Impacts of Contracted Endodontic Cavities on Instrumentation Efficacy and Biomechanical Responses in Maxillary Molars

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Abstract

Introduction: Recently, we reported that in mandibular molars contracted endodontic cavities (CECs) improved fracture strength compared with traditional endodontic cavities (TECs) but compromised instrumentation efficacy in distal canals. This study assessed the impacts of CECs on instrumentation efficacy and axial strain responses in maxillary molars. **Methods:** Eighteen extracted intact maxillary molars were imaged with micro–computed tomographic imaging (12-μm voxel), assigned to CEC or TEC groups (n = 9/group), and accessed accordingly. Canals were instrumented (V-Taper2H; SSWhite Dental, Lakewood, NJ) with 2.5% sodium hypochlorite irrigation, reimaged, and the proportion of the modified canal wall determined. Cavities were restored with bonded composite resin (TPH-Spectra-LV; Dentsply International, York, PA). Another 28 similar molars (n = 14/group) with linear strain gauges (Showa Measuring Instruments, Tokyo, Japan) attached to mesiobuccal and palatal roots were subjected to load cycles (50–150 N) in the Instron Universal Testing machine (Instron, Canton, MA), and the axial microstrain was recorded before access and after restoration. These 28 molars and additional 11 intact molars (control) were cyclically fatigued (1 million cycles, 5–50 N, 15 Hz) and subsequently loaded to failure. Data were analyzed by the Wilcoxon rank sum and Kruskal-Wallis tests (α = 0.05). **Results:** The overall mean proportion of the modified canal wall did not differ significantly between CECs (49.7% $\pm$ 12.0%) and TECs (44.7% $\pm$ 9.0%). Relative changes in axial microstrain responses to load varied in both groups. The mean load at failure for CECs (1703 $\pm$ 558 N) did not differ significantly from TECs (1384 $\pm$ 377 N) and was significantly lower (P < .005) for both groups compared with intact molars (2457 $\pm$ 941 N). **Conclusions:** In maxillary molars tested *in vitro*, CECs did not impact instrumentation efficacy and biomechanical responses compared with TECs. *(J Endod 2016;42:1779–1783)*

Key Words

Endodontic cavity, fracture strength, instrumentation efficacy, minimally invasive, root strain

Significance

Fracture after endodontic treatment is an ongoing concern. Modern dentistry has seen a trend towards minimally invasive treatments. In endodontics, removal of tooth structure increases the susceptibility of teeth to fracture that gave rise to the concept of contracted cavities.

Endodontic treatment aims to retain teeth in health and function for the long-term (1), but teeth may fracture, necessitating extraction (2–4). A fracture risk factor is loss of dentin, including that associated with drilling of endodontic cavities (4). Traditional endodontic cavities (TECs) emphasize straight-line pathways into canals to enhance instrumentation efficacy and prevent procedural errors (5, 6). The associated removal of pericervical dentin (7, 8) can impact biomechanical responses of teeth (9–14). Increased cuspal flexure associated with TECs (9,12–14) may lead to increased strain at the crown and root surfaces (11–13), which, in turn, may increase the susceptibility of treated teeth to fracture under functional loads (4, 9). These biomechanical effects are undesirable, but they may be moderated in the short-term by restoration of endodontic cavities with bonded composite resin (12,15–18).

Contracted endodontic cavities (CECs), inspired by concepts of minimally invasive dentistry (19), emphasize tooth structure preservation including pericervical dentin (7, 8). We previously reported (20) that CECs, compared with TECs, improved fracture strength under a continuous load in unrestored mandibular premolars and molars but not in maxillary incisors, and compromised instrumentation efficacy in distal canals of mandibular molars but not in premolars and incisors. These results, suggesting that the impact of CECs varied in different tooth types when unrestored, might not be extrapolated to restored maxillary molars in which the morphology is distinctly different. Also, unlike available data on fracture strength of intact mandibular molars (21), respective data on maxillary molars are lacking. Therefore, this study assessed the impacts of CECs on canal instrumentation efficacy and biomechanical responses in maxillary molars

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restored with bonded composite resin. We tested the null hypotheses that CECs would not impact instrumentation efficacy, axial root strain, or fracture strength after cyclic fatigue.

