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# Proportion of MB2 Canals Identified at Different Depths of Excavation in Extracted Teeth and Comparison with CBCT Prediction

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Proportion of MB2 Canals Identified at Different Depths of Excavation in Extracted Teeth and Comparison with CBCT Prediction

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# Abstract

Objective: The purpose of this study is to evaluate the depth of troughing needed to locate the mesiobuccal 2 canals in maxillary molars. Troughing the pulp chamber floor can locate hidden or calcified mesio-lingual canals. Materials and Methods: This study utilized 29 extracted maxillary first and second molars with mesiobuccal 2 canals confirmed by sectioning the mesiobuccal root in cross-section 5 mm coronal to the apex. A standard access cavity was prepared and mesiobuccal, distobuccal, and palatal canals were located. A groove was troughed palatal to the mesiobuccal orifice and slightly mesial to the line connecting mesiobuccal and palatal canal orifices until the mesiobuccal 2 canal was visually identified and confirmed with an endodontic file. Troughing depth was determined using digital calipers. Results: The depth of troughing needed to locate the mesio-lingual canal ranged from 0.04 to 2.12 mm. Five teeth needed to be troughed less than 0.5 mm and two teeth needed to be troughed more than 2.0 mm to identify the mesio-lingual canal. Conclusion: In majority of cases, 0.5 mm troughing was sufficient to locate mesio-lingual canals. Clinicians will miss some mesio-lingual canals if troughing is limited to less than 2.0 mm.

# I. Introduction

The goal of root canal treatment is to treat and prevent apical periodontitis by reducing the bacterial load in the root canal system (Kakehashi et al. 1965, Sjogren et al. 1997). Using current chemomechanical disinfection methods, it is currently not possible to completely disinfect the root canal system (Orstavik 2003). Various techniques have been explored to achieve better disinfection with varied results. Some disinfection techniques include ultrasonic activation, negative pressure irrigation, innovative file designs, heating of irrigation, use of different combinations of irrigation, and multisonic technology (Van der Sluis et al. 2007, Brunson et al. 2010, Sirtes et al. 2005, Gu et al. 2009). Despite all these innovations, the success rate of root canal treatment has not seen a substantial increase, if any. This attests to the importance of following the basics principles of endodontics, rather than relying on technological gadgets.

## Steps of an endodontic access

Root canal treatment can broadly be categorized into three phases: biomechanical preparation, microbial control, and complete obturation. In order to achieve success in any of these goals, all root canal systems must be identified. A proper access is the first step to achieving this goal. The endodontic access has been divided into three phases: pre-access analysis, removal of the pulp chamber roof, and identification of the root canal orifices (Krasner et al. 2010).

Pre-access analysis focuses on the principle that the pulp chamber of every tooth is located in the center of the tooth at the level of the CEJ (Krasner and Rankow 2004).

This is especially important in today's practice of endodontics with more and more treatment being performed through full-coverage restorations. Full coverage restorations can disorient the clinician as the original landmarks of cusp tips and occlusal grooves are no longer visible. Studies have shown that approximately 17% of teeth that have full-coverage restorations will require endodontic treatment (Valderhaug et al. 1997). Full-coverage restorations can be difficult to access because the occlusal shape may not be representative of the angulation or location of the canals.

The second phase is removal of the pulp chamber roof. Historically, creating straight line access has been advocated (Patel and Rhodes 2003). Advantages of this traditional approach are that it places less stress on instruments, facilitates obturation, and allows for easier visualization of the pulp chamber floor. Recently, a trend toward more conservative access has been noted, with emphasis on minimal dentin removal (Clark and Khademi 2010). Various studies have suggested conservative accesses may result in greater fracture resistance than a traditional access (Plotino et al. 2017, Krishan et al. 2014). However, smaller access will also make visualization of the pulpal floor more difficult, increasing the risk of missed canals. A point access cavity was shown to detect an MB2 43% of the time compared to 73% for a conservative access cavity and 82% for a traditional access cavity (Saygili et al. 2018). With this growing trend towards smaller access, the difficulty with locating all canals should not be overlooked.

Once the pulp chamber floor is observed, the search for canals can begin. Three principles are used to identify canals: the laws of symmetry, law of color change, and law of orifice location (Krasner and Rankow 2004). The law of symmetry states that orifices of the canal are equidistant and perpendicular from a line through the tooth from mesial to distal. The law of color changes states that the pulp chamber floor is always darker than the walls. The law of orifice location states that orifices are located at the vertices of the pulp chamber floor and at the intersection of the floor and walls. These principles greatly assist dental clinicians in identifying canal orifices. However, the task of finding all canals is still challenging, especially in identification of the MB2 canal.

## Factors affecting the identification of mesiobuccal 2 canal

Several factors have been associated with identification of the MB2 canal. Reis et al. found the prevalence of MB2 canals was lower in older patients than younger patients using CBCT as the gold standard. In patients aged between 20 and 30 years of age, an MB2 canal was identified in 90.7% of cases compared to 81.9% in patients aged between 60 and 70 years of age (Reis et al. 2013). Studebacker et al. found that an MB2 canal was identified at a higher rate in maxillary first molars in initial treatment when a crown was not present (66.1%) compared to with a crown (50.0%) (Studebaker et al. 2018). Pettiette et al. found that patients that use statins for lowering cholesterol levels had lower pulp chamber volume compared to patients not taking statins (Pettiette et al. 2013). Decreased volume of the pulp chamber will make identification of the MB2 canals more difficult.

## Mesiobuccal 2 canal prevalence and anatomy

The prevalence of the MB2 canal has been reported in many studies. A recent study looking at the worldwide prevalence of mesiobuccal 2 canals in 21 regions of the world using CBCT as the gold standard concluded the overall prevalence to be 73.8%

(Martins et al. 2018). The prevalence was found to be lowest at 48.0% in Venezuela and highest at 73.8% in Belgium. This study reported a lower prevalence of MB2 canals in females and older groups (Martins et al. 2018). A systematic review from 2006 that looked at 8399 teeth from 34 studies found the incidence of two canals in the MB root to be 56.8% (Cleghorn et al. 2006).

The two most common root canal morphologies of maxillary molars are one or two canals in the mesiobuccal root and one in the distobuccal and palatal roots. However, variations have been noted. Koottor et al. reports a case with three MB canals, 3 DB canals, and 2 P canals (Koottoor et al. 2011). Two other case reports have reported teeth with three MB canals but with fewer DB and P canals (Kottoor et al. 2010, Martinez-Berna and Ruiz-Badanelli 1983, Raghavendra et al. 2014). Furthermore, maxillary molars can present with C shaped configuration, with a suggested prevalence of 1.1% in maxillary first molars and 3.8% in maxillary second molars (Martins et al. 2016).

Although some teeth with missed canals will heal, root canal treated teeth with missed canals are 4.38 times more likely to be associated with a periapical lesion compared to root canal treated teeth where all canals were found (Karabucak et al. 2016). Sufficient disinfection of the root canal system is needed to provide the body with the right environment to perform periapical healing. Persistent infection and reinfection are two possible sources of failure for root canal treatment (Nair 2006). An untreated canal is more likely to exhibit persistent infection as the canal has not had any chemomechanical disinfection. An unobturated canal is more likely to become reinfected because there is no seal in the canal space and possibly remaining pulp tissue that can serve as nutrients for bacteria (Schilder 2006). Maxillary first molars have the highest incidence of missed canals with 41.3% and 46.5% for the right and left sides respectively. The most commonly missed canal was determined to be MB2 (Karabucak et al. 2006).

## Instruments and techniques that aid in identification of mesiobuccal 2 canals

CBCT, magnification, and ultrasonics are important technological advances that aid in identification of the MB2 canal. Traditionally, two-dimensional radiographs have been used to gain information about the canal space that cannot be seen visually. However, two-dimensional radiographs have limitations, in particular inability to determine spatial location in the bucco-lingual plane (de Souza et al. 2017). Cone beam computed tomographic (CBCT) radiographs are a relatively new introduction to the field of dentistry that provides an accurate three-dimensional image. The American Association of Endodontics and the American Association of Oral Maxillofacial Radiology published a joint position statement on the use of the CBCT in endodontics in 2016. The position statement states that that a limited field of view CBCT is the imaging modality of choice for initial treatment of teeth with the potential for extra canals (Fayad et al. 2015).

The benefits of CBCT usage has been supported in literature. Some clinicians prefer to take a CBCT image preoperatively while others prefer to obtain a CBCT if unable to locate an MB2 canal. According to Studebaker et al. 55.8% of maxillary molars have an MB2 canal. CBCT was helpful in identifying the canals in 11.7% of cases (Studebaker et al. 2018). A preoperative CBCT was taken in 5.6% of cases. In cases where a preoperative CBCT was taken, an MB2 was found in 76% of teeth compared to 54.5% when a preoperative CBCT was not available. Hiebert et al. reported that an MB2 canal was identified in 78% of maxillary molars when an operating microscope was used (Hiebert et al. 2017). After looking at a CBCT and using the operating microscope, MB2 canals were identified in 87% of maxillary molars.

