Title
Mandibular Molar Access: Outline Form, Orifice Relocation and resulting Canal Curvatures According to Specific Root Canal System Landmarks using Micro-CT

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Abstract

Objectives: By visualizing an appropriate access form before treatment is initiated, root canal treatment may be accomplished more predictably and with reduced risks. The aim of this study was to determine (by non-destructive means) using micro-CT the influence of anatomic root canal system landmarks on access outline forms of mandibular molars and correlate these to the theoretical distance of orifice relocation and changes in canal angle of curvature (AOC).

Methods: Thirty relatively calcified human mandibular molars were selected and examined by micro-CT. Three-dimensional volume reconstructions were made, root canal system landmarks identified and plotted: canal orifices, canal position at the furcation level and pulp horn location. By visualizing these landmarks separately onto the occlusal surface, three access designs were proposed for each mandibular molar specimen based on each anatomic landmark respectively: 1) minimally invasive, 2) straight-line furcation and 3) straight-line radicular. For each access design, the theoretical distance of orifice relocation, AOC and changes in root canal AOC were determined using the VG Studio Max and the Image J software. Data were submitted to a two-way repeated-measures ANOVA and Tukey test (α<0.05).

Results: The AOC for each access outline type was statistically different from each other (p<0.0001), whereas the minimally invasive access showed the highest mean angle (40.1° ± 8.4) followed by the straight-line furcation (30.7° ± 7.5) and the straight-line radicular access (24.2° ± 8.4). The orifice relocation distance required to obtain each type of access outline was greater for the radicular-based access (0.97mm ± 0.32) than for furcation access (0.52mm ± 0.30; p<0.001) and resulted in greater change in AOC (p<0.001; 15.9° ± 4.6; 9.4° ± 4.3, respectively). There was a direct correlation of the amount of orifice relocation to the resulting change in canal AOC (p < 0.0001). The amount of orifice relocation required for the straight-line radicular access form was greater for the ML canal than for the MB canal (1.06mm vs. 0.88mm, p = 0.003). This correlated to significantly more change in AOC resulting in the ML canal than the MB canal (17.2° vs. 14.7°, p = 0.008).

Conclusion: Orifice relocation and changes in canal curvature should be taken into consideration when choosing an anatomically based access design.
Keywords: endodontic, access, orifice relocation, straight-line access, radicular access, minimal invasive access, microCT
Introduction

Previous examination of the root canal systems in mandibular molars has been performed to determine the prevalence and mean angle of curvature (AOC) of curvatures in the radiographic clinical and proximal views (1, 2). Primary, or first negotiated curvature, secondary and apical patency canal curvatures have been described. The primary canal curvature is described as the first curvature to be encountered while negotiating down the canal. Both studies found that the clinical view AOC for the MB canal could exceed 30°, which according to the AAE Case Difficulty Assessment Form (2006) identifies cases of high difficulty. Cunningham and Senia (1992) further showed that coronal flaring significantly reduced the primary curvatures in both the clinic and proximal views, however secondary curvatures remained unaltered. This gives support to the view that mid-root transportation is strongly affected by primary canal curvature (3), that canal curvature is decreased by altering the entry angle for the instrument (4), and that the ability to alter the entry angle is dependent on the coronal access form. Additionally, in a subset of relatively calcified mandibular molars, the mean AOC of primary clinical view canal curvatures has been correlated to variables that can be applied to case difficulty assessment (2).

The relationship of the pulp chamber to the crown in mandibular molars was previously examined using a sectioning technique (5). The pulp chamber was consistently located in the center of the tooth at the level of the cementoenamel junction, being equidistant to the external surface of the tooth. Because the walls of the chamber have the same relative thickness circumferentially, this suggests that reactionary, secondary and age-related decreases of the pulp chamber space occur by peripheral dentin deposition. Subsequently, peripheral dentin deposition will likely move the canal orifices to a more central location over the furcation. A change in the previously accepted outline form may be warranted due to the anatomic changes of the chamber that normally occur.

