Treatment Rate Of Second Mesio-Buccal Canals In Maxillary Molars In A Musod Endodontic Resident Patient Population

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TREATMENT RATE OF SECOND MESIO-BUCCAL ROOT CANALS IN MAXILLARY MOLARS IN AN MUSOD ENDODONTIC RESIDENT PATIENT POPULATION

by
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A Thesis submitted to the Faculty of the Graduate School,
Marquette University,
in Partial Fulfillment of the Requirements for
the Degree of Master of Science

Milwaukee, Wisconsin

May 2013

ABSTRACT
TREATMENT RATE OF SECOND MESIO-BUCCAL CANALS
IN MAXILLARY MOLARS WITHIN AN MUSOD
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Purpose: The primary reason for non-surgical root canal treatment (NSRCT) failure in an upper molar is inadequate cleaning, shaping and filling of the second mesio-buccal root canal (MB2). Failure to locate and treat a present MB2 will lead to a worsened long-term prognosis. This retrospective study investigated the treatment rate of MB2s in a sample of patients who were treated in Marquette University School of Dentistry's (MUSOD) advanced dental education program in Endodontics.

Materials and Methods: The study protocol was approved by Marquette's IRB. Data were gathered from records of 447 patients who received endodontic treatment between 2008 and 2012 and include; presence of an MB2 (dependent variable), tooth number, patient age (<90 years), and gender (independent variables). Personal identifiers subject to HIPAA regulations were not collected. Presence of an MB2 was determined from clinical notes and verified radiographically. Frequencies of present or absent MB2s were tabulated as a function of various independent variables and statistically analyzed using chi-square tests.

Results: Overall, 50.3% of all patients presented with an MB2. Male and female patients had MB2s in 60.6% and 43.8%, respectively. MB2s were found in 53.1% (172 out of 324) and 43.1% (53 out of 123) of maxillary first and second molars, respectively. The mean age of the sample was 42.4 years. Below the mean age, MB2 canals were found in 56.0%, while above the mean age, they were present in 43.2%. There was no statistically significant difference in side distribution (left side of maxillary arch compared to right side). Respective frequencies were 49.3% and 51.4%.

Conclusion: MB2 treatment rates may serve as a guide for practicing endodontists because they were achieved with the most current treatment techniques, advanced visualization, adequate time, and clinical expertise.

ACKNOWLEDGMENTS

Ryan Yale Margel, D.M.D.

I would like to thank my family, especially my parents, for their love and support both inside an outside the world of academia. I thank Drs. Jim Bahcall, Kris Olsen, and Sheila Stover for their work as directors in the Graduate Endododontics Program during my time at Marquette University. Drs. Sheila Stover and Lance Hashimoto have been a bright light for the program ever since championing its leadership positions, and I valued their friendship and mentorship. Dr. Kris Olsen has served as the thesis director for this study, and his guidance throughout the process has been invaluable. I would like to thank Dr. Arthur Hefti for his vital involvement throughout the process. I am grateful for the countless hours he spent proofreading my drafts and crosschecking references and results, among other things. I would also like to thank Dr. Joseph Gaffney for serving on the thesis committee, and for his feedback during Friday morning case-review sessions. Samantha Synenberg has played a vital role throughout the research process, and I look forward to calling her my Endodontic colleague in the future, as she will pursue a career in the specialty herself. I would also like to thank Mr. Thomas Wirtz for his role in patient record data extraction, and Dr. Jessica Pruszynski for her help with statistics. Last but not least, I would like to thank my good friends and co-residents, Drs. Kenan Tarabishy and Benjamin Baker. Together we made the most of our time learning our profession and had fun along the way.

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INTRODUCTION

Non-surgical root canal treatment (NSRCT) has evolved and improved over the years, but treatment failures continue to occur. The primary reason for failures in upper molars is inadequate cleaning, shaping and filling of the MB2 (Weine et al., 1969). A study by Ingle concluded that 58% of failures in NSRCT were attributable to incomplete obturation of the root canal system (Ingle et al., 1994). This was corroborated by Wolcott et al. (2005), who suggested that failure to locate and treat a present MB2 will lead to a worsened long-term prognosis. A major cause of persistent post-treatment disease was the inability of the dentist to recognize the presence of all the canals in the root canal system, and as a result, failing to clean and obturate these missed canals (Ingle, 1965).

The American Association of Endodontists (AAE) defined endodontic failure by an updated set of criteria (AAE 1998). Accordingly, a failed root canal treatment includes any tooth with previous NSRCT that exhibits clinical signs of pathosis, new or persistent, and/or radiographic evidence of rarefaction, not eliminated or arrested.

Hess in the 1920's published the first anatomical article noting the complexity of the root canal system (Hess & Zurcher, 1925). He found that the mesio-buccal (MB) root of the upper first molar and the mesial root of the lower first molar had the most ramifications of any teeth in the mouth.

In the early 1990's, there became a newfound focus that likely many MB2s existed that were not being treated (Kulild & Peters, 1990). Many canals previously believed to be type I (Weine's Classification) were actually type II or III canals (Gilles & Reader, 1990). Weine's classification consists of four types, and has been used to

describe root canal configurations (Weine, 1989). A type I canal configuration has a single canal with a single orifice and apical foramen. A type II canal configuration has two canal orifices, which come together, and exit through a common apical portal of exit. A type III canal has two separate canals with two coronal orifices and two separate apical exits. A type IV canal configuration has one canal with one orifice, and then bifurcates to form two canals apically with two apical foramen.

Treatment failure is expected to occur at a higher rate if the MB2 is not treated when the MB root contains two separate apical foramina, as is the case for type III canal configurations (Fogel, Peikoff, & Christie, 1994). Prior to the 1990's, a widespread belief existed that the MB2 need not be filled if it joined with the MB1, leaving the root through a common exit portal, in a type II arrangement (Pineda, 1973). The rational supporting this scenario was that a good seal can be achieved via the obturated main canal. Microorganisms and their toxic byproducts would remain encased within the sealed canal system, and therefore cannot elicit a pathologic response in periapical tissues (Nair et al., 1990). This may have lead to a lower priority in pursuing treatment of the MB2 of many maxillary molars. However, advancements in treatment methodology, armamentarium, and improved visualization of MB2 have improved treatment prognosis (Stropko, 1999).

