Middle mesial canals in mandibular molars: incidence, prevalence, anatomical characterisation and clinical implications

KEY WORDS
anatomical irregularities, mandibular molars, middle mesial canals, procedural outcomes

ABSTRACT
Objective: In recent years attention has been given to the presence of the middle mesial canal (MMC) in mandibular molars. This attention has caused a proliferation of case reports and even some systematic reviews. However, little attention has been paid to the actual presence of a ‘separate canal’, as opposed to the presence of an anastomosis that is patent or partially calcified that allows the penetration of an instrument. Furthermore, due to the complexity of this anatomical entity, even less has been addressed regarding the thorough management of this challenge and its potential impact on procedural outcomes. The aim of this review was to address the latter issues in an attempt to clarify and provide clinical directives.

Materials and methods: Case reports and series published on MMCs were included and relevant data was extracted. They were analysed and interpreted to address the aim of the review. Other pertinent published data regarding true MMCs versus anastomoses were also reviewed.

Results: Published case reports and series were majorly on true MMCs. However, evidence showed that the majority of MMCs were anastomoses. The clinical importance of managing anastomoses is emphasised. This paper also identifies areas that require more research and evidence regarding the management of MMCs.

Introduction
For over 125 years, studies have addressed the intricacies of tooth anatomy using various techniques. Historically few have addressed the unique anatomical variations found in the mesial root of mandibular molars, in particular the first molar. While most publications tend to focus on the work by Hess and Zürcher (1925) as being the definitive anatomical treatise, it was in 1922 that Lenhossék from Budapest identified an unusual anatomical variation in the mesial roots of mandibular molars, which was presented in the Julius Scheff's Handbook of Dentistry (Fig 1). While not identifying this entity as being of significant clinical concern, his drawings depicted, almost 100 years ago, what is considered today as a major challenge – the middle mesial canal (MMC). The presence of this entity is of paramount concern in the contemporary pursuit of successful root canal procedures.

Almost 80% of teeth requiring treatment have been reported to be the mandibular first and second molars, of which 47% presented varied anatomy such as C-shaped canals, extra roots or extra root canals. 90% of the mesiobuccal (MB) and mesiolingual (ML) canals were independent and usually took a curved course at their apical terminus. The presence of an additional mesial canal, also called the MMC, has been reported in
Materials and methods

Information sources and search strategies

A thorough literature search for case reports and case series was conducted and completed on 4 February 2019. The primary databases used were Medline (via PubMed), Cochrane Central Register of Controlled Trials (CENTRAL) and Database of Abstracts of Reviews of Effects (DARE). The search strategy used was (((middle mesial (canal OR root canal))) AND (root canal (therapy OR treatment))) AND (endodontic OR endodontics)) AND (mandibular (molar OR molars)) and a combination of presented keywords. This was further supplemented by hand searching of relevant references from review articles and other eligible studies. No limits were applied to the year of study, but only studies published in English were included. The detailed search results are presented in Fig 2.

Eligibility criteria

Case reports and series on healthy human participants referred for root canal treatment of mandibular first or second molars with MMCs were included. Only papers published with clear presentation of materials and techniques used in every step of root canal procedure of the MMC were included. The involved teeth might or might not have had additional roots or canals. Studies performed on laboratory casts, mannequins or plaster mounted teeth were excluded.
Study procedure

The first (GS), third (MA) and the last (KS) authors, under the guidance of the second author (JLG), independently screened the above-mentioned databases based on the eligibility criteria, and the necessary data was extracted. Full-text articles were obtained for articles found to be eligible and for articles that were inconclusive during abstract screening. A pretested data extraction form was created, and two authors independently extracted all the required data on the root canal treatment protocol and clinical implications while managing the MMC of mandibular molars. Disagreement between the authors was resolved through discussion and consensus.

Results

Included studies

82 studies were obtained after the initial screening of the search strategy, of which 22 studies were included. The search results are presented in Fig 2.
- Case series: 713-19
- Case reports: 1616,20-34
- Teeth studied: 43 mandibular first molars and seven second molars
- The age range of participants was 19 to 45 years.

Root canal morphology of mesial root of mandibular molars

In the included case reports and series, 59 patients had two rooted mandibular first or second molars, and two had three-rooted first molars. All of the mesial roots had three canals (MB, ML and middle mesial [MM]), except one with four canals (MB, ML, 2-MM). The majority of the cases with MMC or additional canals in the mesial root, also presented with additional canals in the distal root. This is similar to the findings reported by Nosrat et al35.

