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Residual Dentin Thickness of the Danger Zone in Mandibular Molar with Variable Sizes of Nickel-Titanium Rotary Instruments

Andrew Y. Xu

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Residual Dentin Thickness of the Danger Zone in Mandibular Molar with Variable Sizes of Nickel-Titanium Rotary Instruments

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Thesis Submitted to the School of Dentistry of Robert C. Byrd Health Sciences
Center at West Virginia University in partial fulfillment of the requirements for the
degrees of

Masters of Science in Endodontics

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2015

Keywords: Residual dental thickness, Nickel-Titanium, Danger zone,
EndoSequence® NiTi rotary instrument, mandibular mesial root, Microcomputed
tomography (microCT)

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Abstract

Residual Dental Thickness of the Danger Zone in Mandibular Molar with Variable Sizes of Nickel-Titanium Rotary Instruments

Andrew Y. Xu, D.D.S.

Introduction:

Mechanical cleaning and shaping is an important component to the long term success of endodontic therapy. A larger diameter canal preparation allows for more penetration of antimicrobial solutions into the root canal system with resultant improved disinfection. The objective of this study was to determine the residual dentin thickness (RDT) of the distal wall of mandibular mesial roots after mechanical preparation by using 4% constant tapered Nickel-Titanium rotary (NTR) files with various tip sizes as evaluated utilizing microcomputed tomography (microCT).

Methods:

Twenty-five mandibular molars were mounted at the cemento-enamel junction (CEJ) in modified polypropylene 50 ml centrifuge tubes using a non-radiopaque methyl methacrylate acrylic resin. All specimens were preoperatively scanned with microCT-40 (Scanco Medical, Switzerland). Images from the microCT-40 were transferred to ImageJ® image analyzing software (NIH, Bethesda, MD) to assess the initial dentin thickness of the distal wall measured 7mm from the apices of the mandibular molar mesial roots. Canals were then instrumented to length with 4% tapered NTR files (EndoSequence®) with varying apical sizes based upon group designation, either size 35.04, 40.04, 45.04, 50.04, 55.04. Each specimen was measured after canal preparation in a manner identical to the pre-instrumentation measurement using ImageJ®. Pearson correlation test was used to determine the correlation between preoperative mesio-buccal (MB) and mesio-lingual (ML) distal wall dentin thickness. The Kruskal-Wallis test was used to detect the amount of dentin that was removed and corresponding RDT among the five groups

Results:

Preoperatively, distal wall dentin thickness of MB and ML canals was found to be highly correlated (Correlation = 0.743). A statistically significant difference was observed between the five groups with respect to dentin that was removed ($p = 0.031$) and the resulting RDT ($P = 0.001$). The median value of RDT for Groups A, Group B, Group C, and Group E were found to be close to 1mm with the exception being Group D (0.596 mm).

Conclusion:

Root anatomy and preoperative dentin width thickness are the biggest factors that determine the amount of dentin removed by the files in the mid-root of the canal during mechanical root canal preparation.

Dedication

To my father, XiaoDong Xu, my mother, Jun Lu: Thank you for the unconditioned love and ongoing support since the day I was born. I am so lucky to have you as my parents. You both are the best.

To my wife, Kristi Xu: Thank you for all these years you have stood behind me and supported me. There are no words to describe what a great wife and mother of our children you are.

To my children, Autumn, Macie, and Lydia: You are the best kids I can ask for. Thank you for being understanding when daddy has to do work. Daddy will always love you.

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List of Symbols, Abbreviation, or Nomenclature

Nickel-Titanium rotary – NTR

Residual dentin thickness - RDT

Microcomputed tomography – microCT

Millimeters - mm

Mesio-buccal - MB

Mesio-Lingual – ML

Sodium hypochlorite - NaOCl

Ethylenediameteraacetic acid – EDTA

Chlorhexidine – CHX

Working Length – WL

Institutional Review Board – IRB

National Institute of Standards and Technology - NIST

Chapter I

Introduction

It has long been known that the presence of bacteria in the pulp is the primary cause of periapical infection.¹ Reduction of bacterial load in the root canal system plays a major role in determining the success of the endodontic therapy.² In order to reduce the microbial load, chemo-mechanical preparation must be accomplished to ensure disinfection of the root canal system in order to achieve long term success of endodontic therapy.^{3,4} A proper mechanically shaped root canal space enhances both the quality of the obturation and the disinfection of the root canal space.³ Numerous studies have shown that the larger the diameter of canal preparation, the more the volume of bacteria can be reduced⁴⁻¹² as the result of allowing for more volume of antibacterial irrigant into the canal system to flush out debris and bacterial by-products.¹³⁻¹⁵ However, there are surgical risks such as apical transportation, strip perforation, and instrument separation that can be involved when utilizing a larger apical preparation, particularly in curved and narrowed canal spaces.¹⁶

The mesial root of the mandibular molar is one of the most difficult roots to treat during endodontic procedures due to its acute inherent curvature in the middle root area. This is part of the so called danger zone, the area where the greatest narrowness of the diameter of the root, along with the distal surface concavity is located.^{17,18}

The invention of the Nickel-Titanium rotary (NTR) instruments has greatly improved the quality of mechanical shaping.^{5,19} These instruments not only increase the efficiency of preparation time, but also reduce clinical errors during mechanical shaping, and create less

canal transportation when compared to stainless steel files.^{5,20,21} NTR instruments have now gained acceptance by the majority of clinicians for root canal therapy.¹⁹ Currently, the major commercially available NTR files are produced with both 4% and 6% constant tapers. These tapered files create a greater continually tapering root canal preparation as compared to conventional 2% tapered files, facilitating better root canal obturation. To the author's knowledge there are several studies on measurement of residual dentin thickness (RDT) after mechanical preparation with 2% tapered files. However, there are limited studies assessing the RDT of the distal walls of mandibular mesial roots as measured by microcomputed tomography (microCT) after canals have been shaped with 4% constant tapered NTR files, specifically when employing medium to large tip sizes.

