Natural root canal deviation and dentin thickness of mandibular first molars assessed by microcomputed tomography

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Research Article

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Abstract

Objective: To assess the centralization and dentin thickness of mesial root canals by microcomputed tomography (micro-CT).

Methods: Ninety-nine mandibular molars Vertucci’s type IV mesial canals were scanned by micro-CT. The mesiodistal deviation; and the centroid were calculated for mesiobuccal (MB) and mesiolingual (ML) canals (apical 4 mm and full canal).

Results: The centroid was deviated in MB and ML canals in full canal (MB=0.83 mm, 0.02-2.30 mm, and ML=0.83 mm, 0.05-3.99 mm), and in 4mm (MB=0.18mm,0.01-1.01 mm and ML=0.21 mm, 0.01-1.01 mm). In the full canal, both MV (69%) e ML (57%) deviated to mesial (M). In 4 mm, the deviation was M in 51% for MB canals and 52% of ML to distal (D). The dentin thickness was similar for MB and ML canals and their walls. Distal wall was lower for MB canal (0.07 mm) and M wall the higher in the MB canal (2.46 mm).

Conclusions: There is no centrality of mesial canals in mandibular first molars. The M deviation was frequent in the full canal. Dentin thickness were similar between mesial canals.

INTRODUCTION

The root canal anatomy is one of the most complex and ancient challenges that Endodontics tries to overcome in pursuit of successful endodontic treatment [1, 2]. Its complexity may vary according to the tooth, age, gender, and ethnicity of the patient [3, 4]. Due to this and other difficulties, many treatments fail because they may reach regions like apical deltas, isthmus, lateral and accessory canals. These regions impair the cleaning, modeling, and obturation of the root canal system (RCS), which may perpetuate the action of pathogenic microorganisms [5, 6].

One of the most common anatomical challenges is the presence of curvatures in the root canal path, which is the main cause of accidents such as deviations, steps, and perforations [7]. There is a possibility that the root canals are not centralized with the dental roots, as was traditionally believed. In this way, root canals may be closer to the external surface of the roots in some regions, which increases the risk of accidents. Indeed, in mandibular molars, a thin layer of dentin is usually present in the distal area of the mesial root, making it a preferable location for perforations or tears during instrumentation [8].

Despite some previous studies evaluating dentin thickness in determined points [9–12], the centralization of the root canals with their roots has never been deeply studied. This is particularly important in molars due to the high frequency of accidents, such as perforations [13], ledge formation [20], root canal deviation, and apical deviation [22,23]. With the advent of computerized microtomography (micro-CT), better recognition of this anatomy has been achieved. Curiously, the natural centralization of the canals with their roots was never studied using micro-CT [14]. These results may help the clinician plan instrumentation to prevent trans-operative accidents.
The objective of the present study was to assess the centralization and dentin thickness of mesial root canals of mandibular first molars by micro-CT.

**METHODS**

**Specimen selection and micro-CT scanning**

The institutional ethics committee approved the study protocol. Ninety-nine extracted mandibular first molars [50 left and 49 right] with mesial root canal configuration Vertucci’s type IV [15] were selected for the study. Buccolingual and mesiodistal radiographs confirmed the presence of two independent canals.

The teeth were scanned in a micro-CT scanner (SkyScan 1174.v2; Bruker-micro-CT, Kontich, Belgium). The parameters used for the scan included 360º rotation about the vertical axis, a rotation step of 1.0, isotropic resolution of 19.9 mm, 800 mA, 50 kv, and a 0.5 mm-thick aluminum filter. The images obtained were reconstructed with the NRecon v.1.6.9 software (Bruker micro-CT, Kontich, Belgium) through axial and transversal sections of the internal structure. The quantitative evaluation by three-dimensional reconstruction of root and root canal volumes was obtained using the software plug-in three-dimensional analysis tool CTVol v. 2.2.3.0 (Bruker microCT, Kontich, Belgium).

In the CTAn v.1.14.4.1 + software (Bruker micro-CT, Kontich, Belgium) were selected the top [referring to the apical end] and the bottom [referring to the most coronary portion] of the tooth. With the top selected, through Raw Images, the line corresponding to the initial Z-position value was displayed.