Clinical examination for the MMC

Four patients were referred for retreatment and the reason for failure was a missed MMC. Initial intraoral periapical (IOPA) radiographs did not reveal the presence of MMC except in two studies24,26, where angulated radiographs were taken and a MMC was detected. Only one study used cone beam computed tomography (CBCT) for pre-operative assessment24.

Root canal morphology of the MMC in the included literature

- Confluent: 26 (19 joining the MB canal and seven joining the ML canal)
- Fins: 15
- Independent: 11
Techniques used to locate the MMC

All cases assessed the presence of MMC using one or more of the following techniques:
- Preoperative CBCT.
- Conventional access, careful clinical examination and anastomosis probing using ultrasonic tips, DG-16 explorer or a size 8 or 10-H file or a K-file13,14,19-21,23,28,29,33.
- Microscopic access and careful microscopic clinical examination using ultrasonic tips, DG-16 explorer, size 8 or 10 H-file or K-file16,34.
- Conventional or microscopic access followed by troughing the groove between the MB and ML canals using a long shank round bur17,27,34. Troughing was performed to a depth of no more than 2 mm at the expense of the mesio-axial wall away from the furcation area. None of the case reports or series mentioned the clinical implications of troughing. None of the studies reported complications or failures. The MMC orifices were located 2 mm apical to the MB and ML canals or in the interconnecting groove between the canals close to the MB or ML canal orifice, or in between the two.

Enlarging, shaping, cleaning and obturation of the MMC

- Conventional techniques or operating microscopes were used for the root canal procedure with magnification ranging between 2.5 to 8X.
- Gates-Glidden orifice shapers were used along with ProTaper Nickel-Titanium (NiTi) rotary instruments (Dentsply Sirona, Tulsa Dental Specialties, Tulsa, OK, USA), and the EndoSequence file (Real World Endo, Brasseler Savannah, GA, USA) were used in most (55.5%) cases.
- Number 8 or 10-H or K-files were used to check the patency of the MMC, followed by radiographic verification.
- 37% of the studies used a crown-down technique, 14% used a step-back technique. The working length ranged between 20 to 25 mm and the maximum file size used for enlarging was 25 to 30.
- Sodium hypochlorite (NaOCl) and ethylenediamine tetraacetic acid (EDTA) were used as standard irrigants, although their concentration varied among studies. Calcium hydroxide was used as a temporary intracanal medicament in most cases.
- Gutta-percha was used as a standard obturation material with cold lateral compaction (51%) or hybrid or warm vertical compaction (7.4%) for obturation along with a resin or a zinc oxide-eugenol based sealant. None of the studies reported problems encountered while enlarging, shaping, cleaning or obturating the MMC.

Postoperative care and maintenance

All cases reported successful procedures with no pain postoperatively and the posttreatment IOPA radiographs were taken in all the cases. Additionally, CBCT images were taken in four studies24,26,30,31 to confirm the obturation of the MMC. 55.5% of the studies recalled their patients, ranging from 3 months to 4 years. None of the patients reported with pain or any other postoperative complications.

Discussion

The present assessment of the MMC attempted to collate the available evidence on the clinical protocols for MMC management, which is found in many mandibular first and second molars, and their implication in the prognosis of treatment.

True canal versus anastomosis

The case reports and series included here showed only cases in which the MMC had been detected using the above-mentioned techniques. However, only 10 to 18% of the MMC were true mesial canals and 60 to 70% were anastomoses35-39. Table 1 highlights a few studies10,38-41 reporting the prevalence rates and techniques used to study anastomoses versus true MMCs. This indicates that most of the MMCs were anastomoses and not true canals. Similar findings were reported from...
Table 1  Prevalence of anastomoses and true canals in mandibular molars reported in literature