High magnification provides clinicians with significantly better visual acuity, allowing clinicians to more clearly see signs of where the canal is located that otherwise would not be visible. Perrin et al. reported a microscope was the only means to achieve accurate vision into the mesiobuccal canal of a maxillary molar compared to Galilean loupes and natural vision (Perrin et al. 2014). Using Galilean loupes, clinicians were able to detect a structure of 0.05mm at the mesiobuccal orifice. In contrast, a microscope allowed clinicians to see up to 50 $mm^{-1}$ (Perrin et al. 2014). High magnification also aids clinicians with performing endodontic motor skills more effectively (Bowers et al. 2010). Bowers et al. evaluated the impact of magnification on accurately placing the tip of a #10 C file on a target. They found that, compared to unaided vision, 2.5x loupes increased accuracy by 17.5% and 8x operating microscopes increased accuracy by 57.7%. Clinicians with more than three years using the microscope were able to perform the motor task 32.1% faster than those with less than three years of experience (Bowers et al. 2010).

Use of ultrasonics and small round burs has been recommended for identification of MB2 canals. Ultrasoncic instruments allow for very specific removal of dentin because they allow significantly better visualization of the active tip (Plotino et al. 2007). Ultrasonic tips are able to remove pulp calcifications without excessive removal of dentin. Typically the head of the handpiece will obstruct direct vision when a bur is used. Studebaker et al. reports 14.3% of MB2 canals required the use of ultrasonic tips or troughing burs to locate the canal orifice (Studebaker et al. 2018).

The use of irrigants that help identify the location of the MB2 canal has also been suggested. The reaction of sodium hypochlorite and pulp tissue creates bubbles which can be used to locate an MB2 canal (Coelho et al. 2018). EDTA and other chelating agents can assist in softening calcifications in the pulp chamber, facilitating entry into the canals (Davich). The use of sodium fluorescein, an ophthalmic solution that binds to connective tissue and shines when exposed to blue light, has been investigated (Pais et al. 2014). The use of fluorescein can cause staining of the tooth, therefore it should not be used for more than two minutes and thorough irrigation should be performed afterward (Pais et al. 2014).

## Current literature and shortcomings

Successful identification of the MB2 canal requires exploration in the correct horizontal location and performing sufficient excavation in the corono-apical direction to bypass coronal canal calcification. Use of CBCT can be of tremendous help in achieving these two goals.

There are many studies reporting the horizontal location of the MB2 canal (Betancourt et al. 2015, Gorduysus et al. 2001, Zhang et al. 2017). Troughing in the corono-apical direction of the pulp chamber floor from the first mesiobuccal canal to the palatal canal has been recommended to uncover MB2s that may be calcified in the coronal portion or enter the pulp chamber at a sharp angle. A balance is needed for depth of troughing. Insufficient depth of troughing will result in MB2 canals not being identified (Gorduysus et al. 2001). However, excessive troughing will increase fracture susceptibility and risk of perforation (Cantatore et al. 2006). No studies have evaluated depth of troughing as the primary objective. There is limited data from four studies that evaluate the incidence of MB2 canals as the primary objective (shown below). The limitations of these studies are that the proportion of MB2 canals is only provided at one depth, insufficient details about the method and reliability of measurement technique, depths are chosen empirically, and do not report if MB2 was missed because of insufficient depth or incorrect horizontal location. Therefore first objective of this thesis is to evaluate the proportion of MB2 canals identified at different depths of excavation.

*Table 1. Current Literature*

| Study primary author and year | Depth of excavation | Proportion of MB2s identified |
|---|---|---|
| Gorduysus et al. 2001 | Up to mid root | 100.0% |
| Yoshioka et al. 2005 | Up to 2mm | 78.5% |
| Park et al. 2014 | Mean of 2.7mm | 94.7% |
| Hiebert et al. 2017 | Up to 2mm | 84.7% |

CBCT is helpful for identifying MB2 canals (Studebaker et al. 2018). However, some studies have shown that CBCT is still not the gold standard and will miss an MB2 in 6-9% of teeth (Parker et al. 2017, Hiebert et al. 2017). These studies evaluated the presence or absence of an MB2 canal as predicted by a CBCT, compared with a gold standard. However, few studies have evaluated the distance of excavation needed to identify the MB2 canal as predicted by CBCT compared with a gold standard. The second objective of this thesis is to compare the depth of excavation to identify the MB2 canal as predicted by CBCT with clinical findings in extracted teeth.

# II. Research aims

The two objectives of this thesis are to: 1) evaluate the proportion of MB2 canals identified at different depths of excavation, and 2) compare the depth of excavation to identify the MB2 canal as predicted by CBCT with clinical findings.

# II. Materials and methods

## Collection of teeth

The study was performed on extracted teeth. To obtain teeth, plastic cups with screw-on lids were left at each clinic. Twenty-four oral surgery offices were contacted by phone to see if the office was willing to collect extracted teeth for a research study. Plastic cups were dropped off at each office. All of these oral surgery offices were located in Connecticut and were private clinics. In addition, plastic cups were left at the emergency clinic run by the Advanced Education in General Dentistry (AEGD) program at the University of Connecticut Health. The emergency clinic is a walk-in clinic where patients can present for emergency visits. Depending on the clinical diagnosis and treatment selection by the patient, AEGD residents will extract teeth as needed for emergency patients. As a rule, third molars are not extracted in the AEGD emergency clinic and are instead referred to the oral surgery clinic.

The staff at each clinic were advised that the collection of teeth was for the purpose of a research project. They were asked to place all maxillary molars that are extracted with the roots intact into the jars. Staff was told that all maxillary molars can be placed in the jar, in particular stressing the tooth could be a virgin tooth, carious tooth, and with or without a crown. The offices were given a contact phone number for when they wanted to have the jars picked up. Periodic phone calls were made to the offices to reaffirm the instructions and see if new jars were needed. Upon collecting the jars, new jars were given to the clinics.

## Inclusion criteria

After collection of jars, teeth were evaluated for meeting of inclusion criteria. Inclusion criteria were as follows:

1. Three separate roots
2. Fully formed apices
3. Distolingual cusp must be present
4. Caries or existing restoration present
5. Confirmed MB2 by sectioning MB root 5mm from the apex.

The purpose of some of these criteria was to exclude wisdom teeth from the sample. A tooth was considered to have three separate roots when there was no joining of the roots at the tips. Apices were evaluated visually and those that appeared to be immature were excluded. Typically, maxillary molars have four cusps: mesiobuccal, mesiolingual, distobuccal, and distolingual. The distolingual cusp was considered to be present when a distinct protuberance was present. If three or fewer cusps were present, the tooth was excluded from the sample. The presence of caries or existing restorations was evaluated under 8x loupes. Caries were identified by the feeling of a sticky feeling upon poking with an endodontic explorer. Existing restorations were identified by visual inspection.

The MB roots in all teeth were sectioned using a carbide bur in a high speed hand piece. A measurement was made using an endodontic file bent at 5mm. The measurements were taken perpendicular to the long axis of the tooth. The roots were cut in cross-section perpendicular to the long axis of the tooth. The cross-section of the root was evaluated under 8x loupes for presence of an MB2 canal. A separate MB2 canal was considered to be present when there was widening of the canal space thicker than at the isthmus. If there was an isthmus extending from the MB1 canal but no widening of the canal space, it was only considered to be and MB1 with an isthmus extending lingually.

## Sample preparation

After selection of teeth that met inclusion criteria, the occlusal surfaces of the teeth were flattened using a diamond bur in a high speed handpiece. Flattening of the cusps was performed until the occlusal grooves could no longer be seen. The presence of mesial caries and/or restorations was recorded. All existing restorations were removed at this point. If a crown was present, it was cut off by creating a groove in the buccal and separating it from the crown using a crown splitter. If it could not be removed with just a groove on the buccal, then the groove was extended to the occlusal surface. For purposes of recording presence of caries and/or restorations. A crown was considered to have restorations on all surfaces.

Each tooth was mounted so that the long axis of the tooth was parallel to the radiograph sensor. If there was difficulty with maintaining the tooth in the proper position, then a ball of rope wax was placed to ensure proper positioning. Digital radiograph sensors were used for this process. The two types of sensors used were XDR or Schick. A measurement was taken from the top of the pulp chamber to the floor of the pulp chamber using the measuring tool equipped in the Mipacs software for viewing radiographs. Any of the digital modifications in contrast and/or sharpness could be used to aid in visualization of the pulp chamber. This measurement was recorded for each tooth.