Materials and Methods

After research protocol approval by the University of Toronto Research Ethics Board, 59 extracted human noncarious, mature, intact, maxillary molars were stored in 0.1% thymol solution at room temperature until used. The absence of preexisting cracks was verified under the operating microscope. Crown dimensions, length, and canal curvature of teeth, determined by 2 perpendicular radiographic exposures, were considered for matching teeth allocated into groups.

Sample and Groups

The sample size was estimated based on studies comparing fracture strength for TECs and CECs (20) and the proportion of untouched canal wall (20, 22–24), both with 10 teeth per group. Accordingly, for analysis with $\alpha = 0.05$ and 80% power, at least 10 teeth were allocated for each of the following groups: CEC (experimental), TEC (control), and intact (negative control for fracture strength testing) for different aspects of the study.

Instrumentation Efficacy

A subset of 20 teeth assigned to the CEC and TEC groups was imaged with micro–computed tomography (micro-CT) (SkyScan 1172; Brüker MicroCT, Kontich, Belgium) at 12-μm voxel size, 70-KVp beam energy, 10 frames/view, and 400-millisecond exposure, and the canals were captured (pretreatment volumes). Mineral density was calibrated with mineral analogue rods and ReCon software (Brüker MicroCT) used for 3-dimensional (3D) reconstruction.

Eighteen teeth (1 tooth/group was lost during processing) were accessed under the operating microscope. In the CEC group (n = 9), endodontic cavities were drilled with high-speed Endoguide burs (EG1A; SSWhite Dental, Lakewood, NJ). Cavities were accessed at the central fossa and extended only as necessary to access canal orifices while preserving pericervical dentin and part of the chamber roof or "soffit" (7, 8) (Fig. 1*A*). In the TEC group (n = 9), endodontic cavities were drilled with tapered high-speed diamond burs (F392-016; Axis Dental, Coppell, TX) following conventional guidelines (5, 6). Outline and pericervical dentin were modified as needed until all orifices could be visualized in the same field of view.

Canals were negotiated with size 10 K-type files (Flexofile; Dentsply Maillefer, Ballaigues, Switzerland) to the major apical foramen and the working length established 0.5 mm shorter. After initial preparation with PathFile instruments (Dentsply Maillefer), canals were instrumented with V-Taper2H rotary instruments (SSWhite Dental) to size 20/v06 and 30/v06 in buccal and palatal roots, respectively. These heat-treated instruments were precurved to facilitate placement into canals. New instruments were used for each tooth. Intermittent irrigation with 5 mL 2.5% sodium hypochlorite was applied with ProRinse side-vented 30-G needles (Dentsply International, York, PA).

Instrumented canals were captured with micro-CT (post-treatment volumes) as described previously. Reconstructed 3D volume data were converted from a bitmap image file to the Digital Imaging and Communications in Medicine format and processed with Scanco 3D morphometry analysis software (Scanco Medical, Brüttisellen, Switzerland). Coronal canal boundaries were set at orifice levels. Isthmus pathways in mesiobuccal roots were excluded. Where a wide isthmus was present, canal boundaries were set at the transition between the main canal and the isthmus. Customized script for algorithm-based registration (20, 22, 24) was used to process pre-

