Impacts of Contracted Endodontic Cavities on Primary Root Canal Curvature Parameters in Mandibular Molars

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Abstract

Introduction: The purpose of this study was to provide information regarding the debate on contracted endodontic cavities (CECs); their impacts on angle, location, and radius of the primary canal curvature (PCC) were assessed in type IV mesial root canals of mandibular molars at different stages of instrumentation. Impacts on treatment time were also assessed. **Methods:** Twenty-four teeth were matched by radiographic and micro–computed tomographic criteria and accessed via CECs (CEC, *n* = 12) or nonextended traditional endodontic cavities (TECs, *n* = 12). PCC parameters were radiographically determined using a repositioning apparatus before glide path preparation (PI), after glide path preparation, and after final instrumentation (FI). Instrumentation was performed with PathFiles (13/.02, 16/.02; Dentsply Maillefer, Ballaigues, Switzerland) and ProFile Vortex files (Dentsply Tulsa Dental Specialties, Tulsa, OK) to size 30/.04 at the working length under copious irrigation. Changes in PCC were measured with ImageJ (National Institutes of Health, Bethesda, MD). The instrumentation time was recorded. Data were analyzed with 2-way repeated measures analysis of variance ($\alpha < .05$) and Tukey honest significant difference tests. **Results:** A significant ($P < .001$) decrease in the mean angle and increase in the mean radius were detected at each instrumentation stage for both CECs (angle: PI = 42.57° ± 8.00°, FI = 32.61° ± 5.17°; radius: PI = 6.48 ± 1.81 mm, FI = 10.55 ± 1.48 mm) and TECs (angle: PI = 38.80° ± 7.15°, FI = 30.08° ± 6.99°; radius: PI = 6.97 ± 2.31 mm, FI = 11.01 ± 2.20 mm). PCC location shifted apically ($P < .001$). Changes in PCC parameters did not differ significantly between CECs and TECs ($P > .05$). The treatment time was significantly ($P < .0001$) longer for CECs (83.17 ± 6.71 minutes) than for TECs (33.18 ± 9.20 minutes). **Conclusions:** Instrumentation of curved mesial canals reduced the severity and abruptness of PCC and shifted the PCC location apically similarly in mandibular molars with CECs and those with nonextended TECs. The extended treatment time with CEC merits consideration when debating CECs versus TECs. *(J Endod 2018;44:1558–1562)*

Key Words:

Dental pulp cavity, endodontic cavity, instrumentation efficiency, nickel-titanium instrument

Significance

No significant differences were found in PCC angle, radius, and location between the CEC and the TEC groups. The canal preparation time was significantly increased when working through a CEC access design.

Endodontic treatment of mandibular molars may challenge even experienced clinicians because of the curved canals in the mesial root. Root canal curvature and instruments' design (1), alloy, and mode of use (2) are the main factors governing instrumentation. Canal curvature has been characterized in regard to its angle and radius (3); a greater angle makes the curve more severe, and a smaller radius makes the curve more abrupt. As both curvature severity and abruptness increase, the strain on instruments and their pressure on the dentin walls also increase (1), potentially leading to transportation of canal pathways (4, 5). The location of the primary canal curvature (PCC) (ie, the distance of its center from the root apex) may also impact the cyclic fatigue and the point of maximal flexure of instruments as they engage the canal walls (3).

To facilitate treatment of the curved mesial root canals in mandibular molars and to prevent procedural errors, the traditional endodontic cavity (TEC) guidelines highlight an adequate "outline form" but also "convenience form" and "extension for prevention" (6, 7), specifically intended to reduce the severity of canal curvature. Accordingly, the cavity is extended beyond just a direct instrument pathway into canal orifices (6); however, the associated loss of tooth structure undermines the tooth's biomechanical responses to functional loads (8–10) and is a recognized risk factor for fracture in root-filled teeth (11, 12).