Statement of the Problem

It is unknown what affect using a 4% constant tapered, medium to large sized tip NTR files would have on the dentinal integrity in the danger zone of mandibular mesial root canals. The objective of this study was to determine the median RDT of the distal walls of mandibular mesial roots measured in millimeters (mm) after mechanical preparation using 4% constant tapered NTR files with various tip sizes as assessed by microCT.

Significance of the Study

The results of this study will give clinicians a greater understanding of the margin of safety and the tendencies of various sized NTR instruments to compromise the structural integrity of mandibular molar mesial roots.

Null Hypothesis

There is no statistically significant difference in the residual dentin thickness at the mid-root level of mandibular mesial roots when endodontically prepared with NTR files of sizes 35.04, 40.04, 45.04, 50.04, and 55.04.

Assumptions

- 1) Mandibular mesial roots have a curvature in the mid-root section.
- 2) The danger zone is located in the distal wall of the mid-section of the mandibular mesial roots.
- 3) Mesio-buccal (MB) and mesio-lingual (ML) canals are similar in structure to each other.
- 4) Larger size apical enlargement reduces more dentin on the distal surface than the mesial surface in the mid-root section.
- 5) Larger size apical enlargement removes more dentin at the mid-root section than smaller apical preparation when using 4% constant tapered files.
- 6) Measurement by micro-CT is the most accurate way to determine dentin removal utilizing current technology.

Limitations

- 1) This is an in-vitro study of a clinical procedure; therefore, the results may not correlate to an in vivo condition.
- 2) Small sample size.
- 3) Root canal anatomy can be widely varied from tooth to tooth.
- 4) Lengths of the roots are not standardized.
- 5) Diameters of the root canals can be varied, indicating that dentin thickness can be variable in each tooth as well.
- 6) Degree of curvature of the mesial canals can be varied.

Delimitations

- 1) Each tooth was examined radiographically preoperatively with mesial to distal and buccal to lingual views.
- 2) All roots selected preoperatively have curvatures between 11° to 35°.
- 3) All teeth were accessed by one clinician in the same systematic approach utilizing identical methods, thereby keeping procedures as consistent as possible.
- 4) The use of microCT is a non-destructive way for measurement.

Question to be answered

- 1) Are MB and ML canals similar to each other in regards to pre-instrumented dentin thickness?
- 2) Will any strip perforation occur using larger apical tip sized files in the danger zone?
- 3) Will there be enough post-instrumented dentin to maintain the integrity of the root structure?
- 4) What is the ideal apical size using 4% constant tapered NTR files for enlargement of the MB and ML canals?

Chapter II

Review of literature

1. Anatomy of the mandibular mesial root and the danger zone
2. Apical enlargement to reduce bacterial load
3. Larger apical preparation to promote irrigant efficacy
4. The danger of strip perforation
5. Residual dentin thickness (RDT)

1. Anatomy of the mandibular mesial root and the danger zone

The morphology of mandibular molar canals has been extensively studied. The mesial canal has been described as one of the most difficult canals to treat.⁵⁵ The danger zone is commonly referred to as the area of the distal wall of the mid-section of mandibular mesial root of mandibular molars. Root canals of these teeth are ribbon shaped and often located closer to the furcation than to the mesial surface, with the degree of the concavity being more on the distal wall than the mesial wall. Due to this unique shape of the root, a strip perforation can occur during root canal mechanical preparation in the distal wall much easier than in the mesial wall.^{17,22,23}

It is universally accepted that a one dimensional view of the radiograph can often present insufficient information to the clinician to assess the complexity of the root canal system of mandibular molar mesial roots. Cunningham et al.²⁴ selected 100 mandibular molars to evaluate the curvature of mesial roots. These teeth were radiographed and assessed with an

endodontic hand file in place. The conclusion of the study was that 100% of mandibular mesial roots had curvatures that most complexity of the curvature cannot be determined by clinical radiographs, and that proximal view of the mesial root can exhibit greater curvature than the mesio-distal view.²⁴

Berutti et al.²² measured the thickness of cementum/dentin in mesial roots of mandibular first molars. The teeth were fixed in a resin block and machine disc was used to slice the root in 90 sections immediately below the bifurcation. The sections were photographed by using stereomicroscope. The cementum/dentin thickness from the images was then measured and recorded. Berutti noted that the thickness of the cementum/dentin in the distal surface of the mesial mandibular root was less than that of the mesial surface of the root. Of note, 1.5 mm below the bifurcation was shown to have the least amount of dentin, approximately 1.2 mm to 1.3 mm. This area has the greatest risk of strip perforation during instrumentation.

In a more recent work, Harris et al.²⁵ used microCT to investigate mandibular first molar mesial roots and concluded that the thinnest dentin is located at the inner curvature, about 1.5 mm below the furcation. The average minimum dentin thickness of the inner curvature of mesial roots was 1.28 mm at the furcation region. Harris recommended that the furcation of mesial roots should be considered the “danger zone” during endodontic procedures.

