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File Breakage in Conventional Versus Contracted Endodontic Cavities

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ABSTRACT

Objective: To compare rotations to failure and tip separation length of a nickel-titanium (Ni-Ti) rotary instrument within a simulated mesio-buccal canal of a mandibular molar with a conventional or contracted endodontic cavity.

Methods: Two identical lithium disilicate #30 crowns were milled. A conventional or contracted endodontic cavity was prepared. A custom glass tube was fabricated with taper and length replicating a mesio-buccal canal, including buccal and lingual curvature, and placed at the mesio-buccal orifice of each crown, held in a silicone mold. Instrumentation was simulated using 30/.04 Ni-Ti rotary files following manufacturer recommended 1.8 Nm torque and 500 RPM (n=20 per access type). Instrumentation was video recorded to determine time (seconds) and rotations to failure. The length of broken tips was measured. The experimental data were compared using a t-test (significance level 0.05). Stresses in the instruments were examined using finite element analysis.

Results: Number of rotations to failure (mean±standard deviation) was 599±126 for conventional and 465±65 and for contracted access; tip separation lengths (mean±standard deviation) were 3.99±0.29 for conventional and 4.90±1.02 mm for contracted access. Number of rotations to failure and tip separation lengths were significantly different between the two access openings ($p<0.001$). Finite element analysis confirmed higher file curvature and accompanying higher stress levels with contracted access and the maximum stress further from the tip.

Conclusion: Within the limitations of this study, the contracted access caused earlier failure of the Ni-Ti instrument with longer tip separation lengths than the conventional access due to higher stresses towards the middle section of the instrument.

Keywords: Contracted endodontic cavity, conventional endodontic cavity, endodontic access, fatigue, file breakage, stress

HIGHLIGHTS

- Contracted access caused higher stresses towards the middle section of the instrument.
- Contracted access led to earlier failure of Ni-Ti instruments than conventional access.
- Contracted access led to longer tip separation lengths than conventional access.

Part of this study has been presented at the annual meeting of the American Association of Endodontists in Phoenix, AZ (April 2022).

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INTRODUCTION

The design of an endodontic access cavity is a key first step in performing sound root canal therapy. Traditionally, endodontic cavities were designed to allow straight-line access into all canal orifices, which describes a preparation that provides a straight, unobstructed path to the canal system and ultimately to the root apex (1, 2). This access design allows for improved debridement of the canal space and reduces the risk of file breakage (2), but at a cost of removing a substantial amount of tooth structure. As minimally invasive dentistry becomes more practiced, the principles behind the endodontic access cavities are changing (3).

An alternative to a traditional endodontic cavity, the contracted cavity, decreases the amount of coronal dentine removal, which is linked to long-term survival of a tooth (4). Contracted endodontic cavities are therefore performed to conserve tooth structure and improve fracture resistance (5). However, there is still controversy. Studies have shown that a contracted endodontic cavity did not offer any advantage when evaluating efficacy of canal instrumentation and fracture resistance in mandibular and maxillary molars (6, 7). Moreover, the contracted endodontic cavity is less accessible and requires an increased angle of file access, which has been shown to decrease cyclic fatigue resistance of heat-treated rotary instruments (8).

Fatigue is an incremental crack propagation process induced by the cyclic loading to which rotary instruments are subjected during instrumentation. Even though nickel-titanium (Ni-Ti) alloy, first introduced for endodontic instruments in the late 1980's (9), has great elasticity and shape memory, Ni-Ti file breakage still happens during clinical use (10). Careful cross-section design and shaping as well as complex heat-treatment processes have improved the cyclic fatigue resistance of Ni-Ti (11–13). Manufacturers have also incorporated controlled memory wire into these instruments for greater flexibility and further improved fatigue resistance (14). Notwithstanding the rapid advances in file technology (15), file breakage is still a concern.

Both endodontists and general practitioners have experienced fractured instruments at rates of 94.8% (endodontists) and 85.1% (practitioners) (16). This higher rate of instrument separation for specialists is likely due to the volume treated and treatment of more difficult cases. The mesiobuccal canal of mandibular molars claims most of the fractured instruments (17). This is due to several factors, including the radius, location, and degree of canal curvature (18, 19). Canals with a >25° curvature had the highest rate of instrument fracture with an overall mean separated fragment length of 2.96 mm, and 91.4% of these instrument separations occurred in the apical third (20).