The emerging concept of contracted endodontic cavity (CEC) designs focuses on strategic dentin preservation (13–15), which is in-line with the concepts of minimally invasive dentistry (16). The main features of CECs in mandibular molars are partial preservation of the pulp chamber soffit and pericervical dentin extending 4 mm coronal and 4–6 mm apical to the crestal bone (13, 14). CEC designs not only feature

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contracted outline forms but, notably, they also forego convenience form and extension for prevention. Recent studies assessed the biomechanical (17–20) and canal instrumentation efficacy (17, 18) impacts of CECs to explore the potential benefits and risks. Fracture strength in mandibular premolars and molars with unrestored CECs was improved compared with teeth with TECs (17). When CECs were restored with bonded composite resin, the fracture strength of maxillary molars was comparable with that of similar teeth with TECs in 2 studies (18, 20), and improved for maxillary and mandibular premolars and molars in another study (19). Instrumentation efficacy appeared to be compromised only in distal canals of mandibular molars (17, 18). All studies reported no instrument fracture during instrumentation of canals in teeth with CECs (17, 18, 20, 21).

Because the mesial canals' curvature is not intentionally reduced in mandibular molars with CECs, the angle of file access in the mesial canals is greater than in molars with TECs (21), which may lead to accentuated transportation of canal pathways during instrumentation compared with molars with TECs (21). Furthermore, the contracted cavity is likely to increase instrumentation difficulty and time (15, 20, 21). To investigate the specific impacts of CECs on instrumented curved canal pathways, the aim of this study was to assess the changes in angle, radius, and location of PCC in type IV (22) mesial root canals of mandibular molars with CECs that occur at different phases of instrumentation. The time required for complete instrumentation also was recorded. Both the changes in curved canal pathways and the instrumentation time are potential concerns to clinicians. It was hypothesized that no significant difference would be detected in both outcome measures between molars with CECs and TECs.

Material and Methods

Tooth Specimens

Extracted human mandibular molars obtained from a bank of teeth were evaluated in 2 perpendicularly oriented radiographic views subsequent to institutional review board approval (#14-03591-XM). Twenty-four teeth were selected according to the following inclusion criteria: intact or minimally restored crowns, radiographic pulp chamber height <2 mm, mesial canal PCC angle > 30° according to Pruett et al (3), average length of 21 mm, and 2 distinct pathways and foramina as verified by micro–computed tomographic (μ-CT) imaging (ACTIS BIR 150/130; Varian Medical Systems, Palo Alto, CA). Images were acquired at 75 kV and 100 μA through 360° of rotation around the vertical axis, resulting in an approximate cross-sectional pixel size of 30 μm.

Selected teeth were embedded in epoxy resin (Stycast 1266; Henkel Electronic Materials, LLC Salisbury, NC) to allow precise positioning on the radiographic and μ-CT stages. PCC parameters were only determined for the mesial-buccal (MB) and mesial-lingual (ML) canals.

Groups and Endodontic Procedures

One operator (J.D.M.) performed all endodontic procedures under a clinical microscope (OPMI Pico; Carl Zeiss Meditec Inc, Jena, Germany) at ×10.9 magnification. Specimens were divided into CEC and TEC groups (n = 12). CEC was initially prepared in all teeth with new #392 mosquito burs (Spring Health Diamonds, St Louis Park, MN) in a high-speed handpiece under water spray (17). Vertical lines were drawn on the buccal and mesial surfaces of the mesiobuccal root bulges and extended to the occlusal surface, where their intersection corresponded to 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 soffit and pulp horns. Pulp tissue from undercut pulp horns and calcified tissue were removed with a modified DG-16 explorer. In the nonextended TEC group (n = 12), cavities were subsequently expanded with LA Axxess burs (SybronEndo, Glendora, CA) and refined with BUC-1 ultrasonic tips (SybronEndo). The outlines corresponded to the locations of canal orifices, resulting in centrally located cavities without radicular straight-line extension. Representative CEC and TEC outlines are shown in Figure 1*A–D*.

MB and ML canals were negotiated with ISO size 6, 8, and 10 K-type files (Roydent Dental Products, Johnson City, TN) to the minor apical foramen, and the working length (WL) was established 0.5 mm shorter. The specimen was inserted into a fixed mold mounted on a radiographic Plexiglas apparatus (23). A preinstrumentation (PI) radiographic image was captured with a size 10 file at the WL after rotating the stage to capture the maximum angle of curvature separately for the MB and ML canals (23). The stage positions for viewing the MB and ML were recorded as reference for subsequent radiographic capture.

