Original Research
Endodontic Therapy

Diamond-coated ultrasonic tip decreases debris and uninstrumented surface after preparation of curved canals with isthmus

Maria Luiza GIOSTER-RAMOS[(a)]
Mariana Mena Barreto PIVOTO-JOÃO[(a)]
Jáder Camilo PINTO[(a)]
Juliane Maria GUERREIRO-TANOMARU[(a)]
Mário TANOMARU-FILHO[(a)]

[(a)]Universidade Estadual Paulista – Unesp, School of Dentistry, Department of Restorative Dentistry, Araraquara, SP, Brazil.

Abstract: The aim of this study was to evaluate root canal preparation with nickel titanium rotary instruments and complementary preparation with ultrasonic tip in curved canals of mandibular molars with isthmus. Twenty-eight mesial roots of mandibular molars with curvature between 20° and 40° and presence of isthmus throughout the entire extension of the root canals were prepared using ProDesign Logic CM (PDL) up to size 40.05, or HyFlex EDM (HFEDM) up to size 40.04. Complementary preparation was performed in the isthmus region using the ultrasonic insert E18D (Helse, Istmo Diamantada). The root canals were scanned using micro-CT (SkyScan 1176) at 9 µm voxel size before and after each preparation step. Transportation, percentage of increase in volume, debris and uninstrumented surface (UNS) were evaluated. Mann Whitney, Wilcoxon, paired and non-paired t-tests were used for statistical analysis ($\alpha = 0.05$). The canals prepared with PDL and HFEDM obtained similar results for all the variables assessed before using E18D ($p > 0.05$). E18D significantly decreased the percentage of debris and UNS values in both Groups ($p < 0.05$). The complementary preparations with E18D caused a smaller quantity of debris in the isthmus of the canals previously prepared with PDL in comparison with HFEDM ($p < 0.05$). PDL and HFEDM provided similar root canal preparation. PDL promoted a smaller quantity of Debris in the isthmus than HFEDM after using E18D. E18D significantly improved cleaning, and reduced Debris and UNS.

Keywords: Dental Pulp Cavity; Root Canal Preparation; X-Ray Microtomography.

Declaration of Interests: The authors certify that they have no commercial or associative interest that represents a conflict of interest in connection with the manuscript.

Corresponding Author:
Mario Tanomaru-Filho
E-mail: tanomaru@uol.com.br

https://doi.org/10.1590/1807-3107bor-2023.vol37.0102

Submitted: January 25, 2022
Accepted for publication: April 29, 2023
Last revision: May 9, 2023

Introduction

During root canal preparation, the use of mechanized instruments promotes a smear layer that can accumulate, particularly in the anatomic complexities of the root canal.[1,2] The presence of complexities in the root canal system (RCS), such as isthmus and curvatures, make it difficult to perform cleaning and disinfection.[3] The isthmus area is capable of maintaining microorganisms,[4] accumulating debris after root canal preparation[5,6] with different cleaning protocols.[7,8] The presence of isthmus occurs with high frequency in the mesial roots of mandibular first molars,[9,10] particularly in the middle third.[9,11,12]

Preparation of root canals with Nickel Titanium (NiTi) instruments maintains their original anatomy.[13,14] NiTi instruments with heat treatment have high flexibility and cyclic fatigue resistance, making it possible to perform greater apical enlargement[15–17] with centralized preparation in root canals with curvature[18,19]. Apical enlargement improves the cleaning of root canal systems[19], by diminishing the area of uninstrumented surface[8] and favoring irrigation.[2,20]

ProDesign Logic (PDL) (Easy Equipamentos Odontológicos, Belo Horizonte, Brazil) is a rotary system manufactured with NiTi alloy with heat treatment Control Memory, (CM).[21] The HyFlex EDM (HFEDM) System (Coltene/Whaledent, Altstätten, Switzerland) is manufactured with NiTi alloy with heat treatment CM and an additional process of electro erosion, that favors mechanical strength, and increases both the flexibility and cyclic fatigue resistance.[22,23] PDL and HFEDM are capable of maintaining the preparation centralized in curved canals.[24]

However, no instrumentation technique has been capable of preparing all the root canal walls.[25–27] The use of ultrasonic activation in the root canal preparation of flat and oval canals promoted greater reduction of uninstrumented surface.[28] The ultrasonic tip E18D– Istmo Diamantada (Helse Ultrasonic, Santa Rosa de Viterbo, Brazil) has been proposed for preparing areas of isthmus. It has a tip diameter 33, active part of 12 mm with conicity of 0.02, and cutting action for areas of isthmus. There are no studies that have evaluated the action of the E18D tip.

The aim of the present study was to compare the root canal preparation performed by using NiTi rotary systems up to size 40, and the efficacy of complementary preparation using ultrasonic E18D tip in canals with the presence of isthmus and curvature. The first null hypothesis was that PDL and HFEDM would have similar preparation ability. The second null hypothesis was that the E18D insert would have no influence on the percentage of debris and uninstrumented surface in root canals with the presence of isthmus and curvature.