Contracted access adds an additional curvature in the instrumentation path, which will cause higher stresses in the files, potentially increasing the fracture risk further. To the best of our knowledge, no other studies have directly compared the difference in file breakage between straight-line access in conventional preparations and angle access in contracted preparations. Therefore, the purpose of this study was to compare file breakage during instrumentation when accessed through conventional or contracted endodontic cavities. Rotations or time to failure and tip separation lengths of Ni-Ti rotary instruments within an *in vitro* simulated mesio-buccal canal of a mandibular molar were recorded and stress distributions were examined using finite element analysis. The null hypothesis was that the rotations to failure and tip separation lengths would not be significantly different between the conventional and the contracted endodontic cavities.

MATERIALS AND METHODS

The study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board as Not Human Subjects Research since it did not involve "human subjects" as defined in 445CFR46.102(e)(1) (IRB #22-09137-NHSR; 12 December, 2022).

In vitro Analysis

Two identical lithium disilicate (IPS e.max CAD LT B1/C14, Ivoclar Vivadent, Buffalo, NY, USA) mandibular right first molar (#30) crowns were milled with CAD/CAM (Sirona MC X Dental Lab CAD/CAM, Ivoclar Vivadent) according to average dimensions (occlusal table: mesio-distal 11.0 mm, buccal-lingual 10.5 mm; mesio-buccal cusp to CEJ 6.5 mm) (21–23). Both crowns were then placed in a furnace (Programat CS2, Ivoclar Vivadent) to crystallise for 15 minutes. A conventional and contracted endodontic cavity was prepared using a round #2 diamond bur (Kerr, Brea, CA, USA) in each crown along with creating a mesio-buccal orifice with a taper diamond bur (Kerr, Brea) (Fig. 1a, b). The conventional endodontic cavity was 5 mm bucco-lingually, 5 mm mesio-distally and the contracted endodontic cavity was 3 mm bucco-lingually, 3 mm mesio-distally.

A custom glass tube (Precision Glassblowing, Centennial, CO, USA) was fabricated with taper and length replicating a mesio-buccal canal of tooth #30, including mesio and distal curvature. The glass tube was 13 mm long, the inner diameter at orifice level was 2.5 mm and at apical level 2.0 mm, the wall thickness was 0.8 mm, and the mesio-distal bend was 28° at 5 mm from the orifice. During fabrication of the glass tube, the glass blower could not add a secondary curvature in the buccal-lingual direction. A cut was made 5 mm below orifice level and the apical segment was rotated towards the lingual to obtain the second curvature (buccal-lingual). This secondary curvature was added in an attempt to resemble a natural mesio-buccal canal of a lower first molar. The glass tube was placed at the mesio-buccal orifice of each crown in a silicone mold (Megabite, DenMat, Lompoc, CA, USA) (Fig. 1c), and fixed to a three-pronged laboratory clamp stand for file breakage testing.

Forty Endosequence Controlled-Memory Ni-Ti rotary files (Brasseler, Savannah, GA, USA) in size 30/.04 and 21 mm length were used following manufacturer-recommended 1.8 Nm torque and 500 RPM (n=20 per access type). A Promark endodontic motor (Densply Sirona, York, PA, USA) along with an endodontic contra-angle handpiece (Tulsa Dental Specialties Contra Angle, Densply Sirona) was used for handheld instrumentation in both accesses. The access cavities affected the angle of file insertion, with the contracted endodontic cavity causing the handpiece to deviate to the distal-lingual (Fig. 1d, e). Instrumentation and time to failure (seconds) were video recorded with a smartphone camera (iPhone SE, Apple, Cupertino, CA, USA). After each test, the broken file tip was removed from the glass canal. The number of rotations to failure was calculated from start of instrumentation to the time to failure, and the length of broken tips (mm) was measured with digital calipers (Swiss Precision Instruments, Altstätten, St Gallen, Switzerland).

