Molar Root Furcation: Morphometric and Morphologic Analysis

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The objective of the present study was a morphometric and morphologic analysis of maxillary and mandibular first and second molars using three different techniques. Measurements of 207 maxillary molars (105 first and 102 second molars) and 207 mandibular molars (110 first and 97 second molars) were measured: root length (RL), root trunk length (RTL), mesiodistal and buccolingual diameters (BLD) at the cementoenamel junction, inter-radicular angle (IRA), width, and furcal roof area (FRA) were recorded. No significant statistical correlations were found for most of these measurements, the only exception being the relationship between IRA/FRA, IRA/BLD in maxillary molars, and IRA/RTL in the maxillary first molar.

Morphologic examination was carried out by stereo microscopy, light microscopy of undecalcified sections, and scanning electron microscopy. All of these techniques showed the complexity of the furcation area with a large number of anatomic irregularities and plaque-retentive structures that could hamper adequate cleaning during periodontal treatment.


Periodontal therapy favorably influences the course of periodontitis, arresting periodontal tissue destruction and restoring the clinical conditions consistent with gingival health. The literature, however, suggests that such results are not achieved in a similar way throughout the entire dentition, because single-rooted teeth demonstrate a much more favorable response to periodontal therapy than multi-rooted teeth. The complete removal of plaque, calculus, and bacterial products from the subgingival environment plays an essential role in the success of periodontal therapy. Because it hampers complete subgingival cleaning, the presence of a radicular furcation in multi-rooted teeth may be partially responsible for the poor prognosis of these teeth. The poor accessibility through the furcation entrance and the complex anatomy of the root area may limit the effectiveness of different types of therapeutic...
Instruments, ie, curettes, sonic and ultrasonic scalers, and burs.\textsuperscript{14}

Nonsurgical treatment of periodontally involved molar furcations has been shown to be less effective than surgical instrumentation in removing all calculus from the diseased area\textsuperscript{12,15,16}; however, despite surgical access, complete cleaning of furcal surfaces is often not obtained.\textsuperscript{12,15,17,18} Resective therapy of periodontally diseased molars, which eliminates the anatomic area responsible for the limited access of cleaning instruments, changes multi-rooted to single-rooted teeth; the behavior of resected elements is, however, not comparable with that of monoradicular teeth.\textsuperscript{19} Some clinical studies\textsuperscript{20-22} demonstrate that, despite anatomic limitations, nonresected molars with periodontally involved furcations from patients enrolled in periodontal maintenance programs can remain in functional activity for prolonged periods of time. These findings suggest that an incomplete cleaning could also render fucated molars biologically compatible with functional activity.\textsuperscript{23-25}

If a nonresective treatment can be effective in maintaining the functional activity of periodontally involved molars, a good knowledge of furcation anatomy is certainly useful as the clinician tries to keep the diseased areas as clean as possible. On the basis of such considerations, the aim of the present study was to carry out a morphometric analysis of maxillary and mandibular first and second molars, and evaluate whether a relationship between some anatomic features of the different teeth and their furcal characteristics can be established. Offering a morphologic description of furcation anatomy using three different analysis techniques was another objective.

**Morphometric analysis**

In each tooth the following measurements were recorded:

1. The root length (RL) from the CEJ to the apex of each root; a mean value for each tooth was calculated.
2. The radicular trunk length (RTL) from the CEJ to a horizontal line tangent to the fons of the furca: this measurement was recorded for each furcal entrance (two measurements for mandibular molars and three measurements for maxillary molars), and a mean value was calculated for each tooth.
3. The mesiodistal diameter (MDD) at the CEJ.
4. The buccolingual diameter (BLD) at the CEJ.
5. The inter-radicular angle width (RAW); this measurement was assessed by drawing a line in the center of the cervical third of each root and measuring the value of the angle between each pair of lines with a goniometer; in maxillary molars a mean radicular angle was calculated.
6. The furcal root area (FRA), this value was measured after resecting the roots about 3 mm apical to the fornic of the furcal root. A photograph of the furcal root in a 1:1 ratio was obtained with a camera connected to a Wild Leitz MDG 17 stereo microscope. The area of the furcal root was then delimited on the photos by a continuous line surrounding the furcal edges of each root at the section level and continuing on the tangents to each external edge of the root in correspondence to each entrance of the furcal area. The delimited area was then measured by superimposing a transparent sheet subdivided into 1-mm² squares and adding the total number of squares to within 0.5 mm².