Methodology

Sample calculation

The sample calculation was performed using G* Power software (3.1.7 for Windows, Heinrich Heine, Universitat Dusseldorf, Germany). An alpha–type error 0.05 and power beta 0.80 was established for all the variables. For t–test in two independent groups, previous studies with similar methodology were used to calculate the effect size of each variable: Debris, 1.3782;[2] percentage of increase in volume, 4.0249; uninstrumented area, 1.1773; and transportation, 4.0249.[18] For t–test in dependent means, a previous study[29] was used to determine the effect size for debris, 2.7110 and uninstrumented surface, 2.0064. A total of 13 specimens for each group was indicated as being the ideal size required. A sample of 14 root canals per group was determined.

Sample selection

After approval of the Institutional Ethics Committee (CEP No. 02733618.9.0000.5416), 28 mesial roots of extracted human mandibular molars with a curvature between 20° and 40° (Schneider, 1971)[30] and presence of isthmus throughout extension of the root canal were selected. For specimen selection, the teeth were radiographed (Kodak RVG 6100), and the degree of curvature was evaluated using the Image J program (National Institutes of Health, Bethesda, MD, USA). All teeth selected were scanned, at 35 µm of voxel size, using the micro–CT device SkyScan 1176 (Skyscan 1176, Bruker–microCT, Konttich, Belgium), with the following parameters: copper and aluminum filter, exposure time of 87 milliseconds, frame averaging of 3, rotation of 180°, rotation step of 0.5, 80 kV, and 300 µA. The three–dimensional images were used for evaluating the presence of isthmus and initial volumetric analyses. The roots were divided into two groups (n = 14), by simple random stratified sampling, taking into consideration the initial volume of the canals. The access cavities were performed in the conventional manner, and the working length was defined at 1 mm short of the apical foramen, by using a type K#10 file (Dentsply, Maillefer, Switzerland). The roots were placed in acrylic resin appliances, surrounded with condensation silicone (Oranwash, Zhermack SpA, Badia Polesine, Italy) to simulate the periodontal ligament, as was done in a previous study.[19] All the preparation and complementary procedures were performed by a trained and calibrated operator, under a surgical microscope at 13x magnification (D.F. Vasconcellos, Valença, Brazil).

Root canal preparation

PDL: The Instruments with size 25.01 were activated by means of an electric motor (VDW.SILVER, VDW GmbH, Munich, Germany) at 350 rpm and 1 Ncm in accordance with the manufacturer's specifications, using in-and-out movements up to the working length. After this, the instrument PDL size 25.06 and PDL size 40.05 were used at 600 rpm and 3 Ncm, with in-and-out movements up to the working length, in accordance with the manufacturer's specifications for curved canals.

HFEDM: The Instruments with size 10.05 were used, activated by means of an electric motor (VDW.SILVER, VDW GmbH, Munich, Germany) at 300 rpm and 1.8 Ncm in accordance with the manufacturer's specifications, with in-and-out movements up to the working length. After this, the instrument HFEDM size 25.08 and HFEDM size 40.04 were used at 500 rpm and 2.5 Ncm, with in-and-out movements up to the working length.

Root canal irrigation was performed with 5 mL of 2.5% sodium hypochlorite (NaOCl) for each instrument, using a 30G side-vented needle (NaviTip, Ultradent Products, South Jordan, UT) adapted to a 5 mL syringe (Ultradent Products). As final irrigation, 5 mL of 2.5% NaOCl was used, followed by agitation of 17% EDTA for 3 minutes and application of 5 mL of physiological solution. After the irrigation procedures all canals were dried with absorbent paper cones, corresponding to the preparation (Tanari Indústria Ltda., São Paulo, Brazil).

Complementary preparation with ultrasonic tip

Preparation of the isthmus region was performed with the E18D tip (Figure 1) coupled to the Ultrawave XS ultrasonic device (Ultradent, South Jordan, USA) at a frequency of 50/60 Hz and 20% power. The tip was activated in the buccolingual direction up to 4 mm of the working length. Three cycles of 30 seconds were performed, 15 s towards the mesiobuccal canal and 15 s towards the mesiolingual canal. The tip was positioned in contact with the isthmus, then used with in-and-out movements, thus being activated for 10 seconds without irrigation and 5 seconds with irrigation with water. For each cycle, 3 mL of 2.5% NaOCl were used (1.5 mL before and 1.5 mL after the cycle).

Analysis by micro-CT

Before and after preparation and after the use of the ultrasonic tip, the specimens were scanned using

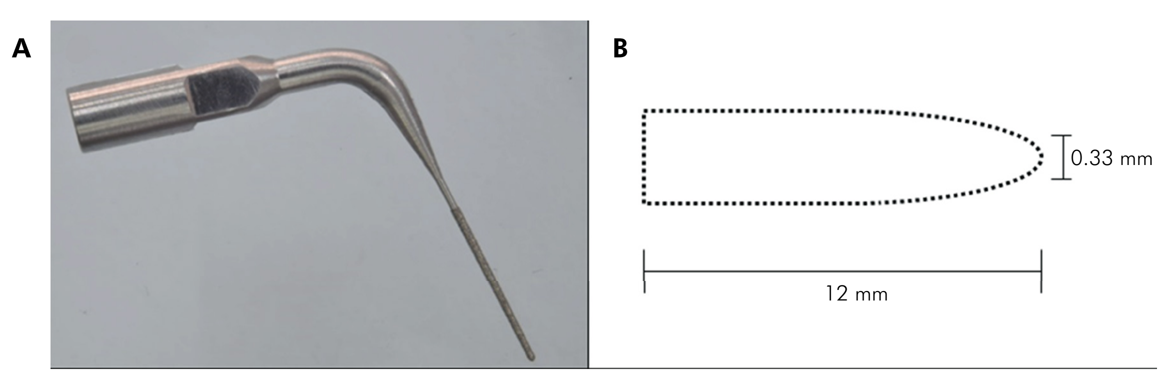

Figure 1. Representative image of ultrasonic tip. (a) E18D– Diamond Isthmus (b) Representative drawing of active part of E18D– Diamond Isthmus.