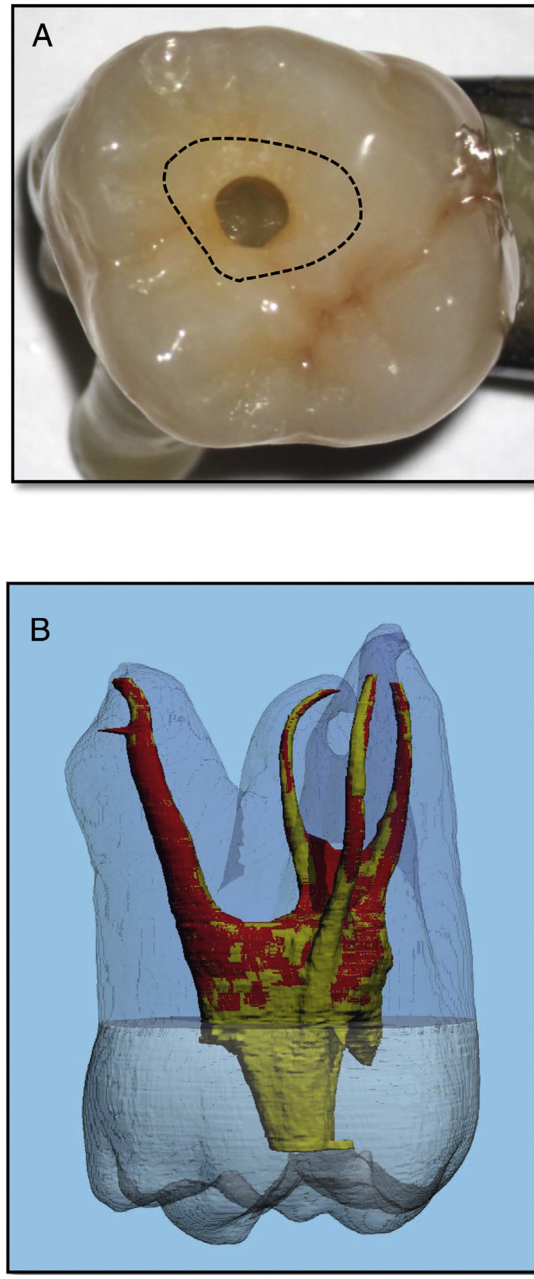

Figure 1. CEC in a maxillary molar. (*A*) The occlusal view; for comparison, a TEC is outlined with a dotted line. (*B*) The distal view of registered 3D reconstructed micro-CT images showing the root canals (*red*) pretreatment and (*yellow*) post-treatment. The pulp chamber and endodontic cavity within the coronal tooth portion are not color coded.

and post-treatment volumes with a precision of 1 ± 1 voxel. Accordingly, dentin removal depth $\geq$24 μm was determined as a modified canal wall (MCW) surface.

Biomechanical Responses

Another subset of 28 teeth was used to record apicocoronal axial strain under simulated physiologic occlusal stresses (10, 11). Teeth were mounted up to 3 mm apical to the cementoenamel junction in customized cylinders fabricated with self-curing resin (SR Ivolen; Ivoclar Vivadent, Schaan, Lichtenstein), with a 0.2-mm-thick lining of polyvinyl siloxane (Aquasil Ultra Monophase Regular Set, Dentsply International) simulating the periodontal ligament. Foil strain gauges (N11-FA-2-120-11; Showa Measuring Instruments, Tokyo, Japan) were glued with rapid-setting cyanoacrylate adhesive (Instant Adhesive Aron Extra 4000; Toagosei, Tokyo, Japan) on the mesiobuccal and palatal cervical root surfaces (10–14) and sealed with polyurethane varnish (PU140; Hottinger Baldwin Messtechnik, Darmstadt, Germany).

Teeth were mounted in the Instron Universal Testing machine (Instron, Canton, MA). Axial forces, directed at 30° angle from the tooth's long axis, were cycled between 50 N and 150 N and the voltage-change outputs from the strain gauges, connected by a half Wheatstone bridge, converted to strain measurements by a data-acquisition module (DQ 430 EspressoDAQ; HBM Canada, Pickering, ON). Microstrain values were recorded using DAQ software (Catman Easy, EspressoDAQ version 1.02, HBM Canada) at each of the mesiobuccal and palatal surfaces. Axial strain was recorded before endodontic cavities were drilled and again after the completion of canal instrumentation.

Canals of the 28 teeth were accessed as per CEC and TEC group designation (n = 14/group) and instrumented as described earlier. Subsequently, endodontic cavities were etched with 38% phosphoric acid gel (Etch-Rite; Pulpdent, Watertown, MA), rinsed with water, air-dried, coated with OptiBond Solo Plus (Kerr Corp, Orange, CA), air-dried, and restored with TPH Spectra Universal Composite Restorative LV (Dentsply International) applied in <2-mm increments, each cured for 20 seconds. Teeth were then stored in 0.1% thymol solution at room temperature for 2 weeks, and microstrain measurements were repeated.

Subsequently, the 28 teeth assigned to the CEC and TEC groups and the remaining subset of 11 teeth were submerged in a water bath at room temperature and subjected to 1 million loading cycles in the Instron Universal Testing machine between 5 N and 50 N at 15 Hz to simulate approximately 4 years of chewing function (25) using forces within the physiological range (26). After this fatigue phase, continuous compressive force was applied with a 5-mm spherical crosshead at 1 mm/min until failure occurred, defined as a 25% drop in applied force, and the load at failure recorded (N).

