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The Effect of Instrumentation Taper on Dentin Conservation

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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

THE EFFECT OF INSTRUMENTATION TAPER ON DENTIN CONSERVATION

By Megan Green, DMD

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

Introduction: The aim of this in vitro study was two part. The first being to assess and compare the amount of dentin removed by an instrument with a taper of 0.04 versus an instrument with a taper of 0.06 using the Edge Evolve® file system at different increments within the canal system. Secondly, this study evaluated whether instrumentation with either taper resulted in a remaining dentin thickness (RDT) of less than 0.3mm. If this RDT was imposed upon, fracture resistance was compromised. Both pre and post instrumentation measurements were taken of samples instrumented with the 0.04 and 0.06 tapered files.

Methods: Ten maxillary premolars exhibiting Weine class III canal systems and minimal to no root canal curvature were mounted in an acrylic resin filled K-cube. Each acrylic resin cube was sectioned horizontally at 3, 6, 9, and 12mm increments from the apex. The K-cube is a device which allows the investigator to disassemble and then reassemble root slices in their original orientation. Dentin thickness was measured at three positions on each canal using the Zeiss Discovery V20 stereomicroscope. The sections were then reassembled into the K-cube. The ten premolar roots were separated into two groups. In half of the teeth the buccal canals were instrumented with 0.04 tapered files and the lingual canals instrumented with 0.06 tapered files. In the other half of the teeth, instrumentation was reversed: the buccal canals were instrumented with 0.06 tapered files and the lingual canals were instrumented with 0.04 tapered files. Root sections were again separated, and the remaining dentin thickness was measured. A repeated-measures mixed-model ANCOVA was performed to analyze the effect of taper on RDT.

Results: The amount of dentin removed was statistically different between the two tapers (P=0.02). Across all of the slices and positions, the 0.04 tapered instruments had an average pre-post difference of 0.1313mm. The 0.06 tapered instruments had an average pre-post difference of 0.1672mm. None of the instruments imposed upon the recommended 0.3mm RDT.

Conclusion: The 0.04 tapered files instrument with greater conservancy than the 0.06 tapered files. The 0.06 tapered files had their greatest effect on the canal in the 9mm and 12mm sections. However, neither taper imposed upon the recommended RDT for optimal fracture resistance within the apical 12mm root portion observed in this study.

Keywords: Instrumentation, Edge Evolve, Root canal preparation, Taper

Introduction

The fundamental goal of endodontics is to prevent or treat periradicular periodontitis(1). Microorganisms can invade the root canal system through the enamel and dentin layers through various modalities including cracks and caries(2). Once the pulp system has been compromised, cleaning and shaping procedures are important to act against these microbial invaders(3),(4). The overall goals of cleaning and shaping include removal of infected tissue, optimal delivery of disinfection solutions to the infected root canal system, create space for both intracanal medications and obturation materials, and to retain the integrity of radicular structures(5). Additional objectives for ideal instrumentation include a continuously tapered funnel shape that preserves the apical foramen size and original position(3).

Understanding the mechanical objectives of the instrumentation process is key in creating the best outcome for each case. First, it is important to be aware that no instrumentation method can completely debride root canal walls,(6)(7). Knowing this emphasizes the importance of preventing procedural mishaps like deviations, zipping, or perforations which may create further challenges for disinfection. Another important mechanical objective is to preserve as much radicular dentin as possible, thus preventing weakening of the root(5) and maximizing fracture resistance(8). This stresses the importance of straight-line access to each canal, which assists in preventing excessive thinning of radicular structures during instrumentation. Resulting dentin thickness is likely the most important factor that correlates with a root's fracture resistance. Lim and Stock proposed 0.3mm of remaining dentin thickness (RDT), canal wall thickness, is necessary to provide adequate fracture resistance(9). Fracture resistance is challenged by procedures such as lateral obturation (10)(11), excessive occlusal forces, and post placement(12).

The decision regarding final apical preparation size and final preparation taper is made based on the clinician's personal philosophy. Differing philosophies have created a long standing controversy that surrounds the cleaning and shaping process. Salzgeber discussed the success of instrumentation with a size 35 hand file (0.02 taper) and a #2 gates glidden in allowing irrigant to reach the apex(13). Boutsioukis compared file sizes and tapers to justify which combination had the greatest impact on cleaning. His results found instrumentation with a size 35 file (0.06 taper) or a size 60 file (0.02 taper) was necessary for effective irrigation(14). The benefits of maintaining a narrow apical size include reduced risk of canal transportation and extrusion of irrigants or obturation material. Combining a narrow apical size with a tapered preparation can help facilitate irrigant in reaching the apex, and thus allow for improved disinfection. However, a narrow apical size can hinder removing infected apical dentin and can impose on the medication's or irrigant's ability to reach the apical portion of the canal. It has also been shown that increasing taper can significantly weaken root structure(15). On the other hand, a wide apical size will more likely remove infected dentin and easily facilitate irrigant and medication in reaching the apical third of the canal. Disadvantages to a wide apical size include an increased risk of preparation errors and extrusion of irrigants or obturation materials(5). Between these various views, what remains common is the importance of maintaining the original canal curvature and minimizing instrumentation errors to allow proper disinfection of the canal. Shahriari compared removed dentin thickness between stainless steel hand files (0.02 taper) and Profile rotary instruments (0.04 taper) on the mesial roots of mandibular molars. He found that ProFile rotary instrumentation actually prepared root canals with a greater conservation of tooth structure, despite the increased taper(16). The idea behind this conclusion is that stainless steel hand files have shape memory and tend to obey this memory within canals, leading to excessive dentin removal in danger zones. This knowledge leads us to the question of whether or not the taper is less of an issue compared to the file's material characteristics.

Understanding the anatomy of each tooth can assist the clinician from the moment he accesses a tooth to the final obturation stage. Canal systems can be visualized in three segments: an apical segment, a middle segment, and a coronal segment. At the most apical extent of the apical segment lies the apical constriction, also known as the cementodentinal junction. Although age can influence predentin and cementum deposition, the apical constriction remains constant at an average width of 0.189mm throughout a patient's lifetime(17). The apical constriction is the furthest extent to which instrumentation and obturation should be carried out. This study utilized maxillary premolars, and as such, their anatomy was reviewed. It is important to note the furcation groove found on the buccal root of maxillary first premolars. The mean depth of the groove was found to be approximately 0.4mm and the typical canal system appeared kidney-shaped. The mean depth from the invagination to the canal wall was a meager 0.81mm(18). Vertucci's review of maxillary second premolars revealed the root curvature was not always indicative of the canal curvature. Approximately 20% of canals had a mesiodistal and buccolingual curvature(19). With this information, it is evident that excessive dentin removal, destructive intracanal forces or post placement could easily compromise these teeth.

The aim of this in vitro study was two part. The first being to assess and compare the amount of dentin removed by an instrument with a taper of 0.04 versus an instrument with a taper of 0.06 using the Edge Evolve® file system. Secondly, this study evaluated whether instrumentation with either taper resulted in a remaining dentin thickess (RDT) of less than 0.3mm.