LITERATURE REVIEW

Clinical factors in MB2 discovery

A) Dental Operating Microscope

The use of a dental operating microscope (DOM) in more recent clinical studies has lead to increases in MB2 detection (Buhrley et al., 2002), (Kulild & Peters, 1990), (Gilles & Reader, 1990), (Stropko, 1999), (Sempira & Hartwell, 2000), (Ruddle, 1997). This has been attributed to improved access and visibility (Kulild & Peters, 1990), (Gilles & Reader, 1990).

Carr describes some of the advantages of using the DOM. He noted that the microscope aids in bringing small details into clear view. He also stressed the importance of the improved light source from the DOM, which parallels the users line-of-sight, providing two to three times the light power of a surgical headlamp (1992).

Stropko also listed some of the benefits of using advanced microscopy. Namely, it helps to visualize the isthmus separating the MB1 and MB2. It also helps to visualize the initial mesial incline of the MB2 in the coronal 3mm and facilitates de-roofing dentin for straight-line access to the canal. It also helps visualize the difficult to find MB2 orifice locations. This includes instances when the MB2 shares a common orifice with the MB1 or when the MB2 is harbored within or just apical to the palatal canal groove (1999).

Khayat noted that the DOM identifies the location of calcified canals (1998). Fogel et al's study predated the widespread use of the DOM, but he surmised that it might reduce the discrepancy between *in-vivo* and *in-vitro* study results (1994).

The benefits of advanced microscopy are exemplified when comparing studies conducted by Seidberg et al (1973) and Wolcott et al (2005). The studies used similar treatment techniques, but Wolcott et al used DOM to identify root canals. Using DOM resulted in a two-fold higher discovery rate of MB2.

Buhrley et al found MB2s in 41 of 58 teeth (71.1%) when using the DOM. Investigators using loupes identified an MB2 in 55 of 88 teeth (62.5%). The lowest detection rate was observed when no magnification was employed. In this group, the MB2 was found in only 10 of 58 teeth (17.2%). Buhrley et al concluded that magnification improved the detection rate of MB2 three-fold for upper molars (2002).

B) Access

In 1982, Hartwell & Bellizzi advocated the creation of a rhomboidal-shaped access for upper molars to account for an outline form conducive to MB2 orifice discovery, as seen in figure 1. This outline form was utilized in most subsequent clinical studies (Neaverth et al., 1987), (Fogel et al., 1994), (Kulild & Peters, 1990), (Stropko, 1999). Acosta & Trugeda found that 93% of maxillary first molars had a tetragonal-shaped pulp chamber, and only 6% were triangular (1978).

Figure 1 – Rhomboidal-shaped access preparation (Cohen's Pathways of the Pulp 10th edition, FIG. 7-103C).
This is conducive to MB2 discover, as seen using x5.1 magnification with cervical fiberoptic transillumination.

Knowing the average orifice distance between MB2 and MB1 can serve as an important reference in searching for the MB2 (Pomeranz & Fishelberg, 1974). Stropko noted that the distance is usually 2-3mm (1999). Kulild & Peters' *in-vitro* study identified a mean distance of 1.8mm (1990). Other studies investigated this distance but noted a wide, variable range (Pomeranz & Fishelberg, 1974), (Gilles & Reader, 1990).

C) Clinical Techniques

In 1989, Weller & Hartwell addressed the importance of troughing and probing along the anatomical grove between the MB1 and palatal canals (Figures 2, 3) (1989). Stropko described the technique that he used to trough the developmental grove. He

advocated using a long-shank Mueller bur on slow speed. He also recommended the Carr CT or Ruddle CPR ultrasonic, which made troughing faster and cleaner. In the event that the MB2 is calcified or torturous, he advised that troughing to depths of 4mm or more may be necessary (1999). Fogel et al described the troughing technique that he used if the MB2 wasn't initially readily apparent. He troughed along the subpulpal anatomical grove until a canal was identified or the subpulpal groove disappeared. This was generally to a depth of approximately 1mm in his experience (1994). Fogel et al also advocated the importance of a clean, and dry chamber floor to assist in visualization. For this purpose, they used a fine (1 mm) suction tip to rinse the chamber with 2.5% sodium hypochloride (1994).

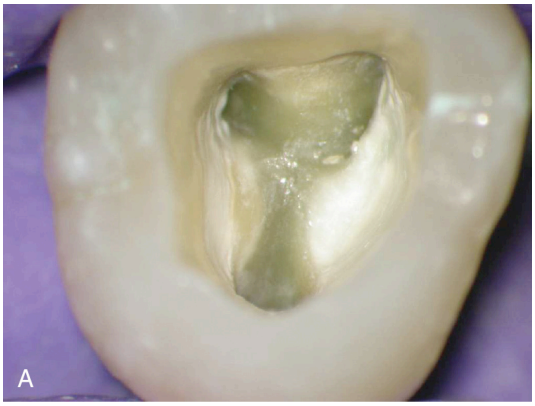

Figure 2 – Rhomboidal-shaped access preparation of a maxillary first molar (Cohen's Pathways of the Pulp 10th edition, Fig. 7-102A)
The figure reveals a mesial ceiling of dentin covering the mesial developmental groove, as seen using x3.4 magnification

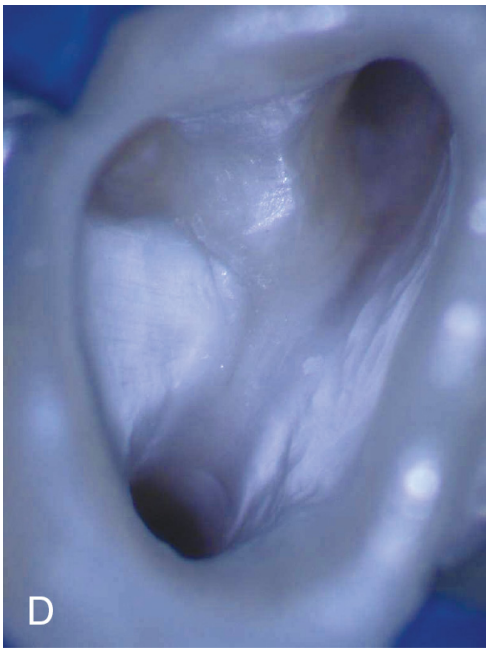

Figure 3 – Removing of the mesial ceiling of dentin. (Cohen's Pathways of the Pulp 10th edition, Fig. 7-102D)
The same tooth from Figure 2, after removing of the mesial ceiling of dentin and troughing the mesial developmental groove, no MB2 canal is found. As seen using x13.6 magnification.