After reconstruction of sections of all teeth using CTAn v.1.14.4.1 + software (Bruker micro-CT), the 99 molar images were converted to the .nrrd format in the software Image J 1.50d (National Institutes of Health, Bethesda, MD, USA) for the division of the MB and ML canals. The images were binarized, separating the images corresponding to the roots (dentin) and the MB and ML canals. The images were segmented through the linearization technique, which allows the division of the image into regions of interest (ROI), recognizing them as objects independent of each other and the background of the image. Thus, a binary image was obtained where black pixels represented the background and regions of white pixels, the object of analysis.

The ROI was duplicated using the Image J 1.50d software, and the images were subtracted. Then, the image corresponding to the root canal was obtained. All this procedure was repeated to the dentin. The saved files were converted into images sequenced in .bmp extension for the following assessments.

**Centroid analysis**

The centroid is the point associated with a geometric shape, also known as the geometric center. If the geometric shape represents a homogeneous section of a body, then the centroid coincides with the center of mass (barycentre). In cases where the body is not only homogeneous but is also subjected to a constant gravitational field, this point coincides with the center of gravity. The coordinate system for calculations of a centroid needs a differential element for integration, which can be in line, area, or
volume. In the present study, the body to be studied are three-dimensional (3D) human dental roots, with a geometric region without material [root canal], fitting into the category of volume centroid [16,23].

From the binary images obtained by CTAn v.1.14.4.1 + software (Bruker micro-CT) the centroid was selected considering the X, Y, and Z coordinates of each sound/prepared canals or dentin model. In order to evaluate the deviation of the canals, only the value of centroid X, which represents deviations in the mesial [M] / distal [D] direction, was considered for the assessment.

**Quantitative analysis of data**

The root/canal diameters ratio of the mesiobuccal (MB) and mesiolingual (ML) canals was calculated using the CTAn v.1.14.4.1 + software (Bruker micro-CT) through the Measure tool. A straight line was drawn from one end to the other corresponding to the root/canal’s diameter, and a second straight line was inserted from the distal wall to the mesial wall to pass through the center of the root/canal, which gives the root/canal diameter. This procedure was performed throughout the root length.

The results of the distances of MB and ML, with respect to the centroid of the root, were positive and negative values, only to indicate which direction the deviation followed: the deviations for M were positive, and the deviations for D were negative.

The dentin thickness was evaluated in the three thirds of the canal using the CTAn software (Bruker micro-CT). The Measure Tool plug-in and line option for linear measurements on the software were used, considering the distance between the two most distant pixels on the dentin object. For this analysis, the number of transversal sections of the canal on micro-CT was divided by three, representing the cervical, middle, and apical thirds of the canals. The dentin thickness was measured in the middle section of each canal third. In addition, a complementary measurement was performed at 1 mm from the root apex. The measurements were performed in the M and D walls of the canals.

The data were analyzed and computed descriptively, calculating the mean, median, minimum, and maximum and verifying the differences between the entire length of the canal and the apical 4 mm. The frequency of deviation to M or D was also calculated. The XLSTAT-3DPlot 2018.7 program for Windows 10 (Addinsoft, New York, NY, USA) was used to construct the canal diagram from the coordinates obtained from the centroid of the mesial roots.

Finally, the CTAn software was used to create the 3D models of the canals and returned to the program CTVol v.2.2.3.0 (Bruker micro-CT) to obtain the images related to 3D models and [green], dentin (transparent gray) and centroid (black) models, allowing a more visually characterized comparison of the MD deviations between the canals and the centroids. BL deviations were not analyzed because of the absence of clinical relevance (explained in the discussion section).

**RESULTS**
The mean deviation of the center of gravity of the canals with the center of gravity of the mesial root was the same for the ML and MB canals (0.83 mm) when analyzing the entire extension of the canals and similar when only the apical region was examined (0.18 mm for the MB canals and 0.21 mm for the ML).

Table 1 shows, for the whole canal, in the MB canal, the mean deviation (0.83 mm) was above the standard deviation (0.71 mm), with a variation of 0.02 to 2.30 mm. In the ML root, the mean deviation was the same (0.83 mm), also above the standard deviation (0.76 mm), with a variation of 0.05 to 3.99 mm. Concerning the apical portion, both canals presented the same variation (0.01 to 1.01 mm). In the MB canal, the mean deviation (0.18 mm) was very close to the standard deviation (0.15 mm ), while in ML, the mean deviation was precisely the same (0.21 mm).