<table>
<thead>
<tr>
<th>Reference</th>
<th>Population</th>
<th>Teeth</th>
<th>Technique</th>
<th>Prevalence of anastomoses in the mesial root</th>
<th>Prevalence of MMCs in the mesial root</th>
<th>Other details from the data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hu et al (2019)29</td>
<td>Mongoloid</td>
<td>Mandibular first molars</td>
<td>CBCT</td>
<td>64.6% (majority in the apical third)</td>
<td>10.8%</td>
<td>Younger age, shorter MB – ML orifice distance, and Weine type II increases the probability of isthmus.</td>
</tr>
<tr>
<td>Srivastava et al (2018)40</td>
<td>Arab</td>
<td>Mandibular first molars</td>
<td>CBCT</td>
<td>78.4% (majority in the apical third)</td>
<td>18.2%</td>
<td>Majority of MMCs join the MB or the ML canals in the apical area. Very few cases reported independent MMC.</td>
</tr>
<tr>
<td>Tahmasbi et al (2017)41</td>
<td>American</td>
<td>Mandibular molars</td>
<td>CBCT</td>
<td>64.7% (the frequency of isthmus was higher in the second molars, but the difference was not statistically significant)</td>
<td>26% in the first molars; 8% in the second molars</td>
<td>Only 16.4% of the MMCs were true canals.</td>
</tr>
<tr>
<td>Akhlaghi et al (2017)41</td>
<td>Iranian</td>
<td>Mandibular molars</td>
<td>Clearing</td>
<td>44.6% (22.5%, 41.7% and 35.8% from 2, 4 and 6 mm from the apex, respectively)</td>
<td>55.4%</td>
<td>Advantages of the clearing technique include retaining the original form of the canal, enabling the assessment of the canal form and isthmus, and maintenance of the samples for a longer time.</td>
</tr>
<tr>
<td>Mehrvarzfar et al (2014)41</td>
<td>Iranian</td>
<td>Mandibular first and second molars</td>
<td>Staining</td>
<td>83% (92% were 6 mm from the apex)</td>
<td>Not mentioned</td>
<td>The prevalence of isthmus was greatest 3 to 5 mm from the apex. 22% were complete and 37% partial.</td>
</tr>
</tbody>
</table>

CBCT, cone beam computed tomography; MB, mesiobuccal; ML, mesiolingual; MMC, middle mesial canal.

different ethnic groups35-39. The studies mentioned in Table 1 used CBCT, clearing or staining techniques on extracted teeth to differentiate the MMC from anastomoses. Figure 3 shows a micro-computed tomography (micro-CT) view from the mesial of a mandibular first molar that shows the position of an MMC along with the complexities of an anastomosis. In this case, the MMC could be considered as a separate canal, and because of its position deep in the root, it could pose significant challenges for its clinical identification and management, similar to an anastomosis. Thus, there is a need to clinically differentiate MMCs from anastomoses before the root canal procedure, if a MMC is suspected, considering factors such as age, mandibular molars, ML-MB orifice distance, etc, which may minimise failures. Clinical techniques other than CT should also be used to generate dependable evidence.

Peters et al42 reported that the variations in root canal anatomy influenced more the outcome of the root canal preparation than the technique.
used to prepare the canal. Failure of root canal procedures in mandibular molars was mainly due to missed or unfilled canals\textsuperscript{12}, although procedural errors could also influence the outcomes. Considering the high prevalence rate of identified anastomoses, it behoves the clinician to be fully aware of the anatomy to avoid failures. Most of the MMCs were anastomoses and when uncleaned, contained necrotic debris and tissue remnants that served as bacteria reservoirs leading to infection and treatment failure. Anastomoses have been classified into five types by Hsu and Kim (1997)\textsuperscript{43}: type I, presence of two canals without a noticeable communication; type II, presence of two canals without a definite communication; type III, similar to type II but with three canals instead of two canals; type IV, extension of the main canal into the isthmus; and type V, presence of a complete communication or corridor between the two canals. They can also be described as no isthmus, incomplete isthmus or complete isthmus\textsuperscript{44}. The apical termination of an anastomosis can be at 2 mm, 4 mm or 6 mm from the apex\textsuperscript{44}. In vitro studies on extracted teeth reported that most of the incomplete anastomoses terminated 6 mm above the apex, and most of the complete anastomoses terminated 2 to 4 mm from the apex\textsuperscript{10,45-47}. This emphasises the clinical importance of identifying and managing anastomoses to avoid failures. The presence of anastomoses has been reported to be more common in second molars, although this finding was not statistically significant\textsuperscript{38}.

**Prevalence of MMCs**

Previous studies reported prevalences of MMCs of 34\%\textsuperscript{38}, 42.6\%\textsuperscript{37}, 58.3\%\textsuperscript{36}, 20\%\textsuperscript{35} and 10.8\%\textsuperscript{39}, with a higher rate in mandibular first molars compared with second molars. The prevalence was higher in younger patients aged between 20 to 40 years; a decrease in prevalence was observed as age increased. Most participants were Asian, and variations due to ethnicity could not be assessed due to constraints in the investigative design of the included studies. This has been identified as a predisposing factor for the anatomical variations in the number of roots and further anatomical complexities\textsuperscript{6}. Previous studies on the prevalence of MMCs in various ethnic groups reported 22.1\% in a Brazilian population, 26\% in an American population, 14.8\% in a Turkish population and 10.8\% in Mongolians\textsuperscript{34-41}. This indicates that there is a definite relationship between ethnicity differences and presence of MMC. Also, in vivo studies have reported higher prevalences than in vitro studies probably due to previous endodontic, periodontal treatment or root canal calcifications\textsuperscript{38}; hence only in vivo studies were included in the present review.