Analysis

MCW was expressed as a proportion of the total canal wall area for the coronal and apical halves of each root. The corresponding mean MCW values for the CEC and TEC groups were analyzed with the Wilcoxon rank sum test. Average pre- and post-treatment microstrain values were calculated separately for the mesiobuccal and palatal surfaces of each tooth. Corresponding median values for the CEC and TEC groups were analyzed with the Wilcoxon signed rank sum test. In addition, the relative microstrain change (pretreatment value divided by post-treatment value) was determined as previously reported for relative stiffness (11). The median relative microstrain at the mesiobuccal and palatal surfaces for the CEC and TEC groups was evaluated qualitatively. The mean load at failure values were calculated for the CEC, TEC, and intact control groups and analyzed with the Kruskal-Wallis and post hoc Dunn tests. All tests were 2 tailed, and significance was set at 5% level.

Results

Instrumentation Efficacy

No instruments fractured during canal preparation. All present second mesiobuccal canals, as verified by micro-CT imaging, were instrumented. Figure 1*B* shows registered pre- and post-treatment reconstructed micro-CT images of a molar with a CEC. The mean proportion of MCW (Table 1) was highest in the coronal half of the distobuccal canals in the CEC group (59.7 ± 16.8%) and lowest in the apical half of the palatal canals in the TEC group (34.6 ± 15.4%). It did not differ significantly (P > .15) between the CEC and TEC groups in any of the roots or canal levels.

Biomechanical Responses

Figure 2 depicts axial microstrain measurements obtained from a molar with a CEC. Pre- and post-treatment microstrain values did not differ significantly between the mesiobuccal and palatal surfaces of teeth and between the CEC and TEC groups. The median relative microstrain values were higher at the palatal surfaces (CEC = 0.74, TEC = 0.94) than at the mesiobuccal surfaces (CEC = 0.33, TEC = 0.37).

The mean load at failure values (Fig. 3) did not differ significantly between the CEC (1703 ± 558 N; range, 1205–3021 N) and TEC (1384 ± 377 N; range, 966–2381 N) groups but were significantly lower (P < .05) for both groups compared with the intact controls (2457 ± 941 N; range, 1252–3806 N). Fractures were mesial distal and buccal palatal with varying levels of apical extension but no apparent pattern observed in any group.

Discussion

To advise the debate on the CEC concept, we previously assessed the net impacts, without restorations, of CEC designs in 3 tooth types (20). Improved fracture strength, a potential benefit, was observed in mandibular premolars and molars but not in maxillary incisors; compromised canal instrumentation efficacy, a potential risk, was observed only in the distal canals of mandibular molars (20). The varied impacts of CECs in the different tooth types (20) warranted the present investigation into specific impacts of CECs in maxillary molars.

The use of mature, intact maxillary molars was a priority to avoid the effects of varying degrees of tooth structure loss. Although matched for external dimensions when allocated to the CEC and TEC groups, some teeth in both groups had short roots and fairly large pulp chambers and canals, limiting the applicability of the results to maxillary molars with similar characteristics. Canals were instrumented with V-Taper2H instruments that, because of regressive taper design, have smaller D12 diameters (0.64 mm for 20/v06) than continuously tapered 20/04 and 20/06 instruments (0.68 mm and 0.92 mm, respectively). Because these slimmer instruments were expected to engage less pericervical dentin than would occur with larger instruments,

TABLE 1. Modified Canal Wall after Instrumentation in Maxillary Molars Performed through a Contracted (CEC) or Traditional (TEC) Endodontic Cavity Assessed by Micro–Computed Tomographic Imaging*

Root (n = 9)	Assessed canal level	Modified canal wall (% of total canal wall surface)	
		CEC	TEC
Mesiobuccal	Coronal half	57.1 ± 18.2	54.3 ± 17.0
	Apical half	49.2 ± 10.1	45.1 ± 18.6
	Total canal	53.1 ± 11.6	49.7 ± 16.5
Distobuccal	Coronal half	59.7 ± 16.8	51.6 ± 12.2
	Apical half	58.3 ± 14.4	46.7 ± 9.8
	Total canal	59.0 ± 14.5	49.2 ± 10.6
Palatal	Coronal half	36.3 ± 17.0	39.4 ± 15.1
	Apical half	40.3 ± 22.8	34.6 ± 15.4
	Total canal	38.3 ± 19.2	37.0 ± 14.4
All roots	Total	49.7 ± 12.0	44.7 ± 9.0

*Modified canal wall is expressed as a proportion of the total canal wall area; mean and standard deviation values presented by coronal and apical halves of the 3 roots.

