Effect of access design on angle, radius and location of the primary canal curvature in Type IV mandibular molars

Investigators
J.D. McFarland, DDS¹
M.A. Marchesan, DDS MS PhD¹
A. Lloyd, BDS MS¹
D.J. Clement, DDS²

¹ Department of Endodontics, University of Tennessee Health Science Center, College of Dentistry
² The University of Oklahoma College of Dentistry
1201 N Stonewall Ave
Oklahoma City OK 73190

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Contact & address requests for reprints
Dr. Adam Lloyd
Department of Endodontics
University of Tennessee Health Science Center College of Dentistry
875 Union Ave
Memphis TN 38163

e-mail: alloyd@uthsc.edu
Tel: (901) 448-1793
Fax: (901) 448-1799
Abstract

Aims This study assessed the effect of access design on angle, radius, and location of primary canal curvature in mesial roots of Type IV mandibular molars at different phases of root canal preparation.

Methodology Twenty-four teeth were selected radiographically and via µCT and accessed with contracted (CEC; n = 12) or traditional endodontic cavity (TEC; n = 12) designs. Angle, radius, and location were determined at: pre-instrumentation (PI), glide path (GP) and after final instrumentation (FI). GP was established with #1 and #2 PathFiles. FI was performed to a 30.04 Profile Vortex. Irrigation was performed using 8.25% NaOCl and 17% EDTA. Time required for complete instrumentation was recorded. A standardized apparatus was used to reposition samples at each phase and a radiograph was taken in maximum curvature view. Changes in the angle, radius, and location were measured with ImageJ. Data was analysed with two-way repeated-measures ANOVA (α < 0.05) and Tukey HSD tests. Results The mean angle decreased at the different phases (P < 0.001) for both CEC (PI: 42.57 ± 8.00; GP: 36.27 ± 4.50; FI: 32.61 ± 5.17) and TEC (PI: 38.80 ± 7.15; GP: 33.76 ± 7.83; FI: 30.08 ± 6.99). Curvature location moved apically at GP and FI (P < 0.001). The changes in angle and location were greater from PI to GP than GP to FI (P < 0.0001). The radius of curvature increased at GP and FI (P < 0.0001). Time required for root canal instrumentation in the CEC group (83.17 ± 6.71 min) was significantly longer than for the TEC group (33.18 ± 9.20 min; P < 0.0001). Access design did not show a significant difference in the evaluated canal curvature parameters (P > 0.05). Conclusions The angle, radius, and location changed at glide path and after instrumentation independent of the access design for the type of teeth and instrumentation protocol used in this study. Instrumentation through CEC took 2.5 times longer than TEC designs.
Introduction

Following the trend of minimally invasive dentistry used in restorative treatments some researchers and clinicians have suggested contracted access outline forms that focus on dentine preservation and account for the endodontic-restorative interface (Clark & Khademi 2010a,b). This approach is suggested instead of traditionally larger shaped designs that are oriented towards a convenience form that facilitated endodontic procedures and minimized iatrogenic complications (Goerig et al. 1982, Peters & Koka 2008). These redesigned access shapes retain a thicker layer of pericervical dentine and suggest incomplete unroofing of the pulp chamber (Clark & Khademi 2010a,b) Pericervical dentine has been defined as an area of dentine 4 mm above and below the crestal bone. The compelling rationale to change is based on the assumption that the long-term retention of an endodontically treated tooth is directly related to the amount of residual tooth structure (Akkayan 2004, Goto et al. 2005).