Methods

Ten maxillary first premolars with mature apices and minimal to no root curvature were selected for this study. Teeth were stored in 10% buffered formalin solution. Digital radiographs were taken from a mesial-distal aspect to confirm each tooth exhibited a Weine class III canal configuration. Each premolar was sectioned using an Isomet low-speed saw with a 0.50 mm thick diamond blade, while irrigating with water, leaving 12 millimeters of root for evaluation. Working lengths of both the buccal and lingual canals were determined in hand using a 15 K-file. The file was inserted into each canal until visibly seen at the apex, and then 0.5 millimeters were subtracted from that length and recorded. Fast-set acrylic resin was poured into a device known as the K-cube(20) and the premolar was then placed into the acrylic, being cautious to not cover canal orifices. The K-cube is a device which allows the investigator to disassemble and then reassemble root slices in their original orientation. This allows the operator to reassemble root slices after initial measurements for instrumentation.

Once the acrylic had set, and the tooth was stabilized, the acrylic cube was removed from the K-cube housing. This was done for each premolar until 10 acrylic cubes had been made. Each acrylic cube was sectioned every three millimeters from the coronal root portion using the Isomet saw and water coolant. This created sections at the following distances from the apical tip: 3mm, 6mm, 9mm, and 12mm.

Five of the ten teeth were randomly assigned to have the buccal root instrumented with the 0.04 taper and the lingual root instrumented with the 0.06 taper (group A). The other five had the buccal root instrumented with the 0.06 taper and the lingual root instrumented with the 0.04 taper (group B). Once a glide path was established in each canal using a size #10 K file, instrumentation via a crown-down approach was achieved to an apical size 35 instrument. Saline irrigation and patency filing was completed throughout instrumentation.

Pre- and post-instrumentation photos of each slice were taken using the Zeiss Discovery V20 Stereo zoom microscope with transmitted, reflected, and fluorescence illumination. A blue ink dot was placed at the distobuccal position of the tooth as reference. Using a #10 blade, grooves were made at three locations on the buccal canal and three locations on the lingual canal. Relative to the buccal canal, grooves were made at the distobuccal (DB), straight buccal (B), and mesiobuccal (MB) locations. Relative to the lingual canal, grooves were made at the distolingual (DL), straight lingual (L), and mesiolingual (ML) locations (Figure 1). These grooves were used as repeatable locations for measuring the distance from the canal to the external root surface before and after instrumentation. In order to determine the amount of dentin removed, the difference between the pre- and post- was calculated. Distances were recorded in µm. Measurements were recorded blind to instrument taper.

Measurements were converted from µm to mm for analysis. Post instrumentation dimensions were observed to evaluate if the 0.3mm recommended RDT had been impinged upon. Additionally, a comparison of the within-tooth differences between the amount of dentin removed by the 0.04 taper and the 0.06 taper was observed. In half of the teeth, the buccal root was instrumented by the 0.04 and in the other half of the teeth the buccal root was instrumented by the 0.06 taper. The repeated-measures in a tooth thus varied by taper (0.04 or 0.06), slice (3, 6, 9, or 12 mm), position (distal, buccal/ lingual, or mesial), and canal (B or L). The differences were modeled using a repeated-measures mixed-model ANCOVA with the following variables in the model: Taper, Slice, Position, and the Slice*Position interaction, Canal. The pre-instrumentation distance was used as a covariate. All analyses were performed using SAS software (JMP Pro version 13.2, SAS version 9.4, SAS Institute Inc., Cary NC) at alpha = 0.05 level of significance.

Results

The raw data on the 10 teeth are given in Appendix 1 and the raw summary values given in Appendix 2. Values in the appendix are show in µm, to display the maximum precision. The observed differences are illustrated in the left-hand portion of Figure 2. The top panel shows the observed differences for the measurements of the 3 mm slice. As the legend indicates, red indicates the measurements of the canal that was instrumented by the 0.04 taper and blue indicates the 0.06 taper. The three positions (distal (D), buccal/lingual (B/L) and mesial (M)) have three different symbols. In all of the panels, the vertical axis is the pre-post difference and the horizontal axis is the pre-instrumentation distance. As the slices move coronally from the root apex, the pre-instrumentation measurements tend to be larger (and you can see that the dots move to the right).

The primary comparison entailed the within-tooth differences between the amount of dentin removed by the 0.04 taper and the 0.06 taper. The repeated-measures mixed-model ANCOVA indicated that there was a taper difference ($P = 0.0241$). The differences also varied by slice ($P = 0.0315$) and position ($P = 0.0021$) but not by the slice*position interaction ($P = 0.0943$). Differences varied by the pre-instrumentation dentin thickness ($P = 0.0405$) but not by canal ($P = 0.8095$). The predicted differences from this model are shown in the right-hand portion of Figure 2. In all figures, there is an upward trend. This indicates that the larger the pre-instrumentation dentin thickness, the more dentin was removed, but this trend is not large.

The estimated differences for each slice, taper and position are summarized in Table 1 and the means shown in Figure 3. That is, at the slice closest to the apex in the distal position, the 0.04 taper instruments had an average pre-post difference of 0.10 mm (SE = 0.04 mm, 95% CI =

0.02 to 0.18 mm) and the 0.06 taper instruments had an average difference of 0.04 mm (SE = 0.04, 95% CI = –0.04 to 0.12 mm). Across all of the slices and positions, the 0.04 taper instruments had an average pre-post difference of 0.131 (SE = 0.011, 95% CI = 0.109 to 0.153) and the 0.06 taper instruments had an average pre-post difference of 0.167 (SE = 0.011, 95% CI = 0.145 to 0.189). This is significantly different (mean difference = 0.036, SE = 0.016, 95% CI = 0.005 to 0.067, P = 0.024).

Tables

Table 1. Estimated Differences (mm)

Position	Taper	Mean	SE	96% CI	
		3 mm			
D	0.04	0.0977	0.0411	0.0167	0.1787
	0.06	0.0357	0.0408	-0.0446	0.1161
B/L	0.04	0.1333	0.0418	0.0508	0.2158
	0.06	0.1195	0.0404	0.0399	0.1992
M	0.04	0.1587	0.0414	0.0771	0.2403
	0.06	0.1859	0.0402	0.1067	0.2650
		6 mm			
D	0.04	0.1643	0.0388	0.0880	0.2406
	0.06	0.2270	0.0387	0.1505	0.3034
B/L	0.04	0.1853	0.0387	0.1091	0.2616
	0.06	0.1699	0.0390	0.0936	0.2462
M	0.04	0.1597	0.0390	0.0829	0.2366
	0.06	0.1907	0.0388	0.1138	0.2676
		9 mm			
D	0.04	0.1612	0.0388	0.0846	0.2377
	0.06	0.1934	0.0387	0.1171	0.2696
B/L	0.04	0.0571	0.0397	-0.0211	0.1353
	0.06	0.0882	0.0402	0.0090	0.1674
M	0.04	0.1743	0.0387	0.0980	0.2505
	0.06	0.2932	0.0387	0.2169	0.3694
		12 mm			
D	0.04	0.0878	0.0401	0.0087	0.1669
	0.06	0.1803	0.0401	0.1013	0.2594
B/L	0.04	0.0667	0.0421	-0.0164	0.1497
	0.06	0.0867	0.0431	0.0016	0.1717
M	0.04	0.1300	0.0393	0.0524	0.2075
	0.06	0.2363	0.0389	0.1596	0.3130

Abbreviations: D=distal position, B/L =buccal/ lingual position, M=mesial position, SE=standard error, CI=confidence interval.
Means and confidence intervals estimated from a repeated-measures mixed-model ANCOVA.