Multiple authors have studied methods for aiding canal preparation and minimizing iatrogenic outcomes in mandibular molars (6, 7). This has been demonstrated by elimination
of cervical dentin that forms a lip over the canal entrance and by orifice relocation to create access to the level of primary curvature.

Another investigation of outline access forms was based solely on the orifice location (8). Molar teeth were decoronated at the level of the pulpal floor with the orifices being projected onto schematic diagrams for first and second mandibular molars. The canal orifices were found located in a consistent pattern on the chamber floor relative to the occlusal surface, resulting in a centered yet somewhat constricted access design. A comparable view of conservative access design has been recently reintroduced (9). Clark and Khademi (2010) state that incomplete removal of the pulp chamber roof, along with preservation of pericervical dentin (PCD, dentin ±4mm to alveolar crest), should be considered key to the restorative success of the tooth. Understanding competing access form philosophies will aid the clinician in choosing appropriate methodology and identify techniques that can be used to reduce risks and improve outcomes when performing root canal therapy.

Microcomputed tomography (micro-CT) technologies have emerged to explore the internal anatomy of the root canal system in fine detail (10, 11). Whereas sectioning of the tooth causes irreversible alterations to the crown and chamber, micro-CT permits non-destructive three-dimensional analysis of root canal morphology.

No prior micro-CT studies have evaluated the interrelationships between the internal shape of the pulp chamber, orifice locations and other root canal system landmarks as they may be related to differing access designs. The aim of this study was to plot three root canal system landmarks and apply them in the design of access cavity outlines for mandibular molars. The secondary aim was to determine the linear measurement of dentin removal required to relocate the orifice for each anatomically based access outline form and the subsequent change on the canal primary AOC for each access design. A third aim was to correlate the difficulty of the case to the amount of orifice modification and resulting changes in AOC required for an anatomically based access.
Materials and methods

Selection Criteria

Human mandibular first and second molars with fully formed apices and minimally restored or intact crowns were obtained from a bank of teeth and screened in clinical and proximal radiographic views (expert DC, Gendex, Hatfield, Pa.). Thirty teeth were selected based on the following inclusion criteria for chamber and root canal anatomy: radiographic pulp chamber height < 2 mm, root length between 19-21 mm, and having a single anatomic apex.

Teeth were then classified based on the case difficulty assessment classification for the clinical estimate of curvature proposed by Clement et. al. (submitted for publication). Using a clinical view x-ray, a straight line was drawn from the orifice to the apex. If this line stayed within the confines of the mesial root, a designation ‘In’ was given, indicating < 30° mean primary canal AOC and moderate difficulty (Figure 1A). When this line was traversed to the furcation side of the mesial root, an ‘Out’ designation was given. The ‘Out’ designation represented teeth of high difficulty based on an AOC > 30° degree Clement et. al. (2) (Figure 1). Of the 30 selected teeth, 15 were classified as moderate and 15 teeth as high difficulty.

Micro-CT Visualization and Measurement

Each specimen was mounted and scanned using SkyScan 1172 micro-CT (Brucker Corp, SkyScan 1172, Kontich, Belgium) at 75 kV and 100 µA through 180° of rotation around the vertical axis and a single rotation step of 0.9° during a 15-minute scan with a source to object distance of 300 mm and a cross-sectional pixel size of approximately 30 µm. Each slice was a 16- bit addressable 1,024 X 1,024 area that was used to create a 1-K 3-dimensional image volume-rendered representation (VG Studio Max 2.2; Volume Graphics GmbH, Heidelberg, Germany). Spherical markers of 0.20 mm³ were placed within each root canal system to identify the positions of specific anatomic landmarks: center of primary curve in the maximum curvature view (12), the center of each canal at the orifice and furcation levels, and the pulp horns (Figure 2).
Access Forms Visualization

Semi-transparent axial view micro-CT images were used to visualize and project each landmark through the occlusal surface of the crown and a screen shot was taken. The images obtained for all specimens for the separate landmarks were overlaid and aligned onto a separate ideal template of the occlusal surface of a mandibular molar crown (Figure 3).