2. Apical enlargement to remove the bacterial load

There is an extensive amount of evidence to suggest that a larger apical preparation is better for disinfection of the root canal system. Even though all bacteria cannot be completely eliminated, studies have shown that larger instrumentation is necessary to reduce bacterial volume.^{4,7-10} The canal diameter of the apical region of mandibular mesial roots is approximately 0.2 – 0.4mm, which suggests the apical region should be enlarged to a minimum ISO size 30.^{25,26} The most complexity of root anatomy is usually found in the apical region. A large apical preparation, then, can include more anatomical irregularities and remove greater bacterial volume.¹³

Rollison et al⁷ investigated the reduction of the bacterial volume after mechanically preparing the root canal with 4% tapered files as opposed to 2% tapered files. In the study, mesial mandibular roots were used and infected with *Enterococcus faecalis*. Half of the canals were mechanically shaped with GT Profile® files to apical size of 35.04 and the other half of the canals were shaped with Power-R® files to an apical size of 50.02. The results of the study showed that the canals prepared with a size of 50.02 were more effective at removing bacteria load than the canals that were prepared with a size of 35.04. The study concluded that the larger apical size and not the size of the taper played a greater role in the reduction of bacterial volume.

Usman et al.¹¹ investigated the efficacy of root canal debridement by using GT NTR files with tip sizes of 20 and 40. After mechanical preparation of the canal, the apical third was sectioned at 0.5 mm, 1.5 mm, and 2.5 mm and prepared for histological examination to assess

the remaining debris. It was found that the size 20 left more debris in the apical third than the size 40. The conclusion was that the larger file had less debris remaining in the canal than the smaller preparation.

In a study by Siqueira, ⁶ the reduction of bacterial population in the root canal was assessed after the canal system had been mechanically shaped with three different file systems and irrigated with sterile saline. It was found that Nitiflex file size 40 removed more bacterial than any of the other size files (35, 30) that were used, regardless of the percentage of the file taper. This study showed that larger apex preparation leads to a significant reduction in the amount of bacteria.

Tan et al. ⁵ compared K hand files and NTR files (LightSpeed®) on the effective removal of debris in the apical region of MB canals of mandibular molars. The study was divided into three groups: 1) Group 1 step-back with K file without coronal flaring; 2) Group 2 step-back with file with coronal flaring; and 3) Group 3 crown down with LightSpeed® with coronal flaring. The specimens were examined under a light microscope and canal cleanliness was assessed. The results showed that the large apical shaping with the LightSpeed® files demonstrated significantly cleaner canals than the hand file groups in the apical regions.

Card et al. ¹² showed undetectable bacteria after mandibular mesial canals were instrumented by 4% tapered size #7 size Profile® Series 29™ file (0.465 mm) in 81.5% of the canals. Even further apical enlargement to size larger than 0.575 mm by LightSpeed®, 89% of the canals showed no evidence of bacteria. This study supported the premise that large apical size reduces more bacteria than do those of smaller size.

3. Larger apical preparation to promote irrigant efficacy

Numerous studies have shown that mechanical cleaning of the root canal system alone is ineffective in completely removing bacteria.^{4-7,11,12} By using a chemical antibacterial agent such as sodium hypochlorite (NaOCl), ethylenediametetraacetic acid (EDTA), or chlorhexidine (CHX) in conjunction with mechanical cleaning, there was a significantly improvement in disinfection of the canal system. This is essential for the success of endodontic therapy.^{8,27} Due to the complexity of root canal anatomy, there is currently no known antibacterial agent or irrigation device that can completely kill microorganisms in the canal system; therefore, adequate enlargement of the canal system allows for irrigation to become a critical step in achieving a high success rate for endodontic treatment.^{28,54}

Chow²⁹ studied the efficacy of irrigation in constructed glass tubes with internal diameter and taper similar to reamer files. The experiment was composed of two parts. The first part examined the apical extent of irrigant deposition in relation to needle depth penetration. Tube sizes of 50, 60, and 70 were used. The second part of the experiment examined the relationship between the needle size and the effectiveness of irrigation. The results showed that the irrigant did not penetrate far beyond the tip of the needle. To facilitate removal of debris, the needle needs to be placed as close to the apex as possible without binding to the wall. Therefore, irrigation was more effective in large canals than in small canals.

Ram et al.¹³ studied the efficacy of irrigation by preparing roots to different apical sizes. In this study, single rooted human teeth were prepared to size 25, 40 and 60, respectively. A radiopaque solution was injected into each canal and verified radiographically. Each root was

then irrigated with saline, and radiographs were then taken to assess the presence of the radiopaque solution. The finding of the study was that the irrigant was ineffective with a root apex prepared to a size 25, while size 40 showed significant improvement, and size 60 had complete removal of the radiopaque solution. This study concluded that the diameter of the root canal at the apex is the most important factor in obtaining the maximum efficacy in root canal irrigation. The apex should be mechanically enlarged to a size 40 for to receive maximum benefits of the irrigant.

Falk et al.¹⁵ investigated the hypothesis that the efficacy of irrigation is dependent upon the size of the apical preparation. Thirty permanent canine teeth were prepared to apical sizes of 36, 60 and 70 by using 4% tapered Profile®, Series 29™ files. Canal spaces were first sterilized and then infected with bacteria. Next, 6 ml of sterile distilled water was delivered with a 28 gauge endodontic needle placed 1 mm from the working length. The results were that sizes 60 and 70 showed significantly reduced bacterial volume as compared to size 36. There was no statistical difference between the canals instrumented to a size 60 or 70. The conclusion was that larger apical sizes can increase efficacy of the irrigant. An enlargement beyond size 60 did not further reduce bacterial volume in the canal, since 10% of bacteria still remained in the canal system after irrigation.