A glide path (GP) was established with size 10 K-files followed by rotary PathFiles 13/.02 and 16/.02 (Dentsply Maillefer, Ballaigues, Switzerland). With size 10 K-files reinserted to the WL in the MB and ML canals, specimens were repositioned on the stage and rotated, and GP radiographic images were captured as described earlier. The mesial canals were instrumented with ProFile Vortex instruments (Dentsply Tulsa Dental Specialties, Tulsa, OK) in a crown-down sequence of 30/.04, 25/.04, and 20/.04 and a subsequently increasing instrument size at the WL to 30/.04. Distal canals were similarly instrumented to size 40/.04 at the WL to enable recording of the total time required for instrumentation of all canals. During instrumentation, canals were irrigated with 2 mL 8.25% sodium hypochlorite between successive instruments (total 10 mL per canal), and size 10 K-files were used to recapitulate canals to the WL. Final instrumentation (FI) radiographic images were captured as before with size 10 K-files in the MB and ML canals.

Outcome Measures

The PI, GP, and FI radiographic images were imported into PowerPoint (Microsoft Corp, Redmond, WA) as previously described (3), and lines were drawn to depict the long axes of canals coronal and apical to PCC (Fig. 2*A–C*). Images were imported into ImageJ 1.41 software (National Institutes of Health, Bethesda, MD), and the angle (degree), radius (mm), and location of PCC (mm) were measured for the MB and ML canals of each specimen. All measurements were performed by 1 examiner (D.J.C.) who coauthored the original canal curvature and radius classification study (3).

In addition, the total instrumentation time (minutes) encompassing active canal instrumentation, instrument changes, and irrigation was recorded for the MB, ML, and distal canals. Recording was suspended during radiographic exposures.

Analysis

Data for each curvature parameter were analyzed with 2-way repeated measures analysis of variance within and between each of the groups. Tukey pair-wise testing was used post hoc. The instrumentation time for both groups was compared using the unpaired t test. Significance was set at .05 (SigmaPlot 13; Systat Software Inc, Chicago, IL).

Results

None of the endodontic instruments used fractured during canal instrumentation. The PI measurements (Fig. 2*A*) revealed that specimens in groups CEC and nonextended TEC did not differ significantly ($P > .1$) in the angle, radius, and location of the primary canal