A recent study evaluated the effect of contracted endodontic cavity (CEC) shapes on the resistance to fracture (Krishan et al. 2014). The authors found an increase in resistance fracture when CEC designs were used. Additionally, micro-computed tomography (µCT) revealed a compromise in root canal instrumentation in the distal canals of mandibular molars. The implications of minimal access designs on the behaviour of endodontic instruments during canal preparation have yet to be fully understood. Multiple factors are considered during mechanical instrumentation of the root canal. This includes, but is not limited to, anatomic configuration, instrument design and presence of irrigant in the canal during cleaning and shaping (Wildey et al. 1992). The anatomic configuration of a root canal may present a challenge even for an experienced clinician. Canal curvature may be observed radiographically only in a mesial to distal direction. This limitation provides misleading information relative to a curvature in the bucco-lingual plane. As canal curvature increases instrumentation becomes more challenging as there is a tendency for instruments to deviate from the canal path (Abou-Rass et al. 1980, Schäfer et al. 2003). Canal curvatures vary in severity and abruptness. The abruptness of curvature determines how the instrument will behave in the canal, as more abrupt curvatures increase the concentration of forces against dentine walls (Wildey et al. 1992). Canal
curvature parameters have been previously described in terms of angle and radius of curvature (Pruett et al. 1997). The authors demonstrated more abrupt curves correspond to a smaller radius. The location of the curve, measured as the centre of the primary canal curvature (PCC) from the apex, is also an important variable that may influence instrumentation.

The aim of the present study was to determine the effect of CEC compared to traditional endodontic cavity (TEC) design on the angle, radius, and location of PCC, in mesial roots of Type IV (Vertucci 1984) mandibular molars during different phases of canal preparation. Time required for complete instrumentation was recorded.

**Material and Methods**

Mandibular human molars obtained from a bank of teeth were evaluated in clinical and proximal oriented radiographic views subsequent to Institutional Review Board approval (#14-03591-XM). Twenty-four teeth were chosen according to the following inclusion criteria: minimally restored or intact crowns, radiographic pulp chamber height of < 2 mm, mesial canals with clinical view PCC greater than 30° according to the methodology proposed by Pruett, et al. (1997) and root length between 19-24 mm. In addition, the teeth were scanned with a μCT machine (ACTIS BIR 150/130, Varian Medical Systems, Palo Alto, CA, USA) to select molars with 2 distinct mesial canals and foramens. The images were acquired at 75 kV and 100 μA through 360° of rotation around the vertical axis resulting in a cross-sectional pixel size of approximately 30 μm. Each backscatter projection had a 16-bit addressable 1,024×1,024 area and was used to create a volume-rendered representation (VG Studio Max 2.3; Volume Graphics GmbH, Heidelberg, Germany). Images were used to help plan the access design.

Upon selection, the teeth were embedded in an epoxy resin (Stycast 1266, Henkel Electronic Materials, LLC Salisbury, NC, USA) to allow precise positioning on the radiographic and μCT stages. PCC parameters were only determined for the mesial-buccal (MB) and mesial-lingual (ML) canals. All endodontic procedures were performed by a single operator under a clinical microscope at ×10.9 magnification (OPMI Pico, Carl Zeiss Meditec Inc., Jena, Germany). Specimens were divided into 2
groups of 12 teeth according to the type of access design established: CEC or TEC. Access cavities were created with a #392 mosquito bur (Spring Health diamonds, St Louis Park, MN, USA) in a high-speed handpiece under water spray (Krishan et al. 2014). A new bur was used for each specimen. To avoid inadvertently entering the mesial buccal pulp horn with the bur, the mesial and buccal root bulges were identified on the buccal and proximal surfaces of the MB root. Lines were drawn parallel to the root long axis and extending in the occlusal direction. The intersection of the lines helped identify the approximate position of the MB pulp horn. Access was initiated immediately mesial to the central fossa and extended in the pulpal, distal and lingual directions maintaining portions of the pulp chamber roof and pulp horn dentin. Care was taken to avoid the marked area on the MB cuspal incline. All teeth were initially accessed with a CEC. A modified DG 16 was used to explore remaining pulp horns and remove calcified tissue. The access cavities of the teeth allocated to the TEC group (n = 12) were expanded with an LA Axxess bur and a BUC-1 ultrasonic tip (SybronEndo, Glendora, CA, USA) to obtain a traditional outline form. A side-vented 30-Ga. needle (ProRinse, Dentsply Tulsa Dental Specialties, Johnson City, TN, USA) was used to deliver copious irrigation of 8.25% sodium hypochlorite (NaOCl; Clorox Professional Products Company, Oakland, CA, USA) following access. Final access outlines are shown in Fig. 1.