Stropko noted that it is sometimes necessary to first clean and shape the MB1 before fully investigating the presence of a hard-to-find MB2 (1999). This can aid in identifying the anatomical line that emanates from the prepared MB1 and extends towards the MB2. Stropko also addressed the coronal anatomy of MB2. He notes that the canal moves from the distal to the mesial from the orifice apically in the coronal 1 to 3 mm. This causes the tip of the initial instrument to catch at the mesial wall, thus limiting its apical progression. He advised that this overlying roof of dentin should be eliminated to achieve straighter access to the apical extent of the canal. Gilles & Reader echoed the recommendation, and advised directing the endodontic explorer from the distal toward the mesial to account for this mesial dentinal extension, in efforts to locate the MB2 orifice (1990).

Ruddle coined the “Champagne or bubble test” (1997). This method uses warm 2.6% NaOCl, with the aim of observing the presence of bubbling that can reveal pulpal tissue at the MB2 orifice. He also advocated staining the chamber floor with 1% methylene blue, use of sharp explorers, looking for bleeding signs, and using obliquely angled preoperative radiographs as aids.

D) Clinical Time, Experience of Clinician, and Clinicians Mindset

Stropko wrote about his abrupt improvement in MB2 discovery rates between the first and second half of 1996, when he began scheduling longer appointments. He took the additional time to focus on the “attention to detail required to better address MB2 systems”. Stropko ascertained that more clinical time was a major factor in the increase in MB2’s located; in 1996 there was a 10.3% increase in MB2’s found compared to the overall percentage. In 1997 there was an additional 9.7% increase in MB2’s found. There was also an increase in the percentage of all teeth that could be instrumented and obturated to its apical terminus. The increase in clinical time played a role in these improvements along with utilization of newer troughing aids and more regular use of the microscope. Stropko also wrote about the clinician’s mindset during treatment, noting that it is important for the clinician to have a strong conviction that the canal is present 100% of the time (1999).

The experience of the clinician is also a factor in MB2 discovery rates. Sempira & Hartwell looked at the discovery rate in a patient sample treated by endodontic residents (2000). The MB2 was found 33% of the time. This result can be compared to that of Wolcott et al who found the MB2 almost twice as frequently. Wolcott et al study utilized six Endodontists with an average of 16 years of practice experience. This

comparison is appropriate in conveying the impact of the clinicians' experience because both *in-vivo* studies utilized similar inclusion criteria and research methodology (2005).

Another consideration is the possibility of different successes among operators in a study. This concern is quelled by Fogel et al who noted that there was no significant difference between the two operators in the identification of the MB2 (1994).

Patient Factors in MB2 discovery

A) Tooth type

The tooth type is relevant because maxillary second molars have fewer MB2's than first molars (Hartwell & Bellizi, 1982), (Kulild & Peters, 1990), (Vertucci, 1984), (Caliskan et al, 1995), (Gilles & Reader, 1990), (Peikoff et al., 1996). Also of interest is comparing whether discovery rates differed on the left side and right side of the mouth. Presumably, any difference might be attributed to the dominant hand of the clinician. Neaverth et al speculated that a tooth positioned on the right or left side should not have any bearing in this regard (1987). Fogel et al validated this notion, as he did not find a significant difference in canal configuration between left and right maxillary arches (1994).

B) Gender

Cleghorn et al conducted a meta-analysis that showed conflicting results with regard to the impact of gender on the presence of the MB2 (2006). Sert & Bayirli examined 100 maxillary first molars and found a single type I canal in 3% of males compared to 10% of females (2004). This finding is in agreement with Fogel et al who concluded that females have one treatable canal more frequently than males (1994).

Neaverth et al found no significant gender difference in the number of discovered MB2s (1987).

C) Age

Previous studies found a single treatable canal more frequently in older patients than younger patients (Neaverth et al., 1987), (Fogel et al., 1994), (Gilles & Reader, 1990). Although canals are narrowing with increasing age, it is improbable that they occlude and close off completely (1990).

Barrett [34] found that the number of canals identified with advancing age is decreasing. Despite this result, the author believed suggested that age itself isn't the direct cause, but rather an associated variable (1925). Neaverth et al agreed with this notion, and attributed the decrease to reparative dentition deposition that obscured the orifice over time (1987). Reparative dentin deposition can be attributed to influences such as trauma, caries, and restorative procedures (Torneck, 1994). Hess also advocated that dentin apposition increases with age and noted that a single broad canal can divide into two canals from dentin deposition bridging the intermediate wall. He found less complicated and larger canals in patients up to 20 years of age. Patients aged over 40 years also displayed less complex canal systems (1925).

Neaverth et al divided their sample into age groups, each group representing approximately 10% of the 100-patient sample. The mean age was 35.3 years. He found fewer canals were discernable clinically before age 20 and after age 40 years. The highest MB2 occurrence rate was 86%, as seen in the cohort that was 28.6 years old on average, and the lowest MB2 occurrence rate of 63.2% in the cohort that was 66.7 years old (1987).

Fogel et al combined gender and age in his analysis and found that both older males and older females had one MB canal more frequently. The mean age of males with one canal was 50.3 years, and females were 46.3 years. The mean age of males with two canals was 41.8 years old, and females were 39.8 years old (1994).

MB2 Discovery Rates

A literature review was conducted that included previously published *in-vivo* and *in-vitro* studies on MB2 identification. Particular emphasis was on those studies that aimed to define the presence of an MB2 based on clinical treatment criteria.

The rate of discovered MB2 canals ranged from 10 to 95% (Weine et al., 1969), (Hartwell & Bellizi, 1982), (Weller & Hartwell, 1982), (Neaverth et al., 1987), (Fogel et al., 1994), (Seidberg et al., 1973), (Henry, 1993), (Kulild & Peters, 1990), (Weller et al., 1995), (Acosta & Trugeda, 1978), (Ting & Nga., 1992), (Vertucci, 1984), (Caliskan et al., 1995), (Thomas et al., 1993), (Pomeranz & Fishelberg, 1974), (Gilles & Reader, 1990), (Yu et al., 1998), (Peikoff et al., 1996), (Stropko, 1999), (Sempira & Hartwell, 2000). This wide range of results can be attributed to a wide variety of studies and methodologies over a span of many years.

