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Assessing Percentage of Touched Surfaces and Changes in Cross-sectional Area in Oval Shaped Root Canals after XP-endo Shaper, IRaCe and HyFlex CM Instrumentation Using AutoCAD Software

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Abstract

AIM: This study aimed to calculate the percentage of touched surfaces and changes in the cross-sectional area of oval-shaped root canals after preparation using (XP-endo Shaper, IRace, and HyFlex CM) rotary systems using AutoCAD software.

MATERIALS AND METHODS: Sixty extracted single-rooted mandibular premolars were collected and divided into three main groups according to the rotary system used (n = 20). Each tooth was impeded in a resin block, coded, sectioned, and photographed under a stereomicroscope, before and after instrumentation. Microphotographs were analyzed using AutoCAD software. Two-way ANOVA was used to evaluate the mean percentage of the touched surface and mean cross-sectional area between the groups and tooth segments, followed by Tukey's *post hoc* test for pair-wise comparisons.

RESULTS: The percentage of touched canal walls was significantly different between IRace group and each of XP-endo Shaper and HyFlex CM groups ($p < 0.001$). A statistically significant difference was recorded for the mean change in the cross-sectional areas of the root canal between IRace group and both HyFlex CM and XP-endo Shaper groups, respectively ($p < 0.001$). For all groups, there was a significant difference in the change in the cross-sectional area between all segments (coronal, middle, and apical).

CONCLUSIONS: Within the limitations of this study, the XP-endo Shaper and HyFlex CM files had a higher cutting efficiency and maintained better root stability than the IRaCe system by preserving the dentin of the oval root canal. This was observed at all the canal levels in the coronal, middle, and apical segments.

Introduction

The primary goal of root canal instrumentation is to remove microorganisms through removing the inner most layer of dentin, because microorganisms were found in the inner dentin layer of infected root canals [1].

Different factors that might influence optimum canal cleaning such as preparation size, taper, motion, and canal anatomy. Complete cleaning, shaping, and obturation of an oval-shaped root canal were hardly so far. Because of the complex anatomical configuration of the canals leaving 30%–40% of the root canal surfaces untouched during root canal preparation, particularly on the buccal and lingual surfaces [2], [3].

The root canal might be enlarged to three sizes larger than the initial binding file. It was likewise proposed that any further increment of apical width did not result in increased debridement of the apical third [4]. However, root canal preparation with tapers 0.04, 0.06, or 0.08 did not affect canal cleanliness. Debris removal was almost complete for all tapers [5]. Furthermore, the cross-sectional design of the ProTaper Next and XP-endo Shaper instruments can perform eccentric or asymmetrical rotary motion with a greater contact surface of the instrument with the canal and more efficiency at removing debris [6].

The uninstrumented root canal surface ratio reflects the cleaning ability of the endodontic tools and preparation procedures. The inherent design of the instrument and the dynamics used during instrumentation determine the cutting efficiency and the ability to clean root canal walls [7].

Motorized equipment with rotary nickel titanium (NiTi) files of various tapers has produced numerous results. NiTi rotary files with a 4% taper can create funnel-shaped canals for optimal obturating material compaction [8].

The XP-endo Shaper is a new file for shaping and instrumenting root canals up to 30 mm in diameter. The XP-endo Shaper file composed of a MaxWire alloy and contain six cutting edges at its booster tip [9].

The IRaCe rotary system is a straight forward method for initializing the Race system. The electrochemically polished cutting areas exhibited twisted regions with cutting edges. In terms of canal curvature preservation, the results of the study of IRaCe tools revealed some advantages over other systems [10].

HyFlex CM files were manufactured utilizing a new thermomechanical process for NiTi alloys with regulated memory, rather than the super-elastic files of other standard NiTi files. These tools are in the martensite phase at human body temperature. The file was three-sided, with three edges and three flutes [11].

The purpose of this study was to evaluate the percentage of touched surfaces and changes in cross-sectional area of oval-shaped root canals after XP-endo Shaper, IRaCe, and HyFlex CM rotary system instrumentation using the AutoCAD software. The null hypothesis of this investigation suggested no difference between the XP-endo Shaper, IRaCe, and HyFlex CM rotary systems in terms of changes in oval root canal parameters.

