Clinical and radiographic methods to find the second mesiobuccal canal in maxillary molars

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SUMMARY

A retrospective clinical study was carried out to determine if cone beam volumetric tomography (CBVT) would aid the practitioner in locating the second mesiobuccal canal (MB2) in maxillary molars during endodontic treatment. CBVT scans of fifty patients who received root canal treatment at a private dental practice limited to endodontics were reviewed for the presence or absence of MB2. The clinical notes and post-operative radiographs were then reviewed to determine whether an MB2 was located and treated by the practitioner.

The prevalence of MB2 in the CBVT images in this study was 92%. This was on the higher end but still consistent with previous *in vitro* studies suggesting CBVT accurately protrays actual anatomy. The prevalence of MB2 that was clinically identified was 89.1%. This finding was higher than previous *in vivo* studies using conventional two-dimensional radiography, suggesting that the use of CBVT can increase the clinical identification and treatment of MB2.

I. INTRODUCTION

A. <u>Background:</u>

The primary objective of root canal therapy is the treatment and/or prevention of apical periodontitis. To accomplish this goal, inflamed or necrotic pulp tissue is removed by complete chemomechanical debridement of the root canal system and this space is then sealed with an appropriate obturating material (Vertucci, 1984). A successful result requires that the operator understands and appreciates the internal anatomy and morphology of the root canal system (Weine, 1969; Vertucci, 1984; Krasner & Rankow, 2004).

The permanent maxillary first and second molars commonly present with three roots and four canals (Vertucci, 2011). The distobuccal root has a conical shape and usually contains one canal. The palatal root, while ribbon-like and broad mesio-distally, also usually only contains a single canal. The mesiobuccal root, on the other hand, is broad in a buccal-lingual direction and usually contains two root canals, the first and second mesiobuccal canals (Ash & Nelson, 2003; Vertucci, 2011). Authors have used various terminologies when referring to the second canal in the mesiobuccal root. It has been referred to as mesiolingual, mesiopalatal, second mesiobuccal, and MB2 (Favieri, 2006; Adanir, 2007; Kottoor, 2010; Karthikeyan, 2010). MB2 and second mesiobuccal are the most widely accepted terms in the literature and will therefore be used in this study.

While previous studies have found the prevalence of a second mesiobuccal canal to be high (up to 95.2%, depending on the method of evaluation), identifying it during endodontic treatment can be a clinical challenge (Cleghorn, 2006; Kulild & Peters, 1990; Stropko, 1999). Traditional means of determining its presence and location include clinical examination and conventional two-dimensional radiography. Clinical examination and identification of MB2 can be a challenge for practitioners for several reasons. Due to its smaller size and location often beneath overlying calcification, searching for its presence may lead to an increased likelihood of iatrogenic errors including perforation (Kulild & Peters, 1990). Conventional radiography, while an essential aspect of endodontic treatment, has several limitations that make it less than an ideal tool for locating MB2. Because periapical (PA) radiography shows only a two-dimensional image, the buccolingual dimension of the root cannot be appreciated (Ramamurthy, 2006; Patel, 2007; Scarfe, 2009). The internal anatomy of the root canal system is also under-represented in two-dimensional images. Moreover, overlying structures and adjacent roots make periapical films of maxillary molars particularly difficult to interpret (Patel, 2007).

Cone-Beam Volumetric Tomography (CBVT) is a relatively recent innovation that overcomes many of the limitations of conventional radiography. It has many applications in endodontics because its three dimensional images allow inspection of the tooth in the axial, coronal, and sagittal planes. The axial plane is particularly useful in helping the clinician determine the number of root canals and their location relative to one another (Patel, 2007; Scarfe, 2009). Studies have also shown that CBVT images accurately depict anatomical structures in their true state without significant magnification or distortion (Kim, 2010).

B. <u>Statement of the problem and its significance</u>

Because success in endodontics requires treatment of the entire root canal system, failure may occur if a canal is unidentified and untreated. The identification and treatment of the second mesiobuccal canal in maxillary first and second molars using traditional methods has proven to be a challenge for practitioners. The limitations of conventional radiography in particular make the pre-operative detection of MB2 difficult. This may lead the practitioner to rely solely on clinical examination for the identification of MB2. Iatrogenic errors may occur while the practitioner searches for a canal that may or may not be present. These problems together may adversely influence the success rate of root canal treatment of maxillary molars.

C. <u>Significance of the study</u>

Considering the many limitations of conventional radiographs in detecting root canals (particularly MB2), it is in the practitioner's best interest to find a modality that can pre-operatively determine the existence and location of MB2 and aid in its clinical detection. CBVT uses focused three dimensional imaging and has gained recent popularity in the dental field. Several *in vitro* studies have shown that CBVT imaging significantly enhances root canal identification compared to conventional radiography (Matherne, 2008; Blattner, 2010). However, few studies have determined its effectiveness in enhancing root canal identification *in vivo*. Therefore, in order to provide a higher level of evidence and clinically relevant data, it was the objective of this study to determine whether pre-operative CBVT imaging can increase the effectiveness of clinical identification of MB2 *in vivo*. If the data supports this hypothesis, then a pre-operative CBVT image may increase success rates and reduce iatrogenic errors while treating maxillary molars.

D. Objectives

The purpose of this study was to determine if a pre-operative CBVT image increases the effectiveness of the clinical identification of the second mesiobuccal canal in maxillary molars.

The secondary objective was to evaluate the effectiveness of CBVT imaging in depicting actual anatomy.

E. Hypotheses

The following null hypotheses were tested:

1- There is no difference in the percentage of MB2 canals detected with the aid of CBVT in this study when compared to the percentage of MB2 canals detected in previous clinical studies using traditional radiographic methods.

2- There is no association between the MB2 canals detected on the CBVT image and those detected clinically during root canal treatment.

II. CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

A. **MB2 detection and prevalence in *in vitro* studies**

In vitro studies concerning the frequency and identification of MB2 far outweigh *in vivo* studies. The techniques used to identify the second mesiobuccal canal in laboratory studies vary widely. Methods include macroscopic examination (Pecora, 1991), grinding or sectioning (Moral, 1914; Barrett, 1925; Weine, 1969; Seidberg, 1973), clearing using decalcification and injection with various inks or dyes (Okamura, 1927; Vertucci, 1984; Yang, 1988; Pecora, 1992; Caliskan, 1995; Imura, 1998; Alavi, 2002; ; Barbizam, 2004; Sert, 2004; Yoshioka, 2005; al Shalabi, 2007), plastic (Gray, 1983) or metal (Hess, 1925; Zürcher, 1925) castings of the root canal system, scanning electron microscope examination of the pulpal floor (Gilles, 1990), access of extracted teeth using endodontic instruments alone (Acosta, 1978; Yoshioka, 2005) or instruments with radiography (Kulild & Peters, 1990; Weine, 1999), radiopaque gel infusion and radiography (Thomas, 1993), radiography alone (Sykaras, 1971; Pineda, 1973; Pineda, 1974), or *in vitro* root canal treatment (Nosonowitz, 1973). The findings of these studies in regards to the prevalence of MB2 are as varied as the methods themselves. In the studies listed above, the percentage of MB2 canals found was as low as 25% and as high as 95.2%, with an average of 60.5%.

Perhaps the most influential study on the prevalence and significance of MB2 was published by Weine in 1969. In this study, maxillary first molars were sectioned and the prevalence of MB2 was determined. The authors also defined and classified canal configurations of the mesiobuccal root into three types. Type I is a single canal from the the pulp chamber floor to the apex. Type II is a larger buccal canal with a smaller lingual canal that merges with the buccal canal from one to four millimeters from the apical foramen. A type III configuration is defined as two distinct canals that have two separate foramen. Of the teeth examined, 48.5% showed Type I configuration, 37.5% showed Type II configuration, and 14% showed Type III configuration. This indicates the presence of MB2 in a total of 51.5% of the sectioned maxillary first molars. To emphasize the significance of the MB2, Weine presented clinical case reports showing the lack of healing or reduction in symptoms until MB2 was found and treated. This acted as a warning for potential failure if MB2 is not located and treated.

Another influential *in vitro* study was published in 1990 by Kulild & Peters. In 51 maxillary first and 32 maxillary second molars, the authors used three sequential methods to locate the second mesiobuccal canal and recorded the prevalence of each. In the first group, the extracted teeth were simply accessed and the pulpal floor was examined for a second mesiobuccal orifice, which was found in 54.2% of teeth. Next, surgical length round burs were used to remove dentin from the 'subpulpal groove' which exposed MB2 in an additional 31%. Finally, the teeth were sectioned with the aid of a microscope and MB2 was located in an additional 9.6%. In total, a second mesiobuccal canal was located in 95.2% of the teeth examined. The data from this stuidy suggests that the normal anatomy of maxillary first and second molars is two canals in the mesiobuccal root. Furthermore, with the use of a microscope and careful troughing, MB2 can often be found clinically.

B. MB2 detection and prevalence in *in vivo* studies

The methods used in the clinical studies concerning the prevalence of MB2 are also quite diverse. Methods include retrospective evaluation of patients that received root canal treatment (Nosonowitz, 1973; Slowey, 1974; Hartwell, 1982; Neaverth, 1987; , 1989, Zaatar, 1997; Hartwell, 2007), clinical evaluation during root canal treatment with the aid of magnification (Fogel, 1994; Stropko, 1999; Sempira, 2000; Wolcott 2002; Buhrley, 2002) and without magnification (Seidberg, 1973; Pomeranz, 1974). In the clinical studies mentioned, MB2 was found in as few as 18.6% and as many as 80.3%, with an average of 54.7%.

In 1987, Neaverth and colleagues conducted a retrospective clinical study in which the records of patients who received root canal treatment in a private practice setting were examined. Of the 230 maxillary first molars included in the study, 80.3% of teeth contained a second mesiobuccal canal. Of the *in vivo* studies concerning the prevalence of MB2, the frequency found in this study was one of the highest. This could potentially be due to the somewhat lenient definition of MB2 compared to other studies (which will be discussed in detail in section C).

The frequency of MB2 found by Sempira and Hartwell in 2000 was far less than that found by Neaverth. In this prospective *in vivo* study, 200 maxillary first and second molars treated by post-graduate endodontic residents with the use of a microscope were included. Of 130 maxillary first molars, only 33.1% contained a second mesiobuccal canal. Of 70 maxillary second molars, even less (24.3%) presented with MB2. A possible explanation for the seemingly low frequency of canal identification in this study could possibly be due to a strict definition of MB2 chosen by the authors.

Another study published by Wolcott et al in 2005 focused on the clinical detection of MB2. In this study, 5,616 maxillary molars that received either initial or retreatment root canal treatment by specialists with the aid of magnification (3.5x or greater) were included. The authors found that 57.9% of initially treated and 66% of retreated first molars had MB2. They also found that 34.4% of initially treated and 39.9% of retreated second molars had MB2. A noteworthy finding from this study was the significantly greater prevalence of MB2 in retreatment cases. This suggests that failure to find and treat existing MB2 canals will decrease the long-term prognosis and potentially cause root canal failure.

C. Factors affecting the prevalence of MB2

Several factors influence the prevalence of the second mesiobuccal canal in maxillary molars. Variations in study design is one of the key reasons why considerable differences occur in reported frequencies of MB2. The differences between *in vitro* vs *in vivo* studies, for example, can have significant effect on the data reported. *In vitro* studies have the ability to examine both the internal and external surfaces of the tooth, manipulate in any way deemed necessary, and even dissect and ultimately damage or destroy the tooth to determine the existence and location of MB2. *In vivo* studies do not have this capability and are therefore considerably disadvantaged in their search for MB2. For this reason, *in vivo* studies generally report a lower prevalence of MB2 than *in vitro* studies (Seidberg, 1973; Pomeranz, 1974). However, this drawback is somewhat balanced by the fact that *in vivo* studies mimic clinical situations much closer and are therefore more relevant to the practitioner.

When considering *in vivo* studies in particular, several factors affect the clinical ability of the practitioner to locate MB2, which can obviously influence its reported prevalence. A comprehensive knowledge of the canal and its common anatomical features, which can be strengthened by reviewing *in vitro* studies, is a prerequisite when searching for and treating MB2. The access preparation should be modified in maxillary molars from a more traditional triangular shape to a rhomboid or heart shape which will allow recognition of the fourth canal. According to Hartwell in 1982, the second mesiobuccal canal is found just mesial to the line connecting the first mesiobuccal and palatal canal necessitating the modified access preparation. There is also a dentinal growth of lip commonly overlying the orifice of MB2 which must be removed for its proper identification (Kulild & Peters, 1990). Studies have shown that modifying the access preparation and careful removal of the dentin overlying MB2 have resulted in a dramatic increase in its detection (Weller, 1989). Studies also indicate that operator experience alone has been shown to increase the identification of MB2 in clinical situations (Stropko, 1999; Corcoran, 2007).