Figures

Figure 1. Canal Measurements by Position

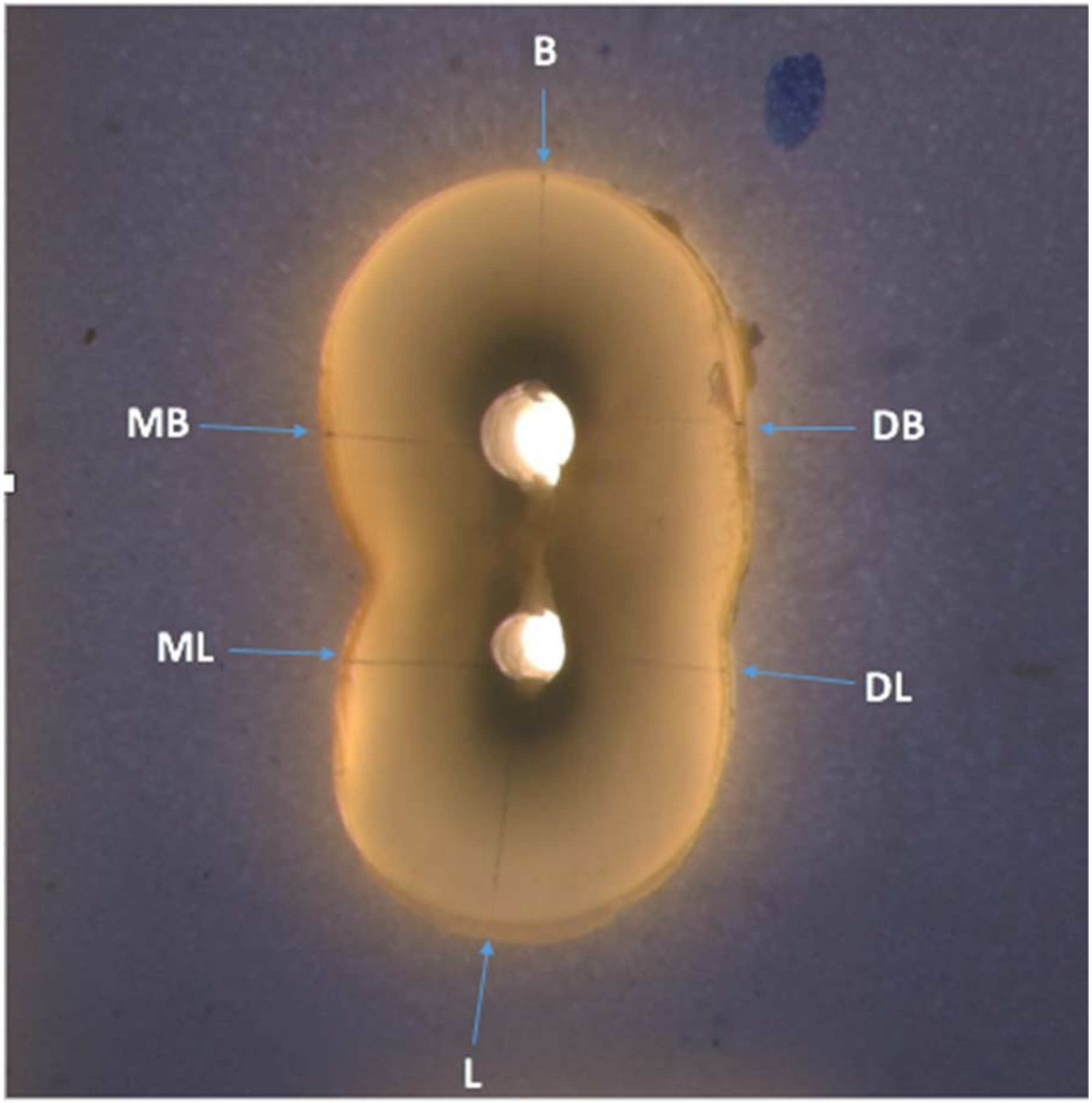
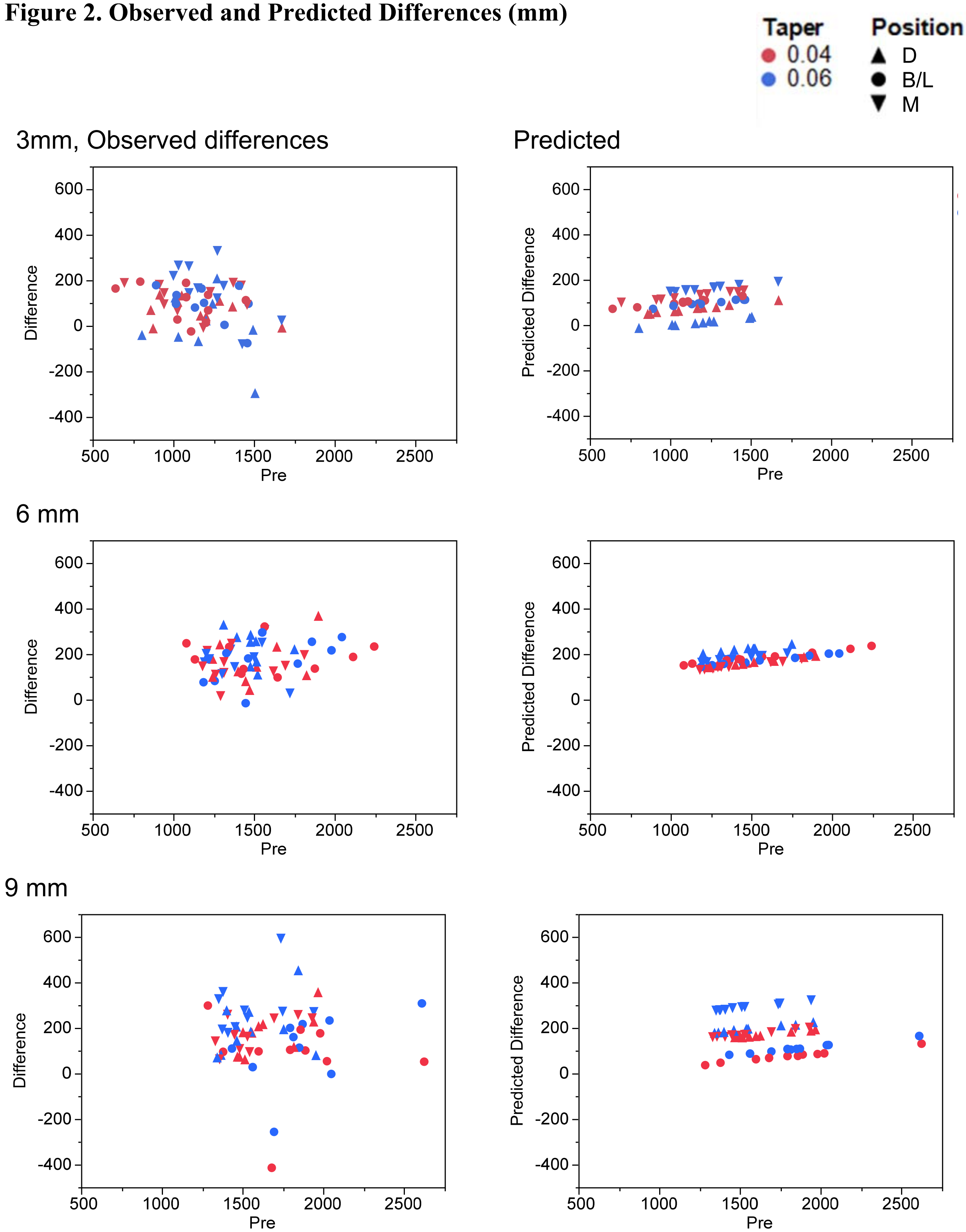