These data were then correlated by evaluation of Pearson’s correlation coefficient. Values of $P < 0.05$ were considered statistically significant.

Morphologic analysis

Among 414 examined teeth, 30 were selected for the morphologic analysis; teeth that presented characteristic measures as close as possible to the mean values observed in the total number of analyzed teeth were chosen. Three different methods were used for the morphologic analysis: five maxillary and five mandibular molars were processed for analysis by obtaining undecalcified sections for observation under transmitted light microscopy; and five maxillary and five mandibular molars underwent scanning electron microscopic analysis.

A stereomicroscope was used to observe the morphology of the furcal root after resecting the roots 3 mm apical to each furcal entrance. The section point was marked on each root with a pencil and the specimen was sectioned with a fine carbobondum disk in a bench lathe. The tooth was stained by immersion in basic fuchsin for 60 minutes, then washed in running water and dried under a gentle air flow. Each tooth was orthogonally placed onto a wax support under a Wild Leitz stereomicroscope and observed at 3× to 50× magnification.

For transmission light microscopy of undecalcified sections the specimens were washed in saline solution and immediately fixed in 10% buffered formalin to be processed for histology. The specimens were processed to obtain thin ground sections with the Precise 1 Automated System (Asling). The specimens were dehydrated in an ascending series of alcohol rinses and embedded in a glycolmethacrylate resin (Technovit 7200 VLC, Kulzer). After polymerization the specimens were sectioned with a high-precision diamond disk at about 150 μm and ground down to about 30 μm. The slides were stained with basic fuchsin and toluidine blue, and observed under normal and polarized light with a Leitz Laborlux microscope.

Electron-microscopic analysis was performed with a Cambridge 360 scanning electron microscope (SEM). After initial preparation each tooth was placed in a 2.5% glutaraldehyde 0.01 mol/L buffered solution for 2 to 4 hours. Teeth were stored in a cacodylate buffer at 4°C until metallization. The samples were then air dried, mounted on aluminum SEM stubs, and sputter coated with gold to a thickness of 10 nm in a Hummer V sputter coater. The samples were then examined at 300 Kv. Photomicrographs of the furcal root were taken at magnifications of 10× to 5000× with Polaroid B/W Type 55 4 × 5 inch P/N film.
Results

Morphometric analysis

Results obtained in the present study are shown in Tables 1 and 2. Table 1 summarizes the mean values of characteristic measures from sample teeth. As already observed,27 in both maxillary and mandibular molars the IRA width decreases from the first to the second molar; this reduction appears to be more pronounced in maxillary molars. Consequently, the width of the FRA is wider in first molars from both dental arches. First molars present longer roots and shorter radicular trunks than second molars. Mesiodistal diameter and BLD are greater in first molars.

Table 2 shows Pearson’s correlation coefficients obtained by the analysis of anatomic measures. A positive correlation for each molar was observed between the FRA and the width of the IRA. The correlation between the BLD and the mean IRA of mesial and distal furcations in both maxillary molars also appeared to be significantly positive; similarly, a certain degree of inverse correlation was evidenced between the IRA and the RTL in the maxillary first molar. All other anatomic measures appeared not to be positively correlated to one another.

Morphologic analysis

Stereo-microscopic examination showed the extreme complexity of the furcal roof surfaces in each tooth observed. In 40% of the mandibular molars observed, furcal ridges were seen in the middle third of the furcal roof (Fig 1), whereas in maxillary molars these ridges were less frequently detected. In 20% of the maxillary molars, furcal ridges tended to converge toward the center of the furcal roof along the inner surface of buccal roots, making it possible to observe concave surfaces between mesial and distal buccal roots (Fig 2). In mandibular molars similar concavities were most frequently observed at each side of the furcal ridge (Fig 1); inside these areas narrow and irregularly shaped dimples were present. This very irregular surface was evidenced in the furcal roof of maxillary and mandibular (Fig 3) molars even when a furcal ridge was not recognizable.
### Table 1 Mean values of anatomic measures