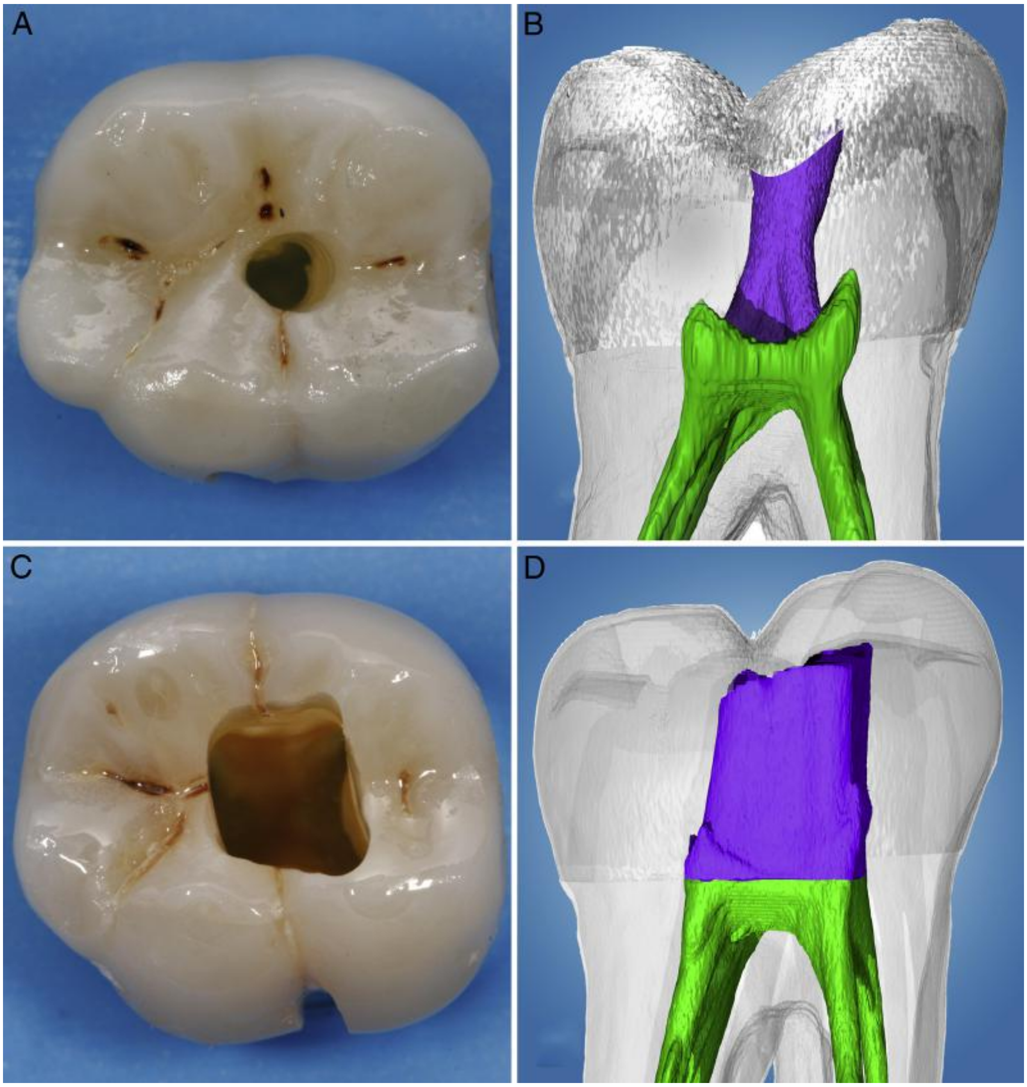

Figure 1. Photographs and sagittal view of μ-CT reconstructions of mandibular molars showing access outlines. (*A* and *B*) CEC. (*C* and *D*) TEC.

curvature, confirming the uniformity of the 2 groups. The PI, GP, and FI images (Fig. 2) revealed significantly ($P < .001$) decreasing angles, increasing radiuses, and decreasing locations of PCC after each instrumentation stage in MB and ML canals in both the CEC and nonextended TEC groups. Changes in all 3 PCC parameters did not differ significantly ($P > .1$) between the MB and ML canals in either group.

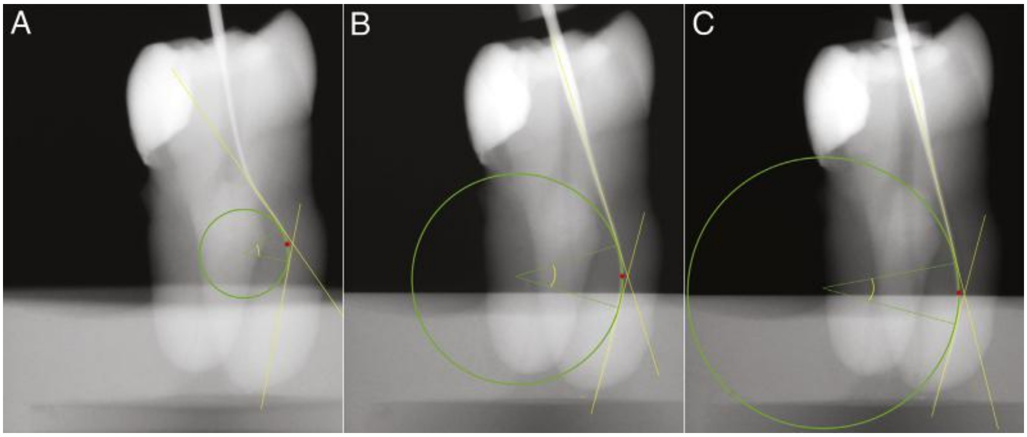

Figure 2. The sequence of radiographs of an CEC specimen at (*A*) PI, (*B*) GP, and (*C*) FI. Note the following changes in the PCC parameters: decreasing angle (*yellow lines*), apically shifting location (*red dots*), and increasing radius (*green lines*).

Because within-group data for the MB and ML canals were homogenous, 1 mean value for each PCC parameter was computed for each group combining both canals (Table 1). The CEC and nonextended TEC groups did not differ significantly in changes of mean angles ($P > .05$), radiuses ($P > .5$), and locations ($P > .05$) of PCC. Thus, the first null hypothesis was accepted.

The total time required for instrumentation of all root canals in the CEC group (83.17 ± 6.71 minutes) was significantly longer ($P < .0001$) than in the nonextended TEC group (33.18 ± 9.20 minutes). Thus, the second null hypothesis was rejected.