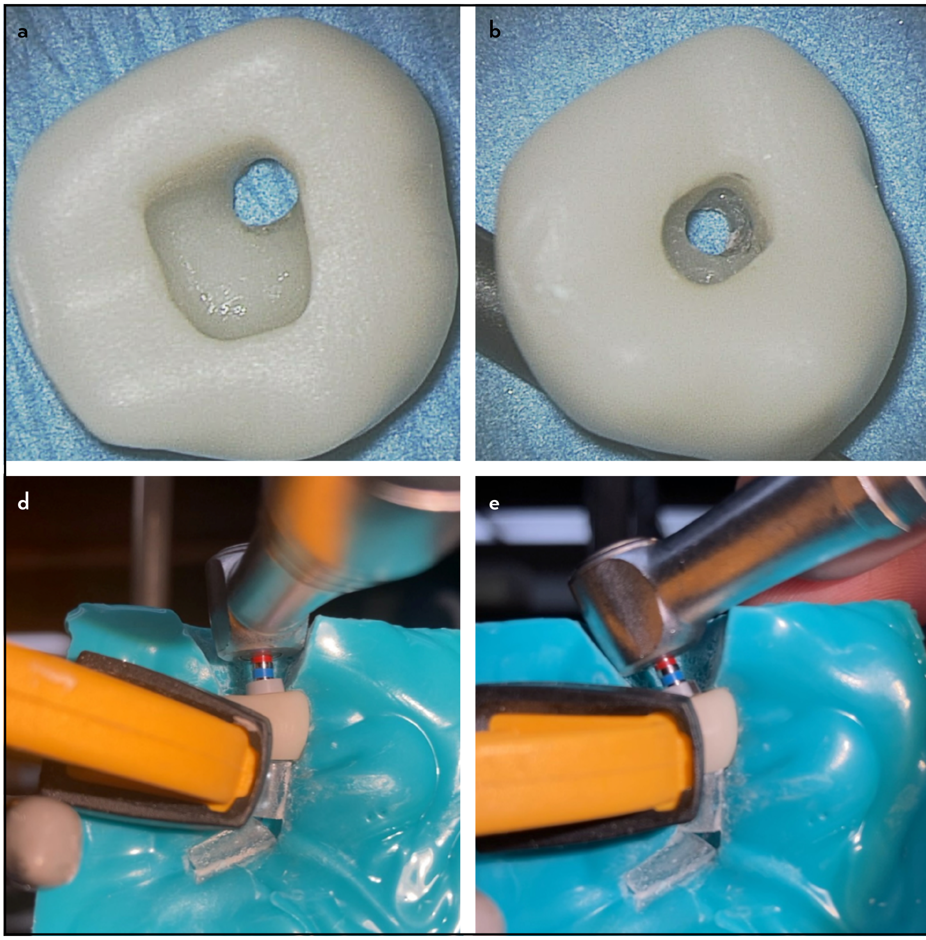

Figure 1. Machined lithium disilicate #30 crowns with (a) conventional endodontic cavity (5 mm×5 mm) and (b) contracted endodontic cavity (3 mm×3 mm) with a mesio-buccal orifice. The curved glass tube was placed at the mesio-buccal orifice of each crown and fixed in a silicone mold for file breakage testing (c). File breakage test with conventional endodontic cavity (d) and contracted endodontic cavity (e), showing the angles of file insertion.

Statistical Analysis

The number of rotations to failure and the tip separation length data for the conventional and constricted access results were compared using a t-test after testing for normality (Kolmogorov-Smirnov test) and homogeneity of variance (Levene's test). Significance level was 0.05. Software used for the statistical analysis were tools available online for the normality and homogeneity calculations (https://www.socscistatistics.com/tests/) and statistical functions embedded in Excel for the t-test (Microsoft Corporation, Redmond, WA, USA).