Brunson et al.¹⁴ studied the effect of apical preparation size and taper on irrigant volume delivered. The study included 40 human single rooted teeth, and was divided into two phases. In the first phase, all samples were prepared with 6% taper and differing tip sizes, ranging from size 30 to 45. In the second phase, canals were prepared using the same tip size, but with different taper, ranging from 2% tapered to 8% tapered files. All samples were

irrigated with a negative pressure micro-cannula with NaOCl at WL for 30 seconds. Irrigant was collected and the volume was measured. The results were a 44% increase in volume of irrigant delivered when increasing apical diameter from ISO size 35 to 40. A change from ISO size 40 to 45 resulted in a 4% increase in volume. When comparing the taper size, a canal enlargement from 40.02 to 40.04, had a 74% irrigant volume increase; 40.04 to 40.06 had a 5.4% irrigant volume increase; 40.06 to a 40.08 had 2.4% volume increase. This study concluded that apical preparation should be enlarged to an ISO size 35 to 40 with a 4% tapered file. Such sizes are well balanced between the volumes of the irrigant introduced to the canal, while maintaining the integrity of the root structure.

4. The danger of strip perforation

Strip perforation is an iatrogenic occurrence.^{30,31} Thinning dentin thickness and strip perforation happen during the negotiation of curved canals or by over enlarging the canal space. A strip perforation creates an artificial communication between the canal space and the surrounding supporting tissue.¹⁷ The flared canal preparation can help to facilitate more effective cleaning and shaping of the canal, can reduce the breakage of endodontic files, and also facilitates better obturation of the canal space.³ However, strip perforation is a potential risk of enlarging the canal space, especially in the mid-root region of the mandibular mesial root where the canal space is curved.^{17,18} Several studies have shown that root perforation occurs approximately 2-12% during endodontic treatment.³²⁻³⁷

Lim and Stock ²³ evaluated perforation tendencies of two different filing techniques, anti-curvature and step-back filing, in mandibular mesial roots of 30 extracted teeth. The authors found that the area most prone to perforation was at a level of 8 mm from the apex on the distal wall of the mesial root. The RDT of roots with moderate curvature and those with severe curvature were not significantly different; therefore, there was no correlation between the curvature of the root and the risk of strip perforation.

5. Residual dental thickness (RDT)

There has been an ongoing clinical dilemma between the importance of adequate apical enlargement for removing bacteria and necrotic tissue and the necessity of preserving the integrity of root structure.³⁸ Many studies have recommended that the root canal space in the coronal segment should not exceed one third of the root diameter in all levels to preserve its mechanical integrity.^{39-41,57} It has also been recommended that a minimum of 1 mm circumference of RDT should be maintained, as to not jeopardize root structure integrity.^{42,43,56}

Zuckerman et al ³⁸ measured the RDT after mandibular mesial root canals were enlarged with LightSpeed® endodontic files. In his experiment, 30 mandibular mesial roots were initially horizontally sectioned at 1, 4, and 7 mm from the apex. The dentin was measured in mesial, distal, buccal and lingual directions. The roots were re-assembled and the coronal third of the canals was flared with a Gates-Glidden #2 and enlarged with LightSpeed® to a size 50 file. The three sections were disassembled and measured. The RDT after instrumentation at levels of 1 mm, 4 mm, and 7 mm was 0.7 mm, 1.04 mm and 1.09 mm. None of the canals exceed one

third of the root diameter. Zuckerman concluded that canal space enlarged to a size 50 Lightspeed® file did not significantly reduce the RDT.

As mentioned in the strip perforation section, Lim et al ²³ also measured RDT of the mesial roots of mandibular molar teeth after these teeth were prepared with two different filing techniques. The RDT of the distal wall at 8 mm was between 0.56-0.59 mm and 0.72-0.80 mm were at 5 mm. The distal wall of the mandibular mesial root showed significantly more dentin being removed at 8 mm compared to the 5 mm from apex.

In a recent publication by Junior et al., ⁴⁴ two NTR file systems, Mtwo and Reciproc NiTi, were compared and evaluated on their removal of dentin in the danger zone of mandibular molars. Original measurements were taken with microCT of twelve mesial mandibular roots. The canal spaces were then mechanically prepared by Mtwo to 40.04 and Reciproc NiTi file systems to 40.06. Root canal volume and dentin thickness at different levels were measured and analyzed. The results showed that the two NTR file systems did not remove a significant amount of dentin, as compared to the original measurement, validating the overall safety of a larger apical preparation.

Chapter III

Material and methods

The application and approval for the Institutional Review Board (IRB) was applied for and obtained at West Virginia University. The IRB protocol tracking number is 1406315761 (Appendix page 57).

Fifty extracted de-identified first and second human mandibular molars were obtained according to protocols approved by the Institutional Review Board (IRB) of West Virginia University. The teeth were each marked with sample numbers for identification and preserved in a normal saline solution (Figure 1). A dental hygiene student performed scaling and root planning to remove gross calculus and plaque from these teeth.

Figure 1. 50 extracted mandibular molars

The cleaned teeth were secured with utility wax to the center of a digital sensor (Kodak RVG 6100; Carestream Health, Rochester, NY). Radiographic images were taken with the X-ray tube in a fixed position (Figure 2), and exposures were made in the bucco-lingual and mesio-distal planes of each tooth. The images were recorded in MiPACS imaging software (Medicor Imaging, Charlotte, NC, USA).

Figure 2. Radiograph for each tooth

The radiographs were examined to ensure that all mandibular root canals were visible radiographically. At the completion of the assessment, 25 (N=25) of the 50 mandibular molars were chosen for inclusion in the study. The mean curvature of the MB and ML roots was 20.4° (Range: 11° to 35°). The calculation of root curvature has been described by Schneider ⁴⁵ as a line drawn parallel to the long axis of the root canal and a second line drawn from the apical foramen to intersect with the first line at the outermost point of the canal (Appendix page 52 - 56). The teeth were randomly divided into five different groups: Group A (35.04), B (40.04), C (45.04), D (50.04), and E (55.04), with five teeth included in each group (Figure 3).

