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Effect of mechanized instrumentation on distal wall thickness of the second mesiobuccal canal

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ABSTRACT

Dentine wall thickness in the mesial roots of molars is critical to prevent root stripping. Understanding the effect of rotatory instruments on the second mesiobuccal canal is crucial to prevent weakening and periodontal communication. ***Aim:*** *To evaluate the effect of different conservative tapered mechanized instrumentation systems on the distal wall thickness of the second mesiobuccal canal of maxillary first molars in 3D dental replicas.* ***Materials and Method:*** *Fifty radiopaque 3D printed replicas were made of a maxillary first molar with Vertucci classification IV and Schneider curvature (<10°), 23 mm in length. The specimens were divided into 5 groups of 10. In all cases, the second mesiobuccal canal was instrumented to the working length. Group 1 was instrumented with Race Evo (FKG) up to file 30/04, Group 2 with AF F One (Fanta-Dental) up to file 35/04, Group 3 with Slim Shaper (Zarc4Endo) up to file 30/04, and Group 4 with Trunatomy, while the control group was not instrumented. Distal wall thicknesses were measured in the cervical, middle and apical thirds by CBCT before and after instrumentation. Descriptive statistics were calculated, after which analysis of variance and Tukey's test for multiple comparisons were performed (p < 0.05).* ***Results:*** *Analysis of variance showed a significant effect of instrumented group and thirds (p < 0.001). The multiple comparison test showed that the control and Race Evo groups differed significantly from the other three groups. Within each group, the differences between thirds were statistically significant.* ***Conclusion:*** *Trunatomy, Slim Shaper and Fanta AF One systems are suitable for shaping second mesiobuccal canals while maintaining critical distal wall thickness.*

Keywords: *endodontics - root canal preparation - molar*

Efecto de la instrumentación mecanizada sobre el espesor de la pared distal del segundo conducto mesiovestibular

RESUMEN

El espesor de la pared distal en las raíces mesiales de molares es crítico para evitar perforaciones radiculares. Conocer el efecto de los instrumentos rotatorios sobre el segundo conducto mesiovestibular resulta crucial para evitar su debilitamiento y comunicación periodontal.

Objetivo: *Evaluar el efecto de diferentes sistemas de instrumentación mecanizada de conicidades conservadoras en el espesor de la pared distal de segundo conducto mesiovestibular de primeros molares superiores en réplicas dentarias 3D.* ***Materiales y Método:*** *Se confeccionaron 50 réplicas 3D radiopacas de un primer molar superior con una clasificación IV de Vertucci y con grado de curvatura de Schneider leve (<10°), de 23 mm de longitud y se dividieron 5 grupos de 10 muestras. En todos los casos se instrumentó el conducto segundo conducto mesiovestibular MB2 hasta la longitud de trabajo. El Grupo 1 fue instrumentado con Race Evo (FKG) hasta lima 30/04, Grupo 2 instrumentado con AF F One (Fanta- Dental) hasta lima 35/04, Grupo 3 con Slim Shaper (Zarc4Endo) hasta lima 30/04, Grupo 4 con Trunatomy (Denstply Sirona) hasta lima 36/03 y el grupo testigo sin instrumentar. Se midieron los espesores dentinarios de la pared distal antes y posterior a la instrumentación de los sistemas mediante tomografía computarizada de haz cónico. Luego del cálculo de los estadísticos descriptivos se realizó el análisis de varianza y las comparaciones múltiples se realizaron por medio de la prueba de Tukey con una p de 0.05.* ***Resultados:*** *El análisis de variancia muestra el efecto significativo de los factores grupo instrumentado y tercio (p<0,001). La prueba de comparación múltiple muestra diferencias estadísticamente significativas entre los grupos control y Race Evo y los otros tres. Dentro de cada grupo las diferencias entre los tercios son estadísticamente significativas.* ***Conclusión:*** *Los sistemas Trunatomy, Slim Shaper y Fanta AF One son adecuados para la conformación del CMB2 manteniendo el espesor crítico de la pared distal.*

Palabras clave: *endodoncia - preparación del conducto radicular - molar*

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INTRODUCTION

Detection and adequate treatment of the second mesiobuccal (MB2) canal in the mesial root of first upper molars are essential to ensure the success of endodontic treatment[1].