the micro-CT device SkyScan 1176 microtomograph (Skyscan 1176, Bruker-microCT, Konttich, Belgium). A Cu + Al filter was used, and the voltage and current applied were 80 kV and 300 mA respectively, with a exposure time of 200 ms, rotation step of 0.05, voxel size 9 µm and 180° rotations around the vertical axis. The datasets obtained were reconstructed using NRecon software (v.1.6.3; Bruker-microCT) and superimposed on the "3D register" function of the Data Viewer software (v.1.5.1; Bruker-microCT). The images were analyzed by the CTAn software (v.1.14.4; Bruker-microCT) and the 3D images were generated in the CTVox software (v.3.2.0.0; Bruker-microCT). Each parameter was evaluated for the entire root canal and in the isthmus. An approximate value of 9 mm was determined for analysis of the total length. CTAn software was used to determine the lower part of the root that corresponded to the the bottom value, and then 9 mm was added to this value to determine the top value..

Initial volume, final volume and final surface after preparation values were obtained. Based on these values, the percentage increase in volume, percentage of debris and percentage of uninstrumented surface of the canal and isthmus were calculated, using the following formulas:[31]

$$\%\ \text{Increase in Volume} = \left(\frac{\text{Final Volume}}{\text{Initial Volume}}\right) \times 100 - 100$$

$$\%\ \text{Debris} = \frac{\text{Volume of Debris} \times 100}{\text{Final Volume}}$$

$$\%\ \text{Uninstrumented Surface} = \frac{\text{Uninstrumented Surface} \times 100}{\text{Total Surface}}$$

Transportation was analyzed by means of the shortest distance between the mesial edge of the root and the canal before (X1), and after preparation (X2), shortest distance between the distal edge of the root and the canal before (Y1), and after preparation (Y2). Cross-sections were determined by the arithmetic mean. Transportation was obtained by means of the equation: (X1-X2) - (Y1-Y2) as proposed by Gambill.[32] Five cross-sections were measured for each third (cervical, middle and apical and determined by the arithmetic mean value. The thirds corresponded to 3, 6 and 9 mm from the anatomic apex, with each third covering 3 mm of the extension of the canal.

Statistical analysis

The data obtained were submitted to the Shapiro Wilk normality test. When data distribution was not normal, the Mann Whitney tests was used for comparisons between groups; and the Wilcoxon Paired test for comparisons between the groups before and after complementary preparation. When data distribution was normal, the non-paired t- test was used for comparisons between the groups, and the Paired t-test for comparisons between the same groups before and after complementary preparation. The level of significance adopted for all analyses was 5%.

Results

The E18D tip significantly decreased the percentage of debris and uninstrumented surface in the canal and isthmus in both groups ($p < 0.05$). The percentage of increase in volume and transportation were similar between Groups PDL and HFEDM before and after use of the E18D tip ($p > 0.05$) (Tables 1 and 2). PDL showed a lower percentage of debris than HFEDM in the isthmus after use of the E18D tip ($p < 0.05$) (Table 3). The 3D reconstruction in the CTVox software (Bruker-microCT) demonstrated accumulated debris (Figure 2) and uninstrumented surface (Figure 3) after preparation with PDL or HFEDM and after preparation with the E18D tip.

Discussion

The first null hypothesis was accepted; the ProDesign Logic and HyFlex EDM systems provided similar results after preparation regarding transportation, volume, uninstrumented surface and debris. Previous studies have reported that these systems have similar capacity for preparation in mesial roots of mandibular molars[24]. HFEDM and PDL provided centralized preparations in canines, maxillary molars and mandibular molars with curvature.[24,33,34]

Table 1. Median, minimum, and maximum values (% and mm^3) of Debris and Uninstrumented Surface (% and mm^2) in canals with isthmus prepared with ProDesign Logic or HyFlex EDM, before and after use of E18D tip.