Group A (35.04)

Group B (40.04)

Group C (45.04)

Group D (50.04)

Group E (55.04)

Figure 3. Specimen teeth were divided into 5 groups (N=25)

The specimen teeth were mounted at the cemento-enamel junction (CEJ) in modified polypropylene 50-ml centrifuge tubes (Thermo Fisher Scientific, Waltham, MA) using a non-radiopaque methyl methacrylate acrylic resin (Varidur® Buehler LTD, Lake Bluff, IL) (Figure 4). Each tooth was embedded upright in one centrifuge tube. The facial and mesial surfaces of each tooth were marked for scanning purposes to ensure operator consistency (Figure 5).

Figure 4. Non-radiopaque methyl methacrylate acrylic resin

Figure 5. Tooth was mounted in the tube and buccal surface was marked

Scanning of the teeth were conducted at National Institute of Standards and Technology (NIST) (Gaithersburg, Maryland). A microCT-40 (Scanco Medical, Switzerland) with an isotropic voxel size ($18\mu\text{m}$) was utilized to scan the specimens. The radiographic settings were 75kVp and $114\mu\text{A}$ (Figure 6). All specimens were covered with wet paper towel and sealed with paraffin wax to keep the tooth moisturized during the experiment.

Figure 6. MicroCT-40 (Scanco Medical, Switzerland).

Images from the microCT-40 were transferred to ImageJ® image analyzing software (NIH, Bethesda, MD) to assess initial dentin thickness of the distal wall of each canal of each mesial root when measured 7mm from the apex of each root. A cross sectional image at 7mm was used for measurement. A straight line (Line 1) was drawn tangent to the outermost cementum layer of the distal wall from MB to ML canals. A second line (Line 2) was drawn parallel to Line 1 and tangent to the MB and ML distal surface of the canal space. Occasionally, a second parallel line to Line 1 (Line 3) would be drawn only if a point of tangency from both the MB and ML canal space could not be captured by Line 2, while maintaining parallelism to Line 1. A perpendicular line (Line 4) was drawn between Line 1 and Line 2, or 3 as needed,

intersecting the MB canal space. A perpendicular line (Line 5) was drawn between Line 1 and Line 2, or 3 as needed, intersecting the ML canal space. Line 4 and 5 were used for pre-instrumentation thickness measurement of the dentin thickness of the distal wall of the mesial root (Figure 7).

Figure 7. Method of measuring dentin thickness

One operator performed the mechanical shaping of the canals to minimize operator variation. The teeth initially were accessed with a 330 carbide bur (Brasseler USA, Savannah, GA, USA) in high speed handpiece with water coolant. Once in the chamber, Endo-Z bur (Dentsply, York, PA, USA) was used to enlarge the access outline and to facilitate locating the MB and ML orifices. Gates Glidden #3 was then used at the orifice level to create straight line access as described by Isom.⁴⁶ Canals were initially negotiated with a size 10 K file (Flexofile®, Dentsply, York, PA, USA). The working length (WL) was established 1 mm short of the

radiographic apex. A glide path was established with size 15 K file, (Flexofile®, Dentsply, York, PA, USA) and canals were sequentially instrumented to length with NTR files (EndoSequence®, Brasseler USA, Savannah, GA, USA) with varying apical sizes based upon group designation. Torque (2 N-cm) and speed (500 rpm) were set on the rotary motor (Endo-MateDT, NSK Dental LLC, Hoffman Estates, IL, USA) according to the manufacturer's recommendations. The NTR files were used in a crown down fashion and followed the manufacturer's recommendations, utilizing an in and out motion. The canals were rinsed with 5ml of 2.5% NaOCl between each file change using a 30 gauge side vented needle (Prorinse®, Dentsply, York, PA, USA). The needle was inserted as deep as possible without binding in the canal. Once the canal was instrumented to length, a final rinse of sterile water was used and the canal was dried with paper points.

The teeth were scanned after canal preparation in a manner identical to the pre-instrumentation scan. Each specimen's images were then transferred to ImageJ® to measure RDT in a manner identical to the pre-instrumentation measurement. All specimens were covered with wet paper towel and sealed with paraffin wax to keep the tooth moisturized during the experiment (Figure 8 - 12).

Group A (35)

Figure 8. Pre-op and post-op measurement images of Group A

Group B (40)

Figure 9. Pre-op and post-op measurement images of Group B

Group C (45)

Figure 10. Pre-op and post-op measurement images of Group C

Group D (50)

Figure 11. Pre-op and post-op measurement images of Group D

Group E (55)

Figure 12. Pre-op and post-op measurement images of Group E

Statistical analysis

The primary outcome variable of root dentin thickness, measured in millimeters, was analyzed. File size, the main predictor of root dentin thickness, was examined by group. Most teeth examined demonstrated multiple mesial canals. The correlation between the distal wall dentin thicknesses of both MB and ML of each tooth was assessed using Pearson correlation test. The mean value of distal wall dentin thickness was calculated in millimeters for each tooth, both for pre- and post-preparation distances. The Kruskal-Wallis test was used to analyze both how much dentin in millimeters was removed, and subsequently, the corresponding RDT between the various groups. All statistical analyses were performed in SAS 9.3 (SAS Institute, Inc., Cary, NC) and R 3.0.1.

Chapter IV

Results

During instrumentation, all 25 specimens were found to be apically patent with size 10 K files, and patency was maintained during the instrumentation procedures. No separation of NTR instruments occurred during the mechanical preparation phase of the experiment. Based upon visual evaluation of radiographs, no visible transportation, perforation, ledge or apical stripping were detected. No post-instrumented roots demonstrated strip perforation in the distal wall at the 7 mm measurement level as seen on microCT images in any of the specimens evaluated.