## CBCT acquisition and measurements

Next, a CBCT scan was taken of the sample teeth. The teeth were then mounted on a plastic lids with nine teeth in three rows and three columns. Sufficient spacing was left between the teeth to ensure no distortion or overlapping of the image. There was minimal presence of artifact distortion because all the restorations were already removed prior to the CBCT scan. A CBCT image was taken using J. Morita Accuitomo 170. A small field of view image was taken. The settings of the CBCT were set to 90kV and 7.0mA with a slice thickness of 0.960mm.

A blinded prediction of the depth of troughing was made by an oral radiology resident from the University of Connecticut oral radiology program. A third year resident was selected who volunteered to participate in the study. The resident was not given any compensation or other incentive for participation. The resident was advised to look at the CBCT images of each tooth and measure the vertical distance from the point where the MB2 canal could be entered with a hand file to the floor of the pulp chamber. This was considered to be the “depth of excavation.” All measurements were taken in a closed dark room. The resident was given the opportunity to ask any questions to clarify the task.

The resident was allowed to use any features available on the work station software including zooming in/out, creating customs planes, and rotating of planes. The resident was permitted to spend as much time evaluating each tooth as desired. The depth of excavation predicted by the resident was recorded. If the resident believed the canal would be visible upon entering the pulp chamber, then the depth of excavation was recorded as “0.00.”

## Access cavity and measurements on extracted teeth

Sample preparation was performed by a third year resident in the University of Connecticut endodontics program. The third year resident had not seen the CBCT images prior to preparing the sample. The bitewing radiographic measurements had been performed by the same resident however sufficient time had passed such that the resident was not able to remember which measurement applied to which tooth. The resident was not given a time restriction on how much time he could take preparing each tooth. The tooth was prepared by holding it in the non-dominant hand under an operating microscope. The hand was rested on a table surface to minimize movement. An operating microscope was used with direct vision of the tooth.

The preparation of the tooth started with an access cavity being made into the pulp chamber. A high speed handpiece was used. In most cases a #6 long shank round bur was used, although other burs were also available if preferred for a specific case. Prior to entering the pulp chamber water and air spray were used to remove debris while working. A constant air spray was not used due to the ex vivo nature of the stud. Air spray was not used after the pulp chamber had been entered to avoid any debris from blocking any orifices. Once the pulp chamber was reached, an endoZ bur was utilized to create straight line. Straight line access was defined as being able to see all canal orifices in full from one view point. In cases with larger pulp chambers, a drop of the bur was felt to indicate entering of the pulp chamber. In cases with smaller pulp chambers, clinical judgement was utilized to determine once the pulp chamber was entered. Care was taken by the clinician to ensure the pulpal floor was not excavated.

Upon accessing the pulp chamber, the presence or absence of pulp stones was recorded. Pulp stones were identified by clinical inspection based on the clinician's judgement. The first measure was taken immediately after entering the pulp chamber. The measurements were taken by placing an endodontic #80 K file with its tip at the predicted location of the MB2 canal if there was not obvious MB2 canal present. The most likely location of the MB2 has been determined to be 1.65mm palatal and 0.69mm mesial to MB1 based on Gorduysus et al (Gorduysus et al. 2001). The distances were estimated under a microscope using the already identified MB1 canal orifice. If an MB2 canal orifice was visible immediately upon access, the tip of the file was placed at the orifice. An #80 K file was used so that the file would not sink into the orifice. The file was held parallel to the long axis of the tooth. A specific landmark on the occlusal surface of the tooth was selected. A rubber marker with a black indicator was positioned such that the black marker just barely touched the landmark. This landmark was used for all subsequent measurements in that tooth to aid in consistent readings. This was done under a microscope. The file was then placed with its tip on a hard surface with the file perpendicular to the surface. A digital caliper was used to measure the distance between the bottom of the stopper and the hard surface. The file and stopper were positioned and the measurement was taken under an operating microscope. Two measurements were taken for each measurement and the mean was taken. Each measurement was taken to the hundredths position. This first measurement was called "depth upon access."

The MB, DB, and P canals were identified and coronal flaring of the orifices was performed using a gates glidden #3 bur. The gates glidden was placed into the orifices with minimal pressure. The depth the gates glidden reached depended on the original size of the canal, with the bur reaching deeper in larger canals. Any calcification in the pulp chamber was removed using a round bur in a slow speed hand piece. Calcification in the pulp chamber was determined to be removed once the pulp floor was reached based on a change in color of the dentin. A second set of measurements were taken using the same methods as described earlier at this time. This measurement was considered “depth to pulp chamber floor.”

After all the initial preparations were performed, the search for the MB2 canal was initiated. The troughing will be performed under an operating microscope using either a Buc1 or long shank round bur in a slow speed hand piece. The troughing was performed starting at the MB1 orifice and extending along the imaginary line connecting the MB1 and P canals and slightly mesial to this line. The mesial wall of the access cavity was modified as needed to retain straight line access. The clinician used a combination of 0.5% NaOCl, EDTA, water, and/or isopropyl alcohol to remove debris. Excess fluid was removed using a surgical suction and paper points. There were no restrictions or specific guidelines as to when or how much of each irrigant could be utilized. These irrigants will be permitted as they may aid in the identification of the MB2. EDTA can decalcify coronal calcification covering the MB2. Isopropyl alcohol can dry out the pulp chamber floor providing better visualization of landmarks. Periodically, the troughing was stopped and the floor of the chamber was evaluated for any suggestion of the location of the MB2 canal.

The depth at which a catch can first be felt with an endodontic explorer will be recorded. A catch was defined as a sensation that the tip of the endodontic explorer was stuck in the dentin. This measurement was taken in the same manner as the previous two measurements. For these measurements, the tip of the #80 K file was placed at the orifice. After the MB2 orifice has been located, it will be confirmed by passing a #8 file through the orifice and out the apical end of the root. In some cases, the apical end of the root was calcified and patency could not be achieved. This may have been from debris accumulation when the MB root was sectioned. In these cases, the root was sectioned further coronally until patency could be obtained. The depth at which a file could achieve patency was recorded. This measurement was also taken in the same manner as the previous measurements.

## Data analysis

Four measurements were taken throughout the experiment: immediately after access (recording A), after identifying pulp chamber floor (recording B), after first sensation of a “catch (recording C), and once patency could be achieved with a hand file (recording D). Two measurements were taken at each recording. The mean of the two measurements was the final measurement at each recording. The depth at each recording was calculated using the formulas below:

$$Depth\ when\ pulp\ chamber\ floor\ identified = Recording\ B - Recording\ A$$

$$Depth\ when\ a\ catch\ was\ felt = Recording\ C - Recording\ A$$

$$Depth\ when\ canal\ was\ patent = Recording\ D - Recording\ A$$

The depth of additional excavation needed to move from one recording to another was calculated using the formula below

$$Additional\ depth\ of\ excavation\ needed\ after\ a\ catch\ to\ gain\ patency$$
$$= Recording\ D - Recording\ C$$

Statistical analysis was performed. The depth of the pulp chamber was divided into two categories: those that had a pulp chamber depth of less than 1.0mm and those that had a pulp chamber depth of more than 1.0mm. The differences in depths of excavation for pulp chamber depth, presence or absence of mesial caries/restorations, presence or absence of pulp stones were evaluated using two-tailed T-test assuming unequal variances. The association between the depths of excavation predicted using the CBCT and the depths of excavation observed clinically was evaluated using a correlation coefficient.

## Reliabilty and Repeatability

Five teeth that did not have an MB2 were prepared as above except a small divit was made on the pulp chamber floor to simulate the orifice of the MB2 canal . A second year endodontics resident measured the distance from the reference point to the predicted location of the MB2 canal in each tooth twice with one week in between. The second year endodontics resident had been shown how the measurements were to be taken and utilized the operating microscope as well. A third year resident also took the same measurements once. The measurements were taken in the same manner as described earlier. Using the measured values, the inter-examiner and intra-examiner reliability will be evaluated. For performing the calculations for intra-class correlation, an online program from the University of Hong Kong Department of Obstetrics and

Gynecology was utilized. For measuring reliability, the first set of measurements taken by the second year resident were compared with that of the third year resident.

# IV. Results

## Reliability and Repeatability

The reliability and repeatability data is shown below. The inter-individual reliability was determined to be high (ICC = 0.9493. The intra-individual repeatability was determined to be high as well (ICC = 0.9767). The greatest difference in any one measurement between the two residents was 0.25mm. The mean difference between the two residents was 0.16mm. The greatest difference in any one measurement between the two sets of measurements taken by the first resident was 0.19. The mean difference was 0.12mm.

*Table 2. Reliability and Repeatability*

| | Resident 1 | Resident 2 | Resident 1 |
|---|---|---|---|
| Tooth #1 | 7.87 | 7.73 | 8.00 |
| Tooth #2 | 7.91 | 7.90 | 7.70 |
| Tooth #3 | 7.04 | 7.25 | 6.98 |
| Tooth #4 | 6.72 | 6.97 | 6.65 |
| Tooth #5 | 6.79 | 6.62 | 6.67 |

## Raw data

The raw data collected from is found in the table below.