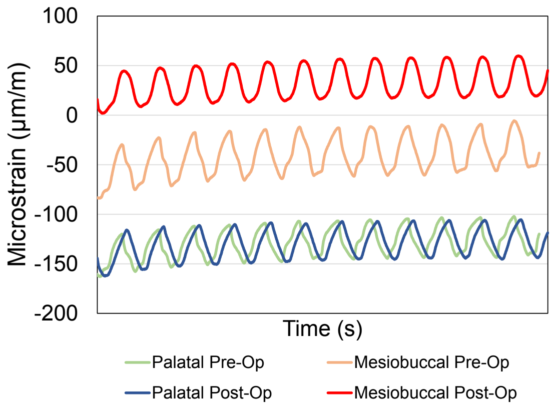

Figure 2. Axial microstrain measured at the mesiobuccal and palatal cervical root surfaces of a maxillary molar under simulated physiologic loads (50–150 N) using the Instron Universal Testing machine. Measurements were obtained before access (pre-op) and after contracted (CEC) access, canal instrumentation, and bonded composite resin restoration (post-op). Although the pre- and post-op measurements at the palatal surface were similar, the measurements at the mesiobuccal surface changed from compressive microstrain pre-op to tensile microstrain post-op.

instrumentation efficacy was assessed with higher-resolution micro-CT imaging than in previous studies (20, 22–24), providing a threshold of 1 ± 1 voxel or 24 μm to detect canal wall modification. Instrument tip sizes of 20/v06 and 30/v06 were preselected to avoid operator bias; however, these sizes turned out to be small for the dimensions of some canals encountered in this study, undermining instrumentation efficacy and the universal applicability of the corresponding results. In addition to the regressive taper, increased flexibility and cyclic fatigue resistance of the heat-treated instruments compared with similar nontreated instruments (27) were deemed desirable considering the constrained pathways to canals. Indeed, no instrument fracture or ledge formation occurred in any of the teeth.

Of several methods applied for axial strain or cuspal deflection analysis (9–11), strain gauges were chosen to detect slight changes in microstrain (10) and to directly compare pre- and post-treatment axial microstrain within the same tooth. The fine metal-foil strain gauge conducts current with given electrical resistance and static voltage. The gauge deforms when underlying tooth structure deflects under loading, and the resulting change in electrical resistance is detected and converted to a measurement. Importantly, although forces in the physiologic range were applied (26), axial microstrain assessment may not reflect complete root strain patterns for the complex chewing process (26).

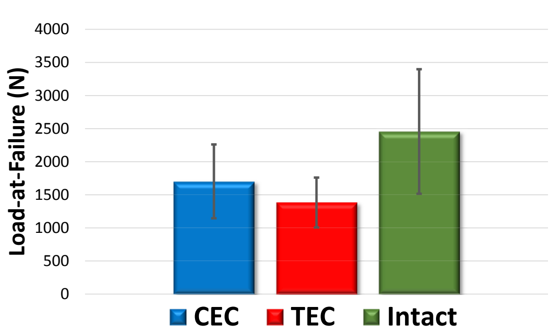

Figure 3. Mean load at failure in maxillary molars, intact (control) or with restored contracted (CEC) or traditional (TEC) access, under a compressive load preceded by 1 million cycles of fatiguing loads using the Instron Universal Testing machine.

Endodontic cavities were restored with bonded composite resin to simulate clinical procedures while facilitating loading, in contrast to our previous study (20). Such restorations may restore fracture strength of teeth up to 72% of that of intact teeth (17). Another difference from our previous study (20) was the fatiguing of teeth with cyclic loading to accommodate the understanding that fractures in root-filled teeth are considered to be fatigue failures, arising from microdefects within the dentin and at the restoration-tooth interfaces (28). Although standard deviations of load at failure values were larger than what we observed in unrestored and nonfatigued mandibular molars (20), they were consistent with other fracture studies of molar teeth (18, 21).

