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Influence of Contracted Endodontic Access on Root Canal Geometry: An In Vitro Study.

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Abstract

Aim: Contracted endodontic cavities (CEC) have developed from the concept of minimally invasive dentistry and provide an alternative to traditional endodontic cavities (TEC). They have been designed in an effort to preserve the mechanical stability of teeth. The contracted cavity design preserves more of the dentin, but may influence the geometric shaping parameters. The aim of this micro-computed tomography study was to evaluate the influence of contracted endodontic cavities on the preservation of the original root canal anatomy after shaping with nickel-titanium rotary instruments. **Methodology:** Thirty extracted human mandibular molars with fully formed apices and independent mesial canals were randomly assigned to Group 1 (TEC) and Group 2 (CEC). Each group was shaped using Proglider and WaveOne Gold (Dentsply Maillefer Ballaigues, Switzerland). Irrigation was performed with 10% EDTA and 5% NaOCl. Samples were scanned before and after canal shaping to match canal volumes (SkyScan, Bruker-microCT, 100 kV, 100 μA, 15 μm resolution) and images were analyzed to evaluate canal volumes, surface areas and centroid shift on cross sections at -1 mm and -3 mm from the apex. **Results:** TEC demonstrated a greater preservation of the original root canal anatomy with less apical transportation than CEC, possibly due to the absence of coronal interferences and therefore fewer pecking motions required to complete instrumentation. **Conclusions:** Within the limitations of this study, TEC may lead to a better preservation of the original canal anatomy during shaping compared to CEC, particularly at the apical level.

Keywords

Minimally invasive, contracted endodontic access, centering ability, micro-CT, NiTi instruments, shaping outcomes.

Introduction

Access cavity preparation is considered a fundamental step in orthograde endodontic treatment (1). Complete removal of the pulp chamber roof is crucial to avoid bacterial contamination from pulp residues (2, 3). Moreover, appropriate access may promote canal detection and enhance instrumentation efficacy by avoiding coronal interferences (4). Contracted endodontic cavities (CEC) have stemmed from the concept of minimally invasive dentistry (5, 6). They have been presented as an alternative to traditional endodontic access cavities (TEC), designed to preserve the mechanical stability of the tooth (7, 8). However, although the contracted cavity design retains more dentin, it may influence the geometric shaping parameters. In contracted access cavities, coronal interference may cause endodontic instruments to work primarily on the internal surface of the root canal, resulting in root canal transportation. Recent studies have demonstrated that root canal transportation negatively affects long-term prognosis following endodontic procedures due to an excessive removal of dentin and straightening of the original root canal curvature (9–13). However, no data are available regarding the influence of contracted cavities on geometric shaping outcomes.

Micro-computed tomography (micro-CT) is considered a reliable method to assess the quality of root canal shaping through the analysis of two-dimensional (2D) and three-dimensional (3D) geometric shaping parameters (14–16). The aim of this micro-CT study was to evaluate the influence of contracted endodontic cavities on the preservation of the original root canal anatomy after shaping with nickel-titanium (NiTi) reciprocating instruments.

Materials and Methods

Freshly extracted mandibular first permanent molars with fully formed apices were used in accordance with the local ethics committee. A sample size of 15 per group was calculated with G*Power 3.1.4 (Kiel University, Kiel, Germany) to set the study power at 80% (a large effect size equal to 1 was considered for the sample size calculated). Following debridement of the root surface, specimens were immersed in a 0.01% NaOCl solution at 4 °C for 24 hours and then stored in saline solution. A total of 40 teeth were selected. Specimens were mounted on a custom-made support in order to perform preliminary low-resolution micro-CT scans (SkyScan 1172: Bruker micro-CT, Kontich, Belgium) to attain an overall outline of the root canal anatomy and to ensure inclusion criteria were met (17). A total of 450 low-resolution preliminary scans were acquired through a 225° rotation (180° plus cone angle of the X-ray source) using a 1.0 mm-thick aluminum filter under the following parameters: voltage = 100 kV, current = 80 μA, source-to-object distance = 80 mm, source-to-detector distance = 220 mm, pixel binning = 8 x 8, and exposure time/projection = 0.2 s. NRecon (Bruker Micro-CT) software was used to reconstruct the axial slices with an isotropic voxel size of 36 μm. Reconstructed axial and volume parameters were visualized using DataViewer software (Bruker, Micro-CT) and morphological parameters of the mesio-buccal (MB) canals were calculated.