<table>
<thead>
<tr>
<th>Measure</th>
<th>Maxillary first molar</th>
<th>Maxillary second molar</th>
<th>Mandibular first molar</th>
<th>Mandibular second molar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inter-radicular angle (degrees)</td>
<td>20.3</td>
<td>15.3</td>
<td>18.2</td>
<td>11.3</td>
</tr>
<tr>
<td>Root trunk length (mm)</td>
<td>3.8</td>
<td>4.4</td>
<td>3.3</td>
<td>4.5</td>
</tr>
<tr>
<td>Root length (mm)</td>
<td>12.8</td>
<td>13.1</td>
<td>13.6</td>
<td>12.3</td>
</tr>
<tr>
<td>Mesiodistal diameter (mm)</td>
<td>9.5</td>
<td>9.1</td>
<td>10.3</td>
<td>10.3</td>
</tr>
<tr>
<td>Buccolingual diameter (mm)</td>
<td>11.1</td>
<td>10.9</td>
<td>9.7</td>
<td>9.1</td>
</tr>
<tr>
<td>Furcal root area (mm²)</td>
<td>60.5</td>
<td>51.1</td>
<td>53.1</td>
<td>42.0</td>
</tr>
</tbody>
</table>

### Table 2 Pearson's correlation coefficients (r) calculated between anatomic measures

<table>
<thead>
<tr>
<th>Correlation</th>
<th>Maxillary first molar</th>
<th>Maxillary second molar</th>
<th>Mandibular first molar</th>
<th>Mandibular second molar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radicular angle/roots length</td>
<td>-0.46</td>
<td>-0.23</td>
<td>-0.13</td>
<td>-0.30</td>
</tr>
<tr>
<td>Radicular angle/roots length</td>
<td>0.17</td>
<td>-0.16</td>
<td>0.15</td>
<td>0.13</td>
</tr>
<tr>
<td>Roots length/roots length</td>
<td>0.06</td>
<td>-0.16</td>
<td>-0.09</td>
<td>-0.01</td>
</tr>
<tr>
<td>Mesiodistal diameter/roots angle</td>
<td>0.07</td>
<td>-0.07</td>
<td>-0.12</td>
<td>0.13</td>
</tr>
<tr>
<td>Buccolingual diameter/mean mesial and distal roots angle</td>
<td>0.54</td>
<td>0.43</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Furcal roof area/roots angle</td>
<td>0.88</td>
<td>0.74</td>
<td>0.69</td>
<td>0.43</td>
</tr>
<tr>
<td>Furcal roof area/roots length</td>
<td>-0.13</td>
<td>-0.13</td>
<td>-0.26</td>
<td>-0.30</td>
</tr>
</tbody>
</table>

*P < 0.05 was considered significant.*
Cross-sectional undecalcified sections of mandibular molars that were obtained as close as possible to the furcal root confirmed the presence of a furcal ridge and showed that it was composed of cementum (Fig 4). More apical sections showed concave surfaces in the furcal sides of mesial and distal roots; cementum layers that formed on top of one another led to a reduction of the degree of concavity (Fig 5).

In maxillary molars, transverse sections showed furcal ridges joining buccal roots, most frequently in second molars (Fig...
In many sections the presence of calculus was evidenced in concave surfaces adjacent to furcal ridges (Fig 6). More apical sections showed the different degrees of molar root divergence in first and second molars (Fig 7). The concave aspect of the furcal side of the mesiobuccal root in the first molar had a typical appearance (9 out of 10 teeth), whereas the second molar more frequently showed a flat or convex surface (7 out of 10 teeth) (Fig 7). The irregularity of the furcal roots was clearly shown by sagittal bucconlingual sections, which presented a considerable variety of depressions, holes, and dimples that were good retention places for plaque and calculus (Fig 8). Another possible retention factor for plaque and calculus was represented by second maxillary and mandibular molars by the proximity that was sometimes observable between the roots and that could be extreme in some cases (Fig 9).

