Abstract: This study evaluated the anatomical profile of the mesial root canals of the Burmese mandibular first molar with Vertucci’s type IV canal configuration (VT4) using microcomputed tomography analysis. Seventy-five mesial roots of extracted mandibular first molars were scanned and evaluated. Fourteen middle mesial canals (MMCs) were observed in the specimens; each specimen had an average of 1.63 lateral canals and 3.77 apical foramina. The lateral canals arising from the mesiobuccal canal, mesiolingual canal, MMC, and isthmus terminated at an average distance of 0.92, 0.73, 2.11, and 1.89 mm, respectively, from the apex. The mean distance between the centers of the mesiobuccal and mesiolingual canals at 1.5 mm coronal to the furcation was 2.60 mm. A higher incidence of isthmus was observed in the apical 2-6-mm region compared with the apical 0-2-mm region ($P < 0.05$). The incidence of lateral canals in the isthmus was similar to that of the mesiobuccal and mesiolingual canals ($P > 0.05$). This study shows that the mesial root of the Burmese mandibular first molar with VT4 has complex anatomical profiles comprising MMCs and isthmus and their lateral canals.

Keywords: root canal anatomy; mandibular first molar; microcomputed tomography; Burmese; Vertucci’s type IV.

Introduction

The major objective of endodontic treatment is preventing or treating apical periodontitis, and to obtain this desired objective, the entire root canal system must be meticulously shaped, cleaned, and obturated three dimensionally. A thorough understanding of the anatomy of the root canal system and its variations plays an indispensable role in endodontic treatment (1). In general, the mandibular first molar is the most frequently endodontically treated tooth (2,3). It reveals various anatomical complexities such as lateral or accessory canals, secondary canals, isthmuses, and additional canals (4-6) and is associated with a significantly lower success rate than other teeth (7).

According to previous studies (8-10), Vertucci’s type IV canal configuration (VT4) is the most common type observed in the mesial root of the mandibular first molar. Moreover, Gulabivala et al. (8) found that the majority of mesial roots of the Burmese (Myanmar) mandibular first molar had VT4. Despite the presence of extensive endodontic literature related to the mandibular first molar, no study has specifically focused on VT4 of the mesial root of this tooth.

Microcomputed tomography (μCT) with its dedicated
Materials and Methods

This study was approved by the Institutional Review Board of the University of Dental Medicine, Mandalay, Myanmar (No. 20150201, 2015). Initially, 181 extracted mandibular first molars with two separate roots were selected from a pool of extracted teeth obtained from the Myanmar population. The teeth were stored in 10\% formalin solution. The reasons for extraction and the age and sex of the patients were not recorded. Teeth with apparent root resorption, apical root fracture, open apex, and previous endodontic treatment were excluded. To identify VT4, the access cavity was carefully prepared to preserve the canal orifices and pulp chamber floor. Pulp tissue remnants were removed using an endodontic excavator. The access cavity was irrigated with saline, and the canal orifices were explored with an endodontic explorer. The presence of two independent canals in the mesial root was clinically identified by gently introducing a size #10 K file in the mesiobuccal (MB) and mesiolingual (ML) canals until they were just visible at the apical foramen. A radiograph in the mesiodistal view was obtained. Finally, 75 specimens with VT4 in the radiographic images were selected for μCT.

The specimens were scanned using a μCT scanner (SkyScan 1272, Bruker MicroCT, Kontich, Belgium) at 10-μm isotropic resolution, 125 μA, 80 kV, 1-mm aluminum filter, and 0.4° rotation step with 180° rotation. After the raw images were reconstructed using the NRecon software v1.6.1 (Bruker MicroCT), 3D models of the mesial root and canal system for the entire root and apex (6 mm) were separately constructed using the CTAn software v1.14.4 (Bruker MicroCT) and visualized using the CTVol software v2.2.3 (Bruker MicroCT). Regions of interest were setup from the pulp chamber floor to the apex. The following parameters were studied using two-dimensional (2D) slides and 3D models: the incidence of the middle mesial canal (MMC) and lateral canal; the distance between the lateral canal foramen to the apex; the number of apical foramina; the incidence of apical constriction; and the incidence and type of isthmus in the apical 6-mm region. All numerical data were expressed as mean ± standard deviation.

For statistical analyses, the incidence of the lateral canal from the MB canal, ML canal, and isthmus was analyzed using Kruskal-Wallis test. The distance between the lateral canal foramen from the MB canal, ML canal, MMC, and isthmus to apex, and incidence of the isthmus among the levels were compared using Kruskal-Wallis test with Bonferroni multiple comparison post hoc test.