**Endodontic coronal access**

Various techniques have been used to study the root canal morphology such as plaster casts, staining and clearing, operating microscope, angulated radiographs and CBCT. However, the use of CBCT scans at the 6x6 field-of-view (FOV) and a voxel size of 0.125 was considered 96\% successful in the identification of MMCs and anastomoses\textsuperscript{47}. This might be the reason why most studies included in this review did not distinguish anastomoses from true MMCs. The CBCT technique is currently the only possible option to detect the presence of this anatomical entity preoperatively, and to distinguish it from a true canal. However, considering the fact that a preoperative CBCT scan is not possible to be performed in all cases, it could be reserved to be used in addition to microscopic access and careful clinical examination if a MMC is suspected.

A systematic review on the use of operating microscopes in the endodontic practice indicated that most clinicians used microscopes to observe the floor of the pulp chamber and location of root canals\textsuperscript{48}. In the present review, most studies also used operating microscopes at 2.5 to 8X magnification to examine the pulpal floor. They were used alone or in conjunction with CBCT scans, angulated radiographs or probing to locate additional canals like the MMC\textsuperscript{48}.

When a traditional access preparation is used without a microscope, a careful clinical examination is of utmost importance, which depends on the experience of the clinician. In the studies included in the present review, techniques such...
as probing, grooving or troughing were used to locate MMCs. However, these techniques could not distinguish anastomoses from true canals, and were used when CBCT scans and microscopes were not an option. Results from previous in vitro studies indicated that troughing detected almost 77% of the MMCs, although a lower percentage was detected in vivo studies. Troughing was performed using a long shank round bur in the groove connecting the MB and ML canals, directed mesioapically at no more than 2 mm. This would avoid the furcation area and prevent perforation. Prade et al observed that the identification of canals was more successful when microscopic viewing followed troughing rather than troughing done after microscopic viewing. The use of troughing followed by microscopic viewing significantly improved the localisation of the canals compared with direct viewing.

None of the available literature reported complications related to troughing; however, failures in this regard may take time to develop such as thinning of the mesial wall with crack development in the cementum. Probing using ultrasonic tips or size 8 or 10 files were also used by clinicians. However, this strategy completely depends upon the tactile sense of clinicians and their experience. These techniques might be more successful under microscopic viewing.

Cleaning and shaping

Achieving debridement of the root canal system, particularly in the presence of complex anastomoses, is a major challenge. Most rotary files have a spiral blade arranged in a helical form that machines the root canal to a circular bore, which makes it almost inaccessible to reach areas such as anastomoses where hard tissue debris predominantly accumulates. The rotary instruments used routinely have greater tendency to pack dentine chips actively into anatomical irregularities that are inaccessible. Although chemical debridement is a suggested adjunct, certain areas in the root canal still pose challenges to irrigant penetration.

Self-adjusting files (SAF) adjust themselves to the shape of the root canal and offer particular advantages in the presence of anastomoses. It offers a continuous delivery of irrigant, uniform layer of dentine removal from around the entire perimeter of the root canal, prevents unnecessary removal of sound dentine thereby preventing crack formation, and has been reported to be more effective than rotary NiTi instrumentation in eliminating debris and viable Enterococcus faecalis cells from the root canal. According to the study by Metzger et al a 1.5 mm SAF can be inserted into any canal previously prepared or negotiated with a size 20 K-file, and a 2.0 mm file can easily be compressed into a canal prepared with a size 30 K-file. Previous studies reported that the SAF system significantly increased the volume of anastomoses; when fully flattened, a 1.5 mm SAF file may assume a mesiodistal dimension of 0.2 mm. Hence, these instruments cannot be used in isthmuses thinner than 0.2 mm. In narrow isthmuses, thinner than 0.2 mm, the SAF system can be expected to be able to clean the entrance to isthmuses and avoid packing debris into the opening. Such narrow isthmuses represent a limitation even for the SAF technology and this issue needs further investigation.