Scanning electron microscopic examination confirmed the observations obtained by the methods described above, and also showed the presence of a large number of small holes widely distributed on the entire furcal root area (Fig 10). These holes represented the external orifices of accessory pulp canals (furcation canals) connecting the pulp chamber to the periodontal inter-radicular tissues. The number of furcal canals on the furcal root varied from 2 to 18 in maxillary molars and from 2 to 15 in mandibular molars. The diameter of their external orifices ranged from 6 to 650 μm (Fig 10). More frequently in maxillary molars, pulp canal orifices converged into larger depressions, which contributed to the largely uneven appearance of the furcal root (Fig 11). In the 30 teeth analyzed neither enamel projections nor enamel pearls were detected.
Discussion

The results obtained in the present study agree with those from other investigations. Morphometric analysis confirmed some already known anatomic characteristics of molars. It showed that, with the exception of the correlations between FRA and IRA and between BLD and IRA of mesial and distal furcations in both maxillary molars, and between IRA and RTL in the maxillary first molar, the correlations between the anatomic measures considered in the present study had very low or no significance. The present analysis of 414 teeth allows the conclusion that tooth size gives very little indication of internal furcal morphology, according to Bowes. The therapeutic outcome of periodontal treatment in furcally involved multi-rooted teeth has usually been considered unsatisfactory. The reason for this limited success has been ascribed to the difficult access for therapeutic instruments in the furcation area, both in surgical and nonsurgical treatments. Many studies have demonstrated that in an important percentage of cases the width of the furcal entrance is insufficient to allow proper accessibility of curettes and ultrasonic scalers. Percentages ranging from 49% to 85% (maxillary molars) and from 44% to 58% (mandibular molars) of furcation entrances in first molars have been demonstrated to be smaller than the mean dimensions of a Gracey curette at the tip of the blade (0.75 mm). Few studies took into consideration the furcal characteristics of the second molar. Hou et al. found, in both maxillary and mandibular molars, smaller entrance diameters of the furcation areas than those found in first molars, with 83% and 82% of maxillary and mandibular second molars, respectively, exhibiting a mean furcal entrance diameter ≤ 1 mm. This result was confirmed by the present study; as shown in Table 1, the width of the IRA decreases from the first to the second molar in both dental arches. With regard to second molars, the present study also evidenced an increase in the RTL compared to first molars. The clinical consequence of this anatomic feature is increased difficulty of periodontal instrumentation of the furcal area that is located in a more apical position during nonsurgical therapy. Although the existence of a long radicular trunk can delay the involvement of the furcal region in periodontal disease, a long radicular trunk also renders furcal areas much more difficult to clean. This hypothesis was confirmed by the clinical study of Wood et al., who reviewed for tooth loss 63 patients attending a dental school clinic for supportive periodontal...
treatment for a mean period of 15.6 years. Maxillary and mandibular second molars represented the teeth most frequently lost to periodontal disease, the only exception being third molars. In absolute terms the maxillary second molar appeared to have the poorest prognosis.

If the limited access to the furcal area plays an important role in conditioning the unsatisfactory outcome of periodontal treatment in furcally involved multi-rooted teeth, a second important factor is the furcal aspect of the root shape. Concavities of the internal aspects of both roots in mandibular molars, and particularly of the mesiobuccal root of maxillary molars, have been evidenced in many studies, and confirmed by the present work. Different therapeutic instruments have been proposed to clean these areas but, at present, none have demonstrated a completely successful outcome. As already shown by Bower, in the undecalcified sections in the present study a decrease in the degree of concavity in the furcal aspect of the molar root has been evidenced because of the subsequent deposition of cementum (Fig 5). No study has been published demonstrating a direct relationship between aging and the reduction of the depth of concavity in the furcal sides of the molar root; however, if cementum deposition is continuous and cementum thickness increases with age, it is possible to hypothesize that, in the elderly patient, concavities of the roots could have a reduced role in hampering proper debridement of the root furcation.