Results

Incidence of MMC and lateral canal

MMCs were found in 14 (18.7\%) specimens. Eight (57.1\%) cases were defined as fin type, three (21.4\%) presented with the confluent type (14), and the remaining three (21.4\%) cases presented with the independent type of canals. Ten of the 14 MMCS (71.4\%) were close to the ML canal, three (21.4\%) were in the middle position, and only one (7.1\%) was close to the MB canal. Eleven (78.6\%) MMCS had their own portals of exit. Each specimen had 1.63 lateral canals on an average, ranging from 0 to 6 lateral canals (Table 1).

Distance between the lateral canal foramen to the apex

The lateral canals arising from the MB canal terminated at an average of 0.92 mm (range, 0.08-5.1 mm) from the apex, whereas those arising from the ML canal, MMC, and isthmus terminated at 0.73 mm (range, 0.02-2.54 mm), 2.11 mm (range, 0.02-7.6 mm), and 1.89 mm (range, 0.16-6.9 mm), respectively, from the apex (Table 2). The termination level of the lateral canals from MMC was significantly more coronal to those from the MB and ML canals (P < 0.05).

Number of apical foramina

Each specimen had an average of 3.77 apical foramina, ranging from 2 to 8 foramina in one specimen (Table 1).

Apical delta

Sixty of the 75 specimens (80\%) showed apical delta formation.

Distance between the MB and ML canal orifices

The longest distance between the buccal margin of the MB canal and the lingual margin of the ML canal was 3.30 ± 0.53 mm (range, 2.28-4.31 mm), and the distance between the centers of the MB and ML canals was 2.60 ± 0.41 mm (range, 1.69-3.48 mm) at a distance of 1.5 mm.
3

coronal to the furcation.

Canal width and apical constriction
The largest and smallest canal widths and the ratio of the largest to the smallest dimension at distances of 0.5, 1, 2, and 3 mm from the apical foramen in the MB and ML canals are summarized in Table 3. The apical constriction, i.e., the narrowest (mesiodistal) dimension of the canal width in the MB canal, was found at 0.5 and 1 mm from the apex in 33 (44%) and 32 (42.7%) specimens, respectively. Similarly, in the ML canal, the apical constriction was found at the 0.5- and 1-mm levels in 31 (41.3%) and 33 (44%) specimens, respectively.

Isthmus in the apical 6-mm region
The isthmus was three-dimensionally classified into the following five categories (Fig. 1A-E): type 1, complete sheet structure containing a narrow sheet-like structure that connects the main MB and ML canals anywhere; type 2, incomplete sheet structure that contains a narrow sheet-like structure extending from either the MB or ML canal or both but not completely connecting each other at any point; type 3, incomplete tubular structure that contains a tube-like structure extending from either the MB or ML canal or both but not completely connecting each other at any point; type 4, mixed complete structure that contains a narrow sheet and tube-like structure

Table 1 Incidence of the lateral canal and apical foramen

<table>
<thead>
<tr>
<th></th>
<th>MB Canal</th>
<th>ML Canal</th>
<th>Isthmus</th>
<th>MMC</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral canal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>0.55 ± 0.84&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.59 ± 0.86&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.41 ± 0.68&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.08 ± 0.32</td>
<td>1.63 ± 1.39</td>
</tr>
<tr>
<td>Apical foramen</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>1.55 ± 0.84</td>
<td>1.59 ± 0.86</td>
<td>0.41 ± 0.70</td>
<td>0.23 ± 0.58</td>
<td>3.77 ± 1.36</td>
</tr>
<tr>
<td>Range</td>
<td>1-6</td>
<td>1-4</td>
<td>0-3</td>
<td>0-2</td>
<td>2-8</td>
</tr>
</tbody>
</table>

(mean ± standard deviation, <i>n</i> = 75)

Table 2 Distance between the lateral canal foramen and apex

<table>
<thead>
<tr>
<th></th>
<th>MB canal</th>
<th>ML canal</th>
<th>Isthmus</th>
<th>MMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>0.92 ± 0.89&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.73 ± 0.56&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.89 ± 2.04&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.11 ± 2.84&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Range</td>
<td>0.08-5.10</td>
<td>0.02-2.54</td>
<td>0.16-6.9</td>
<td>0.02-7.6</td>
</tr>
</tbody>
</table>

(mean ± standard deviation, <i>n</i> = 75)