Stress Analysis

Stress distributions in the file when subjected to instrumentation through a conventional or contracted access were calculated using finite element analysis (MSC.Marc, MSC Software, Santa Ana, CA, USA). The two access cavities and mesio-buccal canals were recreated with three-dimensional rigid surfaces using nonuniform rational B-splines (NURBS), dimensioned after the experimental setup. Dimensions are indicated in Figure 2. A generic constant-taper file instrument with a triangular cross-section (15 threads over 16 mm working length; 0.30 mm diameter at D0 and 1 mm diameter at D16, 0.044 taper) was created using 7650 8-noded hexahedral elements. The applied Ni-Ti properties were an elastic modulus of 36 GPa and Poisson's ratio of 0.30 (24). The file instrument, held and controlled at the end of the shaft, was inserted straight into the canal with the conventional access or under a 25° angle for the constricted access until the file tip was 0.5 mm from the apex (Fig. 2). The file was then rotated within the simulated canal. The friction coefficient between file instrument and the rigid cavity and root walls was 0.25. Von Mises equivalent stress values in the file, which include all three-dimensional normal and shear stress components, were collected for one complete rotation (360°) to study differences in stress distributions between the two access cases.

RESULTS

The time and number of rotations to failure, as well as the tip separation results, are listed in Table 1. The file failed significantly faster (22%) when instrumenting through the contracted access opening than the conventional access opening (t-test, p=0.0002). The contracted access also caused significantly longer file tip separation lengths (23%) compared to conventional access cases (t-test, p=0.0009).

File curvature from tip-to-shaft, measured in degrees, doubled when instrumenting through the contracted access (53.73±0.58) compared to the conventional access (25.47±0.07) (mean±standard deviation). Maximum stress values (von Mises) calculated by the finite element analysis in each cross-section were averaged and plotted along the length of the file (Fig. 3). The maximum stress values in the file were almost 3 times higher when instrumentation was angled through the contracted endodontic access opening compared to the conventional straight-line access. The highest stresses occurred closer to the tip at about 4 mm distance

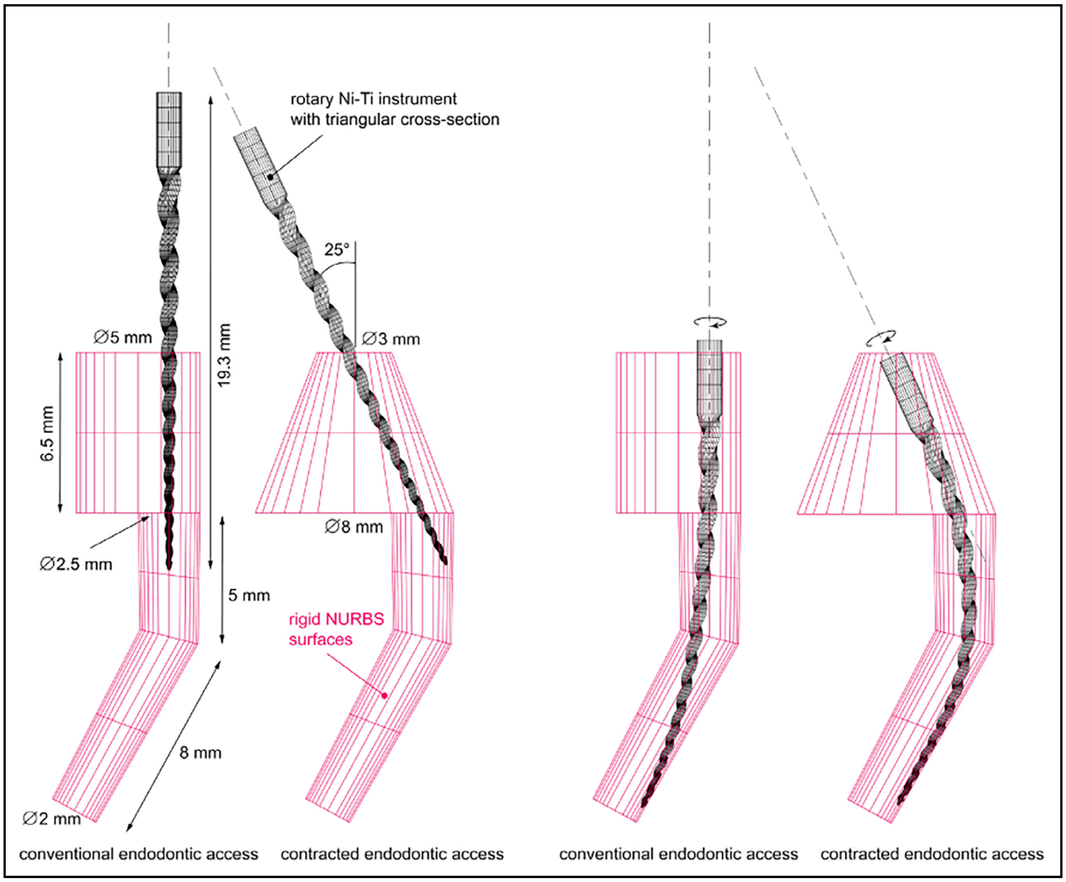

Figure 2. Finite element analysis of instrumentation with a rotary file through a simplified conventional or contracted endodontic access: Model dimensions and rotation after insertion to 0.5 mm from root apex

