2023

Effect of apical preparation size on endodontic treatment outcomes

Joseph Vaughn
Virginia Commonwealth University

Effect of apical preparation size on endodontic treatment outcomes

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

By

Joe Vaughn, DMD

University of Montevallo, 2011

University of Alabama at Birmingham, 2015

Thesis advisor: Garry L. Myers, DDS, FACD, FICD

Department of Endodontics

Virginia Commonwealth University

Richmond, Virginia

May, 2023

Acknowledgements

Thank you to the AAE Foundation for their support of this project by way of the Resident Research Grant. Thank you to Dr. Garry Myers for all of the work and support of this project as well as to my Thesis Advisory Committee.

Table of Contents

List of Tables

List of Figures

Abstract

EFFECT OF APICAL PREPARATION SIZE ON ENDODONTIC TREATMENT OUTCOMES

By: Joe Vaughn, DMD

Objective: Previous authors have attempted to identify the ideal apical preparation size needed to achieve endodontic treatment objectives. Despite vast literature on the topic, there exists a lack of consensus on ideal apical enlargement, with few studies discussing the effect of apical prep enlargement on clinical outcomes. The purpose of this retrospective study was to evaluate the effect of final apical preparation size on endodontic outcomes in maxillary and mandibular molars treated in both a graduate endodontic clinic and a private practice.

Methods: A chart review was conducted for patients seen at the VCU graduate endodontic clinic as well as a private practice. A total of 200 cases were included from each location. Eligible cases included maxillary and mandibular first and second molars that were treated by primary root canal therapy and had at least an 11 month recall available. Healing outcomes by individual root were evaluated radiographically by three board certified endodontists. Patient charts were reviewed by the author for each case, and the ending apical prep size among other variables were recorded. Statistical analysis was performed to assess the correlation of apical prep size with radiographic healing outcomes.

Results: When accounting for each individual root, there were no statistically significant differences in healing outcomes between any of the apical preparation sizes reviewed. While not statistically significant, there was a trend noted wherein the not healing group was prepared to larger apical preparation sizes than the healing group.

Conclusion: While previous studies have shown the debridement and disinfection benefits of larger apical preparation sizes, the present study found no direct correlation between apical preparation size and radiographic healing outcomes.

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, 2023

Thesis Advisor: Garry L. Myers, DDS, FACD, FICD

Department of Endodontics

Introduction

One of the primary objectives of endodontic therapy is to eliminate microbial infection from the root canal system and to prevent reinfection. This is primarily accomplished by way of thorough canal debridement and disinfection through instrumentation and irrigation protocols. Schilder stated that cleaning and shaping of the root canal system is arguably the most important phase of endodontic treatment, with the primary objectives being to maintain the original canal anatomy while also keeping the apical foramen in its original position and as small as possible.(1)

Despite the vast amount of literature on instrumentation and apical preparation size, there still exists a lack of consensus on ideal enlargement. There have only been a few studies that discuss the effect of apical enlargement on clinical outcomes. In 1979, Kerekes and Tronstad found no difference in healing outcomes between roots that were instrumented to reamer sizes of the #20-40 range and roots instrumented to sizes in the #45-100 range. (2) Another retrospective study in 2002 also found no significant difference. However, Hoskinson commented in the study that while no statistically significant difference was found in healing of teeth prepared to master apical file (MAF) sizes ranging from #20 to >40, a surprising trend of a decrease in success rates was evident with an increase in MAF size. (3)

Clinicians encounter unique challenges in attempting to provide complete debridement and disinfection of the root canal system, with perhaps the most challenging area to treat being the apical third in which isthmuses, fins, ramifications, and lateral canals are common. In 1956, Green studied the apical anatomy of 400 maxillary and mandibular anterior teeth and found that as many as 10-12% of anterior teeth contained lateral canals with accessory foramina in the apical third. (4) A second study by Green in 1960 looking at maxillary and mandibular posterior teeth found a high incidence of accessory foramina across all teeth studied. Of note, accessory foramina were found in 32% of mesiobuccal roots of maxillary molars, 35% of distal roots of mandibular molars, and as high as 47% in mandibular premolars. (5) Oftentimes these lateral canals are not visible radiographically and are unlikely to be accessible to instrumentation.

Endodontic literature discussing microsurgery indications has highlighted the incidence of isthmuses in specific roots of molar teeth. A canal isthmus is a narrow, ribbon shaped communication between two root canals that typically contains pulp tissue. It can be observed between any two root canal systems that occur within one root. Hsu’s 1997 paper presents a classification system describing types of isthmuses which can range from relatively small fins and offshoots from the main canal to pronounced corridors that connect the two canals together. (6) In 1995, while looking at the mesiobuccal roots of extracted maxillary first molars, Weller found the incidence of an isthmus to be extremely high. In roots which contained two canals, he noted the presence of a complete or partial isthmus 80-100% of the time when looking at cross sections that were between 3-5mm from the anatomical apex. At the 4mm level, there was an isthmus present 100% of the time. (7)

Several years later, Von Arx studied the incidence of isthmuses in the roots of both maxillary and mandibular molars. His findings for maxillary molars were similar to that of Weller’s in that 76% of resected mesiobuccal roots had two canals and an isthmus. In mandibular first molars, 83% of mesial roots contained two canals with an isthmus, thus highlighting how common anatomical variations are in the apical third in both maxillary and mandibular teeth. (8) These ramifications found in the apical third of the root canal system not only make this area the most difficult to physically reach with instrumentation, but it is perhaps the most critical area to adequately clean and disinfect. (9) Bacteria are the primary etiology of pulpal disease, and so the prognosis of nonsurgical endodontic therapy is dependent on our ability to disinfect the entire root canal system.