Canals were negotiated with ISO #6 and #8 C-files up to a #10 K-file (Roydent Dental Products, Johnson City, TN, USA) until the tip was just visible at the apical foramen. The file was measured and 0.5 mm was subtracted from the total length. This measurement was considered working length (WL).

Specimens were inserted into a fixed mould on a radiographic Plexiglas apparatus (Iqbal et al. 2003). The angle, radius, and location of the PCC were determined at three phases of root canal preparation; pre-instrumentation (PI), glide path (GP), and after final instrumentation (FI). For PI, radiographs were taken with a #8 C-file to WL from a maximum angle of curvature view for the MB and ML canals (Iqbal et al. 2003). The stage was incrementally rotated until the file appeared straight on the radiograph. The maximum angle of curvature was then determined by rotating the stage 90° and capturing a radiograph. This position was recorded for the MB and ML canal of each specimen to allow repositioning at the established evaluation time points.
The GP was established with a #10 K-file followed by rotary PathFiles #1 and #2 (Dentsply Maillefer, Ballaigues, Switzerland). Number 10 K-files were separately placed into MB and ML canals at WL; specimens were replaced on the apparatus and an image was captured at the position previously determined.

Time elapsed for active canal instrumentation, instrument changes and irrigation was recorded for the mesial and distal canals and was considered total instrumentation time (min). Recording time was suspended during radiographic exposures. Instrumentation was performed in a crown-down manner with Profile Vortex instruments (Dentsply Tulsa Dental Specialties, Johnson City, OK, USA). A ProMark endodontic motor (Dentsply Tulsa Dental Specialties) was used to activate all rotary instruments. The specific torque and speed settings for each instrument were pre-programmed. Briefly, canals were prepared with a 30/.04 Profile Vortex rotary file. The file was taken to resistance or WL, whichever occurred first. If resistance was encountered before WL was attained, the next smaller instrument was used with the same protocol until WL was reached. The mesial canals were instrumented up to a size 30/.04. Distal canals were instrumented to a 40/.04 following the same technique.

Canals were irrigated with 2 mL of 8.25% sodium hypochlorite (NaOCl) between instruments (total 10 mL per canal) and a #10 K-file was used to recapitulate and maintain a glide path to the canal terminus. Final irrigation was performed with 5 mL of 17% EDTA (Roth International LTD., Chicago, IL, USA) for 3 min followed by 5 mL of 8.25% NaOCl. Canals were dried with paper points (Lexicon, Dentsply Tulsa Dental Specialties). Each specimen was repositioned on the radiographic stage and a final radiograph was taken (FI).

The radiographic images obtained for each phase during instrumentation were imported into PowerPoint (Microsoft Corp., Redmond, WA, USA) using methodology to draw lines to evaluate the angle and radius of the PCC previously described (Pruett et al. 1997). The images were then imported into ImageJ 1.41 software (National Institutes of Health, Bethesda, MD, USA) to calculate the angle (degree) and radius (mm) of the PCC, as well as the distance of the centre of the PCC to the apex (mm). Data was recorded. All curvature measurements were performed double blinded by a trained and calibrated evaluator.
**Data Analysis**

Statistical analysis was performed with SigmaPlot 13 (Systat Software Inc., Chicago, IL, USA). Measuring the same teeth at different phases of root canal preparation allowed the use of repeated measures statistical tests, thus increasing statistical power by controlling the variability in canal measurements between teeth. A two-way repeated measures analysis of variance was used to analyse the data obtained for each curvature parameter. Tukey’s HDS pairwise testing was used for post-hoc testing. The unpaired t-test was used to compare the data obtained for instrumentation time. The significance level was set to $\alpha < 0.05$.

**Results**

The angle of the PCC was significantly different at each phase evaluated (PI, GP, FI) in both access designs ($P < 0.001$) with the mean angle decreasing over time (Table 1). The curvature changed similarly over time for the MB or ML canals and for the CEC ($P = 0.225$) or TEC ($P = 0.156$) access designs.