The use of magnification has also been shown to be an invaluable tool for practitioners to aid in the identification and treatment of MB2. In 2002, Buhrley et al examined the direct effect that the use of magnification or the surgical operating microscope had on detection of MB2. Endodontists treating patients without magnification only found MB2 in 18.2% of cases. With the use of dental loupes, this frequency increased drastically to 55.3%. The use of the surgical operating microscope allowed the practicioners to increase MB2 identification even further to 57.4%. These results clearly express the importance of the use of magnification when searching for this elusive canal. Without the use of magnification, the reported frequency of MB2 in clinical studies is far less than its true presence.

Another factor affecting the prevalence of MB2 in different studies is the way the authors define the canal itself. These definitions range from very strict to somewhat lenient. For example, in their study in 1973, Nosonowitz & Brenner considered MB2 a separate canal if it simply had a separate orifice on the pulp chamber floor, regardless of if or where it joined MB1. On the other hand, Sempira & Hartwell in 2000 would only consider MB2 a separate canal if it was treatable to 4mm from the root apex. The definitions vary greatly among studies and generally the more lenient the definition, the higher the percentage of MB2 found.

There are also several potential patient related factors that can influence the prevalence of MB2. Age has been found to affect the prevalence of MB2 in some studies. Because of natural calcification of the pulp chamber and canals that occurs with age, fewer second mesiobuccal canals were found in several studies as age increased (Neaverth, 1987; Gilles 1990; Fogel, 1994). Trauma in the form of caries or deep restorations can induce tertiary dentin formation and can have a similar effect, which is a concern specifically in *in vivo* studies. Gender was found to be a significant predictor in some studies (Sert, 2004) but not in others (Neaverth, 1987; Fogel, 1994).

D. <u>CBVT background:</u>

Cone beam volumetric tomography was invented in the late 1990s by Italian and Japanese groups working independently of each other (Mozzo, 1998; Arai, 1999). The original machines were CT scanners that were modified to decrease the field of view, increase resolution, and decrease radiation dose to the patient (Patel, 2007). Many advances and updates were applied to these original CBVT machines and the FDA approved the first CBVT for dental use in the United States in 2001. The Kodak 9000 3D (the unit used in this study) was subsequently approved in 2003 (Scarfe, 2009).

CBVT produces a three-dimensional volume of data with a single sweep of the scanner using a simple, direct relationship between the sensor and source. The x-ray beam is cone-shaped and is directed through the middle of the area of interest onto an x-ray detector on the opposite side of the patient. This allows it to capture a cylindrical or spherical volume of data, known as the field of view (FOV). Unlike the medical CT which emits constant radiation as it scans, the CBVT scanners take sequential planar projections or multiple 'mini-exposures' which effectively reduces the radiation to the patient. These projection images are considered raw data that requires computer software to reconstruct the images into a volumetric data set. This data set is then presented to the clinician as secondary reconstructed images in three orthogonal planes (axial, sagittal, and coronal). (Scarfe, 2008)

The size of the FOV is variable between different scanners, and some machines have the capability to choose the FOV dependent on the practitioner's needs. The dimensions of the FOV are dependent on multiple factors such as detector size and shape, beam projection geometry, and the collimation of the beam. The following categories have been developed based on the size of the FOV: craniofacial (FOV greater than 15cm); maxillofacial (FOV of 10-15cm); inter-arch (FOV of 7-10cm); single arch (5-7cm); and localized/limited (FOV 5cm or less). In general, smaller FOV images will have greater spatial resolution. A smaller FOV also indicates less radiation exposure of the patient. (Scarfe, 2008)

E. <u>Advantages of CBVT imaging</u>

There are several advantages of CBVT over conventional two-dimensional radiography. The most significant advantage is the ability of CBVT to provide images in three dimensions, which is unavailable in intraoral, panoramic, and cephalometric radiography (Scarfe, 2008). Where the clinician is limited to only the mesial-distal view in conventional radiography, with CBVT he/she is able to view the area (or teeth) of interest in three orthogonal planes: axial, sagittal, or coronal. This allows the clinician to view the previously unavailable buccal-lingual dimension. It also allows structures that are usually superimposed in conventional radiography (buccal and lingual cortical plates, zygomatic process, maxillary sinus, exostoses, adjacent roots/teeth, etc) to be viewed separately (Patel, 2009). Having a voxel size of 0.4mm to as low as 0.076mm, CBVT images are spatially accurate and allow for precise measurements for pre-operative surgery assessment (Scarfe, 2008).

There are also advantages of CBVT over medical CT. First, the size of the CBVT machines are considerably smaller than medical CT units which reduces their physical footprint and makes them practical for use in a dental office. These machines are also significantly less expensive than their predecessors, approximately 5-10% of the cost of medical CTs. Because CBVT images distinctly depict highly contrasting structures, they are particularly well-suited to portray dental and osseous structures of the maxillofacial area. (Scarfe, 2008)

Scan times are significantly reduced compared to medical CTs because all of the data is produced in a single rotation as opposed to multiple rotations with conventional CT scans. The scan time of CBVTs is approximately 5-40 seconds, dependent on the machine. This allows less time for patient movement, which could cause image artifacts. The reconstruction time is also short and is dependent on the CBVT, FOV, hardware, and software. The time to reconstruct images is approximately 30 seconds to 10 minutes, which complements patient flow. (Scarfe, 2008)

Because of the single rotation of the x-ray beam, multiple 'mini exposures' instead of a constant exposure, and the practitioner's control of the FOV, the radiation dose to the patient is significantly reduced compared to a medical CT. For example, a medical CT of the maxilla exposes the patient to a radiation dose of approximately 1400 μSv (see Table I). An i-CAT CBCT with a 9-inch FOV (enough to include the entire maxilla) only exposes the patient to approximately 69 μSv. If the FOV is decreased to 1.5 inches (a limited FOV), the radiation dose with a 3D Accuitomo is further decreased to just 7.3 μSv. This is approximately equal to a single panoramic or just a couple periapical radiographs. (Patel, 2009)