Historically, authors have attempted to identify what the ideal apical preparation size should be during instrumentation in order to achieve endodontic treatment objectives. An important role of cleaning and shaping the canal system is to create an unobstructed pathway that allows penetration and distribution of the irrigant used for disinfection. In 1982, Abou-Rass looked at the effectiveness of different irrigation methods in removing root canal debris. One of his main conclusions was that enlarging the apical third to at least a size #30 K-file (0.3mm in diameter at the tip) is necessary to facilitate irrigant penetration and subsequent disinfection. (10) These findings were substantiated in 2006 by an in vitro study by Khademi. The results showed that a minimum preparation to a size #30 was required in order to allow penetration of an irrigant to the apical third. (11)

Brunson, on the other hand, found in his 2010 study that the maximum volume of irrigant reached the apical third when preparing the canal to a size #40 with a 0.04 taper, which equates to two sizes larger than what was recommended by Abou-Rass. (12) Albrecht, in a 2004 in vitro study, also found an apical preparation size of #40 to be most beneficial. While the purpose of the study was to evaluate the effect of preparation taper on the ability to introduce irrigant and remove debris, Albrecht found that preparing the canal to a larger apical size mattered more than the associated taper, showing a significant reduction in canal debris for the groups prepared to a size #40 in comparison to those prepared to a size #20. The only group which had no difference was when the canals were prepared with a taper of 0.1mm, quite a bit larger than what is typical in standard preparations. (13) Another 2004 in vitro study by Usman found almost identical results in that there was a significant difference in debris removal from the apical third when size #40 instruments were used as compared to size #20 instruments. Usman added that there appeared to be no advantage with needle penetration beyond 75% of the working length in regards to canal cleanliness. It was concluded that the size of instrumentation at working length mattered most and not the number of flushes of irrigant or the number of instrument changes. (14)

As mentioned above, another theorized benefit to enlarging canal shapes is that it debrides the canal and reduces the bacterial load. Many authors have weighed in on what instrument size might best accomplish this. In 1998, Dalton compared the debridement ability of nickel titanium rotary instruments with that of conventional stainless steel hand files. He found no significant differences in the type of instrument used for debridement but did find a significant reduction in bacterial loads when larger instrument sizes were used for both nickel titanium and stainless steel. (15) He concluded that the type of instrument did not matter as long as you shaped the canal large enough. Four years later, Card found similar results in his clinical study on bacterial reduction. When preparing anterior teeth and bicuspids to apical sizes of #80-100 (0.8mm - 1.0mm in diameter at the tip), Card saw a 100% reduction of bacteria in those canals. When preparing molar teeth to apical sizes of #57.5 - 65 (0.575mm - 0.65mm in diameter at the tip), there was an 89% reduction in bacteria. Card concluded that if a clinician could instrument teeth to these sizes, a two-stage approach with an intracanal dressing is likely not necessary. However, there may be concerns in preparing canals this large, such as decreased resistance to fracture and a higher likelihood of iatrogenic error. (16)

An in vitro study from the same year (2002) also looked at the efficacy of bacterial removal related to final instrument size. Rollison found that instrumentation to an apical size of #50 was significantly more effective in debriding infected root canals than instrumentation to an apical size of #35. This study used only saline as an irrigant and so the removal of bacteria was attributed to the instrumentation alone. (17) In a 2017 randomized controlled trial, Rodrigues studied the influence of apical preparation size and irrigant type on bacterial reduction. Using a three-file rotary system with each file in the sequence being larger than the one before it, he saw a highly significant reduction in bacterial counts as the size of the file increased. He also noted no difference in bacterial reduction between NaOCl and saline when the canal was prepared with the smallest file size. However, when the canal was prepared with the largest file, he noted a significant difference in the disinfecting ability of NaOCl compared to saline. This finding implies that in order to get the benefits of NaOCl, the canal has to be prepared large enough to allow the irrigant to reach the apical third. (18)

Similar results were found in a 2019 scanning electron microscopy study conducted by Plotino. In comparing four groups consisting of different preparation sizes and tapers, Plotino saw significantly less debris and smear layer in the apical third of canals prepared to a size 25 (with both 0.04 and 0.06 tapers) as compared to those prepared to a size 20. It was noted however, that residual debris and smear layer remained in the apical third of all samples regardless of preparation size. (19) Contrary to the studies mentioned above, Yared found in a 1994 clinical study that there was no significant difference in bacterial reduction between canals enlarged to a size 25 and those enlarged to a size 40, suggesting that perhaps it isn't necessary to enlarge the apical third past a size 25 in order to achieve adequate canal cleanliness. (20)

With endodontic research highlighting the importance of apical preparation size, there have been attempts to 'standardize' the apical preparation size recommendation so that clinicians could apply a simplified rule to most cases. One method recommended increasing the apical preparation to 3 sizes larger than the first apical binding file (FABF). (21) In this technique, a clinician first preflares the coronal aspect of the canal system. Next, small files are taken to the working length in sequential order until one size "binds" or meets resistance just before getting to working length. This is the FABF. The clinician would then attempt to enlarge the apical preparation to 3 sizes larger than this FABF. However, the validity and effectiveness of this approach has been questioned. In 2002, Wu found that oftentimes, even though a clinician felt a file binding, subsequent sectioning of the tooth with the file in place revealed the file to be bound at one side of the canal wall only. In 90% of the teeth examined, the diameter of the file was smaller than the diameter of the canal foramen. (22)

A paradigm shift known as "minimally invasive endodontics" has been gaining popularity in recent years. In a study by Clark and Khademi in 2010, they discussed a new model for endodontic access which aimed to maximize the preservation of tooth structure during access cavities and root canal preparations. (23) While Clark and Khademi's concept was focused more on access preparation designs and pericervical dentin preservation, this philosophy has migrated apically among many clinicians. With the technological improvements in nickel titanium rotary instrumentation, irrigation adjuncts (e.g. ultrasonics, lasers, and multisonics), and modern obturation techniques and materials, the rising sentiment among some clinicians is that the historical recommendations of apical preparation size may be outdated. In a thorough 2014 literature review of minimally invasive concepts, Gluskin states that advocates of smaller apical sizes argue that it conserves dentin, promotes resistance form, a tight apical seal, and a conservative approach to creating sufficient shape for adequate disinfection. As Gluskin also points out, “no matter which school of thought one ascribes to, it is not possible that any apical preparation technique will render the terminus entirely free of bacterial contamination in an infected canal.” (24) Keeping the apical preparation size small has several proposed advantages. Not only does it preserve dentin which could retain more strength and increase long term prognosis, but avoiding over-enlargement reduces the incidence of procedural errors such as a transportation, ledge formation, overfill, perforation or apical zipping. (25)

In a 2012 randomized controlled trial, Saini concluded that increasing the apical preparation 3 sizes larger than the first apical binding file showed favorable healing, but any additional enlargement did not further influence treatment outcome. (21) In a 2015 systematic review by Aminoshariae, better outcomes were found in teeth with necrotic pulps and periapical lesions when increased apical enlargement was performed. However, the author noted that very little information was available on the topic and that more research was needed to come to a definitive conclusion. (26) In a 2018 animal study, Jara concluded that larger apical preparation sizes led to faster healing of apical periodontitis in rats over a short recall period. (27) Most recently, a randomized controlled trial published in 2021 by Fatima found that an apical preparation size corresponding to a size 25/.04 file resulted in significantly lower healing rates when compared to larger preparations. This finding should be of special interest to modern endodontics as a 25/.04 (or smaller) file has become a common ending apical preparation size. (28) It is assumed that there are wide variations in endodontic preparation techniques across the United States, and still the success rate for nonsurgical root canal therapy remains very high.