Materials and Methods

This research was approved by the ethical committee of the Faculty of Dentistry, Suez Canal University, Egypt (222/2019). All methods were carried out in accordance with relevant guidelines and regulations.

Study design and sample size calculation

Power analysis was performed using computer software (G*Power) to determine the appropriate sample size based on the results of a preceding study [2]. The sample size calculation yielded a total of 60 sample (20 sample/each group) using One-way ANOVA test (Effect size = 0.412, Pooled SD = 0.194, Alpha (α) = 0.05, and Power (β) = 0.80).

Randomization and blinding

The study was performed where the observer who obtained the data using AutoCAD software and the data analyst who performed the statistical analysis were blinded. The operator was blinded to the coded blocks which were coded and arranged by the allocator but not to the type of file that must be exposed and cannot be masked.

After tooth length adjustment, each tooth was fixed in a resin block and coded. The allocator divided the teeth into three groups based on the coded numbers. Every 10 teeth were impeded in a silicon block; therefore, two blocks for each group were coded by the allocator and sealed in an opaque envelope. A random sequence was generated using a computer software (http://www.random.org/) [12].

Samples selection

Sixty single-rooted human mandibular premolars with apical diameters not larger than the #15 K-file were selected from a group of teeth then randomly divided. The teeth were disinfected, cleaned, and radiographed using cone-beam computed tomography (Planmeca ProMax 3D Mid machine; Helsinki, Finland) to select teeth with straight, sound, and completely formed roots containing a single canal (Vertucci type I) [13]. The selected teeth must have root lengths not less than 12 mm, and canal curvatures not more than 10°. In addition, teeth must have oval-shaped canals, where the buccolingual canal diameter is at least twice the mesiodistal diameter at 5 mm from the apex [14]. Teeth with an initial file size greater than #15 k, root caries, internal or external root resorption, calcified root canals, previous endodontic manipulation, or signs of cracking were excluded from the study.

Preparation of samples

Root canal instrumentation was done by one operator, according to the manufacturer’s instructions for the three main instruments using a VDW silver endomotor (VDW GmbH, Munish, Germany) under magnification of loupes ×5 (Univet, Italy).

The teeth length were adjusted to 22 mm by trimming the cusp tips and the shorter teeth less than 22 mm were excluded. Access cavities were performed using round diamond burs and Endo Z-bur (Mani Inc. DentSply, Malliefer, Japan), with copious amounts of water for cooling. Patency of the root canal was verified using a #15 K-file (MicroMega, Besancon, France). The working length of the teeth was adjusted to 21 mm by observing the tip of the file projecting through the apical foramen and withdrawing 1 mm from the recorded length. The buccal cusp tips served as reference points for all samples. The apices of all teeth were closed with sticky wax and embedded up to the cervical line in epoxy resin blocks surrounded by a silicon mold. The long axis of the tooth was fixed parallel to the long axis of the mold mesiodistally and buccolingually using a parallel meter. Two longitudinal grooves were created on the epoxy resin on the buccal side of the teeth using a diamond disk. The number of teeth in the three groups was marked by different permanent colors on the two buccal grooves in epoxy resin to differentiate the number of teeth in the same group (Figure 1a).

One longitudinal groove on the lingual side of teeth marked by especial permanent color to differentiate groups from each other Group A: Grey (XP-endo Shaper), Group B: Purple (IRaCe), and Group C: Brown (HyFlex CM), (Figure 1b).

Three horizontal grooves were made on the epoxy resin at 3, 6, and 9 from the apex on the mesial side of all teeth, and each part was marked with a permanent color to differentiate between the