TABLE I
A COMPARISON OF THE EFFECTIVE DOSAGES AND BACKGROUND EQUIVALENT OF DIFFERENT SOURCES OF DENTAL RADIATION

Radiographic source	Effective dose (μSv)	Dose as % annual background radiation
Cone beam CT		
3D Accuitomo (1½ inch)[a]	7.3	0.2
i-CAT[b] (12 inch FOV)	134.8	5.4
i-CAT[b] (9 inch FOV)	68.7	1.9
Conventional CT		
Conventional CT[c]	1400 (maxilla)	38.9
	1320 (mandible)	36.7
Conventional radiography		
Periapical[c]	5	0.14
Panoramic[d]	6.3	0.2
Cosmic radiation on board an aircraft flying a round trip between Paris-Tokyo[e]	150	4.2

(Patel, 2009)

F. Limitations of CBVT imaging

Just like any other radiographic method in use in the dental field, CBVT has certain limitations that the clinician should understand and appreciate. One limitation to consider is the increase in radiation dose compared to conventional intraoral radiography. Radiation dose for CBVTs is dependent on the specific device and the FOV. For greater FOV scans, the radiation dose of the more commonly used CBVTs is approximately equivalent to that of 5 to 33 panoramic x-rays (see Table II). The CB MercuRay is not commonly used, possibly due to its high radiation dose, and was therefore not included in this comparison. For limited FOV scans, the radiation dose is similar to a single panoramic x-ray (see Table I).

TABLE II
COMPARATIVE RADIATION EFFECTIVE DOSE FROM SELECTED CONE-BEAM CT SYSTEMS

		Dose[a]			
		Absolute	Comparative		
			Imaging surveys	Annual per capita background [c]	
CBCT unit	Technique	Effective dose[a] (μSv)	Equivalent panoramic surveys[b]	No. of days	% Annual
CB MercuRay[d]	12-in/9-in/6-in FOV	477/289/169	74/45/26	48.0/29.0/17.0	13.0/8.0/4.7
Galileos[e]	Default/maximum	29/54	5/9	3.0/5.5	0.8/1.5
i-Cat[d]	12-in/9-in FOV	135/69	21/11	13.5/7.0	3.7/1.9
Iluma[e]	Low/high	61/331	10/53	6.2/33.5	1.7/9.2
Newtom 3G[d]	12-in/9-in FOV	45/37	7/6	4.5/3.5	1.2/1.0
PreXion 3D[e]	Standard/high-resolution	69/160	11/25	7.0/16.0	1.9/4.4
ProMax 3D[e]	Small/large	157/210	25/33	16.0/21.5	4.4/5.8

(Scarfe, 2008)

When comparing the radiation dose from a CBVT to natural daily background radiation to the entire body, the Kodak 9000 limited FOV (device and FOV used in this study) was equivalent to approximately 1-5 days (see Table III). For comparison to conventional radiographs, a posterior bitewing was found to be equivalent to 3 days of natural background radiation (see Table III).

TABLE III
KODAK 9000 EFFECTIVE RADIATION DOSE AND EQUIVALENT DAYS OF NATURAL BACKGROUND RADIATION

Dosimetry of the Kodak 9000 3D Extraoral Imaging System		
Technique	**Effective dose***	**Days of per capita background***
Max Right Posterior	9.8	1
Max Anterior	5.3	1
Mand Left Posterior	38.3	5
Mand Anterior	21.7	3
Posterior Bite Wing	22.8	3
Panoramic	14.7	2

*effective dose in μSv ICRP 2007 tissue weights
(Ludlow, 2009)

CBVT images have some inherent limitations to note. One of which is their lower spatial resolution compared to conventional radiography. Conventional and digital radiography have a spatial resolution of 15-20 line pairs mm^{-1}, where CBVT images have a spatial resolution of just 2 line pairs mm^{-1} (Patel, 2009). Another limitation of CBVT images, as with medical CT images, is the occasional presence of artifacts that can make the image difficult to interpret. Beam hardening can cause a cupping effect in which metallic structures are distorted due to differential absorption of x-ray photons. Beam hardening can also cause streaks or dark bands to appear between two dense objects (see Image 1). Patient movement can also produce artifacts during the scan, which can produce a blurry image of minimal diagnostic value (Scarfe, 2008). Lastly, unlike medical CTs, CBVT images have poor soft tissue resolution, making medical CTs a continued necessity in the medical field.

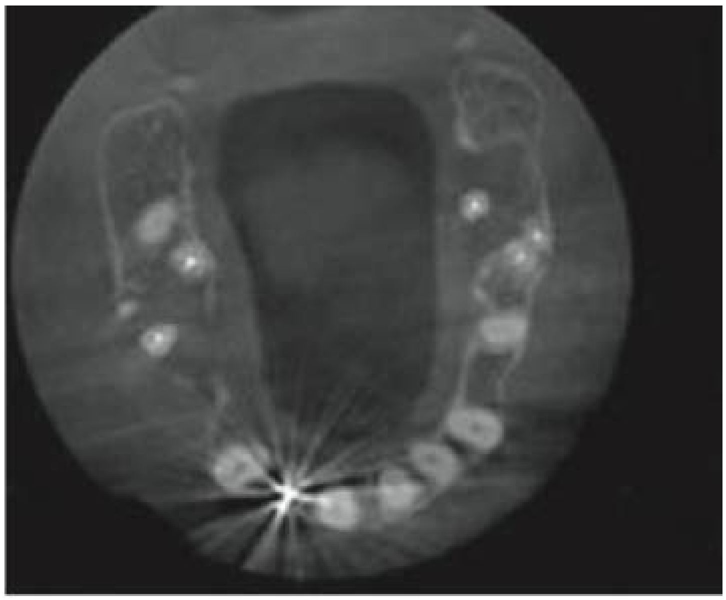

Figure 1: CBVT demonstrating beam hardeningbeam-hardening artifact (Patel, 2009)

G. Applications of CBVT imaging in endodontics

Traditionally, clinicians have used conventional radiography to aid in diagnosis, treatment planning, and post-operative follow-up of endodontic procedures. Due to the limitations of two-dimensional radiographs mentioned previously, practitioners have been in search of a radiographic method that provides the information that 2-D films lack. CBVT has many endodontic applications and has been shown to provide more anatomically accurate information than conventional radiography (Scarfe, 2009).