This raises the question of the relevance of apical enlargement and its effect on prognosis and clinical outcomes.

The objective of this retrospective study was to evaluate the effect of final apical preparation size on endodontic outcomes in maxillary and mandibular molars treated in both a graduate endodontic clinic and a private practice.

Methods

This study was conducted following the approval of the VCU Institutional Review Board (HM20024084). Data for this study were obtained from patients of record at Virginia Commonwealth University School of Dentistry (VCU) as well as from an endodontic private practice in Charlottesville, VA. For data obtained from VCU, a list of electronic dental records collected through axiUm (Exan software, 2023) was used to identify patients treated by residents in the graduate endodontic clinic who received primary endodontic therapy on a first or second molar between July 2010 and July 2020. A more extensive review was then conducted from this list to identify patients who met the inclusion criteria of this study. Cases included in this study were required to meet all of the following criteria:

1. First or second molar of the maxilla or mandible with complete root formation
2. Primary endodontic therapy was completed in the graduate endodontic clinic.
3. A pre-operative periapical radiograph, an immediate post-treatment periapical radiograph, and a minimum of a one-year post-treatment follow-up periapical radiograph were all available for review.

Patients excluded from this study were those with immature permanent teeth and primary teeth. Cases treated by predoctoral students were not included. Medically complex patients with significantly compromised immune status including uncontrolled diabetics, organ failure patients, or patients diagnosed with terminal illness were also excluded from this study. Incomplete electronic records, radiographs not of diagnostic quality, and cases without at least a one-year follow-up were also excluded. If a follow up radiograph had been taken in the 12th month post-treatment but was not yet a full calendar year, these cases were still included if the radiograph was of diagnostic quality.

From this inclusion criteria, patient records were accessed through axiUm and the following information was retrieved from chart notes: gender, age, tooth number, pre-operative pulpal diagnosis, pre-operative periapical diagnosis, the ending apical preparation size for each root, dates of pre-operative, post-operative, and follow-up periapical radiographs, presence of clinical symptoms at treatment visit and recall visit, and the presence of a definitive coronal restoration at the recall visit. This information was de-identified, assigned a case number in consecutive order, and recorded in an Excel spreadsheet on a VCU secured computer. The following radiographs were accessed through VCU's digital database MiPACs Dental Enterprise Viewer (Medicor Imaging, 2023): pre-operative, immediate post-operative, and the longest available follow-up periapical radiographs. If there were additional radiographs available taken from different angulations, then these were also reviewed. All qualifying radiographs were downloaded, labeled with the corresponding de-identified case number from the Excel sheet, and were stored on a VCU secured computer. There were 201 cases collected in total from the VCU graduate endodontic clinic.

For data obtained from the endodontic private practice, a list of electronic dental records of patients receiving primary endodontic therapy on a first or second molar treated by either of the two endodontists at the practice between July 2015 and July 2020 were collected from The Digital Office (TDO® Software, Inc. 2022), the practice management software used at the practice. Using the same inclusion/exclusion criteria as described above, the list was reviewed further to identify eligible cases. This data set was then de-identified, assigned a case number, and recorded in an Excel sheet. In the same manner described above, corresponding radiographs were reviewed and downloaded from the TDO software. All de-identified radiographs and the master Excel sheet were then transferred to a VCU secured computer. There were 200 cases collected in total from the private practice.

Radiographs from records included in both data sets (VCU and the private practice) were compiled together into a single PowerPoint (Microsoft © 2022) presentation. Each case was identified by the corresponding case number, with slides containing the pre-operative, immediate post-operative, and follow-up radiographs. Each radiograph was labeled only with the date it was taken.

Three observers, all board-certified endodontists, were selected to perform the radiographic healing interpretation of all 401 collected cases. The three observers were calibrated using an initial set of 25 cases selected at random from the larger pool of 401 cases. A calibration exercise and an inter-rater reliability test was conducted and the results were assessed by a statistician. It was concluded that the inter-rater reliability from the initial 25 cases was satisfactory and that for the second phase of radiographic interpretation involving all 401 cases, each case would be reviewed by only two of the three observers. In cases of disagreement between the two selected observers on a failure vs healed/healing assessment, the third observer, without knowledge of what the previous observers had rated the case, would serve as a tiebreaker. The initial set of 25 cases selected for calibration were renumbered at random and included in the overall pool of 401 cases to determine intra-rater reliability.

Examiners were instructed to evaluate the radiographs for each case using the PowerPoint (Microsoft © 2022) presentation provided to them and were asked to place each case into one of 3 assessment categories. The three categories were as follows: (2) healed - the complete absence of a periapical lesion on a follow-up radiograph. If the pre-operative radiograph displayed evidence of a periapical radiolucency, the follow-up radiograph showed either complete healing or evidence of a periapical scar formation consistent with complete healing, (1) healing - this assessment was assigned to those cases where there may have been evidence of a periapical radiolucency, however it had decreased in size from the pretreatment radiograph, and (0) failure - this assessment was assigned to cases in which a periapical radiolucency was evident on a follow-up radiograph which appeared to be the same size or larger than on the pre-operative radiograph. A case where a periapical lesion was absent pre-treatment but existed on the follow-up radiograph would be considered a treatment failure. In the occurrence that an observer could not make an accurate assessment on healing, the observer was instructed to assign a (U) grade, which indicated that they were 'unable to determine' the healing status.