*Table 3. Raw Data*

| Raw Data of Depth Measurements and variables | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Pulp chamber depth | Mesial caries/restoration/crown | Pulp stones | Depth upon access | | Depth to pulp chamber floor | | Depth to catch | | Depth to patency | |
| 0.9 | y | y | 8.18 | 8.14 | 8.12 | 8.27 | 8.21 | 8.11 | 8.17 | 8.14 |
| 0.56 | n | n | 7.22 | 7.27 | 7.05 | 7.08 | 8.91 | 8.96 | 8.81 | 8.84 |
| 1.58 | y | n | 7.62 | 7.69 | 7.76 | 7.65 | 7.84 | 7.84 | 7.91 | 7.97 |
| 0.96 | n | n | 7.74 | 7.85 | 7.71 | 7.8 | 7.65 | 7.98 | 7.98 | 8.06 |
| 0.43 | y | n | 7.15 | 7.1 | 7.16 | 7.09 | 8.54 | 8.5 | 8.38 | 8.65 |
| 1.42 | y | n | 7.87 | 7.85 | 7.89 | 7.96 | 7.99 | 8.06 | 7.93 | 8 |
| 0.25 | y | n | 6.8 | 6.85 | 6.85 | 6.95 | 8.2 | 8.15 | 8.85 | 8.75 |
| 0.1 | n | n | 7.75 | 7.92 | 8.06 | 8.07 | 8.12 | 8.16 | 8.31 | 8.12 |
| 0.68 | y | n | 5.43 | 5.44 | 5.31 | 5.73 | 6.17 | 6.53 | 6.5 | 6.59 |
| 1.45 | n | n | 7.12 | 7.17 | 7.1 | 7.2 | 7.22 | 7.14 | 7.17 | 7.11 |
| 1.05 | n | n | 8.41 | 8.35 | 8.42 | 8.37 | 9.01 | 8.76 | 8.71 | 9.03 |
| 1.95 | y | y | 7.14 | 7.27 | 7.27 | 7.2 | 7.35 | 7.19 | 7.36 | 7.41 |
| 0.74 | n | n | 7.09 | 7.37 | 7.26 | 7.24 | 7.3 | 7.27 | 7.34 | 7.41 |
| 0.28 | y | n | 4.99 | 5.13 | 5.34 | 4.97 | 5.38 | 5.35 | 5.48 | 5.52 |
| 0.87 | y | n | 8.17 | 8.19 | 8.26 | 8.19 | 8.46 | 8.05 | 8.21 | 8.32 |
| 1.98 | y | n | 4.64 | 4.83 | 4.7 | 4.91 | 5.13 | 5.3 | 5.17 | 5.23 |
| 1.14 | n | y | 7.67 | 7.75 | 7.67 | 7.68 | 7.77 | 7.57 | 7.74 | 7.58 |
| 1.03 | n | n | 7.85 | 7.95 | 7.98 | 7.92 | 7.9 | 8.17 | 8.05 | 8.11 |
| 1.49 | n | n | 7.66 | 7.73 | 7.48 | 7.86 | 8.19 | 8.36 | 8.24 | 8.53 |
| 0.34 | n | y | 7.47 | 7.38 | 7.52 | 7.43 | 7.59 | 7.69 | 7.75 | 7.59 |
| 0.96 | y | n | 7.4 | 7.02 | 7.24 | 7.05 | 7.33 | 7.52 | 7.55 | 7.49 |
| 1.42 | y | n | 6.47 | 6.21 | 6.43 | 6.32 | 8.1 | 8.31 | 8.08 | 8.01 |
| 0.5 | y | y | 6.57 | 6.92 | 7.1 | 7.51 | 7.56 | 7.33 | 7.61 | 7.68 |
| 1.8 | y | n | 7.97 | 8.13 | 8.12 | 8.18 | 8.23 | 8.18 | 8.08 | 8.07 |
| 1.7 | n | n | 7.21 | 7.08 | 7.18 | 7.02 | 7.51 | 7.52 | 7.6 | 7.52 |
| 0.4 | y | n | 7.3 | 7.2 | 7.21 | 7.4 | 7.08 | 7.3 | 7.4 | 7.58 |
| 0.2 | y | n | 6.32 | 6.42 | 6.29 | 5.86 | 6.83 | 6.69 | 7.08 | 7.31 |
| 0.8 | n | n | 7.08 | 7.19 | 7.3 | 7.21 | 7.12 | 7.36 | 7.25 | 7.1 |
| 0.9 | y | n | 7.39 | 7.47 | 7.4 | 7.44 | 7.44 | 7.5 | 7.56 | 7.9 |

## Analyzed data

The analyzed data is shown below. This is derived from the raw data using the formulas shown in the methods section. A total of 29 teeth were tested. Mesial caries/restoration was present in 17 teeth and not present in 12 teeth. Pulp stones were present in 5 teeth and not present in 24 teeth. Pulp chamber depth ranged from 0.1mm to 1.98mm. The pulp chamber depth was less than 1.0mm in 17 teeth and more than 1.0mm in 12 teeth.

*Table 4. Analyzed Data*

| Analyzed Data of Depths of Measurement and Variables | | | | | | |
|---|---|---|---|---|---|---|
| Sample # | Pulp chamber depth | Mesial caries/restoration | Pulp stones | Depth until Pulp floor | Depth until Catch | Depth until Patent |
| 1 | 0.9 | y | y | 0.04 | 0.00 | 0.00 |
| 2 | 0.56 | n | n | -0.18 | 1.69 | 1.58 |
| 3 | 1.58 | y | n | 0.05 | 0.19 | 0.28 |
| 4 | 0.96 | n | n | -0.04 | 0.02 | 0.23 |
| 5 | 0.43 | y | n | 0.00 | 1.40 | 1.39 |
| 6 | 1.42 | y | n | 0.07 | 0.17 | 0.11 |
| 7 | 0.25 | y | n | 0.08 | 1.35 | 1.98 |
| 8 | 0.1 | n | n | 0.23 | 0.31 | 0.38 |
| 9 | 0.68 | y | n | 0.08 | 0.91 | 1.11 |
| 10 | 1.45 | n | n | 0.01 | 0.04 | 0.00 |
| 11 | 1.05 | n | n | 0.02 | 0.51 | 0.49 |
| 12 | 1.95 | y | y | 0.03 | 0.06 | 0.18 |
| 13 | 0.74 | n | n | 0.02 | 0.05 | 0.15 |
| 14 | 0.28 | y | n | 0.09 | 0.31 | 0.44 |
| 15 | 0.87 | y | n | 0.04 | 0.08 | 0.09 |
| 16 | 1.98 | y | n | 0.07 | 0.48 | 0.47 |
| 17 | 1.14 | n | y | -0.04 | -0.04 | -0.05 |
| 18 | 1.03 | n | n | 0.05 | 0.14 | 0.18 |
| 19 | 1.49 | n | n | -0.03 | 0.58 | 0.69 |
| 20 | 0.34 | n | y | 0.05 | 0.22 | 0.25 |
| 21 | 0.96 | y | n | -0.07 | 0.22 | 0.31 |
| 22 | 1.42 | y | n | 0.04 | 1.87 | 1.71 |
| 23 | 0.5 | y | y | 0.56 | 0.70 | 0.90 |
| 24 | 1.8 | y | n | 0.10 | 0.15 | 0.02 |
| 25 | 1.7 | n | n | -0.04 | 0.37 | 0.42 |
| 26 | 0.4 | y | n | 0.05 | -0.06 | 0.24 |
| 27 | 0.2 | y | n | -0.30 | 0.39 | 0.83 |
| 28 | 0.8 | n | n | 0.12 | 0.11 | 0.04 |
| 29 | 0.9 | y | n | -0.01 | 0.04 | 0.30 |

## Overall depths of excavation

The figure below shows the proportion of teeth that had the pulp floor reached, catch noted, and canal patency achieved at different depths of excavation. Due to some variation in measurement acquisition, some data points had negative values although this is not possible clinically. For this reason, all negative depths were entered as “0” for purposes of fabricating a graph. Negative values were retained for purposes of statistical calculations. In accordance with clinically expectation, the pulp floor was always located with the least excavation. After excavation of 0.10mm of dentin or less, the pulp chamber floor could be identified in 26 out of 29 teeth. The greatest depth of excavation needed to reach the pulp chamber floor was 0.56mm. This tooth had a pulp stone present upon entering the pulp chamber so some excavation of pulp stone tissue was required to reach the pulp chamber floor. A catch was noted in 21 out of 29 teeth within 0.5mm of excavation. After 1.5mm of excavation, a catch was noted in 27 out of 29 teeth. In other words, more than 1.5mm of excavation was needed in only 2 out of 29 teeth to feel a catch of the endodontic explorer. The greatest depth at which a catch was first felt was 1.87mm. Patency was usually achieved with minimal additional excavation. MB2 canal patency was achieved in 21 out of 29 teeth within 0.5mm of excavation, the same proportion as for a catch being noted. After 1.5mm of excavation, patency could be achieved in 26 out of 29 teeth. In other words, more than 1.5mm of excavation was needed in only 3 out of 29 teeth to achieve patency. Two out of the 3 teeth that needed more than 1.5mm of excavation to achieve patency, had a 1-2 canal configuration (one canal bifurcating into two canals). In these teeth, the point of bifurcation location of the MB2 canal from the MB1 canal became accessible with a hand file after the listed depths of excavation. The greatest depth of excavation needed in any tooth to achieve patency was 1.98mm.