Table 1 and Table 2 are pre- and post-mechanical preparation of the distal dentin wall thickness. Appendix (page 51) listed measurements of the preoperative mandibular mesial root curvature.

Table 1. Dentin thickness (pre-preparation)

	MB (mm)	ML (mm)
A1	0.939	1.498
A2	1.371	1.447
A3	1.295	1.498
A4	1.524	1.346
A5	1.473	1.143
B1	1.422	1.346
B2	1.701	1.930
B3	0.990	0.685
B4	1.727	N/A
B5	1.473	N/A
C1	1.117	1.219
C2	1.117	1.219
C3	1.422	1.498
C4	1.270	1.727
C5	1.371	1.346
D1	0.838	0.838
D2	1.295	1.219
D3	0.965	1.092
D4	1.193	1.295
D5	1.295	1.244
E1	1.676	1.625
E2	1.422	1.498
E3	1.854	1.778
E4	1.422	1.295
E5	1.854	1.828

N/A = only one mesial canal present

Table 2. Residual dentin thickness (post-preparation)

	MB (mm)	ML (mm)
A1	0.762	1.0414
A2	1.295	1.270
A3	0.939	1.143
A4	1.498	1.016
A5	1.397	0.838
B1	1.371	1.270
B2	1.320	1.473
B3	0.660	0.355
B4	1.320	N/A
B5	1.117	N/A
C1	0.863	0.711
C2	0.736	0.838
C3	1.193	0.939
C4	0.965	1.574
C5	1.016	1.143
D1	0.254	0.33
D2	1.066	1.066
D3	0.838	0.355
D4	0.508	0.558
D5	0.635	0.660
E1	1.244	1.168
E2	1.117	1.117
E3	1.447	1.270
E4	1.143	0.787
E5	1.498	1.371

N/A = only one mesial canal present

The correlation value between distal wall of preoperative dentin thickness of the MB and ML canals was 0.74 (value of -1 indicate specimen were completely opposite and 1 being the specimen were identical). Based on this result, it is seen that MB and ML canals have a great resemblance to each other and should be treated as a single entity (Figure 7).

Figure 13. Pearson correlation for preoperatively distal wall dentin thickness of MB and ML

The Kruskal-Wallis test was performed to evaluate whether there were differences between the 5 groups with respect to how much dentin was removed, and a statistically significant difference ($p = 0.031$) was found (figure 8). The means and medians of the 5 groups are listed in the Table 3. The column chart is listed in the Figure 9.

Note: top line is 75%, middle line (Median) 50%, bottom 25%. The dot is the mean. The top line from the dotted line is measure of max and minimum.

Figure 14. Comparison of the dentin was removed by each file size group.

Table 3. Mean (mm) and Median (mm) of the distal wall dentin was removed by NTR Instruments

Group	Mean (mm)	SD	Median (mm)	Lower Quartile (25%)	Upper Quartile (75%)
A (35)	0.233	0.097	0.190	0.178	0.317
B (40)	0.315	0.145	0.355	0.330	0.406
C (45)	0.332	0.742	0.381	0.279	0.381
D (50)	0.500	0.201	0.546	0.431	0.622
E (55)	0.408	0.045	0.406	0.393	0.444

Figure 15. Median (mm) of the dentin was removed by Groups

A statistically significant difference was found between the sizes of the NTR files among the 5 groups when comparing the distal wall residual dental thickness ($P = 0.001$) (Figure 10). The means and medians of the RDT among the five groups are listed in Table 4. The column chart is listed in Figure 11.

Figure 16. Residual dentin thickness by file size

Table 4. Mean (mm) and Median (mm) of RDT by file size

Group	Mean (mm)	SD	Median (mm)	Lower Quartile (25%)	Upper Quartile (75%)
A (35)	1.120	0.242	1.092	0.939	1.295
B (40)	1.111	0.393	1.295	0.889	1.346
C (45)	0.998	0.256	0.952	0.838	1.143
D (50)	0.627	0.289	0.596	0.355	0.838
E (55)	1.216	0.203	1.206	1.117	1.371

Figure 17. Median (mm) of RDT by Groups

Discussion

The aim of this study was to assess the residual dentin thickness of the distal wall of mandibular mesial roots after canals were enlarged with 4% constant tapered NTR files with medium to large size tips. A statistically significant difference in RDT among the five groups after mechanical instrumentation was identified. Most RDT stayed within the 1 mm range except Group D (50.04); therefore, the null hypothesis is rejected.

Mesial roots of mandibular molars were chosen for the study due to their inherently oval and conical shapes.⁴⁷ This uniquely shaped canal creates distinct challenges to mechanically cleaning and shaping the root canal space. According to Muller,⁵⁵ the average primary curvature is between 20° to 30°. This study found that there was a 100% chance of curvature in all molars, with molars instrumented exhibiting a degree of curvature within the previously mentioned 20° to 30° range. Lesberg et al⁴⁸ showed that canal transportation usually occurs at the curvature level of the distal surface of the canal. The author further stated that the greater the curvature, the more likely the operator is to create canal transportation toward the distal concavity of the root. A previous study by Junior et al., showed that the MB and ML canals are often similar to each other in curvature and dentin volume⁴⁴. The current study's analysis between the MB and ML distal surface dentin thickness is similar (correlation = 0.743) which is in accordance with Junior's study; therefore, both canals (MB and ML) were treated as one subject. The mean of MB and ML canals was calculated and utilized during statistical analysis.