The three observers were asked to assign one assessment category for each individual root visible on the radiograph. Therefore, it was possible for a single tooth to have multiple healing categories assigned depending on the number of roots present. All observer responses were recorded in a separate Excel sheet specifically designated for that individual observer, and no shared access was given to the assessments of the other observers. Only the radiographic healing was assessed by the three observers, without knowledge of study purpose, treatment provider, clinic location, patient symptoms or knowledge of subsequent diagnostic testing.

Overall treatment success of an individual root was defined in this study based on the combination of clinical and radiographic assessment. An individual root was considered a success if the follow-up evaluation chart notes indicated that the treated tooth was asymptomatic and if the root received a radiographic assessment of healed or healing from the three observers. Once all data and evaluation responses were collected, they were provided to a statistician for analysis and a request was made for the following information: inter-rater reliability, intra-rater reliability, and healing outcomes as determined by individual root.

Statistical Methods

Inter and intra-rater reliability were measured with Kappa statistics. Differences in final instrument size based on various characteristics were assessed with t-tests and ANOVA. Post hoc pairwise comparisons were adjusted using Tukey's adjustment. Significance level was set at 0.05. SAS EG v.8.2 (SAS Institute, Cary, NC) was used for all analyses.

Results

Two out of three independent endodontic faculty members reviewed each case. For cases with disagreement between the two assigned reviewers, the third reviewer was consulted to reach a consensus. The third reviewer was required to reach a consensus for 65 roots (6.6%). A subset of 56 roots (25 teeth) were reviewed a second time by each rater with no knowledge of their previous score. The inter-rater agreement for the two ratings were: k=0.57, 0.59, and 0.46 for the three raters and the rate of discordant ratings ranged from 12.5% to 30%. For the intra-rater agreement on the subset of 56 cases, the agreement ranged from 0.23-0.49 and the rate of discordant pairs ranged from 20% to 34%.

A total of 401 teeth and 986 roots were considered in the analysis. The average age of patients was 58.5 and 52% of the patients were female. Twenty-six roots were deemed “Unable to determine” during radiographic assessment and excluded from analysis. The final healing status was considered “Healing” for 96% (n=924) of the cases, with 15% (n=143) “Healing” and 81% (n=781) “Healed.” The remainder were considered “Not Healing” (n=36, 4%). The average final instrument size for all roots combined was 30.9 (SD=9.33). Cases are summarized in Table 1.

Table 1: Description of Roots Evaluated

	n	**%**

Healing Status		
Not Healing (0)	36	4%
Healing (1)	143	15%
Healed (2)	781	81%
Root		
Mesiobuccal	174	18%
Distobuccal	170	17%
Palatal	170	17%
Mesial	232	24%
Distal	236	24%
Radix	4	0%
Clinical Failure		
Yes	53	5%
No	933	95%
Periapical Lesion		
Yes	329	33%
No	657	67%
Pulpal Diagnosis		
Necrotic	509	52%
Vital	477	48%
Symptomatic at Recall		
Yes	46	5%
No	940	95%
Symptomatic on Treatment Date		
Yes	755	77%
No	231	23%

When comparing the three levels of healing status, there were significant differences in the average final instrument size (p-value=0.0020). Specifically, cases considered healing had an average final instrument size 4.6 units or 0.046mm smaller than those that were not healing (p-value=0.0238; 95% CI: [0.48, 8.63])). Cases considered healing also had final instrument sizes on average 1.8 units or 0.018mm smaller than the cases considered to be healed (p-value=0.0036; 95% CI:[0.75, 4.73]). The difference between healing and not healing cases was not statistically significant (1.8, p-value=0.4868). Complete results are provided in Table 2.

Table 2: Analysis of Final Instrument Size by Healing Status

Healing Status	**n**	**%**	**Average Final Instrument Size**
Not Healing (0)	36	4%	33.2, 8.55[a]
Healing (1)	143	15%	28.6, 9.20[b]
Healed (2)	781	81%	31.4, 9.36[a]
P-value			0.0020

*Levels with the same letter were not significantly different based on Tukey's adjusted post hoc comparisons

Among all roots considered healing, the average final instrument size was 30.9 (SD=9.4) compared to 33.2 (SD=8.5) for the roots considered not healing. Therefore, roots that were not healing had a final instrument size that was on average 2.2units larger or 0.022mm than those that were healing (p-value=0.1588; 95% CI: [-0.88, 5.36]). Results are provided in Table 3.

Table 3: Analysis of Final Instrument Size by Healing and Not Healing

Healing Status	n	%	Average Final Instrument Size
Not Healing	36	4%	33.2, 8.55
Healing	924	96%	31.0, 9.38
P-value			0.1588

*P-value from t-test

Differences in final instrument sizes between healing and not healing cases ranged from 1.7 to 5.1 based on the particular root. Results by root are provided in Table 4. Due to limited sample size, particularly in the not healing groups, none of the differences were statistically significant. When combining the roots into groups (ABD, CEF), the differences in final instrument size ranged from 2.0 to 4.3 and also failed to reach statistical significance. Results by root group are provided in Table 5.

Table 4: Final Instrument Size by Healing and Not Healing and Root

	Final Instrument Size (Mean, SE)			
Root	**Healing**	**Not Healing**	**Difference**	**P-value**
Mesiobuccal	28.7, 0.60	30.4, 2.43	-1.7, 2.22	0.4441
Distobuccal	28.8, 0.61	32.5, 2.50	-3.7, 3.81	0.3350
Palatal	35.8, 0.84	40.8, 2.71	-5.1, 4.36	0.2460
Mesial	28.0, 0.51	29.3, 2.97	-1.3, 2.96	0.6731
Distal	33.5, 0.68	36.7, 3.33	-3.1, 4.24	0.4614
Radix	30.0, 3.54	N/A		

Table 5: Final Instrument Size by Healing and Not Healing and Root Group

	Final Instrument Size (Mean, SE)			
Root Group	**Healing**	**Not Healing**	**Difference**	**P-value**
Mesiobuccal, Distobuccal, Mesial (ABD)	28.4, 0.33	30.4, 1.59	-2.0, 1.59	0.2175
Palatal, Distal, Radix (CEF)	34.4, 0.53	38.8, 2.14	-4.3, 3.03	0.0720

*p-value from t-test

Discussion

This study's objective was to determine the effect of final apical preparation size on endodontic healing outcomes in maxillary and mandibular molars. The results of this study could not demonstrate a statistically significant effect on outcomes when considering the apical preparation size alone. Radiographic assessment was primarily used in this study to determine healing outcomes, but a chart review was also completed to record any failures for reasons related to clinical signs and/or symptoms. One factor taken into consideration for the present study was the variation in canal sizes based on root. For example, when considering a maxillary molar, a palatal root will typically have a canal that is larger in size than a canal within the mesiobuccal root, which in turn may prompt the clinician to prepare the canals to different final apical sizes based off the starting anatomy. Initially, the results provided by the statistician combined all sizes for all roots together into one large group. However, to allow for more meaningful analysis of the results, it was then requested to determine the final instrument size and corresponding radiographic healing assessment for each individual root.