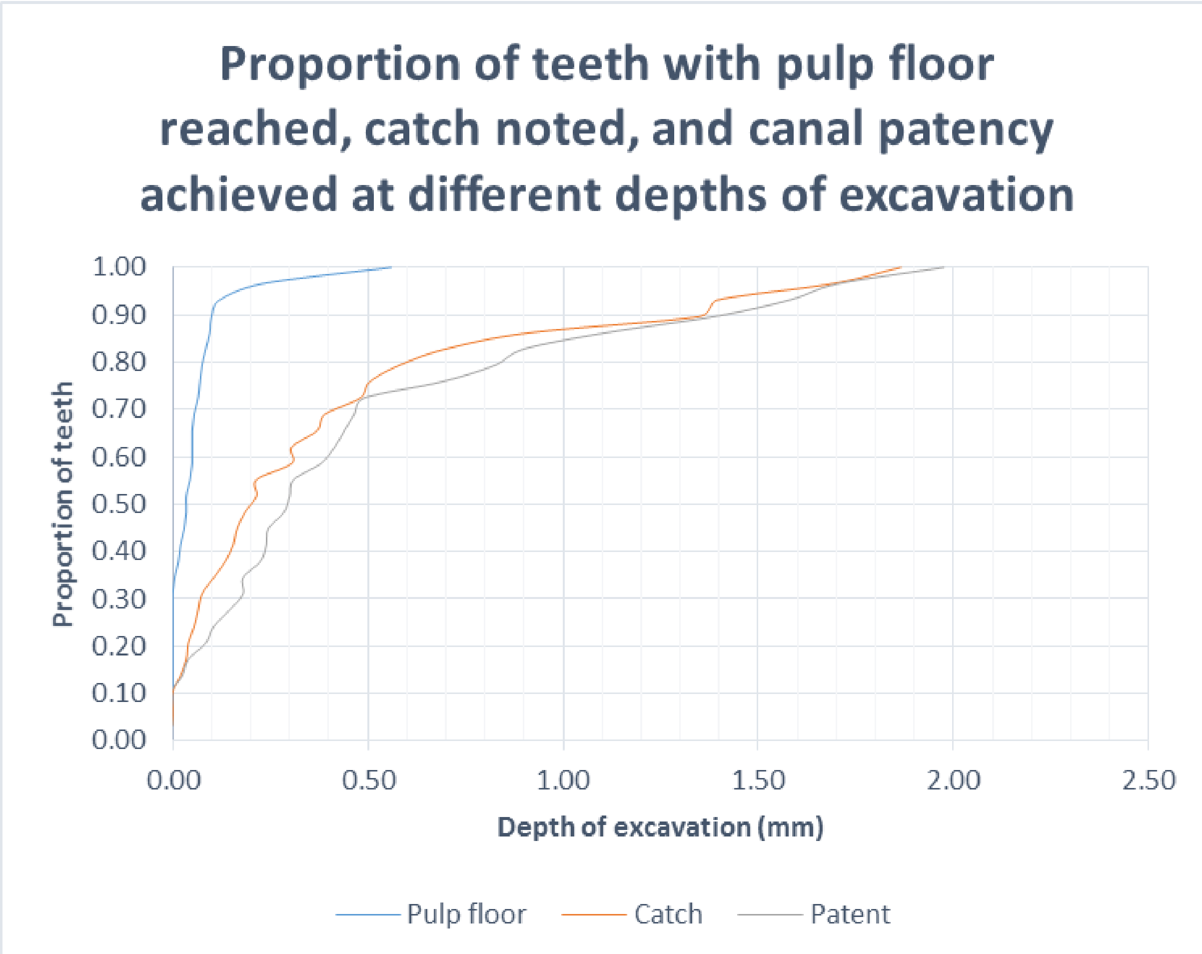


*Figure 1. Proportion of Teeth with Pulp Floor Reached, Catch Noted, and Canal Patency Achieved at Different Depths of Excavation*

## Mesial caries

The graph and table below show the mean depth of excavation needed to reach the pulp floor, feel a catch, and gain patency in teeth with and without mesial caries/restorations. The mean depth of excavation to reach the pulp floor in teeth that had mesial caries/restorations was 0.06mm and in teeth that did not have mesial caries/restorations was 0.01mm. This was not statistically significant. The mean depth of excavation to feel a catch of the endodontic explorer in teeth that had mesial caries/restorations was 0.48mm and in teeth that did not have mesial caries/restorations was 0.33mm. This was not statistically significant. The mean depth of excavation to gain patency in the MB2 canal in teeth that had mesial caries/restorations was 0.61mm and in teeth that did not have mesial caries/restorations was 0.36mm. This was not statistically significant.

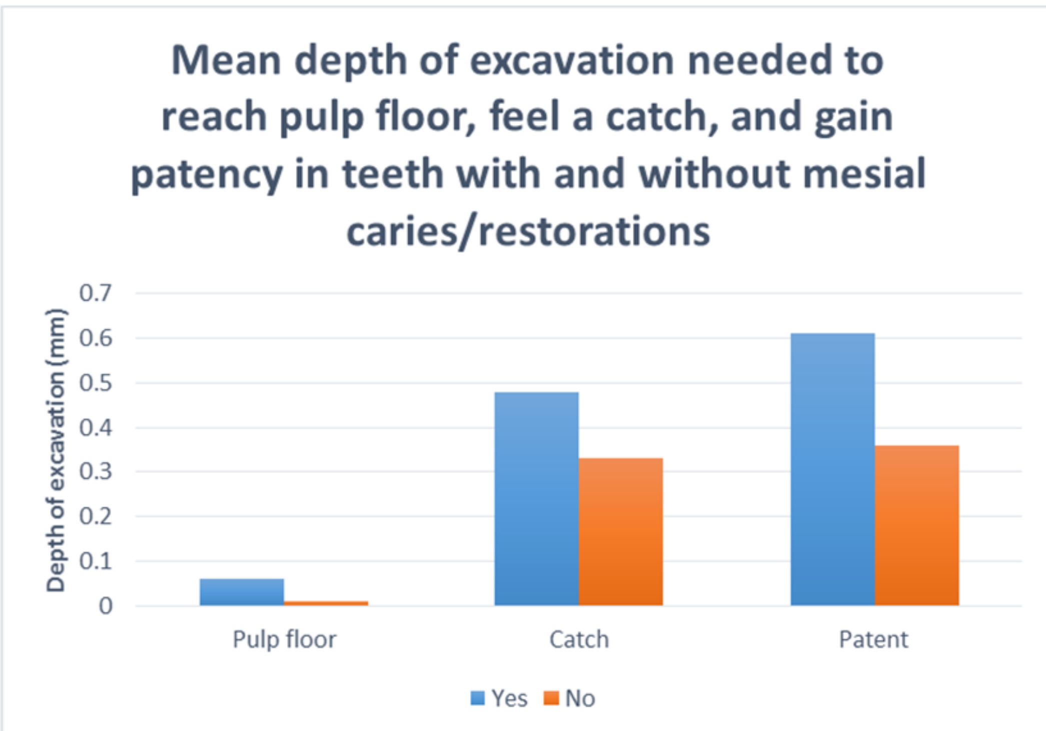


*Figure 2. Mean Depth of Excavation Needed to Reach Pulp Floor, Feel a Catch, and Gain Patency in Teeth with and without Mesial Caries/restorations*

*Table 5. Mean Depth of Excavation with and without Caries/restoration*

| Mean depth of excavation with and without mesial caries/restoration (mm) | | | | | |
|---|---|---|---|---|---|
| Pulp floor | | Catch | | Patent | |
| Yes | No | Yes | No | Yes | No |
| 0.06 | 0.01 | 0.48 | 0.33 | 0.61 | 0.36 |
| p = 0.40 | | p = 0.44 | | p = 0.22 | |

## Pulp stones

The graph and table below show the mean depth of excavation needed to reach the pulp floor, feel a catch, and gain patency in teeth with and without pulp stones. The mean depth of excavation to reach the pulp floor in teeth that had pulp stones was 0.13mm and in teeth that did not have pulp stones was 0.19mm. This was not statistically significant. The mean depth of excavation to feel a catch of the endodontic explorer in teeth that had pulp stones was 0.19mm and in teeth that did not have pulp stones was 0.47mm. This was not statistically significant. The mean depth of excavation to gain patency in the MB2 canal in teeth that had mesial caries/restorations was 0.25mm and in teeth that did not have pulp stones was 0.56mm. This was not statistically significant. However only five teeth had pulp stones present. Due to the small sample size, the mean values are reported when pulp stones were present have risk of being unrepresentative.