NURBS: Nonuniform rational B-splines

for the conventional access. With the contracted access the highest stresses occurred at 5 to 9 mm distance from the tip.

DISCUSSION

Minimally invasive techniques are being introduced to contemporary endodontics treatment in hopes of preserving tooth structure (3). Smaller endodontic accesses, also called contracted endodontic cavities, are being practiced to achieve this goal. This study investigated if smaller contracted accesses could affect when and where files would fracture compared to a conventional endodontic cavity because instrument fracture can negatively affect the outcome of root canal treatment. We found that the number of rotations to failure and mean tip separation length were significantly different between the two endodontic access cavities. The contracted endodontic cavity caused earlier fracture of the file and tip separation length was longer when instrumenting through the contracted endodontic cavity. The null hypothesis that there would be no difference in rotations to fracture and in tip separation length between the conventional and contracted endodontic cavities was therefore rejected.

Although this is the first study to directly compare the difference in file breakage between the two access types, file access at an increased angle has been shown to decrease cycles to failure of Ni-Ti rotary files (8). The current study indicated that the contracted access imposed bending of the rotary instrument that was double compared to the conventional straight-line access, suggesting a significant difference in stress level. To determine how much the increase in curvature would increase stresses and how such stresses would distribute along the file length, further analysis was required. Finite element stress analysis demonstrated that substantially higher stress levels

TABLE 1. Time and number of rotations to file failure and tip separation lengths (mean±standard deviation) for two types of access openings

	Conventional endodontic cavity	Contracted endodontic cavity	p*
Time to failure (seconds)	71.90±15.16	55.75±7.78	0.0002
Number of rotations to failure	599±126	465±65	0.0002
Tip separation length (mm)	3.99±0.29	4.90±1.02	0.0009

*: t-test for unequal variance (significance level 0.05)