Studies have shown that periapical pathosis can be identified earlier and more accurately with CBVT compared to conventional radiography. In 2012, Tsai and colleagues compared the diagnostic accuracy of CBVT to digital periapical radiographs in determining the presence of simulated apical lesions of different sizes in cadaver mandibles. Round burs of varying sizes were used to create artificial lesions at root ends, and the teeth were then subjected to both periapical and CBVT imaging. The images were then reviewed and the data showed that the diagnostic accuracy of CBVT was significantly greater than periapical radiography. The authors showed lesions as small as 0.8mm were detectable on CBVT images with good diagnostic accuracy, where periapical radiography showed poor accuracy for lesions less than 1.4mm.

Studies have also shown that CBVT images can more accurately portray periapical status after root canal treatment. In 2008, Estrela et al examined 1,508 endodontically treated teeth for apical periodontitis using both periapical and CBVT imaging. The authors detected apical lesions in 39.5% of conventional films and 60.9% of CBVT images. They determined that the CBVT images more accurately reflect the actual periapical status of teeth examined. A similar study was conducted in 2009 by de Paula-Silva et al in which dog teeth with apical periodontitis were root canal treated and followed up after 6 months with CBVT and periapical imaging. In this study, the authors found a reduction in apical periodontitis in 79% of periapical films but only 35% of CBVT images. Again, the authors theorized that CBVT more accurately reflected the actual periapical status compared to two-dimensional imaging.

Because of its ability to display teeth and surrounding structures in their true anatomical state, CBVT imaging has also been shown to be an invaluable tool for pre-surgical assessment. In 2010, Kim and colleagues aimed to determine if measurements taken on CBVT images were anatomically accurate. To accomplish this aim, the authors measured the distance from posterior root apices to the mandibular canal on CBVT images of human cadaver mandibles. The mandibles were then dissected and the same measurements were taken directly with a Boley gauge. A comparison of the measurements showed no statistically significant difference. The authors concluded that CBVT images can be used to measure distances with as much accuracy as direct anatomical dissection. Therefore, accurate distances to vital anatomical structures can be determined prior to surgery. In their 2006 case report, Nakata and co-authors showed several additional benefits of CBVT images over conventional radiography in pre-surgical assessment. Using the relevant views and slices, they were able to determine the thickness of the cortical plate, cancellous bone pattern, fenestrations, and inclination of the roots.

The severity, extent, and location of both root resorption and dentoalveolar trauma can be accurately assessed by a single CBVT scan. Using two-dimensional film, on the other hand, would require multiple exposures at varying angles to provide the information required for diagnosis and treatment planning. Even with multiple 2-D images these conditions are difficult to accurately diagnose. In 2009, Estrela and colleagues evaluated 48 periapical radiographs and associated CBVT scans for signs of inflammatory root resorption. Conventional imaging detected resorption in only 68.8% of teeth while it was detected 100% in CBVT scans. Also in 2009, Kamburoğlu et al compared the diagnostic accuracy of analog and digital radiographs with CBVT images in detecting horizontal root fractures. The authors found that the sensitivity of CBVT images was significantly greater than both analog and digital radiographs.

CBVT images can also be used to identify root canals and examine the internal anatomy of root canal systems. It was the goal of Matherne et al in 2008 to compare the ability of CBVT and digital periapical radiography in identifying root canals. In this study, the intraoral radiography failed to identify one or more root canals in 40% of the cases where they were accurately identified in CBVT images. In 2010, Michetti and colleagues compared the cross-sectional area and caliper diameter of 14 root canals as measured from the CBVT image and histological section. The correlations between the two methods were strong to very strong, with the CBVT measurements just slightly smaller (approximately 2.8%) than the histological measurement.

H. <u>The use of CBVT imaging to detect MB2</u>

As mentioned previously, the second mesiobuccal canal in maxillary molars can be a clinical challenge to identify and treat. Any pre-operative method that could aid in determining its presence and location would undoubtedly be widely accepted by practitioners. In 2010, Blattner et al took CBVT images of 20 extracted maxillary first and second molars and subsequently sectioned the mesiobuccal roots using both methods to search for MB2. Sectioning identified MB2 in 68.4% of teeth and CBVT images identified it in 57.9% of teeth. This difference was not statistically significant. In 2011, Bauman and colleagues showed that the voxel size of CBVT images had an effect on identification of MB2. Extracted molars were scanned with CBVTs at different voxel sizes and the identification of MB2 increased from 60.1% at 0.4mm voxel size to 93.3% at 0.125mm voxel size. Evidently the smaller the voxel size, the greater the detection rate of MB2. The CBVT machine used in the current study has the smallest voxel size currently available at 0.076mm.

Clinical studies regarding the use of CBVT to identify MB2 are lacking. A thorough search of the literature only revealed one published and one unpublished study. In a clinical study in 2010, Alomar et al enrolled 50 patients needing root canal treatment on maxillary first molars and compared the detection of MB2 in pre-operative CBVT images and clinical examination with the aid of the surgical operating microscope and ultrasonics. The authors found MB2 in 90% of the CBVT images and 80% clinically. No statistically significant difference was found and a strong correlation (0.67) was seen between the two modalities. Abuabara et al in 2013 compared the efficacy of periapical radiography, CBVT imaging, and clinical examination in determining the existence of MB2. Of the 50 maxillary first molars included in this *in vivo* study, periapical radiography identified MB2 in 8% of cases, CBVT identified it in 54%, and clinical examination with the use of a surgical operating microscope and ultrasonics identified it in 62%. There was a statistically significant difference between MB2 detection in periapical radiography and clinical examination, but none between CBVT images and clinical examination.

III. MATERIALS & METHODS

A. Study design

The aim of this study was to detrmine the effectiveness of pre-operative CBVT as a diagnostic aid in locating MB2 in maxillary first and second molars. To carry out this objective, CBVT images of maxillary molars of patients receiving root canal treatment at a private practice office limited to endodontics were selected at random. Fifty CBVT images of patients that met the inclusion and exclusion criteria were used. All patient identifiers were removed and the pre-operative CBVT was assessed by the principal investigator (TR). The following data were recorded for each image: tooth type, initial treatment or retreatment, and presence or absence of MB2. Next, the clinical notes and post-operative radiographs were reviewed by the principal investigator to determine whether an MB2 was located and treated by the clinician. A single experienced endodontist (MF) carried out all clinical diagnostic and treatment procedures. The treating clinician had the following diagnostic aids available to help identify MB2: pre-operative CBVT (Kodak 9000, Carestream Denatl, Atlanta, GA), surgical operating microscope (Global Surgical Corp, St Louis, MO), and ultrasonics. The treating clinician was uninvolved in data collection to reduce operator bias. The study was approved by the UIC Institutional Review Board under the UIC research protocol number 2012-0882.