B
MB
DB
ML
DL
L

Figure 2. Observed and Predicted Differences (mm)



12 mm

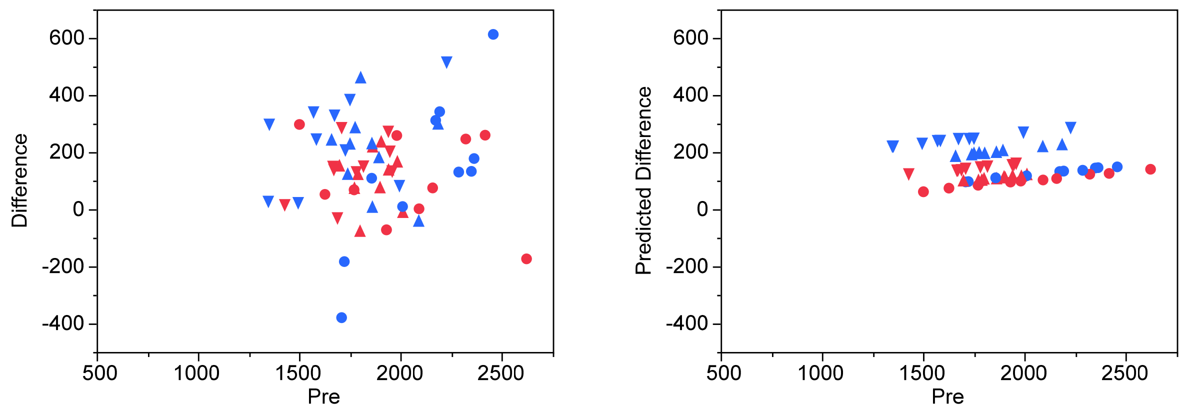


Figure 3. Estimated Differences (mm)

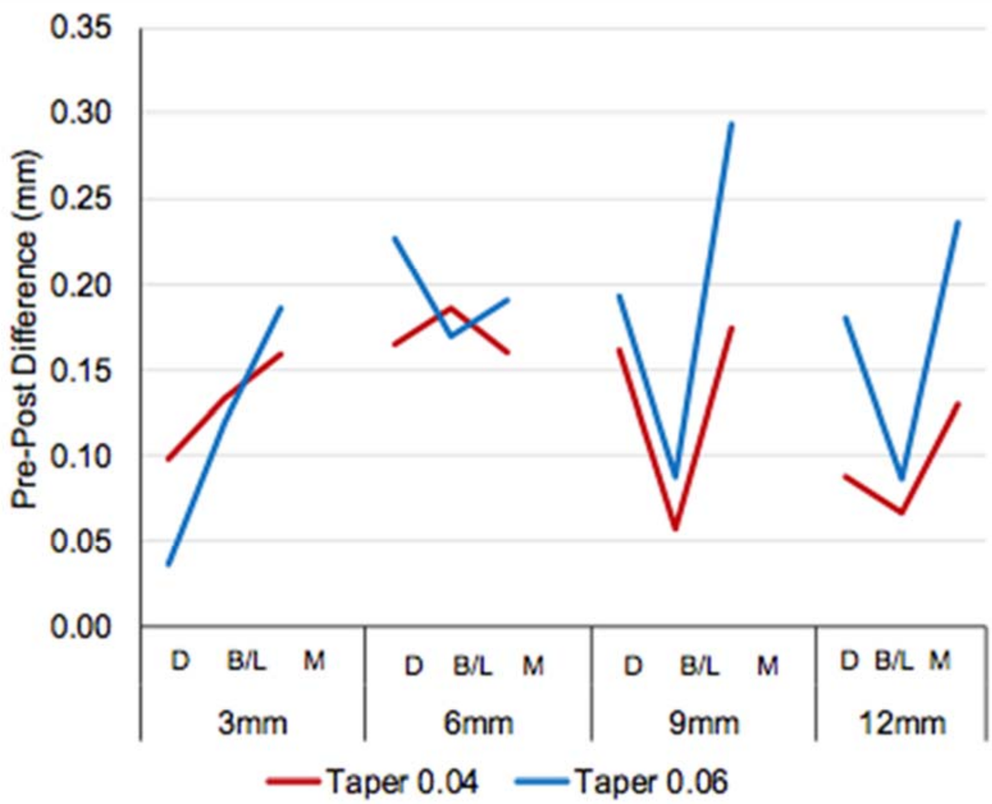
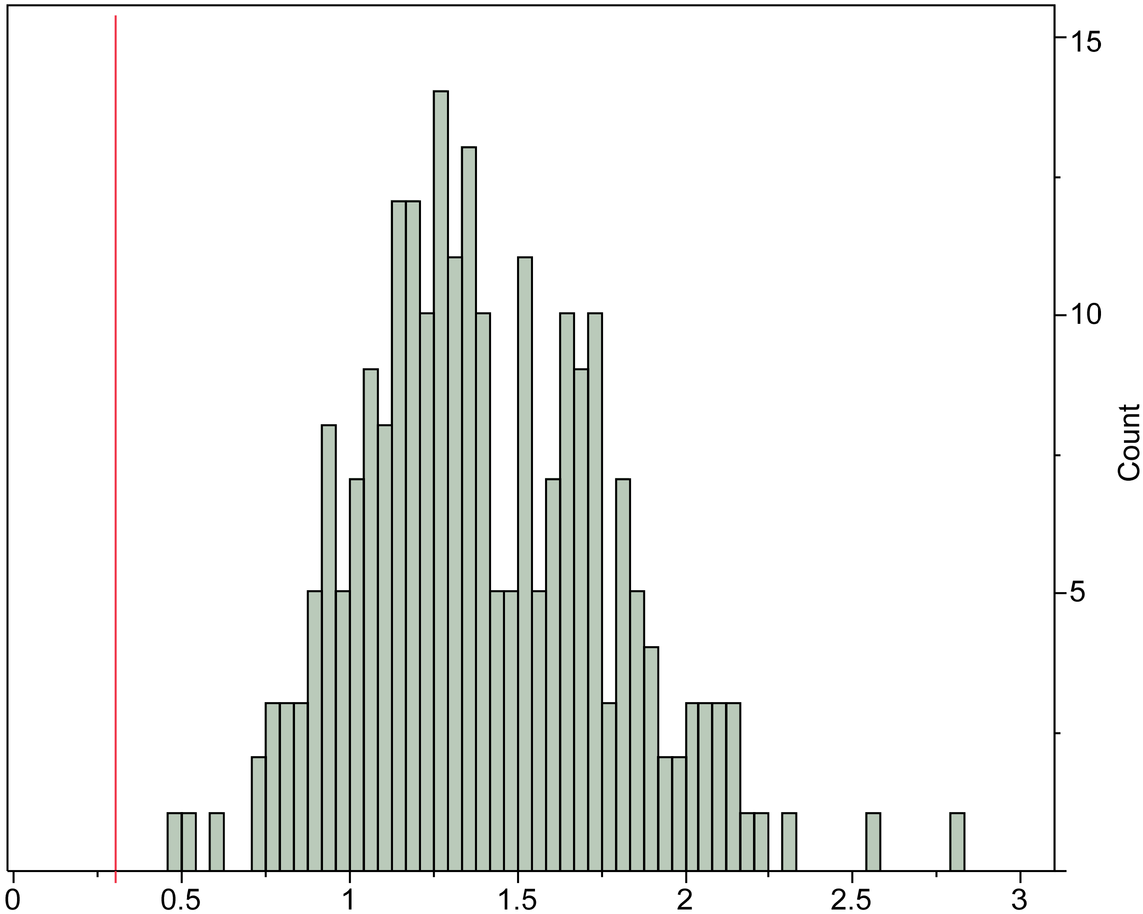