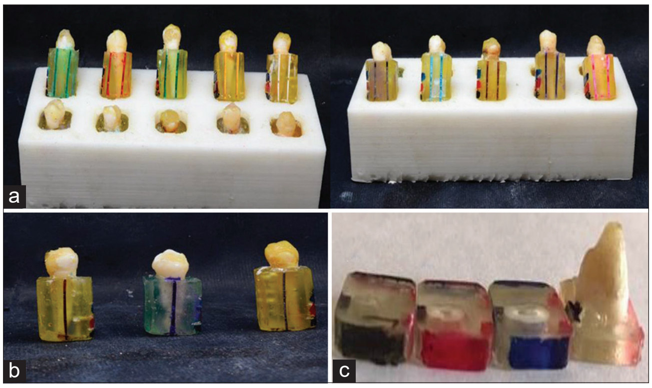

Figure 1: (a) Photographs showing color coding for each tooth number in the same group. (b) A photograph showing color coding for each group. (c) A photograph showing color coding of coronal, middle, and apical parts of each resin block

three parts after root sectioning. Coronal (9 mm), blue; middle (6 mm), red; and apical (3 mm), black. Root lengths and section points were adjusted using a digital caliper, and the root was sectioned from the apex at 3, 6, and 9 using an Isomet (4000 linear precision saw, Illinois, USA) (Figure 1c). Pre-instrumentation images were taken for the coronal, middle, and apical coded sections. Then, the sections were reassembled in their coded silicon molds.

Instrumentation

Every 20 reassembled samples forming a group were placed in a silicon mold. All instrumentation procedures take place in a warm water bath at 35°C–38°C to keep warm to mimic the clinical circumstances of the body temperature throughout the experiment [15].

Group A: XP-endo Shaper (FKG Dentaire, La Chaux-de-Fonds, Switzerland) was used at a speed of 800–1000 rpm and torque of 1 Ncm in long gentle strokes (5–7 mm) to progress down to the working length, with a final root canal size of (30/0.04). Once the working length is reached, the canal was irrigated and the instrument works for an additional 15 gentle strokes. The instrument was always inspected before use and discarded if there were any visible defects; it is a single-use file.

Group B: IRaCe file system (FKG Dentaire, La Chaux-de-Fonds, Switzerland) was used at an optimal speed of 600 rpm and torque of 1.5 Ncm for long back-and-forth stroke light touch, 3–4 s, in sequence file no 1 (15/0.06) then no 2 (25/0.04), and finishing with no 3 (30/0.04), and discard the instrument when all petals on the file stopper have been removed.

Group C: HyFlex CM rotary system (Coltene, Allstatten, Switzerland) was used at speed 500 rpm and torque setting up to 2.4 Ncm in sequence no. 1 (25/08) file was used, as an orifice opener. Slowly advanced without pressure in a pecking motion. The next step was done with File no. 2 (20/0.04) and file no. 3 (25/0.04) were used as the full working length for apical enlargement. File no. 4 (20/0.06) was used to shape the middle part of the root canal then finished with file no. 5 (30/0.04) for the full working length. Files that did not return to their original shapes were discarded.

The preparation protocol was constant for all groups over the entire length of the canal until a size of 30/0.04 gutta-percha master point fit at the working length [10]. The root sections were disassembled after root canal preparation, and post-instrumentation images of the coronal, middle, and apical sections were obtained under the same pre-instrumentation conditions.

Irrigation protocol

All root canals were irrigated with 2 mL of warmed 2.5% NaOCl solution after each of the three in-and-out movements (pecks), and at the end of instrumentation with 5 mL. An additional rinse with 3 mL 17% ethylenediaminetetraacetic acid (META, BIOMED Co. Ltd., Korea), followed by 2 mL saline using a plastic syringe with a 25 gauge irrigation needle (Ameco Co. Egypt).

Evaluation method

Pre- and post-instrumentation images of the coronal, middle, and apical segments were obtained under standardized conditions in the horizontal plane using a stereomicroscope (×35) (Graticules Ltd. Tonbridge, UK). Images were taken with the same code as the cross-sectional tooth in resin blocks and superimposed guided by the outer contour of the root section, traced, and analyzed using AutoCad Software (Autodesk Inc., 2019, San Rafael, CA, USA).