Three types of access outline forms were created:
1. Minimally invasive: based on the location of the orifices on the chamber floor.
2. Straight-line furcation: based on the position of the canals at the furcation level.

Access-Determined Orifice Relocation

For the MB and ML canals, a line was drawn from the height of curvature in the maximum curvature view through the furcation level landmark extending to the occlusal surface. This allowed determination of the amount of selective dentin removal required for straight-line furcation access (Figure 4a). The amount of selective dentin removal needed to obtain straight-line radicular access was determined by drawing a line from the height of maximum curvature to the corresponding pulp horn landmark (Figure 4b). The caliper tool was then applied to measure the 3-dimensional distance from the center of the corresponding orifice to each constructed line (Figure 4c). Minimal access was used as baseline and did not undergo theoretical orifice relocation.

Access-Determined Angle of Curvature

Separate screenshots of the 3-dimensional images were taken for each specimen displaying the maximum view curvature for MB and ML canals. Images were imported into ImageJ software (1.45S, NIH) for AOC measurement. The AOC before and after orifice relocation was determined (13) for minimal access, straight-line furcation and straight-line radicular access designs (Figure 5).
Statistical Analysis

Statistical analysis was performed by one-way ANOVA and Tukey test for the primary angles determined by each access outline design and by a two-way repeated measures ANOVA (two factor repetition) was performed for the interactions between access form (furcation and radicular), the canal location (MB, ML) and case difficulty (clinical estimate of curvature) for the theoretical amount of orifice relocation and the resulting change in AOC. The statistical significance was set to $\alpha < 0.05$. 
Results

The resulting access forms (minimally invasive, straight-line furcation, and straight-line radicular) are shown in (Figure 6). The mean maximum primary angles for mesial canals were significantly different (p < 0.001) for each access form; the minimally invasive access (40.1º ± 8.4) being greater than the furcation access (30.7º ± 7.5) being greater than radicular access (24.2º ± 8.4).

When the minimally invasive access form was used as the baseline representing zero orifice relocation and no change in AOC, within the straight-line furcation and radicular access forms there was a direct correlation of the amount of orifice relocation to the resulting change in canal AOC (p < 0.0001).

The orifice relocation mean distance required to obtain each type of access outline was greater for radicular-based accesses (0.97 mm ± 0.32) than for furcation accesses (0.52 mm ± 0.30; p<0.001). In turn the change in AOC for the access forms were significantly different between the access forms (p<0.001; 15.9º ± 4.6; 9.4º ± 4.3, respectively). The significant difference between the furcation and radicular access forms for the amount of orifice relocation required and resulting AOC carried through in all of the comparisons related to the MB vs. ML canals and the case difficulty assessment.

The amount of orifice relocation and the change in AOC for the access forms were significantly different between the MB and ML canals (p<0.001). The amount of orifice relocation required for the straight-line radicular access form was greater for the ML canal than for the MB canal (1.06mm ± 0.34 vs. 0.88mm ± 0.28, respectively; p = 0.003). This correlated to significantly more change in AOC resulting in the ML canal than the MB canal (17.2º ± 3.7 vs. 14.7º ± 5.2, p = 0.008). The amount of orifice relocation required for the straight-line furcation access was not different between the MB and ML canals (p = 0.801),
however the resultant changes in canal curvature was greater in the MB than the ML canal
(10.4° ± 4.3 vs. 8.5° ± 4.3, p = 0.044).