Figure 4. Remaining Dentin Thickness (mm)



In Figure 4 above, the red line indicates 0.3mm.

Discussion

The aim of this in vitro study was two part. The first being to assess and compare the amount of dentin removed by an instrument with a taper of 0.04 versus an instrument with a taper of 0.06 using the Edge Evolve® file system. Secondly, this study evaluated whether instrumentation with either taper resulted in a remaining dentin thickness (RDT) of less than 0.3mm. Various philosophies and studies exist regarding final instrumentation size and associated taper, however they focus more on comparing instruments of different metallurgy and their success in cleaning canals. In preparation for this thesis, no studies were identified that simply evaluated fixed tapered Nickel Titanium files and their effects on remaining dentin thickness.

Findings in this study are limited by variables such as tooth type, minimal degree of root curvature, measurement locations along the canals, and examination of only the 12mm apical root portion. Due to the difference in canal wall thickness and general anatomy variance between different types of teeth, this study's results can only be applied to maxillary premolars. One of the greatest danger zones on a premolar is found on the palatal aspect of the buccal root, and in this study, this dimension was not analyzed. Evaluating the danger zone on teeth, for example the furcal canal wall on the mesial root of a mandibular molar, may reveal different results. Additionally, evaluating remaining dentin thickness on teeth with dilacerated roots may show more impactful results due to a greater risk of transportation or straightening of the canal. In this study only 12mm of root was evaluated, and thus the fullest extent of either taper file was not able to be determined. A 0.06 tapered instrument assumedly would have its greatest effect in the cervical portion of the root canal, closer towards the furcation. Lastly, more accurate measurement techniques such as micro-CT would provide results with greater precision.

The Shahriari study compared pre and post instrumentation measurements of canals in the mesial roots of mandibular molars which were instrumented with both stainless steel hand files and Profile rotary NiTi files(16). Based on the recommendation that canal walls should not be thinner than 0.3mm after instrumentation, they analyzed their results to find which samples fell into this group. An RDT of less than 0.3mm was found in 7 of 36 samples with stainless steel hand files and 4 of 36 samples with rotary instruments at a level 2mm from the apex. For samples instrumented with stainless steel hand files, the removed dentin thickness on the furcal side of the root curvature in the mid-root (7-mm from apex) and on the outer side of the root curvature in the apical zone (2 and 4mm from apex) was significantly greater when compared to the rotary file measurements. This study followed a similar evaluation method to compare the effects of a 0.04 tapered instrument to a 0.06 tapered instrument.

The results of this study showed a statistical difference in the amount of dentin that was removed between those canals instrumented with 0.04 tapered instruments and those canals instrumented with 0.06 tapered files ($P<0.05$). Across all of the slices and positions, the 0.04 tapered instruments had an average pre-post difference of 0.1313mm. The 0.06 tapered instruments had an average pre-post difference of 0.1672mm. Observing the mean values in Table 1, the results show that the 0.06 tapered instrument removed more dentin than the 0.04 tapered instrument at the 9mm and 12mm sections at all positions. None of the samples in this study were found to have canal walls with a post-operative remaining dentin thickness of 0.3mm or less (Figure 4). These results confirm that nickel titanium files do instrument conservatively, and a change in taper from 0.04 vs 0.06 does not impose a detrimental effect on dentin thickness within the apical 12mm of the root canal in maxillary premolars.

In reviewing this overall study, several notes were made. The Edge Evolve files performed relatively well with no file separations. Unwinding was more common with the smaller sized files than the larger sizes between both tapers. When reviewing the root slices under microscopy, all canals appeared to reveal a centralized instrumentation without obvious transportation. The use of the K-cube was beneficial in re-orienting and realigning root slices, however there were times where significant trimming of the acrylic cube was necessary to fit back into the k-cube for instrumentation. This is an ironic finding as jet acrylic is known to shrink rather than expand.

In conclusion, this study adequately demonstrated the differences in remaining dentin thickness as a result of two different tapers of nickel titanium instruments. Understanding that neither taper left a remaining dentin thickness of 0.3mm or less allows the clinician to safely choose between either taper as dictated by the canal size the clinician is confronted with. Additional studies should be performed on the contribution various taper sizes impose on remaining dentin thickness throughout entire canal systems and in all types of teeth.

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Appendices

Appendix 1: Raw Data (in µm)