Discussion

Key features of CECs include a contracted space for accessing canals, potentially confining instruments and increasing treatment difficulty (15), and preservation of tooth structure, potentially benefitting the fracture strength of teeth (8–10, 17, 24). Recent studies have focused on the potential impacts of CECs on instrumentation efficacy (17, 18), biomechanical responses (17–20), centroid shifts in instrumented canals (21), and the ability to locate canals (20). The current study addressed additional potential concerns related to the confining dimensions of CECs by quantifying changes in canal curvature parameters. It also studied the time required for instrumentation performed through CEC as a measure of treatment difficulty.

Typical anatomic challenges faced by clinicians were represented by selecting mandibular molars with diminished pulp chamber heights (<2 mm), curved (>30° angle) mesial canals, and average lengths of 21 mm. In these teeth, the contracted outline form and the absence of convenience form and extension for prevention particularly restrict debridement of the pulp chamber and instrumentation. Modified DG-16 explorers and ultrasonic tips were used to debride the chambers. Preliminary imaging of specimens enabled the transfer of the MB pulp horn location to the occlusal surface. CEC outlines were kept shy of the pulp horns partially preserving pulp chamber soffits. Nonextended TEC outlines were guided predominantly by orifice locations (25), foregoing convenience form and extension for prevention and, thus, a radicular straight-line.

Although μ-CT imaging would have supported precise tracing of deviations in instrumented canal pathways (20, 21, 26), changes in PCC parameters were captured with radiographs to expedite the experimental process and to reduce cost. The radiographic capture of instruments within the canals was sufficiently sensitive to detect statistically significant changes in the PCC parameters of interest. Impacts on PCC parameters at key stages of canal instrumentation were recorded, including initial negotiation, glide path development, and complete instrumentation. This stepwise recording allowed the detection of potential differential impacts of CECs and TECs throughout the cleaning and shaping procedure of curved root canals.

Although preinstrumentation showed no significant differences in all 3 PCC parameters between the CEC and nonextended TEC groups, numerically the former showed higher initial values for PCC angle and location and lower values for radius. Considering that the samples were carefully preselected following strict inclusion parameters and distributed randomly between both groups, it is possible that the partial removal of dentin over the mesial canal orifices in the latter group minimally affected the PCC parameters.

Changes in the angle, radius, and location of PCC at the glide path and complete canal instrumentation were comparable for molars with CECs and nonextended TECs. This finding was explained by the fact that, with both cavity designs, the original canal pathways were not modified by pericervical dentin removal intended to establish convenience form and extension for prevention. The comparable changes in curvature parameters for the CEC and TEC groups suggested that the flexible and efficient instruments used caused some modification of the cavity walls, corroborating previous reports (17–21) of contemporary nickel-titanium engine-driven instruments used safely in curved canals accessed through contracted cavities. These findings notwithstanding, greater centroid shifts have been reported in mesial canals of mandibular molars (21) and in palatal canals of maxillary molars (20) with CECs, suggesting an increased, even if minor, canal transportation compared with teeth with TECs.

The angle, radius, and location of PCC are all independent variables (3) that affect the difficulty of canal instrumentation. Establishing a reproducible GP is suggested to ensure proper function of engine-driven instruments (27), which, when placed in a curved canal, undergo varying levels of strain depending on the PCC angle, radius, and location according to the Coffin-Manson equation (28). In our study, from start to completion of instrumentation, the angle decreased by about 22%, the radius increased by about 25%, and the location migrated apically by almost 2 mm. GP development, even if only to ISO size 16/.02, produced greater changes than subsequent instrumentation, corroborating a previous report on altered canal trajectory using the PathFile system (29). The reduction in PCC severity and abruptness by GP preparation likely reduced the strain on the subsequently used larger .04 Profile Vortex instruments (30). Also, because the PCC location migrated more apically, it would be engaged by the narrower, more flexible portion of subsequent .04 Profile Vortex instruments, potentially reducing the risk of iatrogenic errors (1, 5).

A noteworthy observation was the removal of dentin in the pericervical area as suggested by the changes in the instrument's coronal position when comparing PI, GP, and FI images (Fig. 2). Engaging dentin in this area with endodontic instruments is specifically what convenience form and extension for prevention were originally intended to avoid (6, 7) in order to prevent transportation and instrument breakage. Although the removal of some pericervical dentin appears unavoidable, a previous study on maxillary molars (6, 7) reported

TABLE 1. Primary Canal Curvature Parameters (Mean ± Standard Deviation [Combined Mesiobuccal and Mesiolingual Canal Data) Determined at the Different Phases of Treatment for Both Endodontic Cavity Designs