The root canal preparation was assessed by calculating the following:

The original canal perimeter was superimposed on the post-instrumentation perimeter to determine the percentage of the touched and untouched areas. The percentage of the canal surfaces touched was determined using the following formula:

Percentage of touched canal = L orig – L unprep/L orig × 100.6 [16]

- Original perimeter length (L orig) Unprepared length (L unprep)

The change in cross-sectional area (A) of the surface of the canal lumen in a horizontal plane to measure quantity of dentin removal was determined using the formula:

Change in area = A post – A pre [2]

- Area before instrumentation (A pre)
- Area after instrumentation (A post)

Statistical analysis

The Shapiro–Wilk test was used to determine the normal distribution of the data. The information was parametric and normally distributed. To compare the mean percentage of touched surface and mean changes in the cross-sectional area (dependent variables) between the groups and tooth segments (independent variables), two-way ANOVA was used, followed by Tukey's *post hoc* test for pair-wise comparisons. If $p < 0.05$ with a 95% confidence interval, it was considered significant. SPSS (Statistical Package for the Social Science) version 22 (SPSS Inc., Chicago, IL, USA) was managed for data analysis.

Results

The highest mean percentage of touched surfaces was noted in the XP-Shaper group, followed by the HyFlex CM group; the lowest mean percentage was noted in the IRaCe group (Table 1).

For all tooth segments, there was a significant difference between the XP-endo Shaper and IRaCe groups and between the IRaCe and HyFlex CM groups. However, no significant difference was noted between XP-endo Shaper group and HyFlex CM groups (Figures 2-4).

There was a significant difference in the mean percentage of touched surfaces between tooth segments (2-way ANOVA, $p < 0.001$). The highest mean percentage of touched surfaces was noted in the apical third, followed by the middle third; the lowest mean percentage was noted in the coronal third. In the XP-endo Shaper group, there was no significant difference in the mean percentage of touched surface between the coronal and middle thirds.

For all tooth segments, there was a significant difference in the mean change in the cross-sectional area of the root canal between groups. The highest mean change in the cross-sectional area of the root canal was noted in the IRaCe group, followed by the HyFlex CM group, and the lowest mean percentage was noted with XP-endo Shaper group, (Table 2).

For all groups, there was a significant difference in the change in the cross-sectional area of the root canal between tooth segments. The highest mean

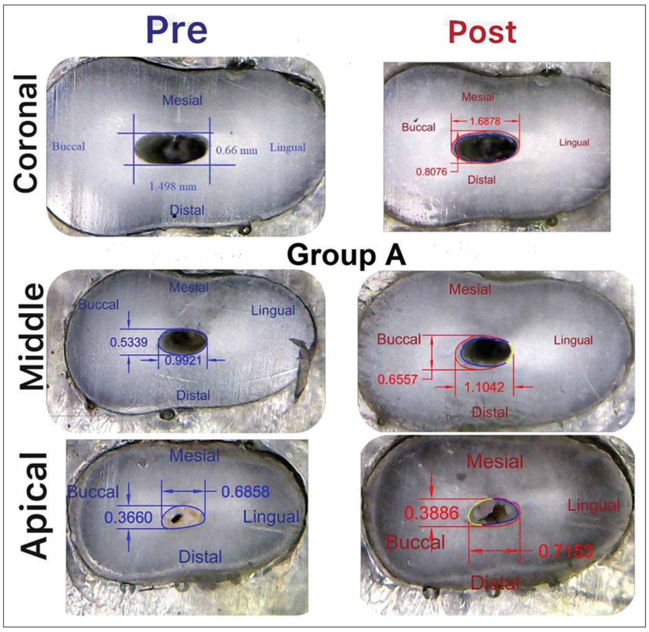

Figure 2: Photographs of pre- and post-instrumented coronal, middle, and apical segments of the root canal using XP-endo shaper (Group A) under stereomicroscope at ×35 traced and analyzed using AutoCad Software. Blue color represented tracing of pre-instrumented outline of the root canal. Red color represented tracing of post-instrumented outline of the root canal. Yellow color represented untouched canal after superimposition of pre- (blue) and post-instrumented outline (red) of the root canal.