Instrumentation efficacy in the maxillary molars with CECs and TECs was poor overall with no significant difference detected. Instrumentation modified 49%–59% of buccal canal walls and about 38% of palatal canal walls, corroborating the limited efficacy of engine-driven instruments previously shown in all tooth types (20, 22, 23). Although in this study we instrumented rather wide canals with relatively slim instruments, instrumentation efficacy was comparable with what we reported in mandibular molars (20) with CECs (43%–52%) and TECs (52%–63%) and only slightly below the 55%–67% reported elsewhere in maxillary molars (22, 23). Instruments' contact with canal walls is needed to mechanically debride pulp tissue and disrupt bacterial biofilm (29). The finding, under the conditions of this study, that CECs did not compromise instrumentation efficacy in maxillary molars suggested no apparent risk in this regard.

Axial microstrain varied without a discernible pattern for the CEC and TEC groups. Intracanal dentin removal increases root deformation (14), and tooth structure loss increases strain in teeth (12, 13). The minimal change in microstrain at palatal root surfaces and greater changes at the mesiobuccal root surfaces in maxillary molars from both groups suggested that the mesiobuccal cusp was more prone to deformation after access and canal instrumentation than the relatively robust palatal cusp. The recorded changes in microstrain might also be affected by polymerization shrinkage of the bonded composite resin restorations (30), whereby resulting contractile forces produced tensile strain (30) leading to increased tooth stiffness (31).

Fracture strength in the restored maxillary molars with CECs and TECs was comparable and consistently lower than that of intact molars. The nonsignificant 23% increase in fracture strength for CECs compared with TECs sharply contrasted with the 247% increase we reported for unrestored mandibular molars with CECs (20), and it did not reach the fracture strength level of intact maxillary molars as it did in mandibular molars (20). Thus, CECs in restored maxillary molars did not positively impact fracture strength, suggesting no apparent benefit in this regard. The compromised fracture strength even with CECs supported the use of cuspal or full-coverage definitive restorations to limit tooth structure deformation and possible fracture, as recommended for posterior endodontically treated teeth (2, 4, 11, 32, 33).

The fracture strength of intact maxillary molars was previously reported at 4960 ± 1147 N (34), considerably greater than the mean load at failure just below 2500 N after cyclic fatiguing herein. That discrepancy might be attributed to the loading of teeth with a 7.5-mm diameter cylinder in the previous study (34) compared with the 5-mm diameter ball herein; with the larger cylinder, a greater force is needed than with the smaller ball to generate the critical pressure required to fracture the tooth. Interestingly, the current load at failure of intact maxillary molars was only 21% higher than the 2029 N we reported for nonfatigued intact mandibular molars (20). Although the use of cyclic fatiguing herein precluded direct comparison, the results suggested greater robustness of maxillary molars that might moderate the risk of fracture after endodontic treatment. Indeed, Zadik et al (33) reported a much lower incidence of fracture among endodontically treated maxillary molars compared with mandibular molars.

Minimally invasive dentistry interventions (19), highlighting the preservation of natural tissues, require successful intersection of (1) specific benefits outweighing potential risks, (2) procedure-driven technologies, and (3) skills adaptation by clinicians (7, 8). Although minimally invasive interventions have been embraced in some areas of dentistry (19), the CEC concept in endodontics has largely been opposed because it poses challenges not encountered with TECs (5). Technologies (eg, operating microscopes and improved nickel-titanium instruments) are available that enable treatment with less "convenience form" (7, 8). Therefore, whether clinicians should strive to adapt skills for the routine use of CECs should hinge on clinically proven benefits (lower fracture rates) and dismissed risks (no compromised healing). Until such clinical evidence becomes available, *in vitro* research can suggest benefits and risks. This *in vitro* study neither supported apparent biomechanical benefits nor an instrumentation efficacy risk associated with CECs in maxillary molars, which was in line with our observations in maxillary incisors but not in unrestored mandibular premolars and molars (20). Considering that maxillary molars present with particularly challenging root canal systems in mesiobuccal roots, where secondary canals are difficult to locate and negotiate (35), the application of CECs in these teeth merits careful consideration. In conclusion, given the limitations of *in vitro* testing and the conditions of this study, CECs in maxillary molars did not appear to impact instrumentation efficacy and biomechanical responses compared with TECs.

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

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