When excluding the roots that were not able to be assessed radiographically, a total of 401 teeth and 960 roots were included for analysis. Radiographic healing outcomes were assessed by endodontic faculty observers. With a total of 960 roots available for evaluation, there was an overall radiographic success rate of 96%, which combined the categories of "Healed"

(81%) and “Healing” (15%). The “Not Healing” category accounted for the remaining 4% of the total. Based on criteria of clinical failures, there was an overall clinical success rate of 95%. In this study, a case was considered a clinical failure if the tooth was retreated or extracted at any point during the recall period or if there were patient symptoms at the time of recall, and this was determined by a review of the chart notes. When attempting to combine the radiographic and clinical success, there were 10 teeth (26 roots) deemed as clinical failures that were not assessed as failures radiographically. There were 10 additional teeth deemed as clinical failures (27 total roots) in which radiographic assessment identified 12 of the 27 roots as “Not Healing.” Therefore, 886 roots were deemed successful both clinically and radiographically, resulting in an overall success rate of 92.3%.

The minimum recall interval in this study was set at one year. Most recall images acquired from the private practice were in the 11th or 12th month, with the longest recall being around 18 months. For the graduate clinic, many patients treated in the endodontic clinic continue their routine care within the dental school and so longer follow-ups were often available. While the minimum was set at one year, there were many patients with follow-up radiographs taken 5-9 years post-treatment. The longest follow-up radiograph for each case was included in the data shown to the independent observers.

Overall, the endodontic healing outcomes found in this study generally agree with many of the previous outcome studies available in endodontic literature. The Toronto Studies: Phases 1 and 2 found overall success rates to be slightly lower, however there were stricter criteria used to determine success. In Phase 1, Friedman found an overall success rate of 81%, 29 whereas in Phase 2, Farzaneh found an overall success rate of 87%. (30) When considering the pulpal status, Friedman found a success rate of 95% in teeth with vital pulps versus 75% in teeth with necrotic pulps. When considering periapical status, Friedman found a success rate of 92% in the absence of a periapical lesion versus 74% when a lesion was present. Farzaneh had similar findings with 94% success when a lesion was absent versus 81% when one was present.

Other classic outcome studies of note include those by Salehrabi, Lazarski, and Ng. Salehrabi's study looked at dental insurance records of over 1.4 million teeth in 1.1 million patients to determine survival of root canal treated teeth over an 8-year recall period and found a survival rate of 97%. (31) The study by Lazarski was also insurance based, finding a 95% survival rate with an average of 3.5 year follow-up. (32) In 2011**,** Ng conducted a prospective clinical study to determine prognostic factors for success and found an overall survival rate of 95% with a 2 to 4-year recall period.(33) The outcomes found in these studies more closely resemble those of the present study, however it should be noted that these three studies focused on "survival" rates as opposed to "success" rates. While the present study found a radiographic healing rate of 96%, this equates more to 'survival' as the independent endodontic observers had no knowledge of clinical signs or symptoms and did not take this information into account when assessing outcomes. When taking the clinical failures into account, the success rate of this study was slightly lower at 92.3%. The study population consisted of a combination of 200 cases from a private practice with two endodontists as well as 201 cases treated by residents in the Virginia Commonwealth University graduate endodontic clinic. Despite varying levels of clinical experience, considerable differences in treatment techniques, and differences in final apical preparation sizes, the success rates across all teeth remained very high, thus validating previous findings that nonsurgical root canal therapy is very predictable in retaining the natural tooth.

When looking at the effect of final apical preparation size, the data was grouped together based on individual root. There was a total of 174 maxillary molar mesiobuccal roots assessed in this study. The average final instrument size in the “Healing” group was 28.7, whereas the average final size in the “Not Healing” group was 30.4, a difference of -1.7 in instrument size. The difference was not statistically significant. A similar trend was noted for the remaining roots assessed, detailed in Table 4. There were no statistically significant differences noted in final instrument sizes for any of the individual roots.

As mentioned previously, the canal anatomy tends to vary by root. Smaller canals tend to present in the mesiobuccal and distobuccal roots of maxillary molars and in the mesial roots of mandibular molars. Larger canals tend to present in the palatal roots of maxillary molars and in the distal roots of mandibular molars. Therefore, the roots were also grouped according to approximate initial canal sizes to assess for any significance. Similar to the individual root groups, there were no significant differences found in these combined groupings when looking at the effect of final instrument size on healing.

There have only been a few previous studies looking at the effect of apical preparation size on endodontic outcomes, three of which finding similar results as the present study. In 1979, the study by Kerekes and Tronstad looked at a total of 501 roots that were endodontically treated and followed up for 3-5 years. When looking at two groups, one group instrumented to reamer sizes of #20-40 and the other group instrumented to sizes #45-100, there were no significant differences in healing, with the groups having 90% and 91% success, respectively. (2) Hoskinson, in a 2002 retrospective study looking at a total of 200 teeth and 489 roots, also found no significant differences in healing among the groups prepared to different master apical file sizes. (3) A 2012 randomized controlled trial by Souza divided a total of 80 anterior teeth and premolars with periapical lesions into two treatment groups. Canals were instrumented up to 3 files (the bound file and 2 files beyond it) in one group (n = 40) and up to 4 files (the bound file and 3 files beyond it) in the second group. At the 2-year recall date, 43 patients were available for follow-up. There were no significant differences in healing, with the 3-file group showing 92% success and the 4-file group showing 89% success. (34)