The radius of curvature increased for both access designs at each of the three phases evaluated (PI, GP and FI; $P < 0.001$). MB and ML canals changed similarly over time regardless of the access design. The location of the PCC decreased at each phase evaluated for both access designs ($P < 0.001$; Fig. 2). Clinically this represents the curvature moving to a more apical location. No differences were found for the MB and ML canals for the CEC ($P = 0.178$) and TEC ($P = 0.104$) access designs. The two types of access designs (CEC and TEC) did not show any significant difference for the evaluated curvature parameters at any of the phases of treatment: PCC ($P = 0.110$), distance of the PCC to the apex ($P = 0.098$) and radius ($P = 0.530$).

Time required for root canal instrumentation in the CEC group (83.17 ± 6.71 min) was significantly longer than for the TEC group (33.18 ± 9.20 min; $P < 0.0001$).

Data obtained for the percentage of remaining obturation materials on the root canal surface and total retreatment time are shown in Table 1. Significantly more time was required for retreatment with the CEC-TS (27.68 ± 1.43 min) when compared with other groups ($P < 0.05$).
**Discussion**

It is important to understand the ramifications of changing the endodontic access design not only from a restorative perspective, that is concerned with the preservation of pericervical dentin, but also from an endodontic perspective that is focused on the preservation of the integrity of the root canal anatomy. This study quantitatively assessed the effect of CEC and TEC access designs on canal curvature parameters at different phases of instrumentation.

The teeth used in this study presented radiographic diminished pulp chamber height of < 2 mm, mesial root canals with clinical view PCC greater than 30°, and root length between 19-24 mm. This inclusion criterion represents typical challenges the practicing endodontist encounters. Accessing these teeth with CEC designs was challenging because of the confined space available to remove pulp stones and calcified tissue. A modified DG-16 explorer, Buc-1 ultrasonic tips, and copious irrigation were used to dislodge and remove calcifications from the restricted access. The time required to access, identify canal orifices, establish WL and radiographic exposures was not recorded.

Instrumentation through CEC took 2.5 times longer than the time required for instrumentation in TEC designs.

The landmarks used for the CEC design were modified from a previous investigation (Krishan et al. 2014). A pilot study showed that the MB pulp horn was included in the access preparation when the proposed methodology was followed. Based on the µCT projections the location of the MB pulp horn was established and lines were drawn to help identify its location on the occlusal surface. This was transferred to the specimen by marking on the occlusal surface. The landmarks used for the TEC design were aimed at orifice location leading to a more centrally located design (Wilcox et al. 1989) and not a straight-line access design (Goerig et al. 1982). Care was taken to extend the distal access buccal-lingually as the access progressed apically in CEC and TEC to match this wide dimension identified on the µCT in distal canals.

Glide path development is necessary for the proper function of rotary instruments and prevention of iatrogenic errors (Berutti et al. 2012). In this study a #10 K-file, PathFile #1 and #2 instruments were used for glide path development. Significant changes in the angle, radius, and location of PCC were observed at this phase of instrumentation and were greater than those seen in the glide path to final
instrumentation phase. These results were unexpected as the maximum instrument size was an ISO 0.16 mm tip with a fixed .02 taper. These findings are corroborated in a recent study that showed that despite the small size of these instruments, movement in canal trajectory occurred with the use of the PathFile system (Kirchhoff et al. 2015).

Instruments placed in a canal undergo strain of varying amounts depending upon the angle, radius, and location of the curve according to the Coffin-Manson equation (ASM International 1996). The angle of PCC diminished approximately 22.5% for both access cavities from pre-instrumentation to final instrumentation. The significant decrease in angle of curvature observed after the use of #10 K-files and PathFile instruments was unexpected and would subject the larger .04 Profile Vortex instruments to less strain than if they were used under the original canal angle, PI (Duke et al. 2015).

In a pilot study, the ProFile Vortex instruments could not be placed into the canal orifices of the CEC, without glide path development, due to obstruction by the remaining pulp chamber roof and dentine shelf. Although there were no significant differences for the PI PCC between the CEC and TEC access designs, numerically it seemed like TEC showed lower initial values for the angle and location of PCC as well as greater values for radius. Considering the samples were carefully pre-selected following strict inclusion parameters and distributed randomly between both groups, a possible explanation for this occurrence is that the partial removal of dentine over the mesial canal orifices to establish the TEC access designs, minimally affected the PCC parameters.