MB canals which met the following criteria were included in the analysis: canals measuring 12 ± 2 mm from the canal orifice to the apical foramen, 10°–30° primary root curvature in the clinical bucco-lingual view according to the Schneider method (18) and in the proximal view after a 90° rotation along the axis, $2 < r \leq 6$ mm main curvature radius (19), and a point of maximum curvature located within the middle third of the root canal. Teeth with confluent canals or accentuated isthmuses were included. Teeth with significant calcifications and those not concurring with the aforementioned inclusion criteria regarding canal curvature and patency were excluded.

Selected samples were then scanned at a higher spatial resolution (SkyScan 1172: Bruker micro-CT, Kontich, Belgium). A total of 2400 projections were acquired through a 360° rotation step using a 1.0 mm-thick aluminum-copper filter. High-resolution scans were conducted under the following parameters: voltage = 100 kV, current = 100 μA, source-to-object distance = 80 mm, source-to-detector distance = 220 mm, pixel binning = 2 x 2, total scan duration of 2 hours and 32 minutes. NRecon software was used to reconstruct the axial slices with an isotropic voxel size of 16 μm, and standardized parameters were used for beam hardening (60%) and ring artifact correction (7%). Reconstructed axial slices and volumes were visualized using DataViewer software. Image stacks were processed for volume registration, and matching and cutting plane selection by DataViewer software. The registration algorithm was based on the mean square difference between the grey values of the two image sets. The alignment steps were set to 0.9 microns with a 0.0001 unit tolerance on the voxel intensity. Root canal paths were analyzed with high-resolution 3D rendering and orthogonal cross sections to assess the baseline homogeneity of the groups (apical cross-sectional diameters 1 mm from the apical foramen, root canal surface area and volume). The Shapiro–Wilk test was used to determine normality, and the degree of homogeneity was evaluated by one-way ANOVA (5% level of significance).

Of 40 teeth assessed for inclusion, 10 were excluded due to anatomical features and severe calcification of the root canal. The remaining 30 teeth were randomly allocated to the experimental groups (n = 15) TEC and CEC (Figure 1). According to previous guidelines for the minimally invasive access, contracted cavities in the CEC group 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 (3, 20-23). The mesial-distal, buccal-lingual and circumferential precervical dentin removal was minimized (23). Traditional endodontic cavities in the TEC group were drilled following conventional guidelines: outline and cervical dentin were modified as needed until all orifices could be visualized in the same field of view and straight access to canal orifices could be achieved without coronal interferences(20-24) (Figure 1). The mean volume of removed dental tissue and the occlusal surface area of the endodontic cavities were measured. The mean angles of file access in the MB root canals was measured for both groups and in the CEC group the actual file access was compared with the assumed straight access (Fig. 3). The straight access design was determined in the maximum curvature view from the line between the center of the primary curvature and the corresponding pulp horn landmark (20). Following access cavity preparation, all MB root canals were shaped. Canal scouting and initial glide path were performed in all specimens with a size 10 K-file at working length (WL) using Glyde™ (Dentsply Maillefer, Ballaigues, Switzerland) as lubricating agent (0.80 mg) (25). WL was established under high magnification (OPMI Pro Ergo, Carl Zeiss, Oberkochen, Germany) by subtracting 0.5 mm from the length at which the tip of the instrument was visible at the apical foramen. The pulp chamber was filled with 5% NaOCl (Niclor 5, OGNA, Muggiò, Italy) throughout instrumentation. Mechanical glide path preparation was performed using ProGlider (PG) (Dentsply Maillefer, Ballaigues, Switzerland) (tip size 0.16 mm, taper 0.02 up to 0.85) and an endodontic engine (X-Smart, Dentsply Maillefer) with 16:1 contra angle at 300 rpm, 4 Ncm at full WL. A clinical professor experienced in endodontics using WaveOne Gold Primary (WOG) (0.25, 0.07 taper) and a X-Smart motor (300 rpm, 4 Ncm) shaped all specimens at WL. New instruments were used for each specimen and instruments were removed from the canal and cleaned after every three pecking motions until WL was reached. Mechanical instruments were used with in and out motion, with no intentional brushing effect. The number of pecking motions required for glide path with PG and shaping with WOG were recorded. Irrigation was carried out with disposable conventional hand-held syringes and 30G endodontic needles taken 2 mm short of the WL without engaging the root canal walls. Specimens were irrigated by alternating 5% NaOCl with 10% EDTA, to a total of 10 mL of each solution per specimen. Recapitulation with a size 10 K-file was performed between each instrument.

Root canals were dried with absorbent sterile paper points and micro-scanned for post-treatment analyses. Three-dimensional models of the root canals before preparation and after shaping with WOG were matched and micro-CT scans were managed to enable pre- and post-operative evaluation for each group.