Variable	Debris (%)		Debris (mm^3)		Uninstrumented surface (%)		Uninstrumented surface (mm^2)	
	Before E18D	After E18D	Before E18D	After E18D	Before E18D	After E18D	Before E18D	After E18D
PDL								
Canal	4.91 (1.70–12.15)^{aA}	2.82 (0.06–8.72)^{bA}	0.41 (0.03–1.30)^{aA}	0.32 (0.03–0.65)^{bA}	46.86 (21.64–64.42)^{aA}	26.08 (8.04–48.32)^{bA}	41.17 (15.05–58.83)^{aA}	20.99 (11.69–26.96)^{bA}
Isthmus	11.97 (4.32–43.79)^{aA}	5.01 (0.91–10.89)^{bB}	0.41 (0.16–0.73)^{aA}	0.24 (0.10–0.40)^{bB}	58.60 (34.47–69.17)^{aA}	38.18 (14.29–86.19)^{bA}	28.55 (14.02–51.30)^{aA}	18.96 (5.80–31.82)^{bA}
HFEDM								
Canal	6.51 (1.68–16.61)^{aA}	3.04 (1.21–6.48)^{bA}	0.71 (0.16–1.50)^{aA}	0.30 (0.15–0.79)^{bA}	46.57 (10.35–86.02)^{aA}	26.49 (21.49–71.81)^{bA}	40.66 (13.17–86.18)^{aA}	21.60 (10.10–45.50)^{bA}
Isthmus	17.42 (4.07–31.05)^{aA}	8.59 (1.41–22.08)^{bA}	0.68 (0.34–0.90)^{aA}	0.34 (0.12–0.57)^{bA}	50.97 (33.74–73.67)^{aA}	34.87 (14.29–134.1)^{bA}	36.03 (15.04–48.92)^{aA}	25.11 (7.86–36.17)^{bA}

*Different superscript lower case letters on same line indicate statistical difference before and after use of E18D tip in same group. Superscript capital letters in the same column indicate statistical difference between the groups ($p < 0.05$).

Table 2. Mean and standard deviations of pre-operative volume and increase in volume (%) in canals with presence of isthmus prepared with ProDesign Logic or HyFlex EDM, before and after use of E18D tip.

Variable	ProDesign Logic	HyFlex EDM
Pre-operative canal (mm3)		
Canal	5.7026 ± 2.2204	6.0870 ± 2.1582
Isthmus	2.106 ± 0.6469	1.992 ± 0.5942
Increase in preparation volume (%)		
Canal	65.95 ±26.82	60.59 ± 20.94
Isthmus	29.68 ± 11.54	37.51 ±13.25
Increase in volume E 18 D (%)		
Canal	141.7 ± 80.03	133.4 ± 56.64
Isthmus	59.87 ± 18.27	66.29 ± 17.54

*There were no statistical differences between the groups.

Table 3. Median, minimum, and maximum of transportation (mm) in canals with presence of isthmus prepared with ProDesign Logic or HyFlex EDM, before and after use of E18D tip.

Variable	ProDesign Logic	HyFlex EDM
Before E18D tip		
Cervical	0.0056 (-0.183-0.1964)	-0.0139 (-0.2028-0.1278)
Middle	-0.0159 (-0.1696-0.09)	0.0002 (-0,138-0.1524)
Apical	-0.0005 (-0.2844-0.1618)	-0.0021 (-0.1234-0.1618)
After E18D tip		
Cervical	-0.0516 (-0364-02634)	0.0432 (-0.2540-3162)
Middle	-0.1132 (-2976-3050)	-0.0309 (-0.2794-0.2008)
Apical	-0.0011 (-2844-0.2078)	-0.0026 (-0.1234-0.1618)

*There were no statistical differences between the groups.

In the present study, the root canals were prepared up to size 40, using a sequence of three instruments. The use of more than one instrument during instrumentation procedures reduce the stress on instruments[17,19] and favors apical enlargement and cleaning,[2,19,31] as well as the flow of irrigant solutions.[24]

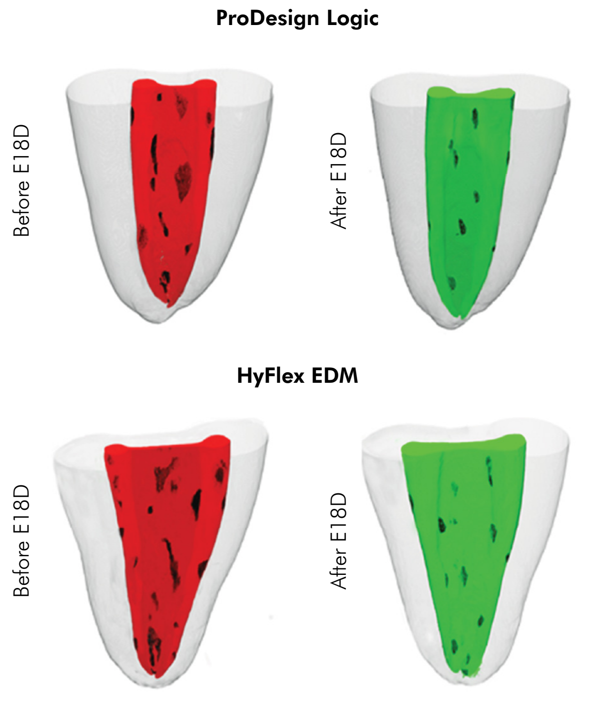

Figure 2. 3D Reconstructions obtained by Micro–CT of mesial roots of mandibular molars with isthmus showing Debris accumulated in canal (Black) after preparation with NiTi (Red) and after preparation with E18D (Green).