A cross section of a molar mesial root shows that its thickest part (safety zone) is away from the direction of its curvature, while the concave interior wall, called Risk/Danger Zone, is located on the distal dentin wall facing the furcation zone in upper and lower molars[2].

“Stripping” is the thinning and perforation of the distal wall of mesial roots as a result of mechanical shaping using excessively tapered instruments. These unwanted perforations are followed by bacterial contamination, periradicular tissue lesion, periodontal inflammation, bone resorption, periodontal ligament destruction, gingival epithelium proliferation and periodontal pocket development[3].

Prakash et al.[4] reported that the diameter of the MB2 canal is smaller and usually narrower than in the first mesiobuccal canal (MB1). In MB2 canals, the thickness of the distal dentin wall is one of the most important factors to consider before instrumentation. The longer the root canal, the more likely it is to undergo root perforation by stripping, because at the distal wall, the dentin is thinner, and the concavity is more pronounced than in shorter molars[5].

Mechanical shaping of root canals can lead to various degrees of dentin removal, depending on the instrumentation techniques and differently tapered mechanized systems used. This can affect the biomechanical response of teeth and weaken their capacity to bear occlusal loads in the long term, leading to tooth loss as a result of excessive wear of distal dentin in mesial roots.

The thickness of the risk zone before and after instrumentation has been measured on extracted teeth using different methods, including tomographic studies[6], micro-CT scan[7] and stereomicroscopy[8]. However, it is often difficult to obtain extracted teeth for *ex-vivo* studies. An alternative solution is to use 3D dental replicas instead.

Extracted natural teeth have certain disadvantages in research compared to 3D replicas, e.g., the time and difficulty involved in finding enough natural teeth to make up a representative sample[9-11]. Another factor to consider is that patients must provide informed consent for the use of natural extracted teeth because they are biological tissue[12]. Moreover, there is a risk of cross-infections if teeth are contaminated. Natural extracted teeth are difficult to sterilize, and common disinfection procedures such as sodium hypochlorite and hydrogen peroxide may destroy them[13-14]. Furthermore, the difficulty in standardizing anatomical evaluations because of the complex anatomy of the root canal system makes it impossible to obtain completely uniform models for scientific studies[15-16].

3D replica printing is a rapidly developing technology that has gained broad acceptance in dentistry and can be used to resolve these difficulties[17]. In a recent study, Ramírez-Muñoz A et al.[18] demonstrated the importance of 3D printed models for endodontic research thanks to the precision with which they faithfully replicate specific anatomy of natural teeth, providing a standardized alternative providing specimens which are much easier to obtain than natural teeth.

The aim of this study was to evaluate and compare the effect of endodontic instrumentation with different mechanized systems in 3D replicas of first upper molars, focusing on the preservation of the MB2 canal’s distal wall thickness.

MATERIALS AND METHOD

A preliminary pilot study was conducted to determine the arithmetic mean of distal wall thicknesses in the cervical, middle and apical thirds of the second mesiobuccal canal (MB2).

We evaluated tomographic images from a database of 137 MB2 canals from mesial roots of 225 first upper molars of patients (mean age 29 ±5.4 years), which had been taken at a dental radiology center specializing in CBCT. Measurements were taken with the calibration software of a Carestream CS 9600 3D scanner with image acquisition parameters established at 82 kV and 8.0 mA, exposure time 19.96 s. Minimum voxel size was 180 µm. The thickness of the distal wall of the second mesiobuccal canal was measured in the cervical, middle and apical thirds. Before this step, the length of each root was measured from the furcation to the root apex in order to divide it into three parts. The arithmetic means were 1 mm for the cervical third, 0.76 mm for the middle third and 0.56 mm for the apical third.

Based on the dentin thicknesses found, a first molar that was representative of the mean value was selected from the DICOM image bank of the patients evaluated: an upper first molar with MB2 canal, Vertucci classification IV and Schneider curvature <10°. This molar was replicated physically in 3D anatomical models.

Sample size was calculated with the Software IBM SPSS Statistics Version 24 (IBM Corp, Endicott, USA), establishing an alpha error 0.05 and 95% power. The result indicated a minimum of 10 specimens per study group.

Thus, fifty (50) radiopaque replicas (LikeReal 3D [Porto Alegre, Rio Grande do Sul, Brazil]) were made of the selected molar. These replicas had pre-made openings, 23 mm root length to the apical foramen, and the same dentin thicknesses in each third as the selected molar (Fig. 1).