Stropko conducted a retrospective study of his cases to determine the discovery rate of MB2s. His survey covered a 8 ½ year period from July 1989 to 1997. During the first 6½ years, he treated 1732 maxillary molars, and found MB2's in 73.2% of first molars, and 50.7% of second molars. In 1997, he found MB2's in 93% of first molars, and 60.4% of second molars. Stropko attributed the increase to operator experience, scheduling more time for appointments, use of DOM, and utilizing microendodontic instruments (1999).

Wolcott & Ishley examined 5616 endodontically treated and re-treated first and second molars over a 5-year period. Six participating Endodontists who had DOMs available conducted the study. In first molars, they found the MB2 in 66% of re-treatments, and 58% in primary treatments. In second molars, the prevalence of MB2 was 40% of re-treated teeth, and 34% of primary treatments. The increased presence of MB2 canals in failed cases might indicate that failure to find and treat MB2 leads to decreased prognosis after NSRCT (2005).

Neaverth & Kotler retrospectively reviewed records from 230 maxillary first molars treated by an experienced clinician without use of the DOM. They found the MB2 in 77.2% of cases (1987). Fogel et al also looked at first molars, and found the MB2 in 71.2% of cases (1994).

A) *In-vivo* and *In-vitro* Considerations

Laboratory studies are important; however they do not reflect accurately what is seen in routine clinical practices of Endodontics (Pomeranz & Fishelberg, 1974). *In-vivo* studies include those that are retrospective (Wolcott et al., 2005), (Hartwell & Bellizi, 1982), (Neaverth et al., 1987), (Stropko, 1999), (Nosonowitz & Brenner, 1973), and prospective (Fogel et al., 1994), (Seidberg et al., 1973), (Henry, 1993) in nature. *In-vitro* studies used a variety of identification techniques including; sectioned roots of extracted teeth (Weine et al., 1969), (Seidberg et al., 1973), (Kulild & Peters, 1990), (Weller et al., 1995), (Acosta & Trugeda, 1978), (Ting & Nga., 1992), (Pomeranz & Fishelberg, 1974), (Pineda, 1973), (Green, 1973), (Nosonowitz & Brenner, 1973), dye injections (Acosta & Trugeda, 1978), (Vertucci, 1984), (Caliskan et al., 1995), (Thomas et al., 1993), (Al Shalabi et al., 2000), scanning electron microscopy (Gilles & Reader, 1990), (Yu et al.,

1998), light microscopy [11], and radiographic analysis (Weller & Hartwell, 1989), (Peikoff et al., 1996), (Pineda & Kuttler, 1972), (Pineda, 1973), (Green, 1973).

Fewer canals are identified in the *in-vivo* studies when compared to the *in-vitro* studies (Hartwell & Bellizzi, 1982). One possible reason for the discrepancy might be the stringent way canals are defined in the *in-vivo* studies. Canals that are identified by their ability to be clinically treated will likely yield lower rates than those identified by using clearing-laboratory techniques. *In-vitro* studies will identify a larger proportion of more complex canal configurations, which may otherwise remain unidentified and/or untreated in a clinical setting (Cleghorn et al., 2006).

Two studies directly compared *in-vivo* and *in-vitro* techniques in MB2 identification. Seidberg et al identified a 33.3% rate of MB2 presence using 201 teeth *in-vivo*, while finding a 62% rate using 100 teeth *in-vitro* (1973). Pomeranz & Fishelberg identified a 31% rate of MB2s using 100 teeth *in-vivo*, while they found 69% using 100 teeth *in-vitro* (1974).

Cleghorn et al conducted a meta-analysis specific to maxillary first molars utilizing 8399 teeth from 34 studies. They found that cumulatively, 56.8% of MB roots had two canals. *In-vitro* studies in the meta-analysis identified MB2s in 60.5% of first molars, compared to the 54.7% rate in the *in-vivo* studies (2006).

B) Common or Separate Apical Foramina

A literature review was conducted to review the rate that a second apical foramen is present, when the MB2 is identified.

Stropko identified a type III orientation in 54.9% of first molars, and in 45.6% of second molars. Additionally, he found that 16% of discovered MB2s did not exist in the

apical half of the root (1999). This can be compared to Kulild & Peters' *in-vitro* study, which utilized sectioned roots and the DOM. They could not identify the MB2 in the apical extent in 24% of MB roots. This bench-top study found the MB2 in 95.2% of maxillary first and second molars, which is currently the highest rate of any study. Type II or type III canal orientations were seen in almost 95% of first and second molars (1990).

Neaverth & Kotler found a type III orientation in 61.8% of first molars (1987). Fogel, et al found a type III orientation in 44.6% of first molars (1994). Cleghorn et al found a type III orientation in 38.3% of first molars (2006).

In-Vivo Research Design

In-vivo studies have defined unique sets of criteria for a canal to qualify as an MB2, however there has been no universally accepted benchmark for this qualification (Wolcott et al., 2005), (Neaverth et al., 1987), (Fogel et al., 1994), (Seidberg et al., 1973), (Sempira & Hartwell, 2000), (Yu et al., 1998), (Stropko, 1999), (Nosonowitz & Brenner, 1973). Some studies defined the MB2 based on its presence coronally at the floor of the pulp chamber (Neaverth et al., 1987), (Fogel et al., 1994), (Seidberg et al., 1973), (Yu et al., 1998), (Stropko, 1999), (Nosonowitz & Brenner, 1973), while others defined its presence based on evidence that the canal extended to the apical aspect of the MB root (Wolcott et al., 2005), (Seidberg et al., 1973), (Sempira & Hartwell, 2000).

A) Defining an MB2 based on Coronal Presentation

Among those studies that define an MB2 based on its coronal presentation, Stropko considered the MB2 canal present if he was able to instrument the canal to a

depth of 3-4mm after a troughing process. He found that 16% of discovered MB2s did not exist in the apical half of the root (1999).

Neaverth et al used both clinical and radiographic means to identify the presence of an MB2. Radiographically, efforts were made to determine if two separate canals could be visualized on radiographic examination, as is the case when instruments or gutta-percha points visibly diverged within the MB root (1987).