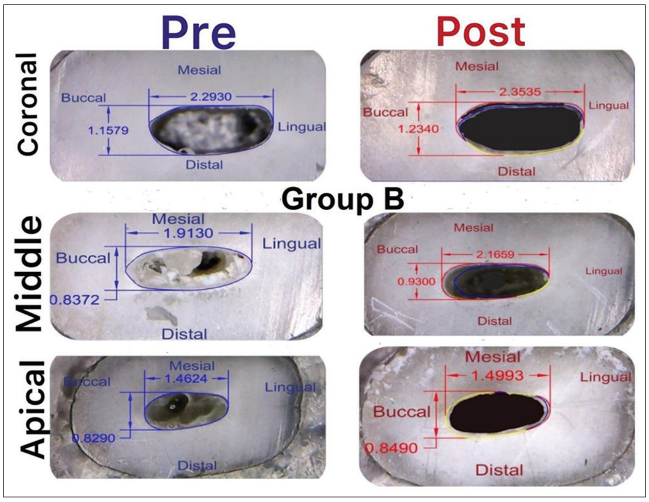

Figure 3: Photographs of pre- and post-instrumented coronal, middle, and apical segments of the root canal using IRace system (Group B) under stereomicroscope at ×35 traced and analyzed using AutoCad Software. Blue color represented tracing of pre-instrumented outline of the root canal. Red color represented tracing of post-instrumented outline of the root canal. Yellow color represented untouched canal after superimposition of pre- (blue) and post-instrumented outline (red) of the root canal

Table 1: Comparison of mean percentage of touched surface between groups and teeth segments

Groups of Rotary Systems	Coronal		Middle		Apical		Two-way ANOVA p-value
	X	SD	X	SD	X	SD	
Group A	64.89A,a	5.72	67.15A,a	5.09	72.54A,b	7.35	<0.001*
Group B	49.93B,a	5.68	55.15B,b	5.94	61.00B,c	6.59	<0.001*
Group C	61.13A,a	7.13	66.40A,b	5.58	71.15A,c	6.11	<0.001*
Two-way ANOVA p	<0.001*		<0.001*		<0.001*		

*p is significant at 5%. Different upper-case letters in the same column show significant difference between each 2 groups (Tukey test, p<0.05) and similar letters showed no significant difference. Different lower-case letters in the same raw show significant difference between each 2 segments (Tukey test, p<0.05) and similar letters showed no significant difference. X: Mean, SD: Standard deviation.

Table 2: Comparison of mean change in cross-sectional area of root canal between groups and teeth segments

Groups of Rotary Systems	Coronal		Middle		Apical		Two-way ANOVA p value
	X	SD	X	SD	X	SD	
Group A	0.385A,a	0.079	0.248A,b	0.068	0.196A,c	0.064	<0.001*
Group B	0.848B,a	0.066	0.760B,b	0.065	0.653B,c	0.060	<0.001*
Group C	0.410A,a	0.082	0.251A,b	0.069	0.199A,c	0.063	<0.001*
Two-way ANOVA p	<0.001*		<0.001*		<0.001*		

*p is significant at 5%. Different upper-case letters in the same column show significant difference between each 2 groups (Tukey test, p<0.05) and similar letters showed no significant difference. Different lower-case letters in the same raw show significant difference between each 2 segments (Tukey test, p<0.05) and similar letters showed no significant difference. X: Mean, SD: Standard deviation.

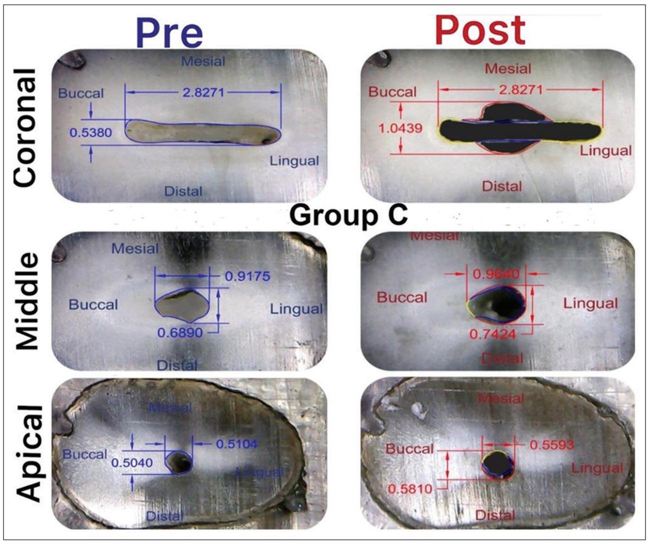

Figure 4: Photographs of pre- and post-instrumented coronal, middle, and apical segments of the root canal using HyFlex CM system (Group C) under stereomicroscope at ×35 traced and analyzed using AutoCad Software. Blue color represented tracing of pre-instrumented outline of the root canal. Red color represented tracing of post-instrumented outline of the root canal. Yellow color represented untouched canal after superimposition of pre- (blue) and post-instrumented outline (red) of the root canal

change in the cross-sectional area of the root canal was noted in the coronal third, followed by the middle third, and the lowest mean percentage was noted in the apical third (Table 2).