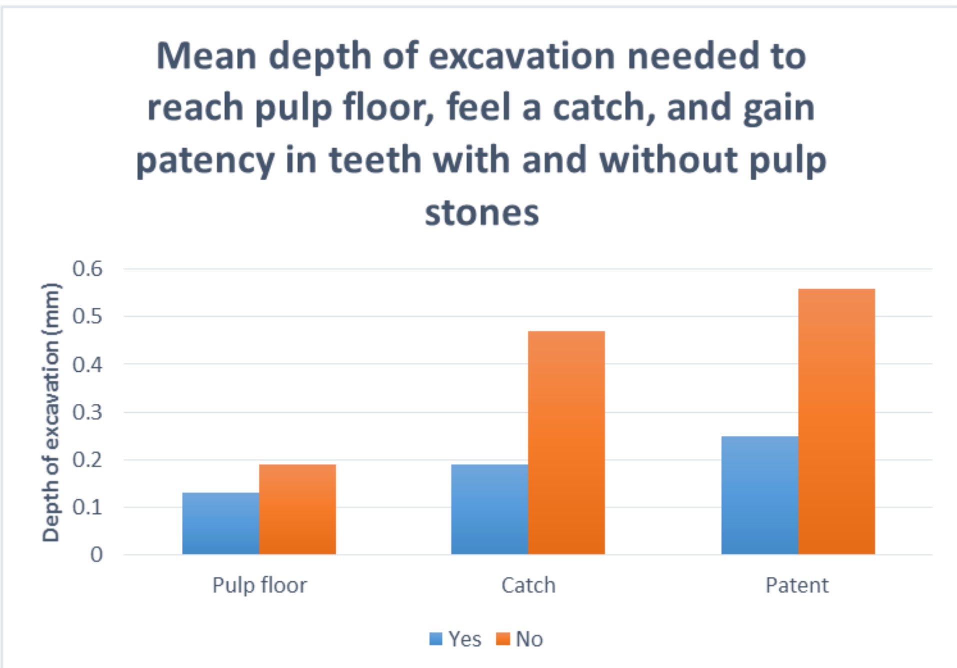


*Figure 3. Mean Depth of Excavation Needed to Reach Pulp Floor, Feel a Catch, and Gain Patency in Teeth with and without Pulp Stones*

*Table 6. Mean Depth of Excavation with and without Pulp Stones*

| Mean depth of excavation with and without pulp stones (mm) | | | | | |
|---|---|---|---|---|---|
| Pulp floor | | Catch | | Patent | |
| Yes | No | Yes | No | Yes | No |
| 0.13 | 0.19 | 0.19 | 0.47 | 0.25 | 0.56 |
| p = 0.38 | | p = 0.14 | | p = 0.18 | |

## Pulp chamber depth

The graph and table below show the mean depth of excavation needed to reach the pulp floor, feel a catch, and gain patency in teeth depending on pulp chamber depth. The mean depth of excavation to reach the pulp floor in teeth that had a pulp chamber depth of less than 1.0mm was 0.0.05mm and in teeth that did had a pulp chamber depth of more than 1.0mm was 0.03mm. This was not statistically significant. The mean depth of excavation to feel a catch of the endodontic explorer in teeth that had a pulp chamber depth of less than 1.0mm was 0.45mm and in teeth that had a pulp chamber depth of more than 1.0mm was 0.38mm. This was not statistically significant. The mean depth of excavation to gain patency in the MB2 canal in teeth that had a pulp chamber depth of less than 1.0mm was 0.60mm and in teeth that had a pulp chamber depth of more than 1.0mm was 0.37mm. This was not statistically significant.

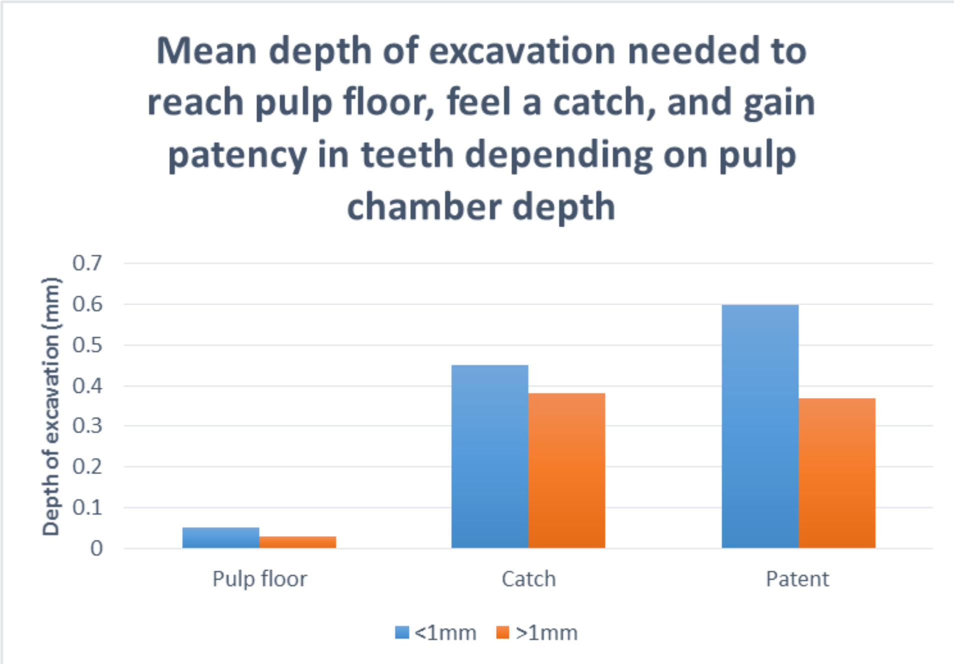


*Figure 4. Mean Depth of Excavation Needed to Reach Pulp Floor, Feel a Catch, and Gain Patency in Teeth Depending on Pulp Chamber Depth*

*Table 7. Mean Depth of Excavation Depending on Pulp Chamber Depth*

| Mean depth of excavation depending on pulp chamber depth (mm) | | | | | |
|---|---|---|---|---|---|
| Pulp floor | | Catch | | Patent | |
| <1mm | >1mm | <1mm | >1mm | <1mm | >1mm |
| 0.05 | 0.03 | 0.45 | 0.38 | 0.60 | 0.37 |
| p = 0.67 | | p = 0.70 | | p = 0.27 | |

## Depth of excavation predicted by CBCT versus observed depth of excavation in extracted teeth

The table and graph below shows the association between the depths of excavation as predicted by the CBCT with the depths of excavation observed in the extracted teeth. CBCT predictions were obtained for 20 teeth. The oral radiology resident predicted the MB2 canal would be patent with the pulp chamber (0mm of excavation needed) in 13 out of 20 teeth based on CBCT assessment. For the remaining 7 teeth, the 3 teeth with the greatest depth of excavation as based on CBCT assessment all had 1-2 root configuration. Teeth with a 1-2 configuration were also the teeth with the greatest variation between the depth of excavation predicted through CBCT evaluation and the depth of excavation until patency could be achieved on the extracted teeth. The overall correlation was poor (r = 0.50). Even if the teeth with a 1-2 configuration were excluded, the correlation was slightly better but still poor (r = 0.62). In all three cases of a 1-2 root configuration, the CBCT assessment resulted in a prediction of greater depth than which was observed clinically in extracted teeth. No such trend was noted for teeth without a 1-2 root configuration.