Root canal sections and volumes were analyzed with CTAn software (Bruker, micro-CT). The volume of interest was set from the furcation to the anatomical root apex, generating 700–900 cross sections for each specimen, saved in bitmap format. Three-dimensional (volume and surface area) and 2D (root canal centroid shift, maximum and minimum diameter and cross-sectional area) parameters were assessed (26). Root canal volumes were calculated as the volume of binarized objects within the volume of interest. Surface areas were calculated from the exposed vertical surfaces by pixel differences between adjacent cross sections (27). Increases in volume and surface areas were analyzed for each group by subtracting the scores of the untreated canals from those of their treated counterparts. Root canal sections orthogonal to the canal axis were set at two levels: 1 mm and 3 mm from the apical foramen. These were selected as the areas most representative of the critical shaping points (13), and 2D parameters were analyzed at each level. The same cutting plane orientation was used for pre- and post-treatment samples. Axial slices were imported and analyzed with CTAn software using an automated minimum threshold algorithm (28). Micro-CT analyses were performed pre-operatively and after shaping by an experienced operator who was blind to specimen allocation. The major diameter was calculated as the distance between the two most distant pixels in the object. The minor diameter was defined as the longest chord orthogonal to the respective major diameter (26). Canal transportation was assessed from the centers of gravity that were calculated for each slice (17). The center of gravity for each scanning slice at the two levels of analysis was traced, and coordinates on both axes of planar images were recorded. Average canal transportation was subsequently calculated by the centroid shift, in millimeters, before and after instrumentation (17).

Data distribution was analyzed with the Shapiro–Wilk normality test. One-way ANOVAs ($P < 0.05$) were used to analyze any differences in the number of pecking motions, the volume of removed dental tissue and cavity surface area, the angles of file access, the increase of surface area and canal volume and shift in canal center of gravity at the two levels of analysis. One-way ANOVAs were performed to evaluate the impact of access cavity design (TEC/CEC) on geometric shaping outcomes. All statistical analyses were performed using the SPSS 24.0 software package (IBM, Endicott, USA).

Results

The mean curvature of specimens was 23.5° ± 3.6° (min = 16°, max = 30°) and 22.1° ± 2.5° (min = 14°, max = 29°) in the TEC and CEC groups, respectively, with no significant differences between groups ($P = 0.11$). Canal volumes, surface areas, and mean apical diameters at baseline are presented in Table 1. The parameters demonstrated pre-operative homogeneity between groups ($P < 0.05$). There was no incidence of instrument fracture during canal preparation. The mean volume of removed dental tissue during the two different access openings was 53.2 ± 8.9 mm^3 in TEC group and 23.01 ± 7.4 mm^3 in CEC group. The mean surface area of the endodontic cavities from an occlusal perpendicular view was 93.7 ± 13.2 mm^2 in TEC group and 63.61 ± 11.2 mm^2 in CEC group (Fig. 1). The mean angle of the file access in the mesial canals was 28.1° ± 4.6° with a traditional endodontic access and 37.6° ± 5.2° with a contracted access (Fig. 3). The mean difference between the actual file access and assumed straight access in the CEC group was 9.8° ± 4.1°. The reported parameters were significantly different between groups ($P < 0.05$).

Figure 2 illustrates the 2D matching of pre-operative (yellow) and post-shaping (red) root canal sections at -1 mm and -3 mm from the WL. The increase in canal volume and surface areas, shift of centroids, and the variations in maximum and minimum diameters and cross-sectional areas are presented in Table 2.

The mean number of pecking motions required to complete glide path was 3.6 ± 1.6 in the TEC group and 5.1 ± 2.2 in the CEC group. The mean number of pecking motions with WOG was 8.2 ± 2.3 in the TEC group and 13.5 ± 2.4 in the CEC group. Both parameters were significantly different between groups (*P* = 0.02).

No differences emerged between groups for the 3D parameters: Δ volume (*P* = 0.64) and Δ surface area (*P* = 0.16) (Table 2). The observed increase in centroid shift was significantly greater in the CEC group compared to the TEC group both at -1 mm (*P* = 0.02) and -3 mm (*P* = 0.01) from WL levels of analysis. The TEC group showed significantly reduced Δ cross-sectional areas at -1 mm from the WL compared to the CEC group (*P* = 0.05). No differences were found between groups for the other 2D parameters at either level of analysis. **Discussion**

The dental pulp chamber resides centrally in the tooth at the level of the cemento-enamel junction and is surrounded by a centrifugal perimeter of dentin and enamel (29). Access cavity has been described as an anatomic projection of the coronal pulp chamber and the clinician is guided during access by landmarks identified at the coronal level (19-24). Correct cavity access provides several advantages, including optimal instrumentation and adequate irrigation of the root canal system, thereby influencing the success of endodontic therapy (3). Although endodontic procedures may reduce the resistance of a tooth, maintenance of a sound tooth structure may result in the improved prognosis of a tooth subjected to cyclical occlusal loads (22, 30–33).