The 3D replicas were divided into four (4) experimental groups in which the MB2 canal would be prepared with different mechanized instrumentation systems for evaluation of residual dentin thickness (Fig. 1), and one (1) control group without instrumentation. The replicas were placed on an acrylic plaque and scanned in the same scanner with image acquisition parameters 90 kV, 4.0 mA, voxel size 0.75 μm and exposure time 20 seconds. The DICOM images were used to measure the furcal dentin thicknesses in the MB2 canals in the cervical, middle and apical thirds (Figs. 2 - 5).

Fig. 1: Vestibular view of 3D replica of upper first molar.

Fig. 2: 3D tooth replicas on a plaque, ready to scan.

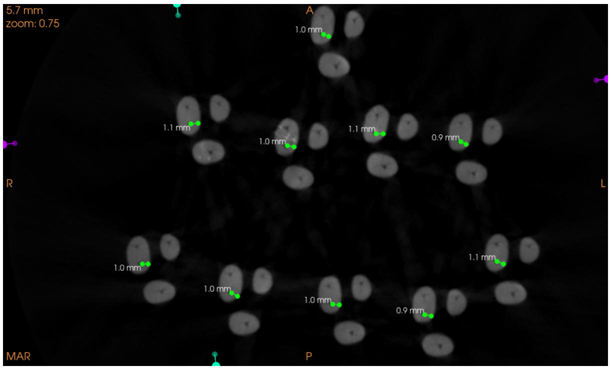

Fig. 3: Measurement of the distal wall in the cervical third of the control group.

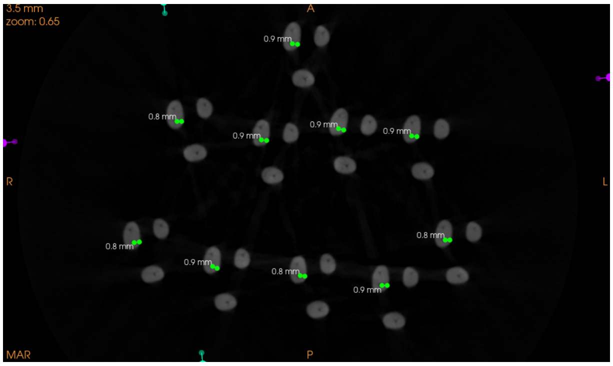

Fig. 4: Measurement of the distal wall in the middle third of the control group.

After recording the measurements, and before shaping, patency was confirmed by inserting a file #10 (Dentsply Maillefer - Ballaigues, Switzerland) up to the 23 mm working length.

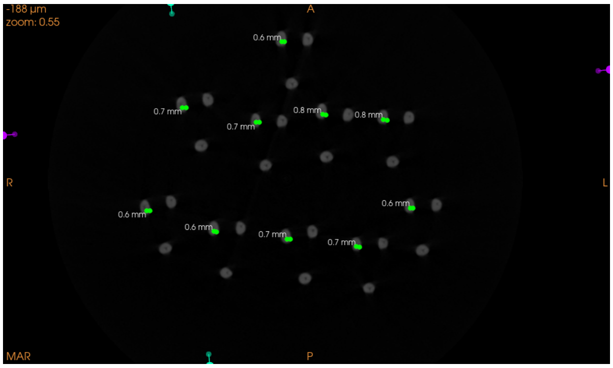

Fig. 5: Measurement of the distal wall in the apical third of the control group.

Each rotary instrument was used to instrument a maximum of four MB2 canals, following the recommendations of the manufacturers of each system.

The rotary file systems were driven by an endodontic motor (Eighteeth - Changzhou, China). In-and-out movements with an amplitude of 3 to 4 mm were made until the working length was reached. Brushing movements were not used at any time. After use, the instruments were cleaned with sterilized gauze and alcohol.

For all experimental groups, root canals underwent an irrigation protocol with 2.5 % sodium hypochlorite using a 21 mm NaviTip 29G needle (Ultradent- Utah, USA) placed at 3 mm from the working length. Four (4) ml of the solution were used between each instrument change and at the end of instrumentation, plus a final irrigation protocol with 10 ml.