*Table 8. Association between the Depth of Excavation as Predicted by the CBCT and the Depth of Excavation Observed in Extracted Teeth*

| Depth until patency (mm) | | |
|---|---|---|
| Sample # | Depth of excavation observed | CBCT prediction |
| 1 | 0.00 | 0.00 |
| 2 | 1.58 | 5.71 |
| 3 | 0.28 | 0.00 |
| 4 | 0.23 | 0.00 |
| 5 | 1.39 | 1.29 |
| 6 | 0.11 | 0.00 |
| 7 | 1.98 | 0.74 |
| 8 | 0.38 | 0.46 |
| 9 | 1.11 | 0.00 |
| 10 | 0.00 | 0.00 |
| 11 | 0.49 | 0.00 |
| 12 | 0.18 | 0.78 |
| 13 | 0.15 | 0.00 |
| 14 | 0.44 | 0.00 |
| 15 | 0.09 | 2.41 |
| 16 | 0.47 | 0.00 |
| 17 | -0.05 | 0.00 |
| 18 | 0.18 | 0.00 |
| 19 | 0.69 | 1.93 |
| 20 | 0.25 | 0.00 |

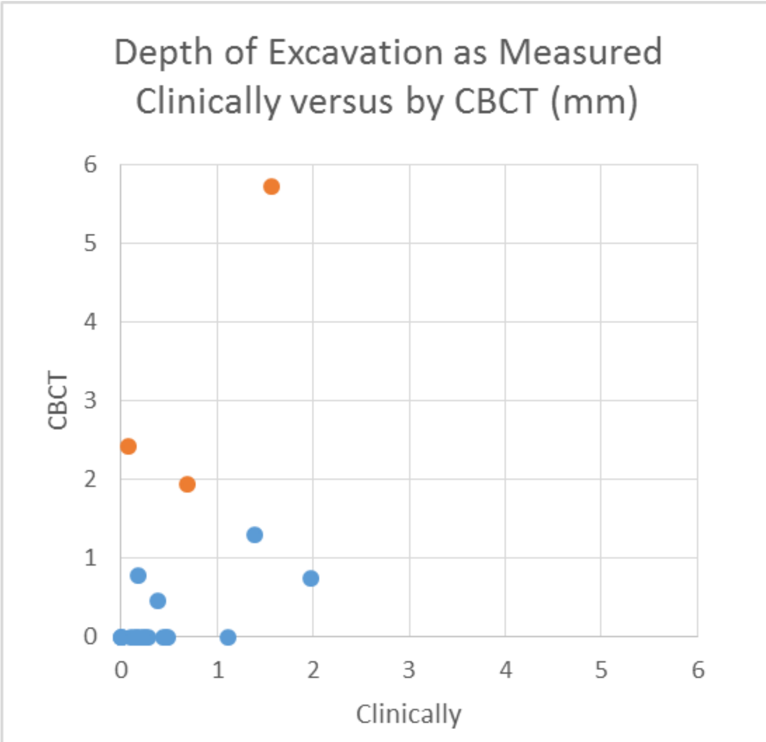


*Figure 5. Depth of Excavation as Measured Clinically Versus by CBCT*

## Iatrogenic complications

Iatrogenic complications were recorded. No perforations were noted on any teeth. However, the root morphology was visible to the clinician during the procedure, which would have benefitted the clinician in proper angulation along the long axis of the root and tooth. One rotary file was separated during confirmation of patency. In this particular tooth, the location of the MB2 was able to be identified visually and with a catch of the endodontic explorer with none to minimal excavation. Insertion of a hand file clearly demonstrated the canal traversed horizontally in a mesial direction upon entering the orifice. A Vortex Blue size 15 taper 0.04 rotary file was utilized at 500 RPM in an attempt to brush the orifice further mesially to reduce the degree of curvature in the coronal third. Approximately 2mm of the file separated at the entrance of the orifice with the top of the file visible at the orifice level. This tooth may have benefitted from further excavation mesially and perhaps apically using an ultrasonic instrument or a round bur in a slow speed hand piece. It was not possible to enlarge the coronal portion of the canal using even the gates glidden #1 due to the sharp curvature immediately upon entering the orifice.

# V. Discussion

The primary goal of endodontic treatment is to disinfect the root canal system. Although complete disinfection is not possible, root canal treatment has a high survival and success rates (Sjogren et al. 1990, Fransson et al. 2016, Ng et al. 2007, Ng et al. 2011A, Ng et al. 2011B). One of the challenges with providing optimal root canal treatment includes treating all canal systems. In particular, the MB2 canal is the most frequently missed canal. Advances in endodontics, in particular use of the operating microscope (Carr and Murgel 2010), ultrasonics (Plotino et al. 2007), and CBCT have assisted in location of MB2 canals (Fayad et al. 2015). On the other hand, recent trends towards conservative accesses (Clark and Khademi 2010, Plotino et al 2017, Krishan et al. 2014, Moore et al. 2016) and minimal dentin removal around the cervical area of the tooth (Plotino et al. 2007, Tang et al. 2010) have made the task more difficult. Identification of the MB2 canal requires careful and strategic removal of dentin to expose the entrance of the canal without causing excessive damage to the tooth (Cantatore et al 2006). Insufficient removal of dentin and coronal calcifications may lead to clinicians not locating the MB2 canal (Ibarrola et al. 1997, Yoshioka et al. 2005).

Teeth with untreated canal space are less likely to succeed (Karabucak et al. 2016). However, aggressive excavation of dentin may lead to a reduction in the fracture resistance (Tang et al. 2010) and iatrogenic perforation. Although some recent studies have suggested high success of perforation repairs (Siew et al. 2015, Gorni et al. 2016, Pontius et al. 2013), it is generally accepted that the success of the root canal treatment is lowered due to the perforation (Fuss and Trope 1996, Tsesis and Fuss 2006, Sinai 1977). The first goal of this study was to evaluate the depth of excavation needed to identify the MB2 canal.

## Depth of Excavation for MB2 Canals

Within the limitation of this study, most MB2 canals are identified with 1mm of troughing depth. In this study the deepest troughing needed to identify an MB2 canal was about 2mm. This study is not able to able to recommend a guideline for how deep a clinician should excavate looking for the MB2, as many other factors must be considered such as clinician skill, availability of technological aids and instruments, tooth related factors, and patient related factors. An argument can even be made for different depths of troughing for vital versus non-vital cases. Instead the purpose of this study is to provide information that the clinician can use to make a decision on a case by case basis.

## Comparison with Present Literature

The current study was able to identify 100% of MB2 canals with 2mm of troughing. In contrast, Gorduysus et al. reports 85% of MB2 canals identified with 2mm of troughing (Gorduysus et al. 2001). Further excavation until the midroot region was needed to negotiate all MB2 canals. Two perforations (out of 45 teeth) occurred in the process (Gorduysus et al. 2001). Park et al. reports that 94.7% of MB2 canals were identified with a mean troughing depth of 2.7mm (Park et al. 2014). Yoshioka et al. reports that 77% of MB2 canals were identified with troughing 2mm (Yoshioka et al. 2005). Approximately 38% of the MB2 canals that were not identified were due to calcification and the remaining 62% were due to deep bifurcation. Hiebert et al. Reports that 85% of MB2 canals were identified with 2mm of troughing (Hiebert et al. 2017). The current study is the only study to not find any canals that needed more than 2mm of excavation. In the current study, excavation for the MB2 canal was performed broadly to ensure no canals were missed from excavation in the incorrect horizontal (mesio-distal or bucco-lingual) location. Hiebert et al. and Park et al. do not report the reason for not findings all MB2 canals. The canals could have been missed due to insufficient depth of excavation or incorrect horizontal location. The difference may also be due to chance associated with the small sample size.

The current study contributes to the literature because it is the only study to the best of our knowledge that reports the exact depth of excavation needed to identify each MB2 canals. All the other studies report the proportion of MB2 canals identified after one or two specific depths of excavation. For example, none of the four previous studies report the proportion of MB2 canals identified at 0.5mm or 1.0mm of excavation. The continuous data provided by the current study supplements endodontic literature. Furthermore, the current study is the only one to detail the method of obtaining the measurement. Park et al. only mentions that a periodontal probe was utilized, but there is no mention if a microscope was used for the measurement, the specific methodology, the exactness of the periodontal probe, or any reporting of reliability or repeatability. The other three studies do not mention how the measurements were taken.

## Comparison with Cone Beam Computed Tomography Prediction

The second objective of the current study was to compare the depth of excavation predicted by an oral radiology resident viewing a CBCT and that which was observed clinically in the extracted teeth. The findings suggest that there was a poor correlation between the two factors, suggesting that CBCT may not be an ideal method for predicting the depth of excavation necessary to locate the MB2 canal. There was a strong tendency for the prediction based on the CBCT to suggest the canal would be visible without the need for any excavation. This was based on the MB2 canal space being in continuity with the pulp chamber. It is possible that in some cases an MB2 canal was immediately patent with the pulp chamber space but due to a horizontal entry into the chamber it was not visible clinically when looking into the access from a vertical point of view. The results may also be suggestive of poor correlation on paper but this may not be true in clinical practice. For example, a difference of 0.25mm between the CBCT prediction and the observed depth in the extracted teeth may drastically reduce the correlation coefficient, but a difference of this value may be clinically insignificant. A difference of 0.25mm may be noticeable when the measurement is taken in a research setting, but this may not be the case clinically. Typically, the most accurate measuring instrument available for a dentist to measure depth into an access cavity is a periodontal probe. Most periodontal probes only have markings at 1mm intervals. In comparison, a difference of 0.25mm may be miniscule when the error associated with the measurement itself may be greater.

