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Comparative Analysis of Continuous versus Reciprocating Instruments in Retreatment of Flat-oval Root Canals

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ABSTRACT

Introduction: Flat-oval root canals of incisors can be problematic in retreatments. This study assessed the efficacy of continuous and reciprocating rotation instruments in retreatment of flat-oval root canals in lower incisors via micro-computed tomography (micro-CT). File systems studied were ProTaper universal retreatment rotary system associated with ProTaper Next (PTUR+PTN), D-RaCe associated with iRaCe (DR+iR), Reciproc (REC), and WaveOne (WO). **Materials and Methods:** Thirty-two mandibular incisors with flat root canal were divided into 4 groups (n=8). The groups were initially prepared with PTN, iRaCe, REC, and WO, then instrumented, filled, and subjected to micro-CT analyses. All the canals were then retreated with the PTUR+PTN, DR+iR, REC, and WO, and then subjected to new micro-CT analysis which allowed quantification of residual filling material volume and change in the diameter of the root canal apical third. Endodontic retreatment time was also quantified. Data were analyzed with One-Way ANOVA and post hoc t tests. **Results:** None of the systems completely removed the filling material. The groups differed in terms of remnant filling material volume (PTUR+PTN=2.9±1.1 mm^3; DR+iR=3.6±3.1 mm^3; REC=4.9±1.9 mm^3; WO=3.1±1.9 mm^3) and retreatment time (PTUR+PTN=1:36±0:12 sec; DR+iR=0:57±0:13 sec; REC=2:10±0:44 sec; WO=2:03±0:31 sec), but had similar values in terms of change in apical root canal diameter (P>0.05). **Conclusions:** Based on this *in vitro* study, the type of endodontic instrument did not affect the diameter of the root canal apical third. However, PTUR with ProTaper Next had the lowest residual filling material volume and second lowest retreatment time, in flat-oval root canals in mandibular incisors.

Keywords: Incisor; Retreatment; Root Canal Preparation; X-Ray Microtomography

Introduction

The removal of root canal filling material is an essential step during endodontic retreatment. Failures during this step can lead to permanence and further infiltration of microorganisms into the root canal system; which is the main cause of endodontic treatment failure [1]. Root canal retreatment can be performed with available automated systems, such as the continuous rotation [2] and alternating reciprocating rotation systems [3].

Continuous rotating systems rotate in a clockwise direction. The ProTaper system (Dentsply Maillefer, Ballaigues, Switzerland) has a progressively conical design and a convex triangular cross-section [2], which are intended to improve cutting efficiency and safety. The ProTaper NiTi rotation system has been upgraded to the ProTaper Universal system, which includes shaping, finishing and retreatment instruments. The three retreatment instruments (D1, D2 and D3) are designed for removing filling materials from the coronal, middle and apical portions of canals, respectively [4].

The Protaper Next system (Dentsply Maillefer, Ballaigues, Switzerland) is also produced from the M-Wire alloy, has an asymmetric design that generates a sinusoidal wave, making the root canal preparation safer [2]. The iRaCe® system (FKG, La Chaux-de-Fonds, Switzerland), on the other hand, is not made of M\ -Wire and features a small cross-section intended to improve flexibility, which also improves debris removal [5]. This system features a rounded tip design that eliminates the screwing effect [6].

D-RaCe retreatment system (FKG, La Chaux-de-Fonds, Switzerland) have been introduced to complete the RaCe NiTi system. These two retreatment instruments, DR1 and DR2, are designed with alternating cutting edges and a triangular cross-section. D-RaCe instruments are used to remove most of the old root filling material. The D-RaCe set consists of two NiTi files-DR1 and DR2. The first instrument, DR1, (size and taper 30/0.10), has an active tip to handle the root filling material and is used in the first millimeters of the coronal and straight part of the canal. Once the access with the DR1 is opened, the second instrument, the DR2, (size and taper 25/0.04) is used to reach the working length (WL) [7].

Alternating reciprocating systems, such as Reciproc (VDW, Munich, Germany) and WaveOne (Dentsply Maillefer, Ballaigues, Switzerland) have the dual features of reciprocating kinematics, including both clockwise and counterclockwise motion directions, and the NiTi alloy files, the latter known as M-Wire [8] that are more flexible with an increased torsional fracture resistance as compared to stainless steel files [9].