All specimens were instrumented by a single operator (P.E.), who is a specialist in endodontics and experienced in continuous rotary instrumentation, using an endodontic Newton MEC XXI microscope (Newton Microcopia, Buenos Aires, Argentina) at 4 X magnification.

Experimental groups were the following:

Group 1: The Race-Evo (RE) system (FKG Dentaire, La Chaux-de-Fonds, Suiza) was used in continuous rotation at 1000 rpm, torque 1.5 N/cm, following the manufacturer's instructions. When the working length was reached, the file was removed from the root canal, and the protocol continued using the following sequence of files: RE1 (15/.04), RE2 (25/.04) and RE3 (30/.04).

Group 2: The AF F ONE (AF) system (FANTA-DENTAL, Shanghai, China) was used at 500 rpm, torque 2.5 N/cm. When the working length was reached, the protocol continued using the file sequence recommended by the manufacturer: AF 20/.04, 25/.04 and 35/.04.

Group 3: The Slim Shaper (SS) system (Zarc4endo, Gijón, Asturias, Spain) was used with continuous rotary speed 500 rpm, torque 3 N/cm. When working length was reached, the protocol continued using the file sequence recommended by the manufacturer: ZS1 (15/.02–06), ZS2 (20/.04) and ZS3 (25/.04). Finally, the apical third was widened with the instrument AS 30 (30/.03) from Apical Shaper (AS) (Zarc4endo, Gijón, Asturias, Spain) at 500 rpm, torque 3 N/cm.

Group 4: The TruNatomy (TA) system (Dentsply Sirona, Ballaigues, Switzerland) was used at continuous rotary speed 500 rpm, torque 1.5 N/cm. When working length was reached, the protocol continued using the file sequence specified in the manufacturer's instructions: TA Glyder (17/.02), Prime (26/.04) and Medium (36/.03).

After all the replicas had been instrumented, the same CBCT scanner was used to scan them with the same image acquisition parameters, to evaluate distal dentin wall thickness remaining after instrumentation.

We evaluated the differences among all five groups (four study groups and control group), and the differences in thickness among root thirds.

After calculating the descriptive statistics (arithmetic mean, standard deviation, and maximum and minimum values for each group of ten data each), two-way ANOVA was performed (group according to instrument and third considered, the latter with repeated measures) after establishing that the homogeneity of variance hypothesis could be accepted for the dependent variable between experimental groups. Multiple comparisons were made through Tukey's test, with significance level set at a probability value (alpha) lower than 0.05 in all cases.

RESULTS

Table 1 shows the descriptive statistics (arithmetic mean, standard deviation, and maximum and minimum values for each group).

Analysis of variance shows the significant effect of the factors "instrumented group" and "third" ($p<0.001$). Interaction is significant, but at a lower level (0.041) (Table 2).

The global multiple comparison test (considering total thirds within each group) shows that the control

Table 1. descriptive statistics of thicknesses in the experimental groups of molar replicas. Values expressed in mm.

Group	Third	n	Mean	S.D.	Minimum	Maximum
Control	CERVICAL	10	1.01	0.07	0.9	1.1
	MIDDLE	10	0.86	0.05	0.8	0.9
	APICAL	10	0.68	0.08	0.6	0.8
Fanta	CERVICAL	10	0.71	0.07	0.6	0.8
	MIDDLE	10	0.54	0.08	0.4	0.6
	APICAL	10	0.37	0.07	0.3	0.5
Race Evo	CERVICAL	10	0.63	0.05	0.6	0.7
	MIDDLE	10	0.43	0.05	0.4	0.5
	APICAL	10	0.31	0.06	0.2	0.4
Slim	CERVICAL	10	0.80	0.08	0.7	0.9
	MIDDLE	10	0.60	0.08	0.5	0.7
	APICAL	10	0.40	0.08	0.3	0.5
Trunatomy	CERVICAL	10	0.75	0.05	0.7	0.8
	MIDDLE	10	0.56	0.07	0.5	0.7
	APICAL	10	0.37	0.07	0.3	0.5

Table 2. Summary of analysis of variance. Interaction is significant, but at a lower level (0.041)

Factor	gl	Sum of squares	Mean squares	F	P
Group	4	2.647	0.662	64.832	<0.001
Third	2	3.134	1.565	763.635	<0.002
Group x third	8	0.035	0.004	2.128	0.041

group and Race Evo differ significantly from the other three (Table 3).