The correlation between the difficulty of the case and the amount of orifice
modification and resulting changes in AOC always showed a difference between the furcation
access and the radicular access design (P < 0.001). However, within the groups a significance
difference in the amount of orifice relocation was only found for the straight-line radicular
access form (P = 0.012). Indicating that more orifice relocation was required when the case
was considered extremely difficult for the radicular access design as compared to a
moderately classified case. There were no differences in for the change in AOC within either
access design. Data is shown in Table 1.
Discussion

This study used non-destructive micro-CT methods to establish anatomically based mandibular access forms in relatively calcified teeth based upon three anatomic landmarks: orifice location, center of the canal at the level of the furcation, and the pulp horns. Using three anatomic positions instead of one, this study expanded on the work of Wilcox, Walton, and Case (8). The difference in suggested access designs based on the position of the canal orifices between the two studies is likely due to tooth selection. Our study evaluated only relatively calcified molars with a maximum chamber height of less than 2mm that corresponded to root canal curvature of moderate to severe. The Wilcox, Walton and Case study made no mention of chamber attributes.

The results of our study discussed the theoretical requirements of anatomically based access designs for relatively calcified mandibular molars. The minimally invasive access design is quite similar to those referenced in a recent study (14) as the smallest conservative access design based on cone-beam computer tomography (CBCT) (Boveda C. Available at: http://www.carlosboveda.com/casosclinicos.htm). The presumption used was that a minimally invasive access required no orifice relocation, would preserve the maximum amount of PCD from the chamber wall, and the maximum canal angle of curvature would be unchanged. The straight-line furcation level access is a new term introduced to describe an occlusal access form that conforms in size to the position of the canals at the furcation level. The required orifice relocation to accomplish this was directional for the mesial canals, anticurvature into the corresponding line angles. Straight-line radicular access form, introduced by Goerig, Michelich, and Schultz (7), is based on the position of the pulp horns. Dentin is removed during coronal and radicular access to provide a straight-line path to apical third of canal. One
important difference in our study is that the straight-line radicular access form was based on a three-dimensional maximum canal curvature view rather than a two-dimensional illustration.

It must be understood that orifice relocation as determined in this study is a theoretical distance that occurred anticurvature into the direction of the line angle. This measurement cannot be equated to orifice opening. Orifice relocation implicitly implies that the center of the orifice has been moved to a new position. Orifice opening suggests that the orifice has been enlarged in its original position, circumferentially and equally on all walls. The danger is that unselective dentin removal would result in thinning of the radicular dentin.

One’s philosophy toward access design likely needs to be consistent with one’s philosophy to cleaning, shaping and obturation of the root canal system. The selective removal of dentin has previously been suggested as a method to ease the difficulty of root canal instrumentation in curved canals, to reduce the risks of iatrogenic transportation errors, and to facilitate the placement of gutta percha during obturation (6). However, it has been suggested that excessive removal of cervical dentin may lead to structural compromise and eventual restorative failure (9). Differing philosophies may be conceptualized for the coronal access based on anatomic landmarks. The distance of orifice relocation and the degree of reduction in canal curvature may then be theoretically quantified.

In the presence of these differing philosophies, this study suggests that an anatomically based access design should be a multifactorial decision that should not be based solely on one objective. This study showed that in relatively calcified molars a decrease in AOC is a direct correlation to the amount selective dentin removal needed for each orifice relocation philosophy. Factors such as entry angles for instrument insertion, finding and negotiating all canals, cyclic fatigue breakage, needle depth for irrigant delivery, irrigation dynamics, and most certainly the skill of the practitioner should be considered. The clinician
therefore needs to assess the risks and benefits of orifice relocation and reduction in canal curvature when choosing an anatomical based access design, and that the concepts should be applied on an individual tooth basis.