Discussion

Understanding the root canal system (anatomy, morphology, and shape) is one of the most important factors for successful endodontic treatment. Root canal shaping and cleaning are critical for endodontic treatments success. Canal shaping should ideally result in a continuous tapered preparation with increasing apicocoronal diameter, while preserving the canal's original path [17], [18].

The present *in vitro* study was designed to simulate clinical situations and allow for realistic instrument performance evaluation. Due to the difficulty of the anatomical configuration of the oval root canal surfaces, where the buccolingual canal diameter was at least twice the mesiodistal diameter so lower permanent mandibular premolars with a single oval canal were included [19], [20]. Many studies have found that after hand and rotary instrumentation, buccal and lingual extensions of oval-shaped canals were untouched, potentially harboring necrotic pulp tissue, bacterial biofilms, and dentin debris [21], [22], [23].

To ensure standardization of the master apical file at 30/04, lower premolar teeth with an initial file size greater than #15 k were excluded from the study. Standardization of the finished apical file is critical for regulating final apical preparation size and ensuring group comparability [24]. To control the variability in root length, only sound straight roots with at least 12 mm length were chosen, and three cross-sectional levels were 3, 6, and 9 mm to signify the apical, middle, and coronal segments of the root canals, respectively [14].

The custom-made silicon mold was a variation of the model proposed by Bramante *et al*. [25] for comparing the root canal anatomy before and after canal instrumentation. Following the pre-instrumentation scanning procedure, the samples were embedded in resin blocks for easy reassembly of the coded sectioned samples for chemo-mechanical preparation. Each sample was immersed in epoxy resin using a parallel meter to ensure parallelism between the sample and mold long axes until setting [26].

For proper pre- and post-instrumentation, imaging, and reassembling, a diamond disk was used to create two longitudinal grooves on the epoxy resin on the buccal sides of the teeth. To differentiate between the numbers of teeth in the same group, the number of teeth in the three groups was marked with a special permanent color on the two buccal grooves in epoxy resin. To distinguish the groups, one longitudinal groove on the lingual side of the teeth was marked with a special permanent color. For all teeth, three horizontal grooves were made on the epoxy resin at positions 3, 6, and 9 from the apex on the mesial side, and each part was marked with a permanent color to differentiate the three parts after root sectioning [27].

To mimic clinical conditions, all instrumentation procedures were performed in a warm water bath (35°C–38°C) and irrigated with preheated sodium hypochlorite, as it has been demonstrated that heat-treated instruments, such as the XP-endo Shaper, can change from the martensitic to the austenitic phase when used in the oral cavity. Furthermore, the simulation of body temperature was deemed critical, as temperature changes were predicted to affect the XP-endo Shaper expansion properties. For standardization, all rotary instruments were used for reaching the full working length in an in-and-out pecking motion with light brushing motion was applied regarding the buccal and lingual walls to improve the file contact with the canal surfaces [28], [29].

In the present study, AutoCAD software allowed the tracing of the root canal outline with high precision. Moreover, the software enabled accurate superimposition and manipulation of the pre- and post-instrumentation images. This helped the evaluator easily detect canal areas that had been touched by the rotary instrument, which ensured reliable calculations while minimizing bias. AutoCAD was used to study different parameters, such as measuring root canal curvature, calculating the number of touched canal walls, determining the instrument's cross-sectional measurements, assessing instrument shaping ability, and during root canal retreatment to evaluate efficacy of various instruments in removing gutta-percha and sealer [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33].

The results of the present study recorded a greater percentage of touched canal surface in the XP-endo Shaper and HyFlex CM groups, with a statistically significant difference compared to the IRaCe group. This was observed at all the canal levels (coronal, middle, and apical).