Within each group, the differences between thirds are statistically significant ($p<0.05$), with values decreasing from cervical to apical.

DISCUSSION

Remaining dentin thickness after endodontic procedures may be the most important factor influencing the future resistance of an endodontically treated tooth, so in the MB2 canal, it is important to consider it during instrumentation in order to avoid perforating the danger zone[19].

This study evaluated the influence of four sixth-generation mechanized instrument systems with conservative taper on the wear of distal wall dentin, by means of standardized 3D replicas of upper molars. Significant differences were found in the remaining thickness of dentin/resin before and after instrumentation with the reduced taper systems.

Table 3. Global Tukey's test (differences between groups in the same subset are not statistically significant). Values are the global arithmetic mean.

Group	Subset		
Race Evo	0.46		
Fanta		0.54	
Trunatomy		0.56	
Slim		0.60	
Control			0.85

Dentin wear as a result of root canal instrumentation is not a simple phenomenon, but the outcome of complex multifactorial interaction which includes:

1. Type of metallurgy: Heat treatments determine an instrument's main mechanical properties. They control the transition of phases between the crystalline structures of austenite (more rigid) and martensite (more ductile and flexible), which in turn determines the instrument's flexibility, resistance to cyclic fatigue and cutting efficiency[20].
2. Instrument geometry: A file's macro- and micro-geometric design is a critical determinant of its clinical behavior. The instrument's cross section, taper, pitch, helicoidal angle and core diameter all directly influence stress distribution, cutting capacity, debris extrusion and instrument safety[21-22].
3. Kinematics and Operational Parameters: The way in which the instrument is used, including rotational speed (rpm), torque and type of movement (continuous rotation or reciprocating), has a profound impact on its performance and safety. These parameters modulate the generation of stress both in the instrument and in the walls of the root canal, affecting cyclic fatigue, formation of dentin microcracks, and wear on the dentin wall[23-24].

Although a definitive minimum dentin thickness of the remaining radicular wall has not yet been established scientifically, 0.3 mm is considered critical for bearing the masticatory impact[25]. In the current study, the arithmetic means of remaining thicknesses of the distal wall post-instrumentation were 0.72 mm in the cervical third, 0.53 mm in the middle third, and 0.36 mm in the apical third with instruments with maximum tapers of 0.04, suggesting that this taper may be safe for maintaining a dentin thickness able to withstand masticatory impact.

The rotary systems evaluated had similar tapering and diameters. Although the Race-Evo system generating significantly greater dentin/resin wear than Trunatomy, AF F One and Slim Shaper, this does not necessarily mean that the differences are clinically significant. The differences in the statistical results may be due to characteristics of the model used for this experiment and the rotary speed established by the manufacturer.

Vertucci type IV classification was selected for the 3D replicas because it is the most common arrangement of root canal system and with independent root canals. This enables a separate analysis of instrumentation effectiveness, and increases the size of the study sample[26]. Moreover, these canals are usually narrow, and the dentin on the distal wall of the mesial root is thin, which makes it interesting for evaluating dentin reduction and unprepared zones[27].

The mechanical properties of 3D resin replicas differ from those of natural dentin. The Young module and maximum tensile strength of the resin used for these replicas are lower than those of human dentin, in which Young's module is approximately 18 GPa[17]. This resin, with a wavelength range of 365–405 nm, probably has a modulus of elasticity closer to 2–3 GPa, i.e., which makes it considerably softer and more flexible than natural dentin.

The rotary speed of the Race Evo system suggested by the manufacturer and used in this study (1,000 rpm) was double that used in the other systems. It may have generated heat by friction which could have softened the resinous material of the replicas, causing greater wear in the wall studied. Although 3D replicas are reliable along most of the length of the root canal, future studies could investigate whether alternative resins with properties closer to the mechanical profile of dentin could improve precision in studies on shaping, especially in anatomically complex areas, and determine whether heat caused by rotation softens the resin used. This information could be used to improve dental replica materials. This is one of the limitations of this study.

The cross section of machined instruments is a critical factor influencing their cutting efficiency. Designs with smaller central mass, such as triangular sections, tend to be more flexible and produce very good cuts[28]. More innovative designs, such as off-centered parallelogram or asymmetrical cross sections, alter the dynamics of rotation to reduce continuous contact with the root canal walls[22]. This reduction in contact reduces torsional stress on the instrument and, importantly, minimizes the dentinal wear caused by friction[28].