Sample	instrument	Slice	Position	Canal	Pre	Post	Difference
1	0.06	3mm	M	L	1096.69	951.75	144.94
1	0.06	3mm	I	L	892.64	714.55	178.09
1	0.06	3mm	D	L	1030.57	1080.57	-50
1	0.06	6mm	M	L	1191.65	1026.35	165.3
1	0.06	6mm	I	L	1186.37	1110.09	76.28
1	0.06	6mm	D	L	1199.95	1020.07	179.88
1	0.06	9mm	M	L	1373.3	1179.04	194.26
1	0.06	9mm	I	L	1561.74	1534.06	27.68
1	0.06	9mm	D	L	1365.88	1285.93	79.95
1	0.06	12mm	M	L	1493.95	1471.77	22.18
1	0.06	12mm	I	L	2456.15	1843.86	612.29
1	0.06	12mm	D	L	1859.72	1851.62	8.1
2	0.06	3mm	M	L	1669.92	1645.02	24.9
2	0.06	3mm	I	L	1316.22	1312.25	3.97
2	0.06	3mm	D	L	1202.5	1180.38	22.12
2	0.06	6mm	M	L	1379.34	1234.81	144.53
2	0.06	6mm	I	L	1447.24	1462.85	-15.61
2	0.06	6mm	D	L	1521.56	1412.76	108.8
2	0.06	9mm	M	L	1408.42	1228.5	179.92
2	0.06	9mm	I	L	1850.12	1736.86	113.26
2	0.06	9mm	D	L	1342.23	1273.23	69
2	0.06	12mm	M	L	1346.73	1319.69	27.04
2	0.06	12mm	I	L	2008.94	1999.63	9.31
2	0.06	12mm	D	L	1658.5	1415.28	243.22
3	0.06	3mm	M	L	1150.88	984.37	166.51
3	0.06	3mm	I	L	1457.57	1533.82	-76.25
3	0.06	3mm	D	L	1154.76	1223.48	-68.72
3	0.06	6mm	M	L	1354.18	1132.69	221.49
3	0.06	6mm	I	L	2042.79	1768.08	274.71
3	0.06	6mm	D	L	1515.3	1349.5	165.8
3	0.06	9mm	M	L	1736.28	1142.92	593.36
3	0.06	9mm	I	L	1694.07	1950.68	-256.61
3	0.06	9mm	D	L	1844.12	1392.65	451.47
3	0.06	12mm	M	L	1749.22	1365.69	383.53
3	0.06	12mm	I	L	1708.31	2087.86	-379.55
3	0.06	12mm	D	L	1857.76	1627.25	230.51
4	0.04	3mm	M	L	942.79	797.49	145.3
4	0.04	3mm	I	L	1215.23	1147.4	67.83
4	0.04	3mm	D	L	874.61	887.3	-12.69
4	0.04	6mm	M	L	1180.38	1032.87	147.51
4	0.04	6mm	I	L	1875.13	1739.02	136.11
4	0.04	6mm	D	L	1243.35	1144.8	98.55

Sample	instrument	Slice	Position	Canal	Pre	Post	Difference
4	0.04	9mm	M	L	1529.01	1366.17	162.84
4	0.04	9mm	I	L	2021.29	1967.47	53.82
4	0.04	9mm	D	L	1513.7	1453.41	60.29
4	0.04	12mm	M	L	1687.63	1718.59	-30.96
4	0.04	12mm	I	L	2090.18	2088.57	1.61
4	0.04	12mm	D	L	1788.31	1665.62	122.69
5	0.06	3mm	M	L	1031.15	764.93	266.22
5	0.06	3mm	I	L	1464.71	1367.53	97.18
5	0.06	3mm	D	L	1493	1512.04	-19.04
5	0.06	6mm	M	L	1223.48	1044.08	179.4
5	0.06	6mm	I	L	1769.61	1611.72	157.89
5	0.06	6mm	D	L	1310.48	982.95	327.53
5	0.06	9mm	M	L	1378.39	1019.34	359.05
5	0.06	9mm	I	L	1870.96	1654.45	216.51
5	0.06	9mm	D	L	1400.45	1124.68	275.77
5	0.06	12mm	M	L	1351.5	1054.3	297.2
5	0.06	12mm	I	L	1721.73	1905.11	-183.38
5	0.06	12mm	D	L	1738.37	1614.84	123.53
6	0.04	3mm	M	L	1420.27	1242.3	177.97
6	0.04	3mm	I	L	1215	1079.19	135.81
6	0.04	3mm	D	L	1285.79	1177.85	107.94
6	0.04	6mm	M	L	1692.75	1542.78	149.97
6	0.04	6mm	I	L	1644.96	1547.42	97.54
6	0.04	6mm	D	L	1640.14	1409.28	230.86
6	0.04	9mm	M	L	1542.54	1447.56	94.98
6	0.04	9mm	I	L	1979.37	1803.2	176.17
6	0.04	9mm	D	L	1939.18	1712.94	226.24
6	0.04	12mm	M	L	1946.33	1743.73	202.6
6	0.04	12mm	I	L	2416.34	2156.83	259.51
6	0.04	12mm	D	L	1771.29	1697.15	74.14
7	0.04	3mm	M	L	913.38	731.69	181.69
7	0.04	3mm	I	L	1079.45	953.6	125.85
7	0.04	3mm	D	L	1027.08	922.82	104.26
7	0.04	6mm	M	L	1209	993.51	215.49
7	0.04	6mm	I	L	2112.35	1924.96	187.39
7	0.04	6mm	D	L	1400.45	1278.01	122.44
7	0.04	9mm	M	L	1694.07	1451.1	242.97
7	0.04	9mm	I	L	2623.23	2571.57	51.66
7	0.04	9mm	D	L	1598.08	1392.45	205.63
7	0.04	12mm	M	L	1938.85	1666.29	272.56
7	0.04	12mm	I	L	2620.17	2793.75	-173.58
7	0.04	12mm	D	L	1983.17	1816.79	166.38
8	0.06	3mm	M	L	1270.7	1148.7	122
8	0.06	3mm	I	L	1189.58	1088.82	100.76

Sample	instrument	Slice	Position	Canal	Pre	Post	Difference
8	0.06	3mm	D	L	1270.33	1063.8	206.53
8	0.06	6mm	M	L	1548.57	1296.9	251.67
8	0.06	6mm	I	L	1462.93	1281.87	181.06
8	0.06	6mm	D	L	1510.5	1255.65	254.85
8	0.06	9mm	M	L	1351.7	1024.17	327.53
8	0.06	9mm	I	L	1813.55	1653.78	159.77
8	0.06	9mm	D	L	1463.69	1321.38	142.31
8	0.06	12mm	M	L	1726.54	1519.41	207.13
8	0.06	12mm	I	L	2285.56	2155.31	130.25
8	0.06	12mm	D	L	1802.16	1340.91	461.25
9	0.04	3mm	M	L	1024.63	957.11	67.52
9	0.04	3mm	I	L	1024.63	997.35	27.28
9	0.04	3mm	D	L	1051.47	919.58	131.89
9	0.04	6mm	M	L	1359.75	1112.52	247.23
9	0.04	6mm	I	L	1433.59	1299.41	134.18
9	0.04	6mm	D	L	1447.24	1367.53	79.71
9	0.04	9mm	M	L	1480.59	1371.89	108.7
9	0.04	9mm	I	L	1857.76	1665.62	192.14
9	0.04	9mm	D	L	1625.36	1410.27	215.09
9	0.04	12mm	M	L	1669.92	1531.08	138.84
9	0.04	12mm	I	L	2157.21	2082.5	74.71
9	0.04	12mm	D	L	1861.02	1641.73	219.29
10	0.04	3mm	M	L	942	846.35	95.65
10	0.04	3mm	I	L	794.68	600.79	193.89
10	0.04	3mm	D	L	860.11	792.22	67.89
10	0.04	6mm	M	L	1260.61	1149.43	111.18
10	0.04	6mm	I	L	1080.57	833.15	247.42
10	0.04	6mm	D	L	1242.22	1064.85	177.37
10	0.04	9mm	M	L	1406.63	1147.4	259.23
10	0.04	9mm	I	L	1284.34	986.26	298.08
10	0.04	9mm	D	L	1556.73	1379	177.73
10	0.04	12mm	M	L	1665.45	1515.79	149.66
10	0.04	12mm	I	L	1500.16	1203.21	296.95
10	0.04	12mm	D	L	1903.39	1666.79	236.6
1	0.04	3mm	M	B	1185.33	1192.63	-7.3
1	0.04	3mm	I	B	1109.51	1134.33	-24.82
1	0.04	3mm	D	B	1167.64	1124.68	42.96
1	0.04	6mm	M	B	1312.47	1193.96	118.51
1	0.04	6mm	I	B	1345.48	1114.11	231.37
1	0.04	6mm	D	B	1471.9	1430.73	41.17
1	0.04	9mm	M	B	1330.71	1188.32	142.39
1	0.04	9mm	I	B	1598.59	1501.65	96.94
1	0.04	9mm	D	B	1479.59	1407.09	72.5
1	0.04	12mm	M	B	1957.65	1824.5	133.15