In this study, significant differences in canal curvature were found between the MB and ML canals when applying concepts for straight-line furcation level and straight-line radicular access forms. For the straight-line radicular access the ML canal required a greater amount of selective dentin removal and consequently, there was a greater resulting decrease in canal curvature for the ML canal (17.2° ± 3.7 vs. 14.7° ± 5.2, p = 0.008). For the straight-line furcation level access form there was no difference in the amount of orifice relocation between the MB and ML canals, but the resulting change in angle of curvature was greater for the MB than the ML canal (10.4° ± 4.3 vs. 8.5° ± 4.3, p = 0.044). These findings appear inconsistent, but again emphasize the correlation between orifice relocation and the potential for lessening the AOC. The MB canal has previously been shown to have a greater mean clinical view angle of curvature than the ML canal (2). This study does not dispute the differences in the original curvature between canals. However, it shows that the ML canal may have a more significant decrease in angle of curvature with an anatomically based straight-line radicular access modification. Perhaps this is because the ML pulp horn is simply located at a further lateral position relative to the corresponding canal orifice than was the MB pulp horn.

The ‘In/Out’ line in this study differentiated case difficulty based on anticipated clinical view AOC and showed a significant difference in the amount of orifice relocation being greater for the severe curvature ‘Out’ designation only in the straight-line radicular access form. There were no differences in the degree of curvature reduction related to this variable. The ‘In/Out’ line is a measure of difficulty from the clinical view AOC (2). In that
study, the ‘In’ primary CV angles had a mean 27.3° and the ‘Out’ primary CV angles were
significantly greater having a mean 43.2°; a difference of 15.9°. The actual AOC measured in
this study was the maximum view AOC, which had a study mean of 40.1°.

The subgroup of teeth pre-selected for this study had reduced chambers with a mean height of
1.1mm ± 0.5. To more appropriately understand the concept of anatomically based outline
forms, one should have a group of mandibular molars that represent an uncomplicated
treatment group with easily visible chamber and no chamber recession. One would expect
access design based on theoretical orifice positions to vary and expand in size. It is quite
possible that without the calcific relocation of anatomic landmarks, in young or immature age
groups of teeth, the canal orifices, location of the canal are the curvature level, and pulp horns
would closely align. Subsequently, the anatomic based access would coalesce to a single
access design. It is likely that the variations in anatomically based access forms and the need
for orifice relocation should be reserved for teeth with calcified reduced chambers and for
practitioners who recognize and accept the risks of unaltered angles of curvature.
Conclusion

Understanding the risks and benefits between competing accesses philosophies can aid the clinician in choosing appropriate an outline design based on morphology. The degree of curvature of canals and the calcification of the pulp chamber should always be assessed before initiating root canal treatment. Orifice relocation and changes in canal curvature could then be taken into consideration when choosing an anatomically based access design for a moderately calcified and moderately to severely curved mandibular molars.
Figure legends

Figure 1. Orifice to Apex Line for Case Difficulty Assessment. Clinical view radiograph of two mandibular molar specimens showing a constructed overlying orifice to apex line within the mesial root of each specimen, demonstrating case difficulty assessment methods for ‘In’ and ‘Out’ designated curvature as outlined by Clement et al (submitted for publication).

‘IN’ Designation

‘OUT’ Designation
Figure 2. Visualization of a 3-dimensional volume rendered from a Micro-CT scanned sample showing a semi-transparent tooth with accompanying canals which contain 0.20mm$^3$ constructed spherical volumes located and labeled at the location of each pulp horn, canal orifice, and corresponding center of the canal at the furcation and height of primary curvature. Colored dots represent different canals: (Yellow) MB, (Green) ML, and (Red) D. The specimen’s corresponding clinical view radiograph taken during experimental screening accompanies the 3-D rendering.
Figure 3. Landmarks Superimposed onto the Occlusal Surface. Template of the occlusal surface of an ideal mandibular molar crown displaying the projection of each separate landmark onto the occlusal surface: (A) Orifice location on the chamber floor; (B) Canal position at furcation level; (C) Pulp horns. Colored dots represent different canals: (Yellow) MB, (Green) ML, and (Red) D.
Figure 4a. Straight-Line Furcation Maximum View Curvatures. Two images are displayed of the same 3-dimensionally rendered sample from two different views demonstrating height of curvature in each the ML and MB canal. Only the pulp space is visible with accompanying 0.20mm$^3$ spherical volumes located at specific anatomic landmarks within each canal: pulp horns, orifices, center of the canals at the furcation level, and center of the canals at the height of primary curvature. On each image (MB and ML), a line has been drawn from the spherical landmark at the height of curvature that trespasses through the spherical landmark at the corresponding level of the furcation and extends to the occlusal surface level. This line indicates visualized straight-line furcation access.