The Fanta AF One (AF-R Wire, Blue) system uses "AF-R" wire technology with the aim of improving both the flexibility and the resistance of the instrument. The Race Evo system uses a surface electropolishing treatment that provides resistance to torsion[29]. Slim Shaper is based on a concept of "3 alloys": a *Gold* alloy for maximum cutting capacity and torsional resistance, a *Pink* alloy providing a balance between cutting and flexibility, and a *Blue* alloy for extraordinary flexibility and high cyclic fatigue resistance[30]. Trunatomy instruments are made of small-diameter Gold alloy NiTi wire, with maximum diameter at D16 (MFD) of only 0.8 mm, compared to the 1.2 mm of many generic systems[31]. Instrument cross section is an important factor that influences cutting efficiency. Designs with smaller central mass, such as triangular sections, tend to be more flexible and cut well[27]. More innovative designs, such as off-centered parallelogram or asymmetrical cross sections, alter the dynamics of rotation to reduce continuous contact with the root canal walls[22]. This reduction in contact reduces torsional stress on the instrument and importantly, minimizes dentin wear due to friction[27]. In addition to influencing cutting efficiency, instrument cross section influences debris elimination capacity, flexibility and stress distribution[21]. Trunatomy has an off-centered parallelogram cross section that generates asymmetric rotation within the root canal, thereby reducing the contact area between the file and the root canal walls at any given time. Fanta AF One has an S-shaped cross section that provides two active cutting points which increase its cutting efficiency[32]. In contrast, Slim Shaper and Race Evo both have flat triangular cross sections.

Some studies highlight the ability of Trunatomy to preserve root canal anatomy, with minimal transportation[33-34]. Khanderparkar et al.[35] compared the machined systems XP-endo Shaper, TruNatomy and HyFlex CM, reporting that Trunatomy eliminated significantly less dentin at all levels measured, even though all three systems have the same taper (0.04). This may have been because Trunatomy has a regressive type taper. In contrast, Vadera et al.[36], in a study using CBCT, found that Trunatomy eliminated significantly more dentin at 3 mm and 7 mm from the apex, compared to the 2Shape y One Curve systems. This discrepancy might be attributable to differences in methodological evaluation between the two studies (one was evaluated by CBCT and the other by micro-CT), or to the specific characteristics of the systems compared.

In some studies that made direct comparisons, Race Evo performed better than Fanta AF F-One regarding dentin preservation in the central and apical regions of the root canal[20,32]. However, in the current study, Race Evo caused the greatest dentin/resin wear.

The Slim Shaper system caused the least wear in all three thirds. This is probably due to its flat triangular cross section, MDF 0.80, and regressive taper. Although the Race Evo system also has a flat triangular cross section and MDF lower than 1, its taper is constant, which may also have had an influence on the greater wear recorded in the current study.

While alloy properties and cross section influence flexibility and cutting efficiency, tapering is key to the instrument's potential to eliminate debris. Thus, the influence of the type and percentage of tapering may also be important to preserving dentin on the distal wall of the MB2 canal. This firmly supports the use of 0.04 tapers or regressive designs, which would minimize the risk of over-instrumentation and stripping the distal dentin wall of MB2 root canals.

An in vitro study[37] found that the Sx file of the ProTaper Gold system on average eliminated 32% of the dentin of the distal wall of the MB2 canal. The next instrumentation in the same study resulted in perforations towards the furcation in 8% of the specimens with a ProTaper Gold F2 file (25.08), and 16% with a Vortex Blue 30.06 file. Camargo et al.[38] reported perforations in MB2 canals prepared with Mtwo (25.06) and Reciproc (25.08) systems. These results would confirm that tapers greater than 0.04 are too large to provide support remaining dentin in these canals.

The results of the current study on shaping MB2 canals suggest that it may be appropriate to use rotary systems with conservative tapering, along with improved irrigation protocols, rather than using machined instruments with large taper, which could weaken the root's dentin support.

CONCLUSIONS

Within the limitations of this study, it can be concluded that the Trunatomy, Slim Shaper and Fanta AF One systems are adequate for shaping the MB2 canal, preserving the critical thickness of the distal wall following endodontic instrumentation.

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CONFLICT OF INTERESTS

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