Another 2012 randomized controlled trial conducted by Saini treated 167 mandibular first molars separated into 5 treatment groups in which canals were enlarged to 2, 3, 4, 5, and 6 files larger than the first apical binding file. At the 12-month follow-up, 129 teeth were available for recall and radiographic healing was assessed using the PAI scale. Improvement in the PAI score was observed in 100% of the cases for all groups, meaning there was healing progress in all cases. However, canal preparation with a 2-size apical enlargement depicted a significantly lower reduction in the mean PAI score than the rest of the groups. It was also noted that the percentage of completely healed cases increased as the apical preparation size increased. Thus, Saini recommended increasing the apical preparation 3 sizes larger than the first apical binding file but added that any additional enlargement didn't seem to further influence the treatment outcome. While the findings of Saini's study suggested that better healing occurred when preparing to a specific instrument size, it should be noted that all cases in that study showed radiographic healing at 12 months regardless of preparation size and that the distinction made was more in reference to the speed of healing.(21)

Upon the author's review of the literature, only one systematic review was found discussing the effect of apical preparation size on endodontic outcomes, conducted by Aminoshariae in 2015. (26) In the systematic review, they noted that due to the variety of methodologies and different techniques used to measure outcomes for apical enlargement, it was not possible to standardize the research data and to apply meta-analysis. After all exclusions, the systematic review included four articles for qualitative analysis. The four articles discussed in the review are also mentioned above: Kerekes and Tronstad, Hoskinson, Souza, and Saini. The author's conclusion of the systematic review was that there is still a great need for more evidence-based research in this particular area, but at that point in time, "the best current available clinical evidence would suggest that, for patients with necrotic pulps and periapical lesions, greater enlargement of the apical size would result in an increased healing outcome in terms of radiographic and clinical evaluations." This of course was in reference to the Saini study. Souza's study also looked at teeth with necrotic pulps and periapical lesions, however it was pointed out in the systematic review that this study only evaluated the radiographic outcome, and they did not discuss using the same exposure parameters for the initial and final radiographic images.

Finally, there are two additional studies by Jara in 2018 and Fatima in 2021. Jara conducted a study on Wistar rats looking at periapical healing after endodontic treatment of mandibular molars. (27) While Jara found more rapid periapical healing with larger final instrument sizes (size #30 providing the most rapid healing as opposed to sizes #20 or #25), it should be noted that the recall period was 3 weeks, typically not a recommended recall period for routine endodontic therapy in humans. The author also made a distinction of the apical size differences between a Wistar rat molar and a human molar. The average working length in a Wistar rat molar was 4mm as compared to 21mm in a human molar. Thus, the ending instrument size of a #30 file in a Wistar rat molar would equate to an approximate instrument size of #60 or #70 in a human molar, which is rarely utilized except perhaps in treatment of large distal canals of mandibular molars or palatal canals of maxillary molars, usually found in younger patients.

Fatima published a randomized controlled trial in 2021 where 120 patients with asymptomatic mandibular first molars with periapical lesions were divided into four treatment groups and underwent endodontic therapy. The four groups included the following preparation protocols: (1) final instrument size at 2 sizes larger than first apical binding file (FABF) and using a 4% taper, (2) final instrument size at 2 sizes larger than FABF with a 6% taper, (3) 3 sizes larger than FABF and a 4% taper, and (4) 3 sizes larger than FABF and a 6% taper. At the 12-month follow-up, 115 patients were available for recall. Success was determined by a PAI score of 2 or less and the absence of clinical signs and symptoms. The success rates were 57%, 93%, 93%, and 96% for groups 1, 2, 3 and 4 respectively, suggesting that preparing the apical third to 2 sizes larger than the FABF with a 4% taper results in a significantly lower healing rate. The intragroup comparison revealed a significant difference in the change in the PAI score from baseline to the 12-month follow-up in all of the groups, however Group 1 was the only group to show a significant difference in healing when compared to the other groups. (28)

In the present study, final apical preparation size did not have a significant effect on healing outcomes. The statistical analysis suggested that the lack of significance may be due to the small sample size included in the “Not Healed” group. When looking at the differences in average instrument sizes between the “Not Healed” and “Healing” groups for each root, the difference equated to one instrument size or less. A difference of this amount would likely not be clinically relevant even in the case of statistical significance. As discussed above, outcomes of root canal therapy have been thoroughly studied in the literature and tend to yield consistently high success rates, and so a large sample size of non-healing cases is typically difficult to come by. While not statistically significant, an interesting trend was noted in the present study wherein the average final instrument size for the “Not Healed” group was larger than in the “Healed” group across all individual roots and combined root groups. This finding was similar to that of

Hoskinson's and Souza's studies where a decrease in success rates was evident with an increase in MAF size, though it was not statistically significant.

One of the expected challenges encountered during this project had to do with the agreement in radiographic assessment between the three endodontic faculty observers. Intrarater and interrater reliability was determined by Cohen Kappa interrater analysis. Values of kappa from 0.21 to 0.4 are considered fair, 0.41 to 0.6 moderate, 0.61 to 0.80 substantial, and 0.81 to 1.00 outstanding agreement. In this study, the reliability between the three observers was rated as fair to moderate, and the intrarater reliability was rated as moderate. One possible explanation provided by the statistician for the relatively low kappa is the small sample size of the "Not Healed" group. The kappa value estimates the agreement after taking into account the probability of agreement "by chance." In a dataset with low numbers of "not healed" cases, the kappa will likely be low because if an observer were to guess "healing" on a particular root, that would be right most of the time. Nevertheless, the difficulty of radiographic assessment has been well documented in endodontic literature. Goldman's 1972 study had 6 independent observers evaluate conventional film radiographs of 253 cases to label the case as a success or failure. The findings revealed that the observers agreed on less than half of the cases. The observers were also asked to evaluate a selection of cases to identify whether or not a periapical lesion was present. The observers again agreed on less than half of the cases. (35)

In 2011, Tewary conducted a similar study using digital radiographs in which 6 observers reviewed a set of 150 cases and determined the presence of either a normal periapical area, a widened PDL, or a periapical lesion. All 6 observers agreed with each other less than 25% of the time, and 5 out of 6 agreed less than 50% of the time. The intrarater reliability was also assessed and found to be moderate, meaning that the observers disagreed with their own previous assessments a fair amount of the time. (36) These findings highlight the difficulties that are encountered in determining endodontic treatment outcomes, not only in academic literature but also in clinical practice.