Table 3 Apical canal width in the mesiobuccal and mesiolingual canals

<table>
<thead>
<tr>
<th>Level from the apical foramen</th>
<th>0.5 mm</th>
<th>1 mm</th>
<th>2 mm</th>
<th>3 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>MB Width</td>
<td>0.38 ± 0.19</td>
<td>0.24 ± 0.06</td>
<td>0.45 ± 0.25</td>
<td>0.24 ± 0.05</td>
</tr>
<tr>
<td>Range</td>
<td>0.13-1.22</td>
<td>0.11-0.37</td>
<td>0.16-1.56</td>
<td>0.12-0.36</td>
</tr>
<tr>
<td>LD/SD</td>
<td>1.58</td>
<td>1.91</td>
<td>2.49</td>
<td>2.61</td>
</tr>
</tbody>
</table>

| ML Width                      | 0.44 ± 0.40 | 0.22 ± 0.07 | 0.55 ± 0.47 | 0.22 ± 0.06 |
| Range                         | 0.14-2.53 | 0.1-0.45 | 0.13-2.48 | 0.12-0.4 |
| LD/SD                         | 2.04    | 2.52  | 2.7  | 3.33  |

(mean, mean ± standard deviation, <i>n</i> = 75)

MB, mesiobuccal canal; ML, mesiolingual canal. LD/SD, the ratio of the largest dimension (LD) to the smallest dimension (SD).

Fig. 1 Types of 3D isthmus; A) type 1 with lateral canal, B) type 2 with lateral canal, C) type 3, D) type 4 with lateral canal, and E) type 5 with lateral canal.
connecting the main MB and ML canals anywhere; type 5, mixed incomplete structure that contains a narrow sheet and tube-like structure extending from either the MB or ML canal or both but not completely connecting each other at any point. In the apical 6-mm region, all specimens revealed the presence of an isthmus; 23 (30.7%) specimens presented with type 1, five (6.7%) with type 2, three (4%) with type 3, 29 (38.6%) with type 4, and 15 (20%) with type 5.

The incidence of partial and complete isthmus in 2D slides from the apex to 1-mm level, 1- to 2-mm level, 2- to 3-mm level, 3- to 4-mm level, 4- to 5-mm level, and 5- to 6-mm level are presented in Table 4. The incidence was significantly higher at the 2- to 3-mm level, 3- to 4-mm level, 4- to 5-mm level, and 5- to 6-mm level compared with that at the 1- to 2-mm level, which had a higher incidence than that at the apex to 1-mm level ($P < 0.05$).

### Table 4 Incidence of the isthmus in 2D sections at the apical 6-mm region

<table>
<thead>
<tr>
<th>Level from the apex (mm)</th>
<th>0-1</th>
<th>1-2</th>
<th>2-3</th>
<th>3-4</th>
<th>4-5</th>
<th>5-6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total isthmus</td>
<td>5.76</td>
<td>44.21</td>
<td>73.41</td>
<td>77.12</td>
<td>74.72</td>
<td>70.88</td>
</tr>
<tr>
<td>Partial isthmus (PI)</td>
<td>5.28</td>
<td>37.57</td>
<td>64.88</td>
<td>63.31</td>
<td>55.65</td>
<td>54.43</td>
</tr>
<tr>
<td>Complete isthmus (CI)</td>
<td>0.48</td>
<td>6.64</td>
<td>8.53</td>
<td>13.81</td>
<td>19.07</td>
<td>16.45</td>
</tr>
<tr>
<td>PCCI</td>
<td>11.00</td>
<td>5.66</td>
<td>7.60</td>
<td>4.58</td>
<td>2.92</td>
<td>3.31</td>
</tr>
</tbody>
</table>

Different superscript letters show the significant difference at $P < 0.05$ level.

### Discussion

The root and canal anatomies may vary with ethnicity. The sex and ethnic origin of the patient must be carefully considered during the preoperative evaluation for nonsurgical endodontic treatment (15). Besides Vertucci’s eight types of canal classification, seven additional canal configurations have been reported in Burmese mandibular molars (8).

In this study, 18.7% of specimens presented with MMCs. The incidence of MMCs in the mandibular first molar ranges from 1 to 36% (1, 8, 14, 16). The occurrence of the ML fin type is reportedly more common than that of the MB fin type, whereas the independent type is not commonly encountered (14). Among the 14 MMCs in this study, 71.4% were closer to the ML canal compared with the MB canal; this finding is consistent with that previously reported (14). Furthermore, consistent with a previous finding by Pomeranz et al. (14), the orifices of MMCs in this study were located in the mesial subpulpal groove. Thus, altogether, our results indicate that MMC is not a rare occurrence in the mesial root of the Burmese mandibular first molar with VT4.