The PCC location migrated to a more apical position in both access designs. Modifying the location of a maximum curve to a more apical region, led to a more flexible part of the file to be engaged in the curvature. The increased flexibility of the instrument is due to a smaller cross sectional diameter and clinically could lead to less iatrogenic errors (Wildey et al. 1992, Schäfer et al. 2003).

The angle, radius, and location are all independent factors that affect the difficulty of canal instrumentation. Two different canal curvatures can have the same angle, but drastically different radii (Pruett et al. 1997). In our study the radius was increased at each phase, producing a less abrupt curve. Therefore, each subsequent file encountered less strain and would be less likely to separate (Pruett et al. 1997).
As changes in curvature parameters behaved similarly between TEC and CEC access designs, we suggest that this could be due to transportation of the original canal geometry, post access removal of coronal dentin, or enhanced flexibility of NiTi instruments. Photographs of the occlusal surface of the specimens were taken throughout the course of treatment and suggested an increasing amount of coronal dentine removal as instrumentation progressed in CEC access designs. Although this was not a measured outcome in this study, future investigations should determine the location and amount of dentine removed in canal preparation of CEC access designs.

**Conclusions**

The obtained data would indicate that CEC and TEC access designs resulted in similar changes in angle, radius, and location of PCC at all phases of treatment for the type of teeth and instruments used in this study. If a clinician elects to establish an access using the CEC design, more than twice the time must be allocated in order to accomplish complete root canal instrumentation.
References


Table 1. Primary canal curvature parameters (mean ± standard deviation) determined at the different phases of treatment for both access designs.

<table>
<thead>
<tr>
<th>Access Design</th>
<th>Treatment Phase</th>
<th>Angle (°)</th>
<th>Location (mm)</th>
<th>Radius (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEC</td>
<td>PI</td>
<td>42.57 ± 8.00(^A)</td>
<td>8.20 ± 1.53 ♣</td>
<td>6.48 ± 1.81 †</td>
</tr>
<tr>
<td></td>
<td>GP</td>
<td>36.27 ± 4.50(^H)</td>
<td>7.16 ± 1.39 ♦</td>
<td>8.08 ± 1.72 ‡</td>
</tr>
<tr>
<td></td>
<td>FI</td>
<td>32.61 ± 5.17(^C)</td>
<td>6.29 ± 1.18 ♠</td>
<td>10.55 ± 1.48 §</td>
</tr>
<tr>
<td>TEC</td>
<td>PI</td>
<td>38.80 ± 7.15(^A)</td>
<td>7.44 ± 1.29 ♣</td>
<td>6.97 ± 2.31 †</td>
</tr>
<tr>
<td></td>
<td>GP</td>
<td>33.76 ± 7.83(^H)</td>
<td>6.81 ± 1.19 ♦</td>
<td>8.21 ± 1.75 ‡</td>
</tr>
<tr>
<td></td>
<td>FI</td>
<td>30.08 ± 6.99(^C)</td>
<td>5.70 ± 1.13 ♠</td>
<td>11.01 ± 2.20 §</td>
</tr>
</tbody>
</table>

CEC, contracted endodontic cavity; TEC traditional endodontic cavity.

PI, pre-instrumentation; GP, glide path; FI, final.

Different superscript letters and symbols in same column indicate significant differences within each access design (\(P < 0.001\)).
**Figure Legends**

**Figure 1** Photographs of the occlusal surface of mandibular molars showing access outlines obtained for: A) contracted- (CEC) pre-instrumentation (PI); and B) traditional endodontic cavity (TEC).

**Figure 2** Sequence of radiographs of a contracted endodontic cavity (CEC) specimen at: A) pre-instrumentation (PI), B) glide path (GP) and C) final instrumentation (FI) showing the: angle of curvature (yellow lines), 2) location of the primary canal curvature (red dots), 3) radius of curvature (green lines). Note that the angle of curvature decreased over time, the location migrated to a more apical position and the radius increased over time.