There is some evidence that cone-beam computed tomography (CBCT) improves sensitivity when evaluating teeth for periapical disease. A 2009 animal study by de Paula-Silva compared the sensitivity of periapical radiography, CBCT, and histological diagnosis. Of the roots evaluated, 93% were diagnosed histologically as apical periodontitis (AP). CBCT identified AP in 84% of roots whereas periapical radiography identified AP in 71%, thus showing a higher sensitivity in CBCT imaging. (37) Patel, in a 2012 study, found similar results where evaluation of CBCT images showed an 30% increase in apical periodontitis identified on the same set of teeth as compared to periapical radiography. (38) CBCT has also shown some promise in improving interrater reliability. A 2020 study by Chogle had 3 examiners review a set of 45 cases initially with periapical radiography only and then later with an accompanying CBCT image. Interrater reliability improved from 65% to 72% with the use of CBCT imaging. (39) In endodontic outcome studies, success rates oftentimes depend on the determination of radiographic "healing," and so it is possible that interobserver reliability could have a small influence on reported success rates. However, with the vast number of published outcome studies having relatively similar success rates, it is unlikely that interobserver reliability has had an impact of any major significance.

Another important limitation of this study was its retrospective design. Recall bias often exists in a retrospective chart review as patients may or may not return for follow-ups for a variety of different reasons such as persistent symptoms, dissatisfaction with the clinician or the treatment rendered, relocation to a different geographical area, etc. There is no randomization with a retrospective design, and there are many variables that are not able to be controlled. In a chart review, there is some uncertainty in the accuracy of the detailed treatment notes. While all information important to the objectives of this study appeared to be well documented in both the private practice software as well as the university's dental record database, the author recognizes that patients included in this study were treated by a variety of different clinicians, and so the true accuracy of the recorded data is an unknown factor.

The variations in clinical experience and treatment techniques of the clinicians could also be a potential factor affecting the results of this study. Patients treated at the graduate endodontic clinic were treated by first and second year residents, whereas the patients of the private practice were treated by two endodontists, one of which having approximately 7 years of experience and the other having several decades beyond their residency training. In general, the endodontists in the private practice kept the final apical preparation sizes smaller, typically ending at sizes ranging from #15-35. There was a greater variety of preparation sizes seen in the graduate clinic, but most sizes were in the range of #30-60. When considering both practice settings, the most common apical preparation sizes fell in the range of #20-45.

Irrigation and obturation protocols tended to differ between practice settings as well. Within the graduate clinic, the irrigation adjuncts available included sonic and ultrasonic activation. In the private practice, while not used by both clinicians, the irrigation adjuncts available included sonic, ultrasonic, and multisonic activation as well as LASER-assisted irrigation. The argument could be made that when preparing the canal to smaller sizes, some type of irrigation adjunct is needed in order to facilitate proper debridement and disinfection. While the private practice did have more adjuncts available, the details of irrigation procedures were not recorded in this study and thus were not looked at as a potential variable. Some differences may also exist in obturation methods, with the private practice clinicians incorporating a mix of the warm vertical condensation and the thermoplasticized injectable gutta percha techniques while the graduate clinic primarily utilized the warm vertical condensation technique. However, the details of obturation technique were also not recorded in this study and thus were not evaluated as potential variables.

The results of the current study confirmed that there is a need for additional research on the topic of apical preparation size and its effect on endodontic outcomes. Specifically, more prospective randomized controlled trials with large sample sizes are needed that not only look at various apical preparation sizes but also have a variety of pulpal and periapical diagnosis combinations. It is important to know if there is a significant effect of apical preparation size not only on necrotic cases with periapical lesions but also with vital cases or necrotic cases without a periapical lesion. In addition to prospective clinical trials, more retrospective studies with long term follow-ups would be valuable to assess the healing of such cases treated to different apical preparation sizes to evaluate any differences in long term outcomes. While periapical radiography is practical and applicable to most clinical environments, there are inherent discrepancies when attempting to determine healing outcomes. Therefore, the author feels there may be some added value with incorporating cone-beam computed tomography scans in future studies to assess outcomes.

Conclusion

In this retrospective study, when evaluating radiographic healing to determine endodontic treatment outcomes in maxillary and mandibular molars with a one-year minimum recall period, there were no significant differences in success rates when looking at final apical preparation size as the primary variable. When instrumenting canals to the average size range seen in this study (#20-45), the true clinical importance of the specific ending apical preparation size is unknown. While the author recognizes the important benefits of enlarging the apical preparation as has been cited in previous literature, a high success rate of 96% noted in this study across all roots despite the considerable range in apical preparation size suggests that there are other treatment variables which likely have a greater influence on outcomes.

References

1. Schilder H. Cleaning and shaping the root canal. Dent Clin North Am 1974;18:269–96.
2. Kerekes K, Tronstad L. Long-term results of endodontic treatment performed with a standardized technique. J Endod 1979;5:83–90.
3. Hoskinson SE, Ng Y-L, Hoskinson AE, Moles DR, Gulabivala K. A retrospective comparison of outcome of root canal treatment using two different protocols. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology 2002;93:705–15.
4. Green D. A stereomicroscopic study of the root apices of 400 maxillary and mandibular anterior teeth. Oral Surgery, Oral Medicine, Oral Pathology 1956;9:1224–32.
5. Green D. Stereomicroscopic study of 700 root apices of maxillary and mandibular posterior teeth. Oral Surgery, Oral Medicine, Oral Pathology 1960;13:728–33.
6. Hsu YY, Kim S. The resected root surface. The issue of canal isthmuses. Dent Clin North Am 1997;41:529–40.
7. Weller RN, Niemczyk S, Kim S. Incidence and position of the canal isthmus. Part 1. Mesiobuccal root of the maxillary first molar. J Endod 1995;21:380–3.
8. von Arx T. Frequency and type of canal isthmuses in first molars detected by endoscopic inspection during periradicular surgery. Int Endod J 2005;38:160–8.
9. Goel S, Tewari S. Smear layer removal with passive ultrasonic irrigation and the NaviTip FX: a scanning electron microscopic study. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology 2009;108:465–70.
10. Abou-Rass M, Piccinino M. The effectiveness of four clinical irrigation methods on the removal of root canal debris. Oral Surg 1982:323–8.
11. Khademi A, Yazdizadeh M, Feizianfard M. Determination of the Minimum Instrumentation Size for Penetration of Irrigants to the Apical Third of Root Canal Systems. J Endod 2006;32:417–20.
12. Brunson M, Heilborn C, Johnson DJ, Cohenca N. Effect of Apical Preparation Size and Preparation Taper on Irrigant Volume Delivered by Using Negative Pressure Irrigation System. J Endod 2010;36:721–4.