B. Sample selection

The patients included in this study presented to a private practice limited to endodontics requiring either initial root canal treatment or retreatment between January 1st, 2010 and September 30th, 2013. Only patients requiring treatment on maxillary first or second molars were chosen. All patients consented to CBVT imaging and treatment. Patients were not made aware of the study because all identifiers were removed before data collection.

1. **Inclusion criteria**

   -patient between the ages of 18-64yrs

   -patient requiring initial root canal treatment or retreatment on a maxillary first or second molar

   -tooth has three roots

   -tooth deemed restorable

   -no periodontal involvement

   -consent obtained for pre-operative CBVT and initial root canal treatment or retreatment

2. **Exclusion criteria**

   -the pre-operative CBVT image determined to be non-diagnostic due to a blurry image, scatter, beam hardening, etc (see image 2)

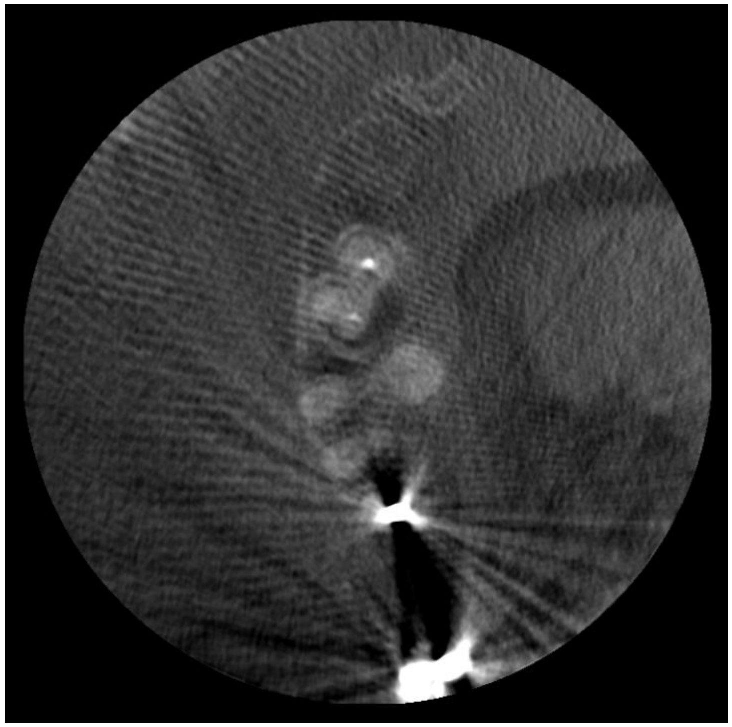

Figure 2: Excluded scan due to non-diagnostic image

C. <u>CBVT analysis</u>

All pre-operative CBVT images were taken with a Kodak 9000 scanner with the FOV centered on the tooth to be treated. The Kodak 9000 is a limited FOV CBVT machine with a voxel size of 0.076mm. Images were analyzed using Kodak Imaging Software by the principal investigator. CBVT analysis included examination of axial, sagittal, and coronal planes to evaluate the presence or absence of MB2. MB2 was recorded as present if two separate and distinct radiolucent canals were noted anywhere below the CEJ in the mesiobuccal root with uninterrupted radiopaque dentin separating the two. All CBVT data was recorded before post-operative clinical notes were examined to reduce bias.

D. <u>Clinical Analysis</u>

After CBVT analysis and data collection was complete, the clinical notes of each patient were reviewed by the principal investigator. MB2 was recorded as present if it was negotiable and treated to the apex, regardless of whether or not it joined MB1.

E. <u>Outcome Measures</u>

The following information was recorded for each of the 50 patients included in this study: tooth type (first or second maxillary molar), initial RCT or retreatment, presence/absence of MB2 in CBVT image, presence/absence of MB2 in clinical notes. All patient identifiers and demographics were not recorded.

IV. STATISTICAL ANALYSIS

The data were entered into SPSS Version 19 for Windows (SPSS, Armonk, NY) for all statistical analysis. The percentage of MB2 canals found for each patient was determined for both CBVT images and clinical notes. These percentages were then subdivided for tooth type (first or second molar) and treatment type (initial or retreatment). A Pearsons correlation test was performed with a level of significance set at $p<.05$.

V. RESULTS

A total of 53 pre-operative CBVT images were reviewed. Three teeth did not meet the inclusion criteria: 2 teeth had less than three roots, and 1 CBVT image was blurry and non-diagnostic (see image 2). A total of 50 CBVT images were analyzed for data collection. CBVT images identified MB2 canals in 46 (92%) of the 50 teeth examined. In the CBVT images, 28 (96.6%) of 29 first molars and 18 (85.7%) of 21 second molars had an MB2 canal. Of the 35 teeth undergoing intial root canal treatment, MB2 was identified in 32 (91.4%) in CBVT images. Image 3 is a CBVT scan of a tooth presenting for initial root canal treatment with a single mesiobuccal canal. Image 4 is a CBVT scan of a tooth presenting for initial root canal treatment with two mesiobuccal canals . Of the 15 teeth underoing retreatment, MB2 was identified in 14 (93.3%) in CBVT images. Image 5 is a CBVT scan of a tooth presenting for retreatment with a missed MB2.