The complex morphology of the furcal roof is a third limiting factor in achieving complete cleaning of the furcal area; this important aspect has been rarely outlined in previous studies. The present material clearly shows that even in the absence of macroscopic structures, i.e. furcal ridges, the furcal roof cannot be regarded as a flat surface, or as a surface that can be completely flattened in clinical conditions, in every case the furcal roof showed an uneven surface characterized by a large number of narrow and irregularly shaped dimples, holes, and crevices. Subgingival calculus can be retained in such structures, and the tactile sensitivity of the clinician with a sharp explorer can be inadequate to detect residual calculus, particularly on surfaces with irregularities and difficult access. Comparing the efficacy of five machining instruments in scaling of molar furcations, Takacs et al. concluded that the furcal roof represents the most difficult part of the furcal area to clean. Scanning electron microscopic examination showed the presence of accessory pulp canal orifices widely distributed on the
entire area of the furcal roof. From the histologic studies by Barrett to the observations carried out in the 1960s, many studies have already demonstrated a high incidence of accessory canals in the furcation areas of molars. More recently, Koenigs et al observed, by SEM analysis, numerous foramina in the furcation surfaces of eight mandibular and seven maxillary molars. Burch and Hulen studied the furcation surfaces of 195 molars with a dissecting microscope and found nutrient openings in 76% of all molars studied. However, only a limited number of canals with an orifice on the furcal roof really establish a communication between the pulp chamber and the furcal area; the number of orifices observed on the pulp chamber floor is largely lower than the number of orifices present on the furcal roof. Perlitz et al, studying the pulp chamber floors and furcal roofs of 62 human molars, found accessory foramina in the pulp side of 5 out of 62 specimens and accessory foramina on the furcal side in 40 out of 62 sample teeth. A certain number of these accessory canals are probably obliterated as a consequence of chronic pulp stimulation caused by pulpal and/or periodontal disease. It has also been demonstrated that these furcation canals establish a direct relationship between periodontal disease and pulpal disease. Even when a complete connection between pulp and periodontium does not exist because of furcal canal obliteration, the orifices located on the furcal roof can cause periodontal damage in the furcally involved molar, which is a plaque retentive site. In the present study, the authors frequently observed furcal canal orifices coming out into larger depressions, representing ideal places for the retention of subgingival plaque and calculus even if mechanical therapeutic instruments could gain access to the furcal roof. Taking into consideration that the capability of subgingival bacterial plaque to invade dentinal tubules has been demonstrated in periodontally involved teeth, it is possible that accessory pulp canals, which are largely wider than dentinal tubules, could represent a favorable niche for rapid bacterial recolonization after therapeutic intervention. This situation could be one explanation for the less favorable results offered by guided tissue regeneration procedures in the treatment of furcally involved teeth compared to intraosseous periodontal defects.

The morphologic images presented here, in addition to the results offered by a number of studies that have shown the difficulties in achieving complete calculus removal from periodontally involved radicular...
furcations even with surgical access, could suggest that furcation odontoplasty, root separation, and root amputation may represent a more reliable means of obtaining deep debridement of furcations that cannot otherwise be properly instrumented. This does not agree with findings from longitudinal clinical studies on the retention of teeth with furcation involvement, which have shown that such teeth may be treated conservatively and retained in function for prolonged periods. In particular, Ross and Thompson monitored 387 furcally involved molars for 5 to 25 years, and observed that only 12% were lost to periodontal disease, and of the teeth lost, 33% were in function for more than 10 years. Total calculus removal is not usually obtained in furcation defects, but the complete removal of subgingival calculus is considered essential for successful periodontal treatment. Some studies indicate that total calculus cleaning or extreme root planing are not necessary to re-establish a biologically acceptable root surface. Fujikawa et al. reported that gingival health can be maintained in the presence of limited amounts of residual calculus. It has been observed in a clinical investigation that the clinical responses 3 months after scaling and root planing were not highly correlated to the small amounts of calculus remaining on root surfaces. The existence of an effective immunologic response in the host probably makes even an incompletely clean radicular surface biologically acceptable.

This study confirms the complex architecture of the furcal area in molar teeth, emphasizing that the limited accessibility to the root furcation represents only one of the obstacles the clinician may face; other obstacles are represented by the inner root shape and by the large morphologic irregularities of the furcal roof, which is an ideal plaque-retentive surface.

Acknowledgment

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