<table>
<thead>
<tr>
<th>Canal</th>
<th>Level</th>
<th>Mean (SD)</th>
<th>Median</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>MB</td>
<td>Total canal length</td>
<td>0.83 (0.71)</td>
<td>0.64</td>
<td>0.02–2.30</td>
</tr>
<tr>
<td></td>
<td>Apical</td>
<td>0.18 (0.15)</td>
<td>0.16</td>
<td>0.01–1.01</td>
</tr>
<tr>
<td>ML</td>
<td>Total canal length</td>
<td>0.83 (0.76)</td>
<td>0.60</td>
<td>0.05–3.99</td>
</tr>
<tr>
<td></td>
<td>Apical</td>
<td>0.21 (0.21)</td>
<td>0.16</td>
<td>0.01–1.01</td>
</tr>
</tbody>
</table>

MB: Mesiobucal, ML: Mesiolingual, SD: Standard Deviation

The frequency of M and D deviation varied according to the canal, with the most frequent deviation to M in all analyses, except for the apical region of ML canals. Evaluating the whole canal, in both MB and ML canals, more than half of the canals presented deviation to M (Table 2). No data acquired was null, which means that even minimal, all the canals presented some decentralization, regardless of the region (Fig. 1).

<table>
<thead>
<tr>
<th>Canal</th>
<th>Level</th>
<th>Mesial deviation</th>
<th>Distal deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MB</td>
<td>Total canal length</td>
<td>57 (58%)</td>
<td>42 (42%)</td>
</tr>
<tr>
<td></td>
<td>Apical</td>
<td>50 (51%)</td>
<td>49 (49%)</td>
</tr>
<tr>
<td>ML</td>
<td>Total canal length</td>
<td>68 (69%)</td>
<td>31 (31%)</td>
</tr>
<tr>
<td></td>
<td>Apical</td>
<td>48 (48%)</td>
<td>51 (52%)</td>
</tr>
</tbody>
</table>

MB: Mesiobucal, ML: Mesiolingual

Data regarding the dentin thickness revealed a similar distribution between the canals (MB and ML), and their walls (M and D), and also comparing the examined level (cervical, middle, apical, and 1 mm from the
The lowest value was found in the D wall of a MB canal (0.07 mm) and the highest in the M wall of a MB canal (2.46 mm) (Table 3).

<table>
<thead>
<tr>
<th>Canal</th>
<th>Canal wall</th>
<th>Level</th>
<th>Mean (SD)</th>
<th>Median</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>MB</td>
<td>Mesial</td>
<td>Cervical</td>
<td>1.47 (0.35)</td>
<td>1.51</td>
<td>0.91–2.46</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Middle</td>
<td>1.20 (0.34)</td>
<td>1.09</td>
<td>0.61–2.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Apical</td>
<td>1.01 (0.19)</td>
<td>1.01</td>
<td>0.52–1.49</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 mm from apex</td>
<td>0.77 (0.16)</td>
<td>0.75</td>
<td>0.46–1.23</td>
</tr>
<tr>
<td>Distal</td>
<td>Cervical</td>
<td>1.25 (0.25)</td>
<td>1.19</td>
<td></td>
<td>0.73–1.79</td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>1.07 (0.23)</td>
<td>1.04</td>
<td></td>
<td>0.49–1.84</td>
</tr>
<tr>
<td></td>
<td>Apical</td>
<td>0.99 (0.19)</td>
<td>0.95</td>
<td></td>
<td>0.61–1.51</td>
</tr>
<tr>
<td></td>
<td>1 mm from apex</td>
<td>0.79 (0.24)</td>
<td>0.81</td>
<td>0.07–1.34</td>
<td></td>
</tr>
<tr>
<td>ML</td>
<td>Mesial</td>
<td>Cervical</td>
<td>1.42 (0.31)</td>
<td>1.42</td>
<td>0.81–2.16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Middle</td>
<td>1.21 (0.28)</td>
<td>1.15</td>
<td>0.60–1.97</td>
</tr>
<tr>
<td></td>
<td>Apical</td>
<td>1.01 (0.18)</td>
<td>0.99</td>
<td></td>
<td>0.61–1.79</td>
</tr>
<tr>
<td></td>
<td>1 mm from apex</td>
<td>0.77 (0.12)</td>
<td>0.77</td>
<td>0.61–1.11</td>
<td></td>
</tr>
<tr>
<td>Distal</td>
<td>Cervical</td>
<td>1.29 (0.26)</td>
<td>1.27</td>
<td></td>
<td>0.23–1.88</td>
</tr>
<tr>
<td></td>
<td>Middle</td>
<td>1.15 (0.22)</td>
<td>1.10</td>
<td></td>
<td>0.75–1.85</td>
</tr>
<tr>
<td></td>
<td>Apical</td>
<td>1.02 (0.20)</td>
<td>1.01</td>
<td></td>
<td>0.49–1.66</td>
</tr>
<tr>
<td></td>
<td>1 mm from apex</td>
<td>0.77 (0.21)</td>
<td>0.80</td>
<td>0.21–1.25</td>
<td></td>
</tr>
</tbody>
</table>