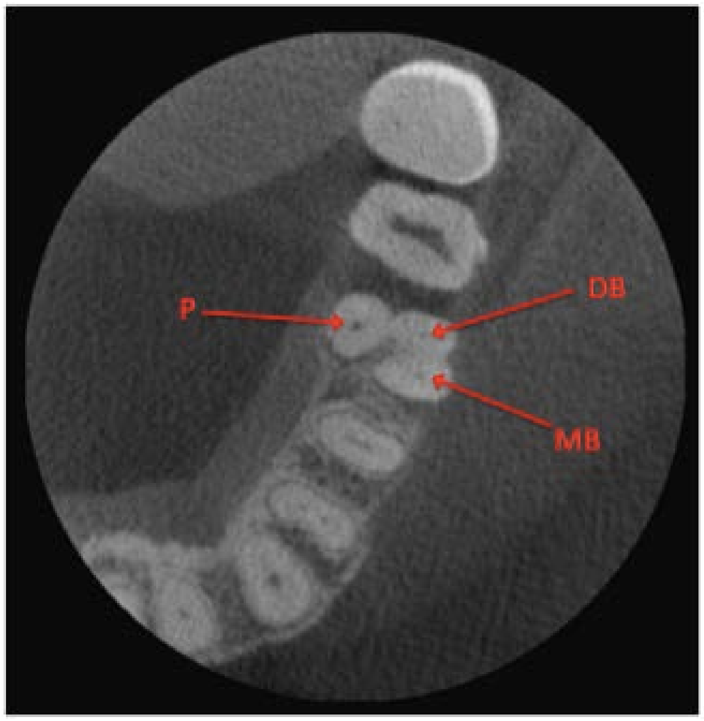

Figure 3: CBVT showing a single mesiobuccal canal

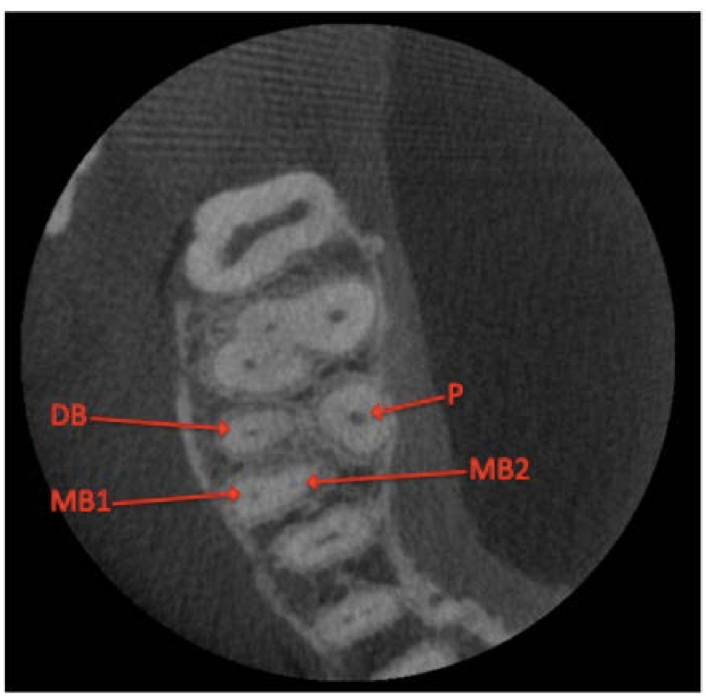

Figure 4: CBVT showing two mesiobuccal canals

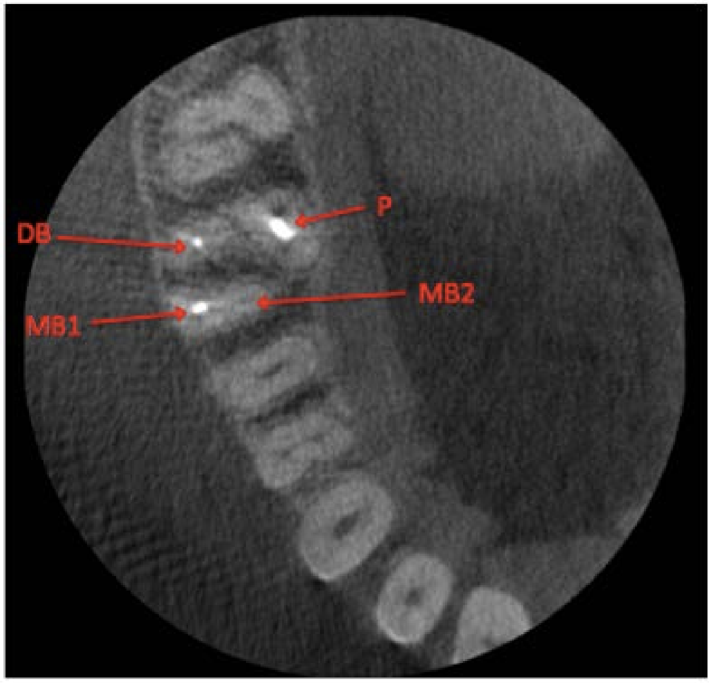

Figure 5: CBVT of reatreatment showing missed MB2

Clinical exploration identified MB2 in a total of 41 (89.1%) of the 46 teeth that had MB2 in a CBVT image. Image 6 is a clinical photo of an accessed tooth showing four canal orifices. Clinically, first molars had MB2 in 26 (92.9%) of 28 teeth, and second molars had MB2 in 15 (83.3%) of 18 teeth. Of the 32 teeth undergoing intial root canal treatment where MB2 was found in the CBVT image, 28 (87.5%) had MB2 clinically. Of the 14 teeth underoing retreatment where MB2 was found in the CBVT images, 13 (92.8%) had MB2 clinically.

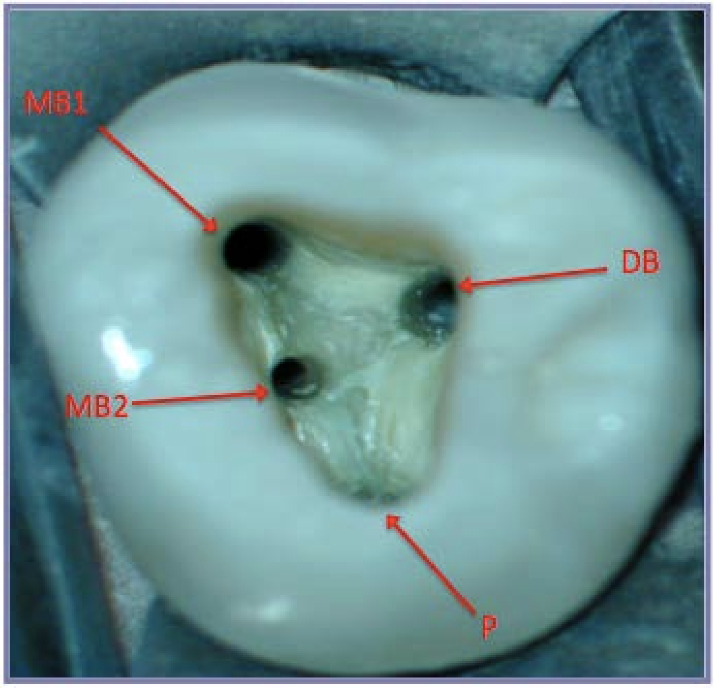

Figure 6: Clinical photo showing four canal orifices

TABLE IV
PREVALENCE OF MB2 IN CBVT AND CLINICAL DETECTION BY TOOTH TYPE

	MB2 (CBVT)	**MB2 (Clinical)**
First Molar	28 of 29 (96.6%)	26 of 28 (92.9%)
Second Molar	18 of 21 (85.7%)	15 of 18 (83.3%)
Total	46 of 50 (92%)	41 of 46 (89.1%)

Statistical analysis showed a strong positive correlation ($r=0.629$) between the presence of MB2 in CBVT images and clinical findings. This was statistically significant ($p<.001$).