Using Gates-Glidden #3 to flare the coronal section is an important step to create so called straight line access. It is recommended to use Gates-Glidden drills in an anti-curvature motion at the orifice level to remove the cervical bulge, but stopping prior to the level of the furcation to prevent any unnecessary dentin removal.⁴⁶

The danger zone can vary in locale among teeth and it can be difficult to determine the exact location of the thinnest and most curved areas in mandibular mesial roots. Studies have considered 1.5 mm to 2 mm below the furcation as a landmark to aid in determining the danger zone location.^{22, 49} Other studies have used between 6 mm to 8 mm coronal from the apex as a landmark to map the danger zone region.^{23,56}

The current study selected 7 mm coronal from the apex, as described in Zuckerman's³⁸ and Ouzounian's study.⁵⁶ The enlargement of the apex from a size 35.04 to the largest size 55.04 in this study was based on Brunson's¹⁴ and Falk's study.¹⁵ It is recommended to enlarge the canal space to a minimum size of 35 to 40 to maintain a balance between the volume of irrigant introduced into the canal and the integrity of the root structure.^{13, 14} According to Falk's study,¹⁵ anything larger than an apical size of 60 did not improve irrigation efficacy. However, in the current study, it is the author's opinion that a size 60.04 preparation of the mesial mandibular roots would compromise the integrity of the root structure; therefore, the current study used a size 55.04 as the largest apical enlargement.

There are many brands of NTR instruments to select from; however, only a few brands of NTR instruments carry sizes larger than size 50. EndoSequence® is one of the few brands of NTR instruments to carry such a size or larger. Their NTR files are a triangular design with no

radial land which enhances the flexibility of the file and increases cutting efficiency. Its lower helical angle with alternating contact points acts similar to a reamer which reduces the NTR files tendency to 'suck into' the canal. ⁵⁰⁻⁵²

Pearson correlation test was used to determine if a correlation existed between the MB and ML canals of distal wall dentin thickness. This is an important step in deciding whether or not the MB and ML can be treated as separate entities during the statistical analysis. The results revealed that the preoperative distal wall distance of the MB and ML were highly correlated (Pearson correlation = 0.743); therefore, the mean of the two canals of each specimen was utilized for further analysis. Because of this determination, the sample size was reduced by half since the MB and ML cannot be considered independent observations. Due to the small sample sizes of this study, the Kruskal-Wallis test, a non-parametric test, was used to analyze the data instead of ANOVA (which is normally reserved for larger sample sizes with the assumption of normally distributed results). The Kruskal-Wallis test utilizes the median of the data (instead of the mean) to determine whether or not there is at least one group that is different from the rest. No further comparison test between each group was employed, also due to the small sample size, which has limited power to detect the true differences among each test group.

The amount of distal wall dentin that was mechanically removed ranged from low of 0.190 mm (Group A) to the high of 0.546 mm (Group D). The Kruskal-Wallis test was able to detect a statistical difference among the five groups ($P = 0.031$). A linear relationship exists between the file size used for canal preparation and the volume of dentin that was removed. As the size of the file used for canal preparation increased, the amount of dentin volume

removed increased, as shown in Figure 9. These findings are in agreement with Junior's study. Junior ⁴⁴ found that the larger tip size removed more distal wall dentin than the smaller file size and dentin volume removal was more significant in the mid-root section than the apical-root section of the mandibular mesial root. Junior also concluded that the distal wall dentin of the mid-root region was removed more than the mesial wall of the mid-root in the canal space. ⁴⁴

Postoperatively, a significant difference was found with respect to the RDT among the five groups based on the Kruskal-Wallis test ($P = 0.001$). This is in disagreement with Zuckerman's study. Zuckerman ³⁸ concluded that with an apical preparation to a size #50, there are no statistically different RDT changes between pre- and post-preparation. Both Zuckerman's and Junior's studies confirmed the overall safety of using NTR files to prepare the apex to larger sizes. ^{38, 44} Based on the current study, Group A (1.092 mm), Group B (1.295 mm), Group C (0.952 mm), and Group E (1.206 mm) had similar median RDT values which agree with Zuckerman's and Junior's investigations. However, Group D (0.596 mm) had a significantly less median RDT value than any other groups, which created the significant difference.

The mean value of pre-instrumented distal wall dentin thickness at 7 mm for the MB canal was 1.361 mm (SD = 0.275) and 1.381 mm (SD = 0.296) for the ML canal. This was similar to the value of 1.21mm (SD = 0.21) that was reported by Zuckerman.³⁸ The mean RDT value of the distal wall reported by Zuckerman ³⁸ was 0.92 mm (SD = 0.19). Ouzounian ⁵⁶ found the mean RDT at 7mm to be approximately 0.6 mm. The RDT of the current study among the five groups ranged from the thinnest of 0.627 mm (SD = 0.274) (Group D 50.04) to the thickest of 1.217 (SD = 0.193) which is similar to Ouzounian and Zuckerman's studies.

Ouzounian⁵⁶ recommended preserving 1 mm of dentin thickness to maintain the integrity of the root structure in the mid-root section. In this study, the mean value of RDT was close to 1mm among all groups, except Group D (50.04) with a significantly lower mean value of 0.627mm. The mean RDT of this study was similar to the Zuckerman's³⁸ study at the 7mm section when the canals were instrumented to size 50 with LightSpeed®. It is also comparable to Junior's⁴⁴ study where the mean RDT was 0.8 mm at the 5mm level after the canals were enlarged to size 40.04.

Canal preparation should not exceed 1/3 of the width of the root width as suggested by other studies³⁹⁻⁴¹ to preserve the integrity of root structure. As this study compares the pre-instrumentation and post-instrumentation value of dentin thickness of the distal surface of the mesial root, it is best to compare investigations that use specific values of RDT, such as 1mm, described by several studies^{42,43,56} as opposed to arbitrary rules, such as the 1/3 rule.