Sample	instrument	Slice	Position	Canal	Pre	Post	Difference
1	0.04	12mm	I	B	1929.52	2001.6	-72.08
1	0.04	12mm	D	B	1798.95	1875.4	-76.45
2	0.04	3mm	M	B	1456.23	1363.03	93.2
2	0.04	3mm	I	B	1201.58	1187.93	13.65
2	0.04	3mm	D	B	1366.17	1283.25	82.92
2	0.04	6mm	M	B	1291.93	1275.03	16.9
2	0.04	6mm	I	B	1420.73	1307.02	113.71
2	0.04	6mm	D	B	1515.48	1372.57	142.91
2	0.04	9mm	M	B	1357	1293.82	63.18
2	0.04	9mm	I	B	1887.61	1786.95	100.66
2	0.04	9mm	D	B	1467.32	1394.87	72.45
2	0.04	12mm	M	B	1781.36	1651.04	130.32
2	0.04	12mm	I	B	1769.87	1701.74	68.13
2	0.04	12mm	D	B	1897.66	1821.36	76.3
3	0.04	3mm	M	B	1370.6	1180.38	190.22
3	0.04	3mm	I	B	1448.34	1335.97	112.37
3	0.04	3mm	D	B	1202.51	1162.32	40.19
3	0.04	6mm	M	B	1810.62	1613.63	196.99
3	0.04	6mm	I	B	2242.89	2009.64	233.25
3	0.04	6mm	D	B	1824.21	1718.59	105.62
3	0.04	9mm	M	B	1842.91	1584.43	258.48
3	0.04	9mm	I	B	1679.55	2093.96	-414.41
3	0.04	9mm	D	B	1966.47	1611.31	355.16
3	0.04	12mm	M	B	1816.02	1665.4	150.62
3	0.04	12mm	I	B	1625.88	1573.64	52.24
3	0.04	12mm	D	B	1940.14	1801.9	138.24
4	0.06	3mm	M	B	1310.55	1133.34	177.21
4	0.06	3mm	I	B	1406.3	1230.47	175.83
4	0.06	3mm	D	B	1010.25	887.72	122.53
4	0.06	6mm	M	B	1499.35	1311.9	187.45
4	0.06	6mm	I	B	1857.36	1603.2	254.16
4	0.06	6mm	D	B	1478.32	1195.44	282.88
4	0.06	9mm	M	B	1510.37	1232.28	278.09
4	0.06	9mm	I	B	2048.03	2050.44	-2.41
4	0.06	9mm	D	B	1539.15	1270.18	268.97
4	0.06	12mm	M	B	1673.27	1344.31	328.96
4	0.06	12mm	I	B	2191.79	1850.12	341.67
4	0.06	12mm	D	B	1892.15	1710.77	181.38
5	0.04	3mm	M	B	1228.87	1078.76	150.11
5	0.04	3mm	I	B	1078.41	889.92	188.49
5	0.04	3mm	D	B	1672.15	1681.76	-9.61
5	0.04	6mm	M	B	1618.93	1493.62	125.31
5	0.04	6mm	I	B	1564.79	1244.1	320.69
5	0.04	6mm	D	B	1897.46	1531.08	366.38

Sample	instrument	Slice	Position	Canal	Pre	Post	Difference
5	0.04	9mm	M	B	1930.22	1686.63	243.59
5	0.04	9mm	I	B	1793.72	1689.89	103.83
5	0.04	9mm	D	B	1816.79	1701.76	115.03
5	0.04	12mm	M	B	1708.31	1422.89	285.42
5	0.04	12mm	I	B	2320.8	2074.92	245.88
5	0.04	12mm	D	B	2010.42	2020.73	-10.31
6	0.06	3mm	M	B	1426.23	1505.55	-79.32
6	0.06	3mm	I	B	1133.34	1053.32	80.02
6	0.06	3mm	D	B	1505.55	1802.73	-297.18
6	0.06	6mm	M	B	1721.35	1692.7	28.65
6	0.06	6mm	I	B	1327.57	1123.44	204.13
6	0.06	6mm	D	B	1749.22	1529.44	219.78
6	0.06	9mm	M	B	1940.14	1668.97	271.17
6	0.06	9mm	I	B	1793.46	1593.4	200.06
6	0.06	9mm	D	B	1953.26	1874.19	79.07
6	0.06	12mm	M	B	1993.44	1911.31	82.13
6	0.06	12mm	I	B	2172.36	1861.02	311.34
6	0.06	12mm	D	B	2088.62	2129.52	-40.9
7	0.06	3mm	M	B	999.87	779.17	220.7
7	0.06	3mm	I	B	1019.34	884.25	135.09
7	0.06	3mm	D	B	1010.99	888.25	122.74
7	0.06	6mm	M	B	1566.28	1258.99	307.29
7	0.06	6mm	I	B	1978.42	1761.96	216.46
7	0.06	6mm	D	B	1476.56	1224.16	252.4
7	0.06	9mm	M	B	1747.09	1474.35	272.74
7	0.06	9mm	I	B	2609.05	2301.28	307.77
7	0.06	9mm	D	B	1753.74	1561.03	192.71
7	0.06	12mm	M	B	2226.59	1711.8	514.79
7	0.06	12mm	I	B	2348.29	2215.64	132.65
7	0.06	12mm	D	B	2184.3	1885.05	299.25
8	0.04	3mm	M	B	696.32	506.74	189.58
8	0.04	3mm	I	B	641.73	477.97	163.76
8	0.04	3mm	D	B	915.52	780.01	135.51
8	0.04	6mm	M	B	1313.03	1146.67	166.36
8	0.04	6mm	I	B	1133.1	956.43	176.67
8	0.04	6mm	D	B	1287.81	1046.85	240.96
8	0.04	9mm	M	B	1449.3	1278.37	170.93
8	0.04	9mm	I	B	1378.73	1283.83	94.9
8	0.04	9mm	D	B	1501.96	1322.51	179.45
8	0.04	12mm	M	B	1427.6	1412.64	14.96
8	0.04	12mm	I	B	1980.26	1722	258.26
8	0.04	12mm	D	B	1697.15	1544.71	152.44
9	0.06	3mm	M	B	1096.24	833.7	262.54
9	0.06	3mm	I	B	1174.68	1010.99	163.69