**MB**

**ML**

Straight-Line Furcation Access Line
Drawn from the center of the primary curvature through the furcation level marker
Figure 4b. Straight-Line Radicular Maximum View Curvatures. Two images are displayed of the same 3-dimensionally rendered sample from two different views demonstrating height of curvature in each the ML and MB canals. Only the pulp space is visible with accompanying 0.20mm³ spherical volumes located at specific anatomic landmarks within each canal: pulp horns, orifices, center of the canals at the furcation level, and center of the canals at the height of primary curvature. On each image (MB and ML), a line has been drawn from the spherical landmark at the height of curvature that trespasses through the spherical landmark identifying the corresponding pulp horn and extends to the occlusal surface level. This line indicates visualized straight-line radicular access.

Straight-Line Radicular Access Line
Drawn from the center of the primary curvature to the corresponding pulp horn marker
Figure 4c. Horizontal Measurements of Orifice Movement. Sagittal and axial micro-CT slices are displayed showing a calibrated caliper measurement (red line) extending from the canal orifice (yellow circle) to a line that extends from the height of primary curvature to the pulp horn, or straight-line radicular access (green line). The caliper measurement is labeled:
Caliper 3: 1.28mm.
Figure 5. Angle of Curvature for Access Variation. A fully rendered volume of a single semi-transparent micro-CT scanned specimen is shown three times from maximum clinical primary angle of curvature for the ML canal. Within the ML canal, the angle of curvature is visualized (blue line) for each theoretical curvature based on anatomical landmarks: (A. Minimally Invasive) Height of curvature through the orifice, (B. Straight-Line Furcation) height of curvature through the center of the canal at the furcation, and (C. Straight-Line Radicular) height of curvature through the corresponding pulp horn.
Figure 6. Anatomically Determined Access Forms. Three semi-transparent axial view micro-CT images of the occlusal surface of an ideal mandibular molar crown is shown. The location of each anatomic landmark from each canal (MB, ML, D) for all the samples (n=30) is projected onto the occlusal surface of the corresponding ideal crown image: (A) plotted orifices, minimally invasive; (B) plotted center of the canals at the furcation level, straight-line furcation; and (C) plotted pulp horns, straight-line radicular. Varying access forms (blue trapezoid) are then displayed for each image: A, B, and C.
Table 1 - Correlation between the case difficulty classification and amount of orifice modification and resulting changes in AOC for each access design.

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<tr>
<th>Orifice relocation</th>
<th>Furcation access</th>
<th>Radicular access</th>
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<tbody>
<tr>
<td>Moderate curvature</td>
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<td>0.87mm ± 0.30b*</td>
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<tr>
<td>Severe curvature</td>
<td>0.60mm ± 0.33a</td>
<td>1.07mm ± 0.31b*</td>
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<tr>
<td>AOC</td>
<td></td>
<td></td>
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<tr>
<td>Moderate curvature</td>
<td>8.5° ± 3.8a</td>
<td>15.5° ± 4.9b</td>
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<tr>
<td>Severe curvature</td>
<td>10.4° ± 4.7a</td>
<td>16.4° ± 4.4b</td>
</tr>
</tbody>
</table>
References


2. Clement DJ, Khajotia SS, Marchesan MA, Lloyd A. Canal curvatures in the mesial root of mandibular molars: Determination of angle and radius of curvature and assessment of clinical difficulty. (Submitted for publication)