Due to the complex anatomy of mesial roots of mandibular molars, even with the larger size NTR instruments, many isthmuses and fins in these roots in this study were left untouched. This is in agreement with Peters et al¹⁹ that 35% of the root canal space is left untouched. Based on this observation, the importance of using antibacterial irrigants such as NaOCl and CHX, along with devices such as passive ultrasonic irrigation systems to further disinfect the canal space, cannot be overemphasized.

In the current study, the unexpected results were observed in Group D for the RDT, which the author considers as an "outlier". The finding of this outlier may be due to the small sample size and non-standardization of canal lengths, degree of curvatures, and preoperative

dentin thickness. In this study, the root lengths were intentionally not standardized in order to more closely simulate clinical conditions. For any future investigations, the author would recommend scanning and measuring the preoperative samples so that specimens can be categorized together with their similarities of root length, degree of canal curvature, and preoperative dentin thickness. The specimens would then be selected from those with similar parameters to form each individual group for the study. With this method, the data would be more accurately and evenly distributed. Even though some of the RDT data appeared to be different within one of the groups, the clinical implication of this study is still significant. Based on observations made from this study, clinicians should proceed with caution during the mechanical preparation in mandibular mesial roots, since a conventional periapical radiograph does not provide the diagnostic means to determine the precise width of dentin thickness. It should not be falsely assumed that a smaller size mechanical preparation would be safer than a larger size in preventing iatrogenic occurrences.

The use of microCT provided a non-destructive way to precisely measure the thickness of the roots investigated. Similar studies have sectioned the roots using disks to pre-measure the thickness of the root and then re-assemble the root to allow for cleaning and shaping. Such a method could lead to inaccuracy by both removing un-necessary dentin and the difficulty in precise alignment of the disk. Correlation between a preoperative periapical radiograph and preoperative dentin thickness would be an interesting area of investigation for a future study. The technology of microCT has opened up many possibilities for future similar studies.

Chapter V

Conclusion

It was concluded that the original root anatomy and the pre-preparation dentin width are the biggest factors that determine the amount of dentin removed by files in the mid-root of the canal. This is best illustrated by the results of the Group D (50.04) as it compares to Group E (55.04). Group E (55.04) had greater value of RDT than Group D (50.04). Logically, one would assume that a larger file would remove more dentin and have a lower value of RDT postoperatively. However, the results of this study were the opposite of what would have been anticipated. The author disagrees with statements made by Garala et al.⁵³ and Junior et al.⁴⁴ indicating that the size of the file (up to 55.04) plays an insignificant role in the amount of dentin removal concerning overall safety of the usage of medium to large 4% tapered NTR instruments during the preparation of mandibular mesial root canals. It is speculation that such statements can only be made when the dentin thickness is determined preoperatively. Cone beam computed tomography has been introduced in recent years. With its ability to capture tooth anatomy in a three dimensional image, a clinician may one day be able to determine a precise size to mechanically prepare the root canal beforehand without potentially compromising the tooth's structural integrity.

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Appendix

Preoperative mandibular mesial root curvature measurements

	pre-op curvature degrees		
A1	15	Group A (35)	
A2	14	Mean	15.4
A3	17	SD	1.36
A4	14		
A5	17		
B1	20	Group B (40)	
B2	21	Mean	22.8
B3	35	SD	6.17
B4	20		
B5	18		
C1	22	Group C (45)	
C2	26	Mean	22.8
C3	20	SD	2.31
C4	21		
C5	25		
D1	25	Group D (50)	
D2	32	Mean	24
D3	15	SD	5.44
D4	25		
D5	23		
E1	22	Group E (55)	
E2	20	Mean	16.8
E3	11	SD	4.45
E4	19		
E5	12		
		Entire Samples	
		Mean	20.4
		SD	5.61

Group A (35.04)

A1 (15°)

A2 (14°)

A3 (17°)

A4 (14°)

A5 (17°)

Group B (40.04)

B1 (20°)

B2 (21°)

B3 (35°)

B4 (20°)

B5 (18°)

Group C (45.04)

c1 (22°)

c2 (26°)

c3 (20°)

c4 (21°)

c5 (25°)

Group D (50.04)

D1 (25°)

D2 (32°)

D3 (15°)

D4 (25°)

D5 (23°)

Group E (55.04)

E1 (22°)

E2 (20°)

E3 (11°)

E4 (19°)

E5 (12°)

**Acknowledgement Letter Not Human Subject Research
NHSR**

To Andrew Xu
From WVU Office of Research Integrity and Compliance
Approval Period 06/02/2014 **Expiration Date** 06/01/2019
Subject **Not Human Subject Research Acknowledgment**
Protocol Number 1406315761
Title Residual dentin thickness on mandibular mesial dental root after shaping with niti rotary files assessing micro CT.

Thank you for your submission to the West Virginia University Institutional Review Board IRB.

It has been determined that your project does not meet the definition of human subject research for the following reasons

- This acknowledgement is under the understanding that these are de-identified collected extracted teeth. The researcher is randomly choosing from these collected teeth.
- Research means a systematic investigation designed to develop or contribute to generalizable knowledge. Most case reports and most oral histories are not generalizable and therefore not research. Many classroom projects if not intended to be published are also not considered research. Many quality improvement or program evaluation studies are not research.
- In order to be considered human subject research individually identifiable private information must be obtained or used in the research. If there is no individually identifiable private information involved the project is not human subject research and does not require being submitted to the Office of Research Integrity Compliance. Private information must be individually identifiable i.e. the identity of the subject is or may be readily ascertained by the investigator or someone else associated with the information in order to constitute research involving human subjects.

If you have any questions, please contact the IRB at 304 293 7073.

Thank you.

A handwritten signature in black ink that reads 'Lilo Ast'.

Board Designee Lilo Ast

Letter Sent By Lilo Ast on 06/02/2014 at 18:37:28-04:00