These findings highlight the unique expansion properties of the Max Wire alloy that constitutes the XP-endo Shaper. Once subjected to body temperature, the alloy undergoes a phase transformation, shifting from the martensitic to austenitic phase, which allows the file to expand beyond its core size and touch more canal walls [17], [34].

Furthermore, the cutting efficiency and flexibility of Hyflex CM files are due to the thermal pretreatment of the CM alloy during manufacturing, which makes the alloy more ductile and reduces the magnitude of the restoring forces. According to a previous study, Hyflex CM files are highly bendable, with comparable torsional resistance and higher fatigue resistance than those of conventional NiTi files [35], [36].

Furthermore, the IRaCe instrument exhibits fewer changes. This is because of their small cross-sectional areas; however, they are flexible and allow for more debris removal. The working part IRaCe was designed with alternating cutting edges. This design feature is said to prevent screwing and thus lower the intraoperative torque values [36], [37]. Besides, the lack of a rigid metal core makes the file extremely flexible, preventing uniform lateral pressure on the dentinal walls [13].

However, one may argue that the current results cannot be directly compared to earlier studies done by Lacerda *et al*. [38], who evaluated the number of canal walls touched by the XP-endo Shaper due to different methodological approaches. However, comparable results were described by Azim *et al*. [17] who realized a statistically significant difference between XP-endo Shaper and another "none adaptive core files."

In all groups, there was a significant difference in the mean percentage of touched surface between tooth segments, with the highest mean touched canal wall values were recorded apical and the lowest mean values being coronally. This can be attributed to the fact that the long diameter of oval root canals generally decreases where the canal progresses apically, resulting in a less oval cross-section and allowing more canal walls to be touched by the rotary instrument [39].

According to the findings of this study, no instrumentation procedure was completely preparing the dentin walls in oval-shaped canals, which is consistent with the findings of Taha *et al*. [40] who assessed the pre-instrumented canal wall in relation to the post-instrumentation outline rather than the original canal outline, as in the present study.

Excessive dentin removal can result in root fractures [41], [42], if the instrument is properly centered during instrumentation of the root canal, this could preserve more dentin to maintaine root strength [43]. The amount of dentin removed was determined by measuring the change in cross-sectional area.

There was a statistically significant difference in the cross-sectional area of the root canal between the tooth segments in all groups. The coronal third had the highest mean change in the cross-sectional area of the root canal, followed by the middle third; the apical third had the lowest mean percentage. This difference could be explained by the number of instruments used and their size, taper, number of flutes, and cross-section [44], [45], [46], [47], [48].

IRaCe instruments enable curved root canals preparation with apical diameters larger than those normally achieved with other rotary NiTi instruments [49]. Versiani *et al*. [10] discovered no significant difference between the XP-endo shaper and IRaCe in touched canal walls in another study. Data on the cleaning ability of XP-endo Shaper are currently scarce. However, due to different methodological approaches, one could argue that the current results cannot be directly contrasted to those of previous studies that evaluated the number of canal walls touched by the XP Shaper.

Root canals should be enlarged to the commonly used preparation diameters, with improved cleaning of oval canals that prevent instrument action on all walls. The greater volume of irrigating solution that can act in this area, such enlargement also favors the removal of more pulpal remains, dentin, and microorganisms, contributing to better root canal disinfection [50], [51].

The null hypothesis was rejected because, there was a significant difference in the touched canal walls and a change in cross-sectional area between the XP-endo Shaper and HyFlex CM groups and the IRaCe group. No significant difference was observed between the XP-endo Shaper and HyFlex CM groups. Except for the XP-endo Shaper group, which was not significant between (coronal and middle) segments, there was a significant difference in the change in cross-sectional area of root canals and touched canal walls between all groups.

Further studies with larger sample sizes, use of different types of files and rotary systems, and comparison with other methods of evaluation such as microCT are needed.

Conclusions

None of the three instrumentation technique either completely or entirely prepared the dentin walls in oval-shaped root canal. XP-endo Shaper group and HyFlex CM group, respectively, have more cutting efficiency and maintain root stability through preserving dentin of root canal compared to IRaCe group. This was observed at all canal levels (coronal, middle, and apical).

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