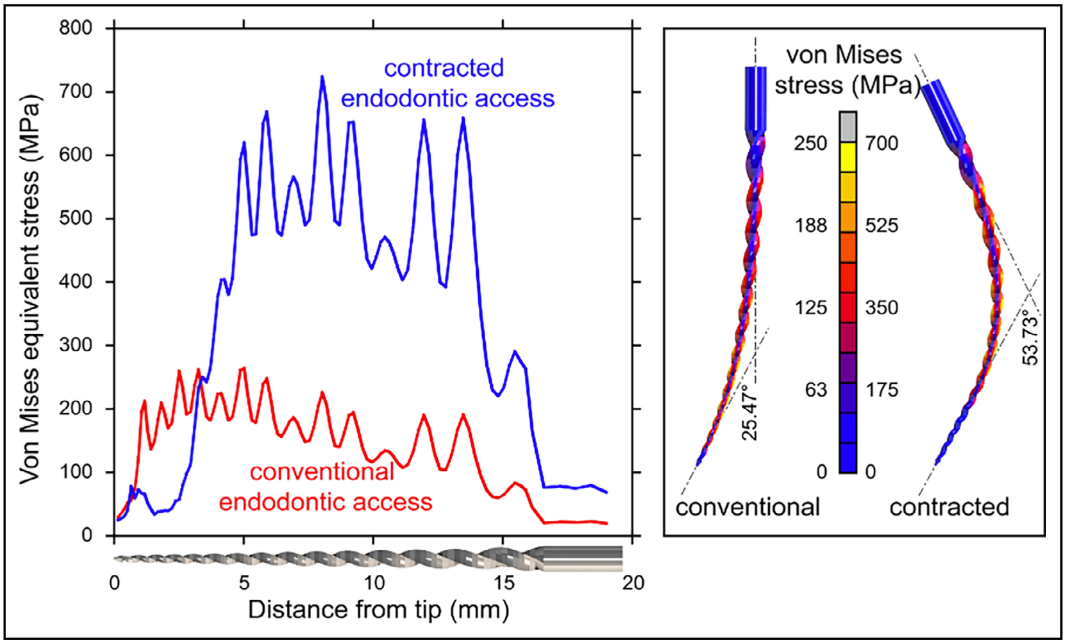

Figure 3. Averaged maximum stress values (von Mises) in cross-sections along the file length during 360° rotation and stress distribution in the file when instrumented through conventional or contracted endodontic access openings. Note the different stress scales for the conventional and contracted access. Tip-to-shaft curvature for both access configurations is indicated in degrees

(almost 3 times higher) were created in a rotary instrument when it was angled through a contracted endodontic cavity compared to a conventional straight-line access. These higher stresses can explain the shorter fatigue life we found for the instruments used in the contracted cavity. Even though most clinicians would not use a file in a single canal for the 71 seconds (conventional) or 55 seconds (contracted) it took to break in this study, instrumenting multiple canals in a single tooth or multiple teeth and re-using instruments could add up to this time, thus increasing the frequency of possible file separation.

Besides the number of cycles to failure, tip separation lengths were also significantly different between the two access cavities in the *in vitro* experiment. The finite element analysis demonstrated that the highest stresses occurred further from the tip when instrumentation was conducted at an angle through the contracted endodontic cavity compared to the more direct conventional access. Since instruments are likely to fatigue fastest in areas of highest stresses, it explains why the longest separation lengths were found with the contracted cavities. The higher probability of fracture further from the tip is clinically relevant because removal of these instruments becomes increasingly difficult with greater separated file lengths and higher degrees of curvature, which can significantly reduce the treatment prognosis (25, 26).

This was an *in vitro* study that could not account for all variables encountered clinically. In order to standardise the experiment, several study design choices had to be made. We chose to simulate dimensions and canal curvature for a mesio-buccal canal of a mandibular first molar due to its high incidence of instrument fracture (17). To ensure all tests were subjected to the same conditions, cavity and root materials were chosen to resist wear. Using a real tooth would have resulted in the removal of tooth structure during instrumentation and therefore a change in the shape of the canal, making standardisation impossible (27). Crowns were therefore fabricated from lithium disilicate crowns and the root from a curved glass tube. Several studies have used glass tubes as surrogate canals to test fatigue failure for the same reasons (28,29). Heat-treated controlled memory Ni-Ti rotary files were used because of their improved cyclic fatigue resistance and ability to navigate difficult anatomy (14). A size 30/.04 file was applied for instrumentation since it is the minimum apical preparation size to adequately debride a mesiobuccal canal of a lower molar (30). Whilst the lithium disilicate cavity and glass canal enabled us to perform a consistent comparison of the fatigue behaviour of the instruments under the two endodontic access conditions, it did not replicate the cutting and debriding processes that take place in a real root canal during clinical instrumentation. Cutting and debriding forces may cause additional spikes in torsion. Future studies could investigate their extent on further reduction of fatigue resistance.

This study mimicked a clinical scenario by using a model that resembled a mesio-buccal canal of a lower first molar. From our results, contracted endodontic access cavities caused earlier failure of heat-treated controlled memory Ni-Ti rotary files with longer separated tip lengths. This result warrants more studies regarding this access design and file breakage. The experimental design developed for this study is well suited for comparing breakage behaviour from different access situations and rotary file types. For example, reciprocating rotary instruments are becoming popular among the many types currently on the market. Reciprocating rotation in rotary Ni-Ti instruments has been shown to have a higher fatigue resistance than continuous rotation (31). A future study should therefore also compare the effect of fatigue resistance in conventional and contracted endodontic cavities for reciprocating instruments.

CONCLUSION

Within the limitations of this study, the contracted access caused earlier failure of a Ni-Ti instrument with longer tip separation lengths than the conventional access due to higher bending and thus higher stresses in the coronal third of the curved canal. Even though Ni-Ti instruments are now heat-treated and more flexible, caution must be taken when instrumenting canals through a contracted endodontic cavity.

Disclosures

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