The presence of debris in the root canal makes it difficult to disinfect the root canal system[8] and adhesion of the endodontic sealer to the dentinal tubules.[35] Apical enlargement reduces the percentage of debris in curved canals of mandibular molars, without causing deviations[24]. However, in the present study a high percentage of debris and uninstrumented surface was found after the use of the two aforementioned systems. Roots with the presence of isthmus throughout their entire extension favored the accumulation of debris because a lower effect of the instruments or irrigant solutions occurred in the region of the isthmus during preparation.[36,37] Since isthmus is a narrow, tape-shaped communication between 2 canals,[9] the mechanized NiTi instruments do not have efficient mechanical action in this region. Mesial roots of mandibular molars were used in the present study due the higher incidence of isthmus along their entire length, which occurs in 16% of cases with isthmus.[38]

Thus, the second null hypothesis was rejected since the use of the complementary preparation with the E18D tip resulted in significant reduction of debris

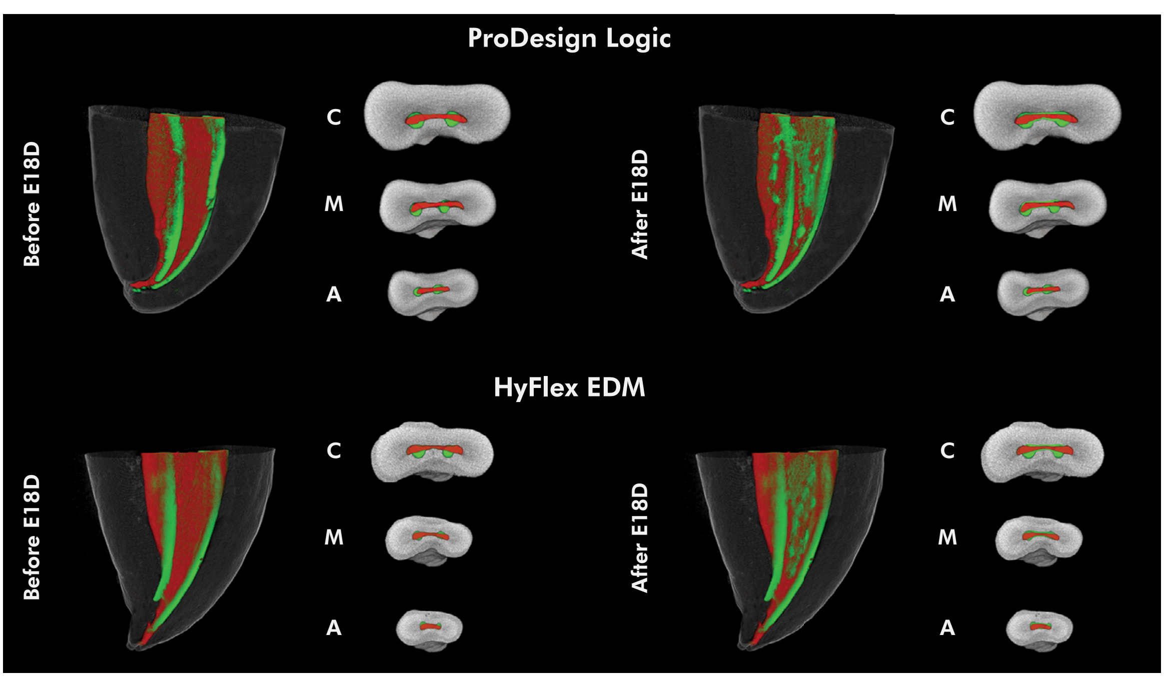

Figure 3. 3D Reconstructions and cross–sectional views of the cervical (C), middle (M), and apical (A) thirds of 2 representative mesial roots of mandibular molars with isthmus prepared by ProDesign Logic and HyFlex EDM before and after preparation with the E18D ultrasonic tip. The uninstrumented surface is in red, and the instrumented surface is in green.

and uninstrumented surface in the isthmus and throughout the canal. E18D tip was developed to allow physical and mechanical action in areas of isthmus and difficult access. For this propose, this ultrasonic tip has conical conformation, with tip diameter 33, conicity 02, and active part measuring 12 mm, favoring both lateral and in–depth action. The greater access gained for preparation of the isthmus region diminished the percentage of uninstrumented surface, thereby improving the flow of irrigant solutions.[37,39]

The mechanical action of ultrasonic tips favors greater contact with the walls of root canals. The Flatsonic ultrasonic tip, used as auxiliary instrument in preparation, demonstrated significant reduction in the percentage of uninstrumented surface and debris in oval and flattened canals.[28,29] The ultrasonic activation performed with the E18D tips in the present study, also promoted physical action, potentiating the action of the irrigant solution. When agitation of the irrigant solution used is increased, as in passive ultrasonic irrigation (PUI), a larger amount of debris is removed from the isthmus region.[40,41] Ultrasound activation promotes the phenomena of cavitation, which improves the action of the irrigant solution in the RCS, favoring cleaning of areas of isthmus.[42]

After use of the E18D tip, a higher percentage of debris was observed in the canals prepared with HEDM in comparison with PDL. Previous studies have shown that the mechanical action of the ultrasonic tip may be influenced by the preparation previously performed.[28,29] In canals that were prepared with PDL, Flatsonic diminished the percentage of debris in all the root canal thirds, however, after preparation with Reciproc Blue, this ultrasonic tip did not reduce the accumulation of debris in the middle and apical thirds.[29] More extensive enlargements favor the use of ultrasonic tips,[7,28] by providing increased access to and action of the insert in both the canal and isthmus.[7] Therefore, the lower quantity of debris accumulated after preparation with PDL could be related to the larger taper of the instrument 40.05 in comparison with HFEDM 40.04, contributing to increased access and effect of the ultrasonic tip. In addition, HFEDM shows 3 different cross sections on the instrument[33] and PDL instruments have a modified S–shaped cross section with 2 or 3 cutting blades[24]. Root canal preparation can also be influenced by tip design and cross–sectional geometry.[13, 24]