## Explanation of Methodology

In this study, all existing restorations were removed prior to obtaining a CBCT scan to reduce any distortion from scatter. The presence of metallic restorations will likely make use of CBCT more difficult than in this study. In this study, complete straight line access was created to the orifices and direct line of sight to the pulp chamber floor was possible due to this being an ex vivo study. In clinical practice where a more conservative access cavity is prepared and where indirect vision is needed, the task of locating the MB2 canals will be more challenging. In this study there was little restriction of the tools and irrigants that could be used. This was done to provide the clinician with all possible tools that are available in typical clinical practice. This may reduce the repeatability of the study but enhances the clinical applicability. A two tailed design was used in this study as it was unclear what the effect of the tested variables would be (mesial caries/restoration, pulp stones, and depth of pulp chamber).

Measurements were taken at four intervals in this study: immediately after accessing chamber, after identifying the pulp chamber floor, after feeling first sensation of a catch, after canal was confirmed patent. The measurement "after identifying the pulp chamber floor" was intended for cases where the pulp chamber was significantly calcified. The pulp chamber floor was defined for purposes of the study as a darkening shade of dentin being visible. In reality, the identification of the pulp chamber floor was not as specific as hoped due to the inexactness of what is considered dark. In many cases, no additional excavation was needed to identify the pulp chamber floor after entering the pulp chamber. So, the two measurements were right after one another.

## Limitations

The reliability and repeatability of this study were done in ideal conditions. A divit was made on the pulp chamber floor with a round bur to mimic the location of an MB2 orifice. The measurements were taken from the divit to an indicated reference point. The tip of the file was able to sit in the divit with little slippage. In contrast when taking measurements in sample teeth, the process was more cumbersome and required more careful measurement. Along the same lines, although the reliability and repeatability were high, some depth measurements were negative (measurement after pulp chamber was located was more than the measurement after pulp chamber entered). It is not possible to have “negative excavation,” however this occurred due to the slight variation in the measurement process. When calculating means and statistical analysis, the negative values were retained. When creating graphs, negative values were rounded to zero.

## Future Studies

Future studies can focus on different measurement methods and testing larger samples. Use of a microCT to measure the depth of excavation may be more accurate that the measurement methodology used in the current study. A preoperative microCT and a postoperative microCT (after identifying the MB2 canal) could be taken and overlaid on each other. The difference in the two microCTs may be a more accurate method to measure the depth of excavation, which may eliminate the challenge of negative depth measurements. This current study had a sample size of 29 teeth. A larger sample would allow better extrapolation of data.

More broadly, further studies should also evaluate the impact of a missed canal and excessive excavation. It is has been shown that a missed canal leads to a higher risk of failure (Karabucak et al. 2016) and biological principles support that remnants of pulp tissue in vital cases and persistent bacteria in non-vital cases could increase risk of failure (Nair 2006). However there are also studies that suggest there is no significant difference in outcome of teeth with separated instruments depending, another example of incomplete debridement (Panitvisai et al 2010). Studies should evaluate the different impact missed canals have in vital and non-vital teeth.

# VI. Conclusion

Within the limitations of this current study, most MB2 canals can be identified within 0.5mm of excavation and almost all MB2 canals can be identified within 1.5mm of excavation. The greatest depth of excavation needed to identify an MB2 canal was about 2.0mm. Mesial caries/restorations, pulp stones, and depth of pulp chamber did not affect the depth of excavation needed to identify MB2 canals. Estimates of the excavation depth needed to find an MB2 canal using a CBCT scan differed from that which was observed clinically in the extracted teeth. However, this difference may be more noticeable in a research study than in a clinical scenario on a patient.

# VII. Appendix

## Appendix 1:

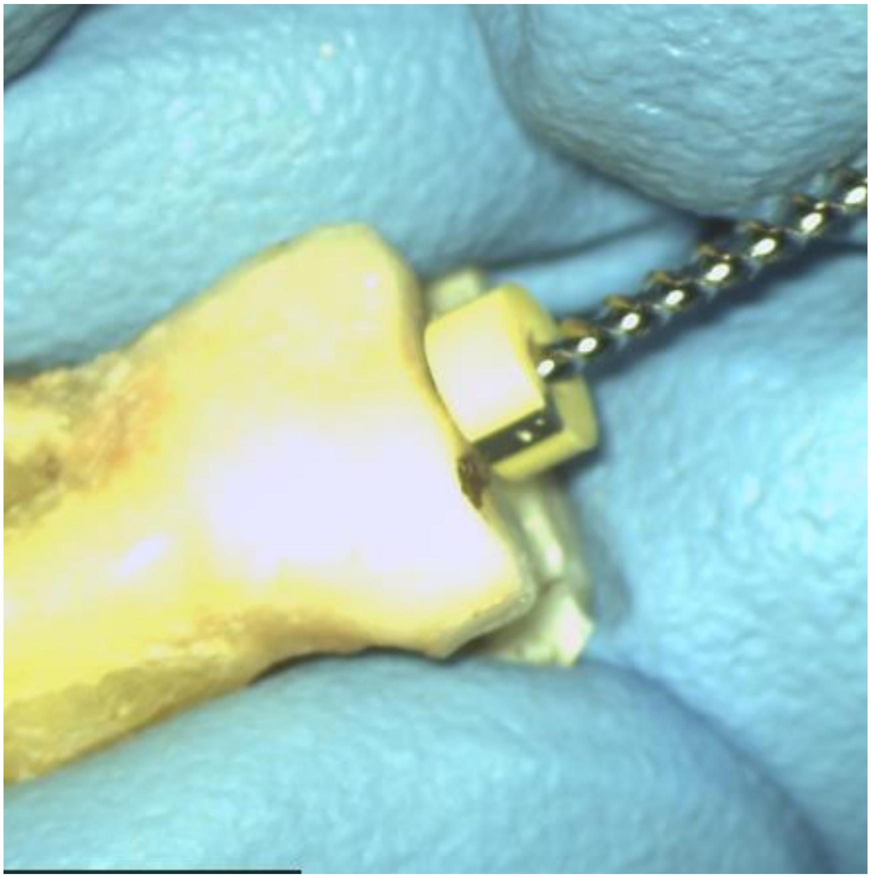

*Figure 6. View under a dental operating microscope showing the use of a file and stopper to measure the depth to a reference point on the cusp.*

## Appendix 2:

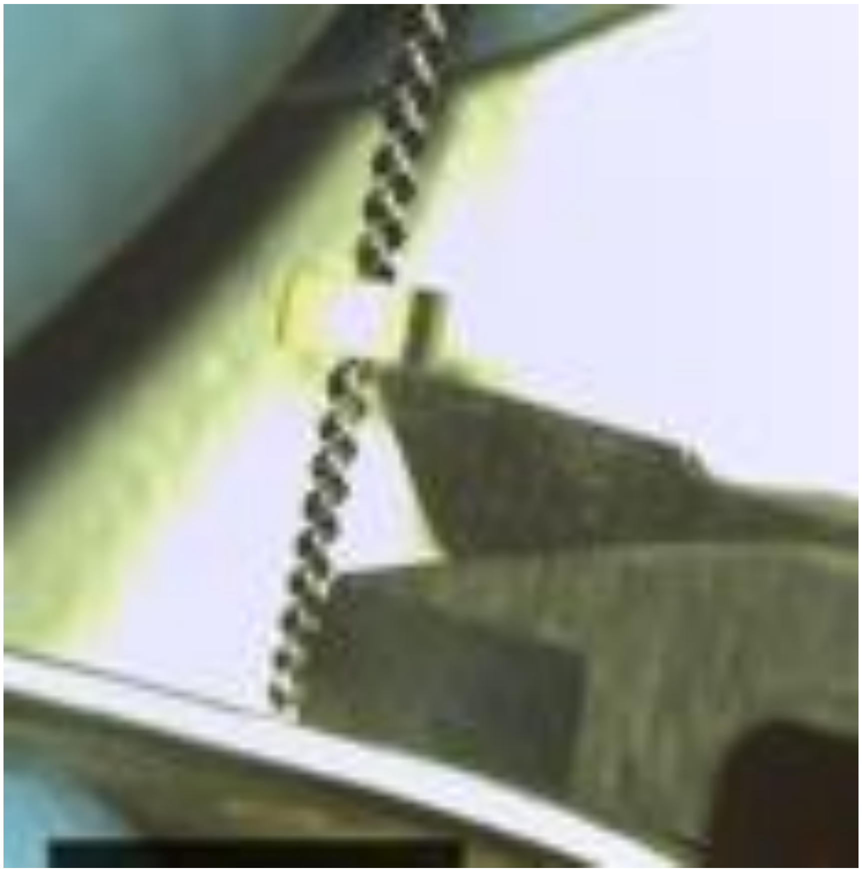

*Figure 7. View under microscope of digital caliper being placed against a flat surface to measure the distance from the tip of the endodontic hand file to the stopper.*

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