The two interesting findings of this study include the following: the incidence of lateral canals in the isthmus was similar to those of the MB and ML canals and the termination points of the lateral canals from MMC and the isthmus were more coronal compared with those from the MB and ML canals. To the best of our knowledge, this is the first study to report this finding. In addition, the lateral canals arising from the MB and ML canals terminated at an average distance of 0.92 and 0.73 mm from the root apex, respectively. Conversely, the lateral canals from MMC and the isthmus terminated at an average distance of 2.11 and 1.89 mm, respectively, from the apex. This finding reaffirmed those previously reported, wherein the majority of canal complexities occurred within the apical 3-mm region (Kim S et al. Color atlas of microsurgery in endodontics. WB Saunders, 2001). Moreover, an average of 3.77 apical foramina was observed in each specimen. This finding is consistent with that reported by Harris et al. (16). The apical delta was observed in 80% of our study specimens, indicating a high possibility of apical ramification.

The longest distance between the MB and ML canals and the distance between the centers of the MB and ML canals at 1.5 mm above the furcation were moderately consistent. The average longest distance between the orifices at 1.5 mm above the furcation in this study was similar to that previously reported (16). We believe that these results may help clinicians in detecting a missed canal with a calcified orifice and minimize the risk for perforation.

In this study, the smallest apical canal width increased from 0.5-mm level to 1-, 2-, and 3-mm levels, and the ratio of the largest to smallest dimensions increased from 0.5-mm level to 1-, 2-, and 3-mm levels in both the canals. These findings may be attributed to the high prevalence of the isthmus in the buccolingual direction in both the canals. The changes in the buccolingual (largest) dimension were more noticeable than that in the mesiodistal (smallest) dimension in both the canals, implying that the mesiodistal canal dimension was more consistent and had more influence on determining the initial apical file. The existence of an apical constriction remains controversial in the literature, with some studies stating...
its condition as uneven, whereas several others reporting either their presence or absence (17-19). In our study, the average smallest dimensions at the 0.5- and 1-mm levels were lower than those at the 2- and 3-mm levels in most specimens, thus creating a barrier similar to an apical constriction. These data may assist clinicians in determining the apical finishing file during conventional root canal treatment.

We found that significantly fewer isthmuses were observed at the apex to 1-mm level and 1- to 2-mm level compared with the more coronal levels. The incidence was suddenly increased at the 2- to 3-mm level and 3- to 4-mm level, with the highest incidence of the isthmus observed at the 3- to 4-mm level. A slight decline was also noted at the 4- to 5-mm level and 5- to 6-mm level. A significant difference in the incidence of the isthmus was observed between the apex to 2-mm level and 2- to 6-mm levels. This finding is similar to that previously reported (6,20). The partial isthmus was more common at all levels compared with the complete isthmus. In this study, Hsu and Kim’s classification (6) was initially applied; however, because of the lack of fit to this study, partial and complete isthmuses were used (21).

A previous study that utilized a 15-μm resolution of µCT found that 32 of 36 specimens had an isthmus somewhere along its length in the apical 6-mm region (11). In addition, two other studies also found the isthmus at 37-μm resolution in 60 of 70 specimens and at 12.5-μm resolution in 17 of 20 specimens (12,20). To detect the fine anatomical features, a 10-μm isotropic resolution was used in this study; all specimens in this study exhibited an isthmus in the apical 6-mm region. This may be because of the finer isotropic resolution, which, at 10 μm, is better than that previously reported. In addition, previous µCT-based studies devised the isthmus types according to their 3D features (11,12). Consequently, we also supposed five types of isthmus in our study. In this study, types 1, 4, and 5 were more common, whereas types 2 and 3 were less common.

The microcomputed imaging method is a nondestructive and reproducible promising tool for the in vitro study of human dental anatomy because it can provide 2D and 3D details of the tooth anatomy. However, the threshold value for whole mesial root specimens was not suitable for detecting the fine anatomical structures in the apical 6-mm region; therefore, the apical 6-mm region was separately evaluated using specific threshold values. Based on these findings, it can be assumed that in addition to the higher isotropic resolution, the specific threshold value for a specific region is also necessary for detecting the fine anatomical structure.

It is generally accepted that the isthmus is important for conventional and surgical endodontic treatments because it is difficult to clean and manipulate endodontically. Moreover, it is a potential space for the proliferation of microbes and the accumulation of debris from mechanical debridement procedures. Therefore, clinicians need to pay attention to the existence of the isthmus and use effective disinfection methods.

In summary, the mesial root of the Burmese mandibular first permanent molar with VT4 revealed complex anatomical profiles. MMCs and the isthmus with lateral canals were observed in the apical 2- to 6-mm level. The isthmus appeared to possess a lateral canal similar to the MB and ML canals. Further studies examining the morphologies of other tooth types from subjects of different ethnicities using µCT are warranted.

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Conflict of interest
The authors have no conflict of interest related to this study.

References