Analysis by micro–CT made it possible to evaluate different quantitative and qualitative variables in the root canal[17,24,27] and changes in the area of the isthmus caused by instrumentation.[5] This data analysis methodology allowed evaluation of the debris and uninstrumented surface in pre–determined regions of the root canal system such as the areas of isthmus.[7]

In spite of having small conicity 0.02, the E18D ultrasonic insert has a tip diameter of 0.33. Therefore, adequate preparation is necessary to enable its passive access without interference in the root canals, so that it can act in the areas of isthmus. The heat treatment CM of the PDL and HFEDM instruments up to size .40, promoted centralized preparations without procedural errors. Apical dilation up to size 0.40 may have favored the action of the ultrasonic tip in areas of isthmus, in addition to allowing increased flow of the irrigant solution.[2,20] Although the association of the E18D ultrasonic tip with preparation performed with NiTi rotary instruments significantly improved the cleaning of root canals with isthmus, a considerable quantity of debris and uninstrumented surface was still observed.

Conclusions

Preparations performed with ProDesign Logic and HyFlex EDM up to diameter 40 were similar, without promoting transportation in canals with curvature and the presence of isthmus. PDL promoted a smaller quantity of Debris in the isthmus than Hyflex EDM after use of the E18D tip. The E18D tip significantly improved the preparation of curved root canals with presence of isthmus, by reducing debris and uninstrumented surfaces.

Acknowledgments

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior/ Coordination of the Improvement of Higher Education Personnel (CAPES) – Brazil (– Finance Code 001, CNPq (302206/2017–5), and was supported by São Paulo Research Foundation – FAPESP (2017/19049, 2018/19665–6).

References

1. Paqué F, Laib A, Gautschi H, Zehnder M. Hard-tissue debris accumulation analysis by high-resolution computed tomography scans. J Endod. 2009 Jul;35(7):1044-7. https://doi.org/10.1016/j.joen.2009.04.026
2. De-Deus G, Belladonna FG, Souza EM, Silva EJ, Neves AA, Alves H, et al. Micro-computed Tomographic Assessment on the Effect of ProTaper Next and Twisted File Adaptive Systems on Dentinal Cracks. J Endod. 2015 Jul;41(7):1116-9. https://doi.org/10.1016/j.joen.2015.02.012
3. Kim S, Jung H, Kim S, Shin SJ, Kim E. The influence of an isthmus on the outcomes of surgically treated molars: a retrospective study. J Endod. 2016 Jul;42(7):1029-34. https://doi.org/10.1016/j.joen.2016.04.013
4. Nair PN, Henry S, Cano V, Vera J. Microbial status of apical root canal system of human mandibular first molars with primary apical periodontitis after "one-visit" endodontic treatment. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2005 Feb;99(2):231-52. https://doi.org/10.1016/j.tripleo.2004.10.005
5. Endal U, Shen Y, Knut A, Gao Y, Haapasalo M. A high-resolution computed tomographic study of changes in root canal isthmus area by instrumentation and root filling. J Endod. 2011 Feb;37(2):223-7. https://doi.org/10.1016/j.joen.2010.10.012
6. De-Deus G, Belladonna FG, Silva EJ, Marins JR, Souza EM, Perez R, et al. Micro-CT evaluation of non-instrumented canal areas with different enlargements performed by NiTi systems. Braz Dent J. 2015;26(6):624-9. https://doi.org/10.1590/0103-6440201300116