13. Albrecht L, Baumgartner J, Marshall J. Evaluation of Apical Debris Removal Using Various Sizes and Tapers of ProFile GT Files. J Endod 2004;30:425–8.

14. Usman N, Baumgartner J, Marshall J. Influence of Instrument Size on Root Canal Debridement. J Endod 2004;30:110–2.

15. Dalton BC, Ørstavik D, Phillips C, Pettiette M, Trope M. Bacterial reduction with nickel-titanium rotary instrumentation. J Endod 1998;24:763–7.

16. Card S, Sigurdsson A, Orstavik D, Trope M. The Effectiveness of Increased Apical Enlargement in Reducing Intracanal Bacteria. J Endod 2002;28:779–83.

17. Rollison S, Barnett F, Stevens RH. Efficacy of bacterial removal from instrumented root canals in vitro related to instrumentation technique and size. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology 2002;94:366–71.

18. Rodrigues RCV, Zandi H, Kristoffersen AK, et al. Influence of the Apical Preparation Size and the Irrigant Type on Bacterial Reduction in Root Canal–treated Teeth with Apical Periodontitis. J Endod 2017;43:1058–63.

19. Plotino G, Özyürek T, Grande NM, Gündoğar M. Influence of size and taper of basic root canal preparation on root canal cleanliness: a scanning electron microscopy study. Int Endod J 2019;52:343–51.

20. Yared GM, Bou Dagher FE. Influence of apical enlargement on bacterial infection during treatment of apical periodontitis. J Endod 1994;20:535–7.

21. Saini HR, Tewari S, Sangwan P, Duhan J, Gupta A. Effect of different apical preparation sizes on outcome of primary endodontic treatment: A randomized controlled trial. J Endod 2012;38:1309–15.

22. Wu M-K, Barkis D, Roris A, Wesselink PR. Does the first file to bind correspond to the diameter of the canal in the apical region? Int Endod J 2002;35:264–7.

23. Clark D, Khademi J. Modern Molar Endodontic Access and Directed Dentin Conservation. Dent Clin North Am 2010:249–73.

24. Gluskin AH, Peters CI, Peters OA. Minimally invasive endodontics: challenging prevailing paradigms. Br Dent J 2014;216:347–53.

25. Buchanan L. The standardized-taper root canal preparation–part 1. Concepts for variably tapered shaping instruments. Int Endod J 2000;33:516–29.

26. Aminoshariae A, Kulild JC. Master apical file size - smaller or larger: A systematic review of healing outcomes. Int Endod J 2015:639–47.

27. Jara CM, Hartmann RC, Böttcher DE, Souza TS, Gomes MS, Figueiredo JAP. Influence of apical enlargement on the repair of apical periodontitis in rats. Int Endod J 2018;51:1261–70.

28. Fatima S, Kumar A, Andrabi SMUN, Mishra SK, Tewari RK. Effect of Apical Third Enlargement to Different Preparation Sizes and Tapers on Postoperative Pain and Outcome of Primary Endodontic Treatment: A Prospective Randomized Clinical Trial. J Endod 2021;47:1345–51.

29. Friedman S, Abitbol S, Lawrence H. Treatment Outcome in Endodontics: The Toronto Study. Phase 1: Initial Treatment. J Endod 2003;29:787–93.

30. Farzaneh M, Abitbol S, Lawrence H, Friedman S. Treatment Outcome in Endodontics—The Toronto Study. Phase II: Initial Treatment. J Endod 2004;30:302–9.

31. Salehrabi R, Rotstein I. Endodontic Treatment Outcomes in a Large Patient Population in the USA: An Epidemiological Study. J Endod 2004;30:846–50.

32. Lazarski M, Walker III W, Flores C, Schindler W, Hargreaves K. Epidemiological Evaluation of the Outcomes of Nonsurgical Root Canal Treatment in a Large Cohort of Insured Dental Patients. J Endod 2001;27:791–6.

33. Ng Y-L, Mann V, Gulabivala K. A prospective study of the factors affecting outcomes of non-surgical root canal treatment: part 2: tooth survival. Int Endod J 2011;44:610–25.

34. Souza RA, Dantas JCP, Brandão PM, Colombo S, Lago M, Duarte MAH. Apical third enlargement of the root canal and its relationship with the repair of periapical lesions. Eur J Dent 2012;6:385–8.

35. Goldman M, Pearson AH, Darzenta N. Endodontic success—Who's reading the radiograph? Oral Surgery, Oral Medicine, Oral Pathology 1972;33:432–7.

36. Tewary S, Luzzo J, Hartwell G. Endodontic Radiography: Who Is Reading the Digital Radiograph? J Endod 2011;37:919–21.

37. Paula-Silva FWG de, Wu M-K, Leonardo MR, Bezerra da Silva LA, Wesselink PR. Accuracy of Periapical Radiography and Cone-Beam Computed Tomography Scans in Diagnosing Apical Periodontitis Using Histopathological Findings as a Gold Standard. J Endod 2009;35:1009–12.

38. Patel S, Wilson R, Dawood A, Mannocci F. The detection of periapical pathosis using periapical radiography and cone beam computed tomography - Part 1: pre-operative status. Int Endod J 2012;45:702–10.

39. Chogle S, Zuaitar M, Sarkis R, Saadoun M, Mecham A, Zhao Y. The Recommendation of Cone-beam Computed Tomography and Its Effect on Endodontic Diagnosis and Treatment Planning. J Endod 2020;46:162–8.