Sample	instrument	Slice	Position	Canal	Pre	Post	Difference
9	0.06	3mm	D	B	1242.3	1146.67	95.63
9	0.06	6mm	M	B	1203.21	1001.08	202.13
9	0.06	6mm	I	B	1549.83	1254.83	295
9	0.06	6mm	D	B	1476.56	1332.61	143.95
9	0.06	9mm	M	B	1453.41	1248.28	205.13
9	0.06	9mm	I	B	2036.9	1804.44	232.46
9	0.06	9mm	D	B	1549.83	1367.53	182.3
9	0.06	12mm	M	B	1569.9	1229.78	340.12
9	0.06	12mm	I	B	2361.63	2184.17	177.46
9	0.06	12mm	D	B	1775.08	1488.94	286.14
10	0.06	3mm	M	B	1272.16	942	330.16
10	0.06	3mm	I	B	1016.04	919.58	96.46
10	0.06	3mm	D	B	805.4	847.34	-41.94
10	0.06	6mm	M	B	1301.42	1187.93	113.49
10	0.06	6mm	I	B	1255.87	1173.97	81.9
10	0.06	6mm	D	B	1392.45	1119.45	273
10	0.06	9mm	M	B	1528.95	1283.25	245.7
10	0.06	9mm	I	B	1433.4	1324.2	109.2
10	0.06	9mm	D	B	1461.21	1256.54	204.67
10	0.06	12mm	M	B	1583.55	1338.06	245.49
10	0.06	12mm	I	B	1856.51	1747.78	108.73
10	0.06	12mm	D	B	1749.22	1520.21	229.01

Appendix 2: Summary Means and Standard Deviations (in μm)

Slice	Pos	Taper	Canal	N	Pre Mean	Pre SD	Post Mean	Post SD	Difference Mean	Difference SD
3mm	D	0.04	B	5	1264.798	279.073	1206.404	324.924	58.394	54.182
3mm	D	0.04	L	5	1019.812	172.038	939.954	143.092	79.858	56.568
3mm	D	0.06	B	5	1114.898	267.571	1114.542	402.706	0.356	179.790
3mm	D	0.06	L	5	1230.232	171.015	1212.054	180.550	18.178	110.766
3mm	I	0.04	B	5	1095.914	292.465	1005.224	335.684	90.690	93.075
3mm	I	0.04	L	5	1065.798	173.189	955.666	211.955	110.132	64.373
3mm	I	0.06	B	5	1149.940	159.369	1019.722	136.016	130.218	41.485
3mm	I	0.06	L	5	1264.144	236.605	1203.394	316.254	60.750	98.348
3mm	M	0.04	B	5	1187.470	295.261	1064.308	327.973	123.162	82.995
3mm	M	0.04	L	5	1048.614	211.871	914.988	200.638	133.626	50.559
3mm	M	0.06	B	5	1221.010	171.187	1038.752	293.955	182.258	156.722
3mm	M	0.06	L	5	1243.868	253.869	1098.954	334.303	144.914	86.761
6mm	D	0.04	B	5	1599.372	254.836	1419.964	246.526	179.408	127.116
6mm	D	0.04	L	5	1394.680	165.221	1252.894	146.008	141.786	61.841
6mm	D	0.06	B	5	1514.622	136.178	1280.220	158.928	234.402	56.034
6mm	D	0.06	L	5	1411.558	148.026	1204.186	193.721	207.372	84.989
6mm	I	0.04	B	5	1541.398	421.986	1326.260	404.942	215.138	76.649
6mm	I	0.04	L	5	1629.320	397.939	1468.792	424.272	160.528	58.159
6mm	I	0.06	B	5	1593.810	317.964	1383.480	282.661	210.330	80.094
6mm	I	0.06	L	5	1581.788	330.297	1446.922	260.410	134.866	109.881
6mm	M	0.04	B	5	1469.396	234.182	1344.582	200.806	124.814	68.229
6mm	M	0.04	L	5	1340.498	208.425	1166.222	219.416	174.276	55.473
6mm	M	0.06	B	5	1458.322	207.498	1290.520	253.722	167.802	104.085
6mm	M	0.06	L	5	1339.444	142.156	1146.966	117.829	192.478	43.457
9mm	D	0.04	B	5	1646.426	230.345	1487.508	160.860	158.918	118.114
9mm	D	0.04	L	5	1646.610	168.929	1469.614	138.886	176.996	67.670
9mm	D	0.06	B	5	1651.438	200.426	1465.894	258.633	185.544	68.418
9mm	D	0.06	L	5	1483.274	206.838	1279.574	98.243	203.700	161.099
9mm	I	0.04	B	5	1667.640	195.360	1671.256	304.662	-3.616	229.666
9mm	I	0.04	L	5	1953.198	477.164	1798.824	570.877	154.374	103.940
9mm	I	0.06	B	5	1984.168	429.259	1814.752	381.445	169.416	119.588
9mm	I	0.06	L	5	1758.088	129.361	1705.966	154.732	52.122	185.918
9mm	M	0.04	B	5	1582.028	283.157	1406.314	216.130	175.714	79.459
9mm	M	0.04	L	5	1530.568	105.756	1356.824	123.788	173.744	75.255
9mm	M	0.06	B	5	1635.992	203.362	1381.426	187.701	254.566	30.339
9mm	M	0.06	L	5	1449.618	161.523	1118.794	93.664	330.824	166.699
12mm	D	0.04	B	5	1868.864	122.802	1812.820	172.640	56.044	98.000
12mm	D	0.04	L	5	1861.436	86.679	1697.616	69.462	163.820	67.295
12mm	D	0.06	B	5	1937.874	192.115	1746.898	266.796	190.976	137.917
12mm	D	0.06	L	5	1783.302	85.635	1569.980	200.636	213.322	167.956
12mm	I	0.04	B	5	1925.266	261.376	1814.780	213.371	110.486	140.255
12mm	I	0.04	L	5	2156.812	423.582	2064.972	566.360	91.840	193.045

					Pre		Post		Difference	
Slice	Pos	Taper	Canal	N	Mean	SD	Mean	SD	Mean	SD
12mm	I	0.06	B	5	2186.116	203.695	1971.746	213.203	214.370	105.840
12mm	I	0.06	L	5	2036.138	333.798	1998.354	127.682	37.784	375.000
12mm	M	0.04	B	5	1738.188	195.859	1595.294	175.815	142.894	96.168
12mm	M	0.04	L	5	1781.636	147.188	1635.096	105.829	146.540	112.471
12mm	M	0.06	B	5	1809.350	289.317	1507.052	290.374	302.298	157.318
12mm	M	0.06	L	5	1533.588	195.813	1346.172	181.699	187.416	161.187

Vita

Dr. Megan Green was born on November 15, 1989 in Atlanta, Georgia. She received a Bachelor of Science and Arts from the University of Georgia in 2012 before attending The Dental College of Georgia at Augusta University where she earned a Doctor of Dental Medicine in 2016. She is a member of the American Dental Association and the American Association of Endodontists. Dr. Green will graduate from Virginia Commonwealth University with a Master of Science in Dentistry and a Certificate in Endodontics.