwealth University School of Dentistry. Dr. Zigo is a member of the AAE, ADA, ODA, Tulsa County Dental Society, and Summit Dental Study Club. Dr. Zigo will enter private practice in Tulsa, Oklahoma upon graduation. He will graduate from VCU with a Master of Science in Dentistry and a Certificate in Endodontics.