MB: Mesiobucal, ML: Mesiolingual, SD: Standard Deviation

DISCUSSION

The present study was groundbreaking when comparing the gravitational centers of the root canals, in their original anatomy, with those of their respective roots. For this, the use of micro-CT was essential since it is a three-dimensional, non-destructive, high-resolution image method. Given the results, all mesial canals are not spatially centralized concerning their roots, but what strikes is the high degree of decentralization in millimeters. This reveals the concern with the possibility of perforation, depending on the root canal preparation size.
The MD deviation is highly relevant in clinical practice due to the small dentin thickness compared to the BL direction, which increases the risk of root perforation or tearing during endodontic treatment [16]. On the other hand, the buccal-lingual (BL) deviation is not very significant in clinical terms because it encompasses a region with a substantial amount of dentin. For this reason, this deviation was not analyzed in the present study. In the present study, the MD deviations occurred in all cases, with values much higher than expected.

The danger zone is traditionally referred to as the distal aspect of mesial roots because of the thinnest dentine, which can predispose strip perforations [7, 9, 17]. However, recent studies demonstrated that the asymmetric position of the canals with their roots resulted in variable dentine thickness at different levels and included areas toward the mesial aspect of the root in a considerable frequency [18]. In one study, the smallest dentine thickness was towards the mesial plane of the roots in 40% of the canals [18]. The present findings reinforce that the danger zone concept should be reconsidered because the mesial canals were more deviated to the mesial aspect of the roots than the distal aspect.

Correctly understanding the relationship between dentin thickness and the selection of niquel-titanium (NiTi) instruments is essential for the success of root canal treatment. The selection of NiTi instruments should match the root canal's dimensions, considering the risk of perforation. In the present study, the average dentin thickness in the apical third of the root canal was 1 mm and 0.77 mm near the apex, in mean. This thickness could be considered safe, but it depends on the instrument chosen for root canal preparation.

One study evaluated the apical dimensions of mandibular molar mesial root canals obtained by micro-CT and compared them with the available NiTi instruments' dimensions [19]. The authors found that based on the mean anatomic diameters, the adequate instrument dimensions would be 40/.10 for MB canals and 45/.08 for ML canals in order to touch the maximum surface area of the canal. However, this could be dangerous considering the dentin thickness. Ideally, root canal preparation should be planned individually for each canal. This strategy was analyzed by a study using cone-beam computed tomography (CBCT), which assessed the amount of unprepared surface areas at the apical 4-mm segment of the root canal of mandibular premolars in human cadavers [20]. With the customized preparation, a very high amount of surface areas over the apical 4 mm of the root canal was included in the final preparation (mean > 90%), and required final instruments one size larger than the initial largest canal, which is a conservative approach. Therefore, clinicians should carefully select NiTi instruments that match the root canal's dimensions to avoid overpreparation and the risk of perforation.

A root fracture is unpredictable and can occur anywhere in the root. A previous study [21] verified that many factors interact in the influence of the susceptibility and the fracture pattern, and any variable can easily predominate over the others. However, much of the fracture susceptibility is intrinsic to root and canal morphology [dentin thickness, canal shape, size, external root shape] and beyond the clinician's influence [22]. In context, endodontic preparation should be as conservative as possible, consistent with proper cleaning and shaping, especially considering the natural canal deviation with the root, as revealed...
in the present study. Clinicians should carefully evaluate the dentin thickness and select the appropriate NiTi instrument to avoid overpreparation and the risk of perforation.

CONCLUSIONS

The mesial canals have no centrality with the external anatomy of their respective roots in mandibular first molars. Considering the whole canal, the mean deviation was expressive (0.83 mm for both MB and ML canals). For the entire extension of the canals, the most frequent deviation was to M. However, the deviation frequency was similarly distributed to mesial and distal in the apical region. The average dentin thickness in the apical third of the root canal was 1 mm and 0.77 mm near the apex. The thickness values were similar between MB and ML canals and their M and D walls.

References


**Figures**
Figure 1

Mesial root and the centre of gravity of both canal and root.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- CentroidHIGHLIGHTS.docx