Fogel et al also utilized radiographs to help identify an MB2 canal when present. They took two radiographs of the working length instrument, one that was straight on and one that was distally angled. If the instrument appeared to be off-centered in the distally angled radiograph, a second canal was suspected. They rejected small, rudimentary MB2 canals that could not be treated (1994). Nosonowitz & Brenner were less discriminatory in their MB2 qualification, and deemed an MB2 canal present as long as a separate orifice was visible on the floor of the pulp chamber (1973).

B) Defining an MB2 based on Apical Presentation

The minority of studies defined an MB2 canal based on its presence in the apical extent of the MB root. MB2s that penetrate the apical aspect of the root were likely to have more impact on treatment outcome than those that existed and terminated coronally (Hartwell & Belizzi, 1982). Wolcott et al's study was among those that applied this more stringent MB2 canal qualification. They defined MB2 based on the requirement that instrumentation and obturation was completed to its apex or within 5mm of the apex when it joined the MB1 in a type II orientation (2005). The MB2 was identified in 58% of first molars during NSRCT in this study. Not surprisingly, studies that defined the

MB2 more liberally, based on its coronal presentation, found higher rates ranging from 71% to 77% (Neaverth et al., 1987), (Fogel et al., 1994), (Henry, 1993), (Stropko, 1999).

Seidberg et al (1973), and Sempira & Hartwell (2000) also conducted *in-vivo* studies that defined an MB2 based on its apical root presence. Seidberg et al defined MB2 canals based on the ability to place two instruments into the two MB canals simultaneously to a minimum depth of 16mm from the adjacent cusp (1973). Sempira & Hartwell imposed the criteria that the MB2 needed to be negotiated and obturated within 4mm of the apex (2000).

Seidberg et al (1973), and Sempira & Hartwell (2000) found MB2 canals in only 33% of first molars, relatively low in comparison to the 58% found by Wolcott et al (2005). This can be explained because Seidberg et al is an older study that predates the use of rhomboidal access designs and the DOM (1973). Although the DOM was used in Sempira & Hartwell (2000), they identified the same relatively low rate of MB2 canals as in Seidberg et al (1973). This can attributed, in-part, to the fact that all treatment was completed by Endodontic trainees, whereas in Wolcott et al (2005), it was done by six experienced Endodontists. The use of the DOM and newer treatment techniques increased the likelihood of MB2 discovery, however the rate remained comparatively low in these studies due to more stringent apical canal qualifications (Wolcott et al., 2005).

C) Defining Type II and Type III Canal Orientations

A variety of clinical and radiographic techniques have been utilized in efforts to determine the type of canal orientation. Stropko noted that if the radiographic terminus was unable to be negotiated, a determination could not be made if the MB canals remained separate or joined apically. He placed a paper point into the MB2, and if the

fluid level in the MB1 decreased, the canals joined prior to the exit. A capillary tip attached to a high-speed evacuator was also used for this evaluation. However, the technique does not work when the thin isthmus of dentin separating the MB1 from the MB2 is obliterated, or when the canals join mid-root and then later separate more apically. To account for this possibility, Stropko added radiographic interpretation. If an off-angled obturation film identified a separation of gutta-percha cones apically, the canals were determined to join but then separate again in a type III orientation (1999).

Radiographic identification methods were also used in Wolcott et al (2005) and Weine et al (1965). Wolcott et al determined that a type III orientation could be corroborated radiographically if a second MB periodontal ligament space or apex was seen, or an instrument appeared to deviate from a central root location apically. They used distally angled radiographs in efforts to look for this finding (2005). Weine et al identified type III canals when two separate files or gutta-percha cones could be placed and visualized at the radiographic working length. Type II canals were identified when two instruments or gutta-percha cones could be seen to join together on the radiograph interpretation (1969).

Fogel et al relied on clinical criteria to evaluate canal orientation. The type II canal orientation was confirmed when a file that was first placed in one canal impeded the subsequent placement of a second file in the other canal. They also used another technique, whereby a gutta-percha cone was first placed at working length, and then a file was placed in the other canal. If the file scored the gutta-percha point, then it was concluded that the canals joined at this depth (1994).

Neaverth et al also utilized clinical criteria to determine if the two canals exited through separate foramina. It was established that a type III canal orientation was present if the master gutta-percha cone, when placed first into one canal, could not be scored above 1mm from its apical extent with a file placed in the other canal. Neaverth et al also used two simultaneously placed size #25 hand-files to make this determination. A type III classification was made if the files can both be placed within 1mm of the working length. If any exudate was evident from the second canal after obturating the first, then it was determined that the second canal accessed a separate apical foramen, yielding a type III orientation. If sealer could be visualized in the unobturated canal, then it was determined that the canals joined in a type II orientation (1987).

D) Purpose of this Study

Residents at MUSOD advanced dental education program in Endodontics had the luxury of time but lacked the experience of a practicing endodontist. Although they personally lacked experience, endodontic faculty was readily available and was recruited when the MB2 canal wasn't found. Residents implemented the use of advanced visualization that facilitated a higher rate of MB2 discovery. Taken together, residents had the combination of lengthy treatment time, modern equipment, and faculty expertise at their disposal to optimally discover and treat the MB2 in maxillary molars, when present. These conditions lead to MB2 discovery rates that can be compared to the large variety of previous studies.

MATERIALS & METHODS

Identification of MB2

Wolcott et al's definition of a true MB2 was applied to the present study (2005). In using Wolcott et al's guidelines, an MB2 with a working length within 5 mm of the MB1 qualified as a true MB2 for the purposes of this study. This stringent canal qualification identified MB2s that had a greater impact on treatment, in contrast to canals that terminate coronally subjacent to the pulpal floor.

The presence of an MB2 was determined from clinical notes and confirmed by radiographic interpretation, as seen in (Wolcott et al., 2005), (Seidberg et al., 1973), (Sempira & Hartwell, 2000). Radiographic interpretation posed inherent challenges with respect to their interpretation because there was no standardized method in obtaining these radiographs. The orientation of the MB2 canal was often directly lingual to the MB1 canal. This necessitated the use of off-angled radiographs to visually separate the canals, if they were indeed separate. This was often achieved in any one of the initial apical file, master apical file, mid-obturation, or post-obturation radiographs. Whether or not the lengths could be corroborated radiographically was noted on a case-by-case basis. An MB2 was corroborated radiographically if a second MB periodontal ligament space or apex was seen, or if an instrument appeared to deviate from a central root location, as in Wolcott et al's study (2005).