		Canal parameters		
Cavity design	Treatment phase	Angle (°)	Radius (mm)	Location (mm)
CEC	PI	42.57 ± 8.00^A	6.48 ± 1.81†	8.20 ± 1.53$^♣$
	GP	36.27 ± 4.50^B	8.08 ± 1.72‡	7.16 ± 1.39$^◆$
	FI	32.61 ± 5.17^C	10.55 ± 1.48§	6.29 ± 1.18$^♠$
TEC	PI	38.80 ± 7.15^A	6.97 ± 2.31†	7.44 ± 1.29$^♣$
	GP	33.76 ± 7.83^B	8.21 ± 1.75‡	6.81 ± 1.19$^◆$
	FI	30.08 ± 6.99^C	11.01 ± 2.20§	5.70 ± 1.13$^♠$

CEC, contracted endodontic cavity; FI, final instrumentation; GP, glide path; PI, preinstrumentation; TEC, traditional endodontic cavity without radicular straight-line extension.

Different superscript letters and symbols in the same column indicate significant differences within each access design ($P < .001$).

that CECs resulted in significantly less pericervical dentin removal than TECs.

Instrumentation time in teeth with CECs was 2.5-fold longer than in teeth with nonextended TECs, reflecting the typical challenges associated with constricted access (15). This finding corroborated the previous report (15) of significantly more pecking motions required to instrument mesial canals in mandibular molars with CECs compared with those with TECs. The considerable prolongation of treatment time merits consideration when the pros and cons of CEC are debated because prolonged treatment time may not be equally tolerated by all patients. Nonetheless, with the improved technical skill gained by the common practice of CECs, the time required for treatment may be reduced (15) so that it does not negatively impact patients' tolerance of the treatment procedure.

In order for minimally invasive interventions to become widely adopted, clear benefits outweighing the potential risks must be demonstrated, supportive technologies must be developed, and clinicians' skills must be adapted to working within confined spaces. Although minimally invasive dentistry and the preservation of tooth structure are well-founded concepts (16), the risk of extended treatment time without demonstrated beneficial clinical outcomes may have hindered the adoption of CEC designs in endodontics despite the availability of supportive technologies that include CBCT pretreatment planning (15), microscope-enhanced visualization (15), heat-treated nickel-titanium instruments with enhanced flexibility and cyclic fatigue (2, 31, 32), and energized disinfection protocols (33). It appears that clear benefits have yet to be supported by research. Thus far, surrogate *in vitro* data on the fracture strength of posterior teeth have varied, from intangible impacts of CECs (18, 20) to improved fracture strength compared with similar teeth with TECs (17, 19).

In conclusion, within the limitations of this study, the results suggested that instrumentation of curved mesial canals with engine-driven instruments reduced the severity and abruptness of PCC and shifted the PCC location apically similarly in mandibular molars with CEC and those with nonextended TEC. Treatment time in the molars with CECs was considerably longer, suggesting that extended treatment time should be taken into account along with other considerations when debating CECs versus TECs.

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The authors deny any conflicts of interest related to this study.