7. Versiani MA, Alves FR, Andrade-Junior CV, Marceliano-Alves MF, Provenzano JC, Rôças IN, et al. Micro-CT evaluation of the efficacy of hard-tissue removal from the root canal and isthmus area by positive and negative pressure irrigation systems. Int Endod J. 2016 Nov;49(11):1079-87. https://doi.org/10.1111/iej.12559
8. Keleş A, Alçin H, Sousa-Neto MD, Versiani MA. Supplementary steps for removing hard tissue debris from isthmus-containing canal systems. J Endod. 2016 Nov;42(11):1677-82. https://doi.org/10.1016/j.joen.2016.07.025
9. Estrela C, Rabelo LE, Souza JB, Alencar AH, Estrela CR, Sousa Neto MD, et al. Frequency of root canal isthmus in human permanent teeth determined by cone-beam computed tomography. J Endod. 2015 Sep;41(9):1535-9. https://doi.org/10.1016/j.joen.2015.05.016
10. Tonelli SQ, Sousa-Neto MD, Leoni GB, Brito-Júnior M, Pereira RD, Oliveira PA, et al. Micro-CT evaluation of maxillary first molars: interorifice distances and internal anatomy of the mesiobuccal root. Braz Oral Res. 2021 Apr;35:e060. https://doi.org/10.1590/1807-3107bor-2021.vol35.0060
11. Mannocci F, Peru M, Sherriff M, Cook R, Pitt Ford TR. The isthmuses of the mesial root of mandibular molars: a micro-computed tomographic study. Int Endod J. 2005 Aug;38(8):558-63. https://doi.org/10.1111/j.1365-2591.2005.00994.x
12. Lima FJ, Montagner F, Jacinto RC, Ambrosano GM, Gomes BP. An in vitro assessment of type, position and incidence of isthmus in human permanent molars. J Appl Oral Sci. 2014;22(4):274-81. https://doi.org/10.1590/1678-775720130585
13. 13 Sousa-Neto MD, Crozeta BM, Lopes FC, Mazzi-Chaves JF, Pereira RD, Silva Sousa AC et al. A micro-CT evaluation of the performance of rotary and reciprocating single-file systems in shaping ability of curved root canals. Braz Oral Res. Apryl 2020;34:e039. https://doi.org/10.1590/1807-3107bor-2020.vol34.0039
14. Pereira ES, Viana AC, Buono VT, Peters OA, Bahia MG. Behavior of nickel-titanium instruments manufactured with different thermal treatments. J Endod. 2015 Jan;41(1):67-71. https://doi.org/10.1016/j.joen.2014.06.005
15. Gonçalves AN, Frota MF, Sponchiado Júnior EC, Carvalho FM, Garcia LFR, Marques AAF. Apical transportation of manual NiTi instruments and a hybrid technique in severely curved simulated canals. J Conserv Dent. 2015;18(6):436-9. https://doi.org/10.4103/0972-0707.168796
16. Karataş E, Gündüz HA, Kırıcı DÖ, Arslan H. Incidence of dentinal cracks after root canal preparation with ProTaper Gold, Profile Vortex, F360, Reciproc and ProTaper Universal instruments. Int Endod J. 2016 Sep;49(9):905-10. https://doi.org/10.1111/iej.12541
17. Drukteinis S, Peciuliene V, Dummer PM, Hupp J. Shaping ability of BioRace, ProTaper NEXT and Genius nickel-titanium instruments in curved canals of mandibular molars: a MicroCT study. Int Endod J. 2019 Jan;52(1):86-93. https://doi.org/10.1111/iej.12961
18. Aydın ZU, Keskin NB, Özyürek T, Geneci F, Ocak M, Çelik HH. Microcomputed assessment of transportation, centering ratio, canal area, and volume increase after single-file rotary and reciprocating glide path instrumentation in curved root canals: a laboratory study. J Endod. 2019 Jun;45(6):791-6. https://doi.org/10.1016/j.joen.2019.02.012
19. Pinto JC, Pivoto-João MM, Espir CG, Ramos ML, Guerreiro-Tanomaru JM, Tanomaru-Filho M. Micro-CT evaluation of apical enlargement of molar root canals using rotary or reciprocating heat-treated NiTi instruments. J Appl Oral Sci. 2019;27. https://doi.org/10.1590/1678-7757-2018-0689