Data Collection

Patient records treated by the MUSOD advanced dental education program in Endodontics over the past 4 years were examined for this study. The inclusion and exclusion criteria are listed below:

Inclusion Criteria:

- Presence of at least one permanent molar with completed root development;
- Being a patient of record;
- Patient age < 90 years;
- NSRCT done within the past 4 years;
- Treatment completed by an Endodontic resident;
- NSRCT was done on a maxillary first or second molar;

Exclusion Criteria:

- Missing or insufficient patient data including radiographs and clinical notes

The Marquette University Institutional Review Board approved the study (Protocol HR-2421, see Appendix). Data were obtained from the endodontic resident patient pool. They included the following independent variables: “treatment date", “tooth number", "patient age", and "gender". Each patient-specific data set received an identification number that was unrelated to any other patient information. Incomplete patient records or records that were missing radiographic or clinical documentation were excluded from the study. Data were extracted from AxiUm (Exan Group - Henry Schein, Coquitlam BC), a dental education management software product, using Crystal Reports (SAP, Newtown Square PA). An algorithm was used to populate an Excel spreadsheet

(Microsoft Redmond WA). The search criteria used included "procedure date"- within the last 4 years, "procedure code"- D3330, and "tooth number"- 2, 3, 14, 15.

The "procedure date" search criterion drew patients randomly. This ensured a process of case selection and data collection free of bias. The 4-year period was a reasonable time period to draw sufficient data from, and ensured similar endodontic visualization methods and techniques over its course.

The patients clinical records and radiographs were subsequently reviewed to evaluate for the additional criteria: "MB1 radiographic verification", "clinical presence of an MB2 ", “MB2 working length within 5mm of MB1”, “MB2 radiographic verification”, and “type of canal”.

The “MB1 radiographic verification” was categorized as “MB1 verified radiographically” - the MB1 was visible radiographically and was obturated within 2mm of the radiographic apex, or “MB1 not verified radiographically”- the MB1 was not visible radiographically or it was visible but not obturated within 2mm of the radiographic apex.

The “MB1 verified radiographically” patient records were further classified via the “Clinical presence of an MB2” categorization: "Found"- there was a record in the clinical notes of a present MB2, or "Not Found"- there was only one MB canal identified in the clinical notes. Maxillary molars containing only two canals in fused-root systems were categorized as "Not Found" for the presence of an MB2. There is evidence that fused-root systems occur more frequently in maxillary second molars than first molars (Ross & Evanchik, 1981).

The “Found” patient records were further classified via the “MB2 working length was within 5mm of MB1” categorization: “Definitely Significant”- a clinical note was made that identified the working length of both the MB1 and MB2, further, the length of the MB2 was within 5mm of the MB1, or “Insignificant”- a clinical note was made that identified the working length of both the MB1 and MB2, further, the length of the MB2 was more than 5mm from the MB1, or “Uncertain”- no clinical notes or incomplete clinical notes were made identifying the lengths of the MB1 and MB2.

The “Definitely Significant” patient records were further classified via the “MB2 radiographic verification” categorization: “Yes”- The MB2 can be distinctly visualized radiographically, or “No”- The MB2 cannot be distinctly visualized radiographically.

The “Yes” data points were further classified via the “type of canal” categorization: “type 2”- radiographic interpretation yielded evidence of the MB1 and MB2 joining prior to the apical extent of the root, or “type 3”- radiographic interpretation yielded evidence of the MB1 and MB2 remaining separate at the apical extent of the root, or “Uncertain”- radiographic interpretation yielded inconclusive results.

Maxillary third molars were excluded in this study because of their limited occurrence and scarcity of third molar NSRCTs.

Sample Size Estimate

The required sample size of maxillary first and second molar NSRCT cases was estimated based on a relevant effect size of 0.2, type I error probability of 5%, and type II error probability of 10%. Given these parameters, the goal was to review 400 records.

Data Analyses

The SAS Statistical System (SAS, Raleigh NC) was used to manage and analyze the data. Descriptive statistics were used to characterize the sample's age and gender composition. The proportion of present or absent MB2s was the primary outcome variable. Contingency tables were constructed for tooth type (1^{st} or 2^{nd} molar), side of maxilla (left or right), gender (male or female), and age (younger or older than sample mean age). Additional tables used the same independent variables, but focused on identified MB2s (significant, insignificant, uncertain), and MB2 types (type II, type III, uncertain). Contingency tables were analyzed statistically using chi-square goodness-of-fit tests. 95% confidence intervals were estimated. Bonferroni's method was used to control the type I error level when multiple comparisons were performed.

RESULTS

545 patient records were reviewed. 98 records had missing data points and were excluded from the study. The remaining sample included 447 patient records. Records were available from 175 male and 272 female patients. The average patient age was 42.4 years. There was no age difference statistically between the original and the final sample (P=0.332).

Table 1 – Age distributions of subjects included in the study and excluded from the sample

Sample	N	Minimum	Maximum	Median	Mean	SD	Test statistic	P-value
Included	447	20.2	88.1	39.9	42.4	15.59	0.972	0.332
Excluded	98	20.0	82.3	44.1	44.1	15.62		

Patient age at time of treatment ranged from 20.2 to 88.1 years (Table 1). In total, MB2s were found in 50.3% of all identified molars (Table 2).

Table 2 - Clinical presence or absence of an MB2

Class	Frequency	Proportion	95% CI	Test statistic	P-value
Found	225	0.503	(0.457, 0.549)	0.02	0.887
Not Found	222	0.497	(0.451, 0.543)		

MB2s were more frequently observed in first molars (53.1%) than in second molars (43.1%) (Table 3, P=0.059). MB2s were found 49.3% on the left side and 51.4% on the right side (Table 4, P=0.670).

Table 3 - Frequency and proportion of MB2 according to tooth type.

	Teeth 2 and 15			Teeth 3 and 14			Test Stat.	P-val.
	n	%	CI	n	%	CI	3.56	0.059
Found	53	0.431	(0.34, 0.52)	172	0.531	(0.48, 0.59)		
Not Found	70	0.569	(0.48, 0.66)	152	0.469	(0.42, 0.52)		

Table 4 – Frequency and proportion of MB2 canals according to jaw side.