VI. DISCUSSION

In their literature review, Cleghorn et al found the average prevalence of MB2 in clinical studies to be 54.7%. The highest prevalence of MB2 from a clinical study, 80.3%, was obtained by Neaverth and colleagues. Our findings showed MB2 in 89.1% of teeth where it was determined to be present on a CBVT image.

The considerably higher clinical detection of MB2 in our study compared to previous studies is likely due to several reasons. The first and most significant is the difference in methodology. While the methods of MB2 identification in these previous studies vary, none of those analyzed by Cleghorn's literature review used CBVT imaging for pre-operative examination. We propose that the lower prevalence found in these previous studies is due, at least in part, to the lack of a CBVT image available to the treating clinicians. Conventional two-dimensional radiography has been shown to be inadequate in the detection of the number and location of root canals (Matherne, 2008; Blattner, 2010; Abuabara, 2013). With only 2-D imaging at their disposal, clinicians in previous studies have been disadvantaged and have had to rely solely on clinical inspection for the detection of MB2. However, the treating clinician in our study was provided with a pre-operative CBVT image that displayed whether MB2 was present or absent, and its location if present. This pre-operative information is advantageous and allows recognition and treatment of MB2 at a higher percentage than information provided by 2-D imaging.

A potential reason for a significantly higher clinical prevalence of MB2 in this study compared to previous studies is a difference in the presentation of findings. In this study, the percentage of MB2 was calculated as the number of canals found clinically out of the total found on the CBVT images. The CBVT images were taken as the gold standard as to the presence or absence of MB2 because previous studies have demonstrated that CBVT images accurately reflect true anatomy (Blattner, 2010; Michetti, 2010). Previous *in vivo* studies, however, have generally presented their prevalence of MB2 as the number found clinically out of the total number of teeth examined. Because the CBVT image mimics actual anatomy, the way the findings were presented in this study is theoretically more accurate because it shows the number of canals found clinically out of the number of canals actually present (which was found on the CBVT). If the findings are presented this way, the readers are able to see when the clinical examination failed to diagnose and/or treat a canal that was actually present rather than one that may or may not be present.

Another potential reason for the higher prevalence of MB2 in this study is the manner in which the canal was defined. In the CBVT, an MB2 was determined as present if a separate canal was identified anywhere apical to the CEJ. Clinically an MB2 was determined as present if it was negotiable and treated to the apex, regardless of whether or where it joined MB1. These definitions are less strict than previous studies where the prevalence of MB2 was found to be much lower.

When considering solely laboratory studies, Cleghorn et al found the average prevalence of MB2 to be 60.5%. The highest frequency was found by Kulild and Peters in 1990 and was recorded at 95.2% of teeth examined. Our CBVT findings showed an MB2 prevalence of 92%, which is on the higher end but still compatible with previous *in vitro* findings. This supports the concept that CBVT imaging accurately depicts actual anatomy.

Statistical analysis showed a strong positive correlation (r=0.629) between the prevalence of MB2 in the CBVT images and clinical analysis. This correlation was statistically significant. These findings indicate that, if MB2 is detected in the CBVT, it is likely that a skilled clinician will find and treat it clinically. It also further supports the understanding that CBVT accurately depicts actual anatomy.

VII. LIMITATIONS

As with most studies, there were several limitations that may reduce the strength of findings. First, only the principal investigator examined the CBVT images and analyzed them for the presence/absence of MB2. The principal investigator is a second year post-graduate resident and has limited experience with CBVT analysis, which may affect the findings. In previous studies, multiple highly qualified endodontists and or dental radiologists have evaluated CBVT images and inter-evaluator agreement is calculated. This may decrease bias and increase the validity of the study.

Another limitation is the lack of 2-D imaging with which a comparison could have been made. If a pre-operative periapical film was available for each case, the number of canals could have been recorded for the PA film and compared to that found in the CBVT image. Also, the clinician could have attempted to locate and treat MB2 using the PA film first before evaluating the CBVT image and attempting again to locate MB2. With this information, a direct comparison could have been made between the prevalence of MB2 from clinical analysis with a periapical film and clinical analysis with a CBVT image. This was the study design of Abuabara in 2013. However, this would expose the patient to additional and unnecessary radiation and may not have received IRB approval.

The inclusion of retreatment cases in this study could also be considered a potential limitation. We chose to include retreatment cases in this study to mimic an actual private practice setting and to increase our sample size. However, in 2005, Wolcott et al found a significantly higher prevalence of MB2 in retreatments than initial RCTs. The authors theorized that this was due to a higher potential for failure when

MB2 is missed. If this is in fact the case, then the prevalence of MB2 in our study could have been increased because of the inclusion of retreatment cases.

VIII. FUTURE RESEARCH

Future research in the area of MB2 detection and treatment should include prospective clinical trials that include either a preoperative periapical film or CBVT image. If the methodology of the studies is standardized and the only difference is the preoperative imaging modality, the clinical prevalence of MB2 can be compared and any difference can be attributed solely to the type or preoperative imaging. An ideal study would include both 2-D and 3-D images, however this subjects the patients to excessive and unwarranted radiation.

IX. CONCLUSIONS

The identification and treatment of the MB2 canal in maxillary molars can be a clinical challenge. Different methods have been proposed to increase its clinical detection, including a modified access cavity, the use of a surgical operating microscope, and the use of ultrasonic devices to remove overlying calcifications. While these methods have proven to increase the clinical identification of MB2, a preoperative method that provides information on its presence and location is still lacking. Two-dimensional periapical films have been shown to add little benefit in diagnosing the presence of an MB2 canal. Based on the results of this study and comparing them to previous studies, it can be concluded that a pre-operative CBVT image can increase the effectiveness of clinical identification of MB2. Further high-quality clinical studies are needed to substantiate our findings.

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