Conventional irrigation techniques using syringe and needle are generally considered ineffective where anatomic irregularities are present. This is of concern because almost 35.2% of the anastomoses volume has been reported to be filled with dentine debris following instrumentation, which prevents the penetration of the filling material and sealant. Alternative irrigation techniques currently available include passive ultrasonic irrigation (PUI), EndoVac system, Easy Clean instrument (Easy Equipamentos Odontológicos, Belo Horizonte, MG, Brazil). An in vitro study by Silva et al in 2019, reported no significant differences between the above mentioned techniques using 16 ml of 5.25% NaOCl and 4 ml of 17% EDTA for 5 minutes for the MMC in mandibular molars; however, these techniques resulted in better debris removal compared with manual techniques. Techniques using apical negative pressure prevented the apical extrusion of the irrigant, although evidence does not support the prevention of apical extrusion of the debris. Another recent system...
was developed based on fluid dynamics, acoustics and tissue dissolution chemistry: the GentleWave system (multisonic ultracleaning system [MUS]), (Sonendo, Laguna Hills, CA, USA). Haapasalo et al\textsuperscript{58} compared the GentleWave system with other apical negative pressure based systems and reported that the GentleWave system provided seven times faster tissue dissolution with minimal canal preparation. Also, the success rates of this system have been reported to be 97.4\% and 97.3\% at 6 and 12 months, respectively\textsuperscript{69}. There is a need for further randomised clinical trials on different irrigation systems to understand any significant differences between the techniques, in particular when dealing with the potential for anastomoses in any root canal system.

**Obturation**

Alternatives may be considered when traditional sealants available in the market lead to possible treatment failure because of the technical difficulties involved while managing anatomical irregularities, such as the MMC. The BC HiFlow Sealer (Brasseler USA, Savannah, Georgia, USA) is a bioceramic sealant that is heat resistant, shows excellent biocompatibility, incites odontoblastic proliferation, mineralisation and osteogenesis and has been reported to have significant antibacterial properties. This sealant has also been shown to produce expansion rather than shrinkage, observed in other sealants, making this a viable option in the hands of clinicians of any experience level. The single-cone obturation technique with this sealant has been shown to produce better results compared with the lateral condensation technique, and could be used as an alternative while obturating the MMC\textsuperscript{60}.

**Intracanal medicament**

Commercially available intracanal medicaments contain 20 to 42\% calcium hydroxide by weight. Other ingredients include a vehicle such as water or saline, a thickener such as methylcellulose or polyethylene glycol, and a radiopaque agent. The pH of pure calcium hydroxide, between 12.5 to 12.8, produces dissociation into calcium and hydroxyl ions in an aqueous solution for effective use as an intracanal medicament\textsuperscript{61}. However, the pH in commercially available products may not reach these levels due to the variable release of hydroxyl ions and the buffering effect of dentine; therefore, these products may have reduced antibacterial and tissue dissolving efficacy\textsuperscript{62}. Root canals with anatomical irregularities benefit from the antimicrobial, tissue-dissolving, anti-resorptive and hard tissue repairing properties of calcium hydroxide, especially when the canals are difficult to negotiate, achieving complete disinfection. Therefore, its use is highly recommended in these cases\textsuperscript{63,64}.

**Postoperative care**

Since none of the studies reported complications or failures, the advantages or disadvantages of these techniques used to manage the MMC could not be determined from the reviewed literature. The reason might have been that most published studies did not present negative or contradictory results\textsuperscript{65}.

**Failure and retreatment**

The present review did not identify failure and retreatment rates in cases with MMC or anastomoses. As reported by Ingle et al\textsuperscript{66}, results from the Washington study indicated that the causes of failure of root canal procedures can be classified into three main groups:

- 63.5\%: apical percolation, as a result of incomplete obturation and unfilled canals
- 14.5\%: operative errors, such as root perforation, gross overfilling and broken instruments
- 22\%: errors in case selection, and the treatment of cases with coexisting periodontal or any other pathology.

The first two categories of failures mentioned above can be more common when MMCs or anastomoses are detected and treated. Any case of endodontic failure is usually associated with apical pathosis and related symptoms that require...
retreatment. The possibility of future failure and further case management must be considered and planned even in cases that indicate clinical and radiographic success. Periodic assessments in the form of radiographs should be performed, especially in cases with MMCs or anastomoses, and root canal procedures should be termed satisfactory or unsatisfactory. Furthermore, future failures may be triggered in unsatisfactory cases by prosthetic intervention. This calls for a continued follow-up in all cases requiring additional prosthetic interventions, as prosthetic restorations may restrict and complicate the endodontic access, should retreatment be indicated in the future.

Conclusion

To conclude, the case reports and series that have been published clearly indicate the lack of exact evidence on the protocol to manage MMCs. This finding suggests the need for high quality clinical trials that could provide information on the best available technique for the intracanal management of both MMCs and any adjoining anastomoses. Though patient-related factors play an important role on the prognosis, evidence-based protocols that could possibly produce the best possible treatment outcome, should be identified. Furthermore, the failures and complications resulting from these techniques must be studied and reported in detail, as literature in this field is lacking.

Disclosure

The authors deny any conflicts of interest.

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