	Left Side			Right Side			Test Stat.	P-val.
	n	%	CI	n	%	CI	0.18	0.670
Found	111	0.493	(0.43, 0.56)	114	0.514	(0.45, 0.58)		
Not Found	114	0.507	(0.44, 0.57)	108	0.487	(0.52, 0.65)		

MB2's were more frequently observed in female patients than in male patients (Table 5, P=0.0005).

Table 5 – Frequency and proportion of MB2 canals according to patient gender.

	Male			Female			Test Stat.	P-val.
	n	%	CI	n	%	CI	12.05	0.001
Found	106	0.606	(0.53, 0.68)	119	0.438	(0.38, 0.50)		
Not Found	69	0.394	(0.32, 0.47)	153	0.563	(0.50, 0.62)		

Finally, MB2s were more frequently found in patients below the mean sample age than above then mean sample age (Table 6, P=0.007).

Table 6 – Frequency and proportion of MB2 canals according to two age groups, i.e., below the sample mean age and above the sample mean age.

	Above Mean			Below Mean			Test Stat.	P-val.
	n	%	CI	n	%	CI	7.28	0.007
Found	85	0.432	(0.36, 0.50)	140	0.560	(0.50, 0.62)		
Not Found	112	0.569	(0.50, 0.64)	110	0.440	(0.38, 0.50)		

The results of the analyses within the "MB2 Found" category are shown in Tables 7 to 11. The proportions of significant, insignificant, and uncertain MB2s are listed in

Table 7. Only 1.3% of listed data were “Uncertain”, lacking complete clinical notes. Significant MB2s were more frequently found in first molars than in second molars, but the relative proportions of significant, insignificant, and uncertain MB2s were similar for both tooth types (Table 8, P=0.257). In addition, the proportions of “Uncertain” records were very small for both tooth types, too.

Table 7 – Significance within MB2 found

Significance	Frequency	Proportion	95% CI	Test stat.	P-val.
Definitely Significant	192	0.853	(0.81, 0.90)	278.64	<.001
Insignificant	30	0.133	(0.09, 0.18)		
Uncertain	3	0.013	(0, 0.03)		

Table 8 – Site distribution across MB2 found subcategories

	Sites 2 and 15			Sites 3 and 14			P-val.
	n	**%**	**CI**	**n**	**%**	**CI**	0.257
Definitely Significant	42	0.793	(0.68, 0.90)	150	0.872	(0.82, 0.92)	
Insignificant	10	0.189	(0.08, 0.30)	20	0.116	(0.07, 0.16)	
Uncertain	1	0.019	(0, 0.06)	2	0.012	(0, 0.03)	

Note: Due to the low cell counts in the uncertain category, the Fisher’s exact test was used in place of the chi square test.

The proportions of significant, insignificant, and uncertain MB2s were not different statistically for jaw side (Table 9, P=0.883) and gender (Table 10, P=0.291). However, the proportions were strongly affected by patient age. MB2s in the younger patient cohort were more frequently diagnosed as “Significant” than in the older cohort (Table 11, P=0.031).

Table 9 – Side distributions across MB2 found subcategories

	Left Side			Right Side			P-val.
	n	%	CI	n	%	CI	0.883
Definitely Significant	96	0.865	(0.80, 0.93)	96	0.842	(0.78, 0.91)	
Insignificant	14	0.126	(0.06, 0.19)	16	0.140	(0.08, 0.20)	
Uncertain	1	0.009	(0, 0.03)	2	0.018	(0, 0.04)	

Table 10 – Gender distribution across MB2 found subcategories

	Male			Female			P-val.
	n	%	CI	n	%	CI	0.291
Definitely Significant	90	0.849	(0.78, 0.92)	102	0.857	(0.79, 0.92)	
Insignificant	16	0.151	(0.08, 0.22)	14	0.118	(0.06, 0.18)	
Uncertain	0	0	--	3	0.025	(0, 0.05)	

Note: The Fisher's exact test was used.

Table 11 – Age distribution across MB2 found subcategories (Mean: 42.4)

	Above Mean Age			Below Mean Age			P-val.
	n	%	CI	n	%	CI	0.031
Definitely Significant	68	0.800	(0.72, 0.89)	124	0.886	(0.83, 0.94)	
Insignificant	17	0.200	(0.12, 0.29)	13	0.093	(0.05, 0.14)	
Uncertain	0	0	--	3	0.021	(0, 0.05)	

Note: Fisher's exact test was used.

Tables 12 to 15 display proportions for various Weine's canal types. Overall, type II and type III canals occurred similarly frequently. Uncertain canal types were found in 15.6% (Table 12). The proportions of type II and type III canals were reversed in first and second molars. Type II canals were more frequently observed in second molars, whereas first molars exhibited type III more frequently (Table 13, P=0.047). Neither gender nor age affected the proportional findings of canal types (Table 14, P=0.836; Table 15, P=0.268).

Table 12 – Canal types within definitely significant

Type	Frequency	Proportion	95% CI	Test statistic	P-value
Type II	71	0.394	(0.32, 0.47)	26.43	<.001
Type III	81	0.450	(0.38, 0.52)		
Uncertain	28	0.156	(0.10, 0.21)		

Table 13 – Site distribution across canal types

	Sites 2 and 15			Sites 3 and 14			Test Statistic	P-value
	n	**%**	**CI**	**n**	**%**	**CI**	6.12	0.0469
Type II	19	0.514	(0.35, 0.68)	52	0.364	(0.29, 0.44)		
Type III	10	0.270	(0.13, 0.41)	71	0.497	(0.42, 0.58)		
Uncertain	8	0.216	(0.08, 0.35)	20	0.140	(0.08, 0.20)		

Table 14 – Gender distribution across canal types

	Male			Female			Test Statistic	P-value
	n	**%**	**CI**	**n**	**%**	**CI**	0.36	0.8359
Type II	35	0.417	(0.31, 0.52)	36	0.375	(0.28, 0.47)		
Type III	36	0.429	(0.32, 0.53)	45	0.469	(0.37, 0.57)		
Uncertain	13	0.155	(0.08, 0.23)	15	0.156	(0.08, 0.23)		

Table 15 – Age distribution across canal types (Mean: 42.4)