Contracted endodontic cavities are characterized by a smaller morphology, and therefore a more conservative appearance, than their traditional counterparts. They increase endodontically treated tooth resistance, resulting in a greater preservation of dental tissue (8, 20-22). Furthermore, prior study has demonstrated that TEC leads to lower fracture strength than CEC (22, 32-33).

It is crucial to shift the modern operative approach towards a conservative philosophy (6), but it is also mandatory to ensure sufficient endodontic access to enable optimal shaping. It is argued that contracted endodontic cavities may lead to operative difficulties during canal shaping, with coronal interferences having the potential to cause root canal transportation towards the outer aspect of the curvature.

Micro-CT scans represent an effective, validated and reproducible tool to evaluate root canal preparations (12, 14–17). The micro-CT analysis described here highlighted some statistical differences between the tested groups in terms of the maintenance of the original canal anatomy. The use of micro-CT to match volume rendering of teeth before and after treatment enables the 3D analysis of canal volume and surface area, and 2D analysis of root canal sections orthogonal to the canal axis at different levels (17, 26).

In this study, shaping outcomes after instrumentation with WaveOne Gold Primary were analyzed. The centroid shift observed in the CEC group was statistically higher than that observed in the TEC group, at each analyzed level. This may be due to coronal interferences that led to excessive pressure of the instrument against the outer aspect of the root canal curvature, and to the increased number of pecking motions required to reach the WL. Moreover, the cutting ability of the instrument could have been affected by a more difficult removal of debris during shaping. It is suggested that WaveOne Gold Primary should provide well-centered and conservative preparations due to its flexibility (34). This instrument shows a decreasing taper from D1 to D16 in order to minimize coronal dentin removal and thinning of radicular walls towards the respective danger zone. The use of even less tapered instruments could be preferred in terms of root canal transportation, especially in the mesial roots of lower molars (35).

In the present study, no instrument fracture occurred. Although this is a potential risk when accessing canals through a restricted access, the occurrence was mitigated by the use of WaveOne Gold instruments, which have a higher resistance to fatigue than rotary instruments (22, 36). Moreover, WaveOne Gold single file system was selected in order to reduce the operator influence on shaping outcomes and on the number of pecking motions required for the instrumentation up to working length (22). However, the analyzed data showed a statistical difference between groups in terms of the number of pecking motions required to reach the full WL. The higher number of pecking motions in the CEC group was possibly related to the presence of coronal interferences, which may have led to an increased straightening of the root canal curvature and apical transportation (17, 21-22).

In conclusion, within the limitations of this in vitro study, TEC seems tolead to a better preservation of the original canal anatomy during shaping compared to CEC, particularly at the apical level. Future experiments with higher sample sizes and shaping instruments with lesser taper and long-term clinical studies should be encouraged about this topic.

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Figure legends

Fig. 1. TEC and CEC in mandibular molars. The occlusal view from micro-CT cross-sections perpendicular to the occlusal plane of TEC (A) and CEC (B). The sagittal view of TEC (C) and CEC (D) from 3D volumetric representations.

Fig. 2. Image matching of pre-instrumentation and post-shaping sections according to the previously selected cutting plane at -3 mm (A - B) and -1 mm (C - D) from WL. Traditional endodontic access group (TEC) (A - C) and contracted endodontic access group (CEC) (B - D). Note the difference between pre-treatment (green) and post-shaping (red) with WaveOne Gold Primary.

Fig. 3. Three-dimensional volumetric representation of micro-CT data showing the angle of file access in the MB canals in the maximum curvature view for TEC (A) and CEC (B) groups. The blue line in B shows the different access angle after a complete removal of the pulp chamber roof and coronal interferences.

Table 1. Sample baseline characteristics in all groups (mean ± SD). Apical diameters (mean ± SD) at 1 mm from apical foramen. (TEC = Traditional endodontic cavity; CEC = Contracted endodontic cavity) (*$P < 0.05$).

Table 2. 3D and 2D parameters utilized for post-instrumentation analysis in each group (TEC = Traditional endodontic cavity; CEC = Contracted endodontic cavity). Different superscript letters in the same column indicate statistically significant differences between groups ($P < 0.05$). For 2D parameters (centre of gravity shift, Δ min diameter, Δ max diameter and Δ cross sectional areas) consider comparison of significance for the same level of analysis (- 1 mm, - 3 mm). Statistically significant differences among groups are listed for the center of gravity shift parameter.