20. Pinto JC, Torres FF, Santos-Junior AO, Duarte MA, Guerreiro-Tanomaru JM, Tanomaru-Filho M. Safety and Effectiveness of Additional Apical Preparation using a Rotary Heat-treated Nickel-Titanium file with Larger Diameter and Minimum Taper in Retreatment of Curved Root Canals. Eur J Dent. 2021 May;15(2):247-52. https://doi.org/10.1055/s-0041-1723065
21. Tanomaru-Filho M, Galletti Espir C, Carolina Venção A, Macedo-Serrano N, Camilo-Pinto J, Guerreiro-Tanomaru J. Cyclic Fatigue Resistance of Heat-Treated Nickel-Titanium Instruments. Iran Endod J. 2018;13(3):312-7. https://doi.org/10.22037/iej.v13i3.18637
22. Pedullà E, Lo Savio F, Boninelli S, Plotino G, Grande NM, La Rosa G, et al. Torsional and Cyclic Fatigue Resistance of a New Nickel-Titanium Instrument Manufactured by Electrical Discharge Machining. J Endod. 2016 Jan;42(1):156-9. https://doi.org/10.1016/j.joen.2015.10.004
23. Pirani C, Iacono F, Generali L, Sassatelli P, Nucci C, Lusvarghi L, et al. HyFlex EDM: superficial features, metallurgical analysis and fatigue resistance of innovative electro discharge machined NiTi rotary instruments. Int Endod J. 2016 May;49(5):483-93. https://doi.org/10.1111/iej.12470
24. Pivoto-João MM, Tanomaru-Filho M, Pinto JC, Espir CG, Guerreiro-Tanomaru JM. Root canal preparation and enlargement using thermally treated nickel-titanium rotary systems in curved canals. J Endod. 2020 Nov;46(11):1758-65. https://doi.org/10.1016/j.joen.2020.08.007
25. Lacerda MF, Marceliano-Alves MF, Pérez AR, Provenzano JC, Neves MA, Pires FR, et al. Cleaning and shaping oval canals with 3 instrumentation systems: a correlative micro-computed tomographic and histologic study. J Endod. 2017 Nov;43(11):1878-84. https://doi.org/10.1016/j.joen.2017.06.032
26. Arias A, Paqué F, Shyn S, Murphy S, Peters OA. Effect of canal preparation with TRUShape and Vortex rotary instruments on three-dimensional geometry of oval root canals. Aust Endod J. 2018 Apr;44(1):32-9. https://doi.org/10.1111/aej.12201
27. Pérez AR, Alves FR, Marceliano-Alves MF, Provenzano JC, Gonçalves LS, Neves AA, et al. Effects of increased apical enlargement on the amount of unprepared areas and coronal dentine removal: a micro-computed tomography study. Int Endod J. 2018 Jun;51(6):684-90. https://doi.org/10.1111/iej.12873
28. Rivera-Peña ME, Duarte MA, Alcalde MP, Furlan RD, Só MV, Vivan RR. Ultrasonic tips as an auxiliary method for the instrumentation of oval-shaped root canals. Braz Oral Res. 2019 Feb;33:e011. https://doi.org/10.1590/1807-3107bor-2019.vol33.0011
29. Santos-Junior AO, Tanomaru-Filho M, Pinto JC, Tavares KI, Pivoto-João MM, Guerreiro-Tanomaru JM. New Ultrasonic Tip Decreases Uninstrumented Surface and Debris in Flattened Canals: A Micro-computed Tomographic Study. J Endod. 2020 Nov;46(11):1712-8. https://doi.org/10.1016/j.joen.2020.07.012
30. Schneider SW. A comparison of canal preparations in straight and curved root canals. Oral Surg Oral Med Oral Pathol. 1971 Aug;32(2):271-5. https://doi.org/10.1016/0030-4220(71)90230-1
31. Espir CG, Nascimento-Mendes CA, Guerreiro-Tanomaru JM, Freire LG, Gavini G, Tanomaru-Filho M. Counterclockwise or clockwise reciprocating motion for oval root canal preparation: a micro-CT analysis. Int Endod J. 2018 May;51(5):541-8. https://doi.org/10.1111/iej.12776
32. Gambill JM, Alder M, Rio CE. Comparison of nickel-titanium and stainless steel hand-file instrumentation using computed tomography. J Endod. 1996 Jul;22(7):369-75. https://doi.org/10.1016/S0099-2399(96)80221-4
33. Venino PM, Citterio CL, Pellegatta A, Ciccarelli M, Maddalone M. A Micro-computed tomography evaluation of the shaping ability of two nickel-titanium instruments, HyFlex EDM and ProTaper Next. J Endod. 2017 Apr;43(4):628-32. https://doi.org/10.1016/j.joen.2016.11.022
34. Stringheta CP, Bueno CE, Kato AS, Freire LG, Iglecias EF, Santos M, et al. Micro-computed tomographic evaluation of the shaping ability of four instrumentation systems in curved root canals. Int Endod J. 2019 Jun;52(6):908-16. https://doi.org/10.1111/iej.13084
35. Freire LG, Iglecias EF, Cunha RS, Santos M, Gavini G. Micro-Computed Tomographic Evaluation of Hard Tissue Debris Removal after Different Irrigation Methods and Its Influence on the Filling of Curved Canals. J Endod. 2015 Oct;41(10):1660-6. https://doi.org/10.1016/j.joen.2015.05.001
36. Keleş A, Keskin C. A micro-computed tomographic study of band-shaped root canal isthmuses, having their floor in the apical third of mesial roots of mandibular first molars. Int Endod J. 2018 Feb;51(2):240-6. https://doi.org/10.1111/iej.12842
37. Xu K, Wang J, Wang K, Gen N, Li J. Micro-computed tomographic evaluation of the effect of the final apical size prepared by rotary nickel-titanium files on the removal efficacy of hard-tissue debris. J Int Med Res. 2018 Jun;46(6):2219-29. https://doi.org/10.1177/0300060518757607
38. Tahmasbi M, Jalali P, Nair MK, Barghan S, Nair UP. Prevalence of middle mesial canals and isthmi in the mesial root of mandibular molars: an in vivo cone-beam computed tomographic study. J Endod. 2017 Jul;43(7):1080-3. https://doi.org/10.1016/j.joen.2017.02.008
39. De-Deus G, Belladonna FG, de Siqueira Zuolo A, Perez R, Carvalho MS, Souza EM, et al. Micro-CT comparison of XP-endo Finisher and passive ultrasonic irrigation as final irrigation protocols on the removal of accumulated hard-tissue debris from oval shaped-canals. Clin Oral Investig. 2019 Jul;23(7):3087-93. https://doi.org/10.1007/s00784-018-2729-y

40. Cheung AW, Lee AH, Cheung GS. Clinical efficacy of activated irrigation in endodontics: a focused review. Restor Dent Endod. 2021 Jan;46(1):e10. https://doi.org/10.5395/rde.2021.46.e10
41. Silva EJ, Carvalho CR, Belladonna FG, Prado MC, Lopes RT, De-Deus G, et al. Micro-CT evaluation of different final irrigation protocols on the removal of hard-tissue debris from isthmus-containing mesial root of mandibular molars. Clin Oral Investig. 2019 Feb;23(2):681-7. https://doi.org/10.1007/s00784-018-2483-1
42. Sluis LW, Versluis M, Wu MK, Wesselink PR. Passive ultrasonic irrigation of the root canal: a review of the literature. Int Endod J. 2007 Jun;40(6):415-26. https://doi.org/10.1111/j.1365-2591.2007.01243.x