	Age Above Mean			Age Below Mean			Test Statistic	P-value
	n	**%**	**CI**	**n**	**%**	**CI**	2.64	0.2682
Type II	30	0.469	(0.35, 0.59)	41	0.353	(0.27, 0.44)		
Type III	24	0.375	(0.26, 0.49)	57	0.491	(0.40, 0.58)		
Uncertain	10	0.156	(0.07, 0.25)	18	0.155	(0.09, 0.22)		

DISCUSSION

By and large, residents in advanced dental education programs have the luxury of abundant clinical time for each patient. In addition, faculty members are readily available to assist when the MB2 isn't found. Also, the residents implement the procedural techniques and advanced visualization that facilitates a higher rate of MB2 discovery (Weller & Hartwell, 1989), (Buhrley et al., 2002), (Kulild & Peters, 1990), (Stropko, 1999), (Sempira & Hartwell, 2000). Taken together, residents should have ways and means at their disposal to optimally discover and treat an MB2, when present. This makes the found percentage of MB2s a realistic estimate of the true frequency of MB2 in endodontic patients.

In the present study, MB2's were found in 50.3% of all maxillary first and second molars. 85.3% of the results were "Definitely Significant". This large percentage is a testament also to good clinical note taking, and that when MB2 canals were found coronally, they often extended to the apical portion of the MB root. This further emphasized the importance of fully instrumenting and obturating an MB2 canal when present. "Insignificant", rudimentary canals were found in only 13.3% of all cases. MB2's were found at a higher rate in first molars (53.1%) than in second molars (43.1%). Previous studies also identified the higher rate in first molars (Hartwell & Bellizi, 1982), (Kulild & Peters, 1990), (Vertucci, 1984), (Caliskan et al., 1995), (Gilles & Reader, 1990), (Peikoff et al., 1996). The difference that was observed in the present study, however, was associated with statistical uncertainty (P=0.059) and should be further substantiated in a study with a larger sample size. The 53.1% rate of MB2 discovery in first molars was within the range distribution of previous *in-vivo* studies that defined the

MB2 by its apical extension. Reported rates ranged from 33 to 58% (Wolcott et al., 2005), (Seidberg et al., 1973), (Sempira & Hartwell, 2000). Further, Cleghorn et al's meta-analysis specific to maxillary first molars found that cumulatively, 56.8% of MB roots had two canals. *In-vitro* studies in the meta-analysis identified the MB2 in 60.5% of first molars, compared to the 54.7% rate in *in-vivo* studies (2006). Literature for second molars is scarcer.

87.2% of first molars and 79.3% of second molars yielded "Definitely Significant" results. The difference between the two molar types could be best explained by chance. Literature is undeveloped for this comparison. In summation, MB2 canals are found more often in first molars than second molars, and when found, they are more likely to extend to the apical extent of the MB root.

Weine's canal type classification is also an important factor that is thought to impact treatment outcome in two-canalled roots (Fogel et al., 1994). If an MB2 is present in the root apically, remains separate from the MB1, and exits through its own unique portal of exit, then fully instrumenting and obturating this canal is of heightened importance (Nair et al., 1990). This scenario outlines the type III canal orientation, which was found in 45.0% of molars, specifically 49.7% of first molars, and 27.0% of second molars. Gender and age were not a significant factor for the discovery of type III canals. However, type III canals were found 22.7% more often in first molars than second molars. The clinician should be aware of these subtle patient demographics that could potentially pose a greater impact on treatment outcome when the MB2 canal is difficult to diagnose.

The MB2 was found in 60.6% of males and 43.8% of females, a difference that is statistically significant. This result, yielding a higher identification rate in males, is in agreement with some previous studies (Fogel et al., 1994), (Sert & Bayirli, 2004). However, other studies found no significant differences in patient gender (Neaverth et al., 1987), (Cleghorn et al., 2006). The age distribution is similar among males and females. While we didn't investigate the interaction between age and gender, it is of interest to verify the balance of gender between the two age groups.

The age of the patient is a reasonable variable to consider since dentin gets deposited throughout life, and this calcification process can make locating an MB2 more difficult (Hess & Zurcher, 1925). The MB2 was found in 56.0% of patients below the mean age, and 43.2% above the mean age of 42.4 years. This difference was statistically significant and in agreement with previous studies (Neaverth et al., 1987), (Fogel et al., 1994), (Gilles & Reader, 1990), (Pineda & Kuttler, 1972), (Pineda, 1973), (Barrett, 1925). With a larger patient sample size, this data could be further divided into smaller age groups. Neaverth et al divided his patient population into smaller age groups consisting of 10% of the 100 patient sample, with a mean age of 35.26 years. He identified the MB2 23% more often in the high occurrence mean age group of 28.6 years, than with the low of 66.7 years (1987).

Although MB2's were found less frequently with advancing patient age, it is unlikely that the canal occludes entirely (Gilles & Reader, 1990). This underscores the importance that the clinician is diligent during MB2 identification, specifically with the older patient population, as finding the canal becomes more difficult and therefore less likely.

As determined in previous studies, the side of the arch did not have a significant impact on MB2 discovery rates (Neaverth et al., 1987), (Fogel et al., 1994). MB2s were found 49.3% on the left arch and 51.4% on the right arch, a difference that was not statistically significant. The rationale for this further analysis is that the clinician's dominant hand, left or right, could possibly favor identification on one side of the arch. For example, a right-handed clinician might have better visibility and accessibility to an MB2 on the left side of the mouth when compared to the right side.

In summary, endodontists should be aware of the factors that influence MB2 discovery, and their impact on treatment. Knowing the MB2 discovery rates from an MUSOD Endodontic resident patient population can serve as a landmark because it employed the most current treatment techniques, advanced visualization, adequate time, and faculty expertise.

CONCLUSION

In this study, the overall discovery rate of MB2 was 50.3% in both first and second maxillary molars, with 53.1% in first molars and 43.1% in second molars. There was a significantly higher rate in males (60.6%) compared to females (43.8%). The mean age in the study was 42.4 years old. Below the mean age, MB2's were discovered at a significantly higher rate (56.0%), compared to above the mean age (43.2%). There was no statistically significant difference in side distribution on the maxillary arch, as the MB2 was discovered at a rate of 49.3% on the left side, and 51.4% on the right side.

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