References

1. Wildey WL, Senia ES, Montgomery S. Another look at root canal instrumentation. Oral Surg Oral Med Oral Pathol 1992;74:499–507.
2. Alapati SB, Brantley WA, Iijima M, et al. Metallurgical characterization of a new nickel-titanium wire for rotary endodontic instruments. J Endod 2009;35:1589–93.
3. Pruett JP, Clement DJ, Carnes DL. Cyclic fatigue testing of nickel-titanium endodontic instruments. J Endod 1997;23:77–85.
4. Abou-Rass M, Frank AL, Glick DH. The anticurvature filing method to prepare the curved root canal. J Am Dent Assoc 1980;101:792–4.
5. Schäfer E, Dzepina A, Danesh G. Bending properties of rotary nickel-titanium instruments. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2003;96:757–63.
6. Ingle JI, Beveridge EE, Luebke FL, et al. Endodontic cavity prepartion. In: Ingle JI, ed. *Ingle's Endodontics*, 1st ed. Philadelphia: Lea & Fabiger; 1965:106–67.
7. Patel S, Rhodes J. A practical guide to endodontic access cavity preparation in molar teeth. Br Dent J 2007;203:133–40.
8. Kishen A. Mechanisms and risk factors for fracture predilection in endodontically treated teeth. Endod Topics 2006;13:57–83.
9. Reeh ES, Douglas WH, Messer HH. Stiffness of endodontically-treated teeth related to restoration technique. J Dent Res 1989;68:1540–4.
10. Pereira JR, McDonald A, Petrie A, et al. Effect of cavity design on tooth surface strain. J Prosthet Dent 2013;110:369–75.
11. Chen SC, Chueh LH, Hsiao CK, et al. First untoward events and reasons for tooth extraction after nonsurgical endodontic treatment in Taiwan. J Endod 2008;34: 671–4.
12. Toure B, Faye B, Kane AW, et al. Analysis of reasons for extraction of endodontically treated teeth: a prospective study. J Endod 2011;37:1512–5.
13. Clark D, Khademi JA. Modern molar endodontic access and directed dentin conservation. Dent Clin North Am 2010;54:249–73.
14. Clark D, Khademi JA. Case studies in modern molar endodontic access and directed dentin conservation. Dent Clin North Am 2010;54:275–89.
15. Bóveda C, Kishen A. Contracted endodontic cavities: the foundation for less invasive alternatives in the management of apical periodontitis. Endod Topics 2015;33: 169–86.
16. Murdoch-Kinch CA, McLean ME. Minimally invasive dentistry. J Am Dent Assoc 2003;134:87–95.
17. Krishan R, Paqué F, Ossareh A, et al. Impacts of conservative endodontic cavity on root canal instrumentation efficacy and resistance to fracture assessed in incisors, premolars, and molars. J Endod 2014;40:1160–6.
18. Moore B, Verdelis K, Kishen A, et al. Impacts of contracted endodontic cavities on instrumentation efficacy and biomechanical responses in maxillary molars. J Endod 2016;42:1779–83.
19. Plotino G, Grande NM, Isufi A, et al. Fracture strength of endodontically treated teeth with different access cavity designs. J Endod 2017;43:995–1000.
20. Rover G, Belladonna FG, Bortoluzzi EA, et al. Influence of access cavity design on root canal detection, instrumentation efficacy, and fracture resistance assessed in maxillary molars. J Endod 2017;43:1657–62.
21. Alovisi M, Pasqualini D, Musso E, et al. Influence of contracted endodontic access on root canal geometry: an *in vitro* study. J Endod 2018;44:614–20.
22. Vertucci FJ. Root canal anatomy of the human permanent teeth. Oral Surg Oral Med Oral Pathol 1984;58:589–99.
23. Iqbal MK, Maggiore F, Suh B, et al. Comparison of apical transportation in four Ni-Ti rotary instrumentation techniques. J Endod 2003;29:587–91.
24. Lang H, Korkmaz Y, Schneider K, et al. Impact of endodontic treatments on the rigidity of the root. J Dent Res 2006;85:364–8.
25. Wilcox LR, Walton RE, Case WB. Molar access: shape and outline according to orifice locations. J Endod 1989;15:315–8.
26. Bergmans L, Van Cleynenbreugel J, Wevers M, et al. A methodology for quantitative evaluation of root canal instrumentation using microcomputed tomography. Int Endod J 2001;34:390–8.
27. Berutti E, Paolino DS, Chiandussi G, et al. Root canal anatomy preservation of WaveOne reciprocating files with or without glide path. J Endod 2012;38:101–4.
28. ASM International. *Fatigue and Fracture*. Materials Park, OH: ASM Handbook; 1996:19.
29. Kirchhoff AL, Chu R, Mello I, et al. Glide path management with single- and multiple-instrument rotary systems in curved canals: a micro-computed tomographic study. J Endod 2015;41:1880–3.
30. Duke F, Shen Y, Zhou HM, et al. Cyclic fatigue of ProFile Vortex and Vortex Blue nickel-titanium files in single and double curvatures. J Endod 2015;41: 1686–90.
31. Johnson E, Lloyd A, Kuttler S, et al. Comparison between a novel nickel-titanium alloy and 508 nitinol on the cyclic fatigue life of ProFile 25/.04 rotary instruments. J Endod 2008;34:1406–9.
32. Acosta ECP, Resende PD, Peixoto IFD, et al. Influence of cyclic flexural deformation on the torsional resistance of controlled memory and conventional nickel-titanium instruments. J Endod 2017;43:613–8.
33. Neuhaus KW, Liebi M, Stauffacher S, et al. Antibacterial efficacy of a new sonic irrigation device for root canal disinfection. J Endod 2016;42:1799–803.