During root canal preparation, specifically in narrow flat-oval canals, the use of effective automated systems might still leave poorly cleaned areas where bacteria and necrotic tissue remain [10]. This in turn may cause recurrent periapical lesion, where endodontic retreatment would be recommended [11]. Narrow oval flat canals may therefore be a good starting point for an investigating efficacy of filing. The ideal instrument for endodontic retreatment should allow complete removal of the obturation material (gutta-percha and sealer) in a short time, without alteration of the root canal anatomy or damage/weakness to the root [12].

Micro-computed tomography (micro-CT) is a noninvasive technique that allows tridimensional analysis of various endodontic outcomes. It has been used in various studies that evaluated efficacy of endodontic instruments in the preparation of flat-oval root canals [13] and the removal of the filling material [12, 14, 15].

We have realized that there is lack of comparative data on the effect of different continuous rotation and reciprocating endodontic instrumentation techniques on endodontic retreatment outcomes in flat-oval root canals. Thus, our study investigated endodontic instrumentation technique (using four systems) in retreatment of obturated canals with three different outcomes: *(i)* the volume of remnants of endodontic root canal filling material after retreatment (phase of root canal filling removal and preparation); *(ii)* the root canal diameter at the apical third after endodontic retreatment and subsequent obturation; and *(iii)* the preparation time required for retreatment of single root canals.

Materials and Methods

Ethical aspects

This *in vitro* study was approved by the Human Research Ethics Committee of the Institute of Health Sciences of the Federal University of Bahia (Salvador, Bahia, Brazil). This study was permitted according to the register number 1.736.909.

Samples and groups

Thirty-two extracted human lower incisor teeth were selected for this *in vitro* study. X-ray tomography was performed prior to initiating the investigation to assist in sample selection. All extracted teeth were vertically mounted (incisal edge upwards) in a plastic container and submitted to X-ray tomography (model CS9000, Carestream, United Kingdom) operating at 70 kV, 10 mA, exposition time of 10.3 min, and using voxel size of 0.076 mm and field of view of 53×74 mm. Single-rooted sound virgin teeth (without prior endodontic treatment) with straight root canal, and no signs of internal root resorption and fracture were selected. All the incisors chosen had flat-oval root canals (the ratio between the major and minor canal diameters was >2 and <4 mm/mm) [16]. These teeth also presented with similar dimensions at the middle root third (4-5 mm in mesiodistal direction, and 5-6.5 mm in bucco-lingual direction), and had complete root and root apex formation. Micro-computed 3D tomography (micro-CT) analysis (see details below) was performed to confirm sample selection criteria. After root surface cleaning, all teeth were stored in a 0.1% Thymol aqueous solution and refrigerated until use. Tooth crowns were then removed by performing horizontal sections located 2 mm occlusal to the enamel-cementum junction (from which point measurements were done) by using a carbon disk coupled to a low-speed handpiece under water irrigation. We measured the length of roots following crown removal with calipers and the average length was 16 mm.

Based on the removal technique of root filling material, teeth were divided into four experimental groups: ProTaper Universal

retreatment rotation system + ProTaper Next (PTN) rotary system (PTUR+PTN, Group 1, G1), D-RaCe retreatment system +iRaCe® NiTi rotary system (Group 2, G2), Reciproc alternating reciprocating system (Group 3, G3), and WaveOne alternating reciprocating system (Group 4, G4). Each individual group consisted of 8 teeth (n=8). Samples were used in a chronological sequence of study phases: endodontic retreatment (Phase 1), and endodontic obturation after retreatment (Phase 2).

Endodontic treatment instrumentation and obturation

Root canal instrumentation was performed following each manufacturer's recommendations using a VDW Silver torque-control motor (VDW, Munich, Germany). Root canal irrigation with 2.5% sodium hypochlorite solution was performed in all teeth following the filing instruments. The working distance was assessed using a K-file#15 (Dentsply, Maillefer, Switzerland) inserted up to root apex when its tip was visible close to the apical foramen, and the working distance was determined to be 0.5 mm short of the apical foramen.

In G1, root canal was instrumented with ProTaper Next (PTN) rotary system using the following sequence of rotary files: X1 (17/0.04), X2 (25/0.06), X3 (30/0.07), and X4 (40/0.06). In G2, instrumentation was performed with iRaCe (iR) rotary system using the following sequence of rotary files: R1 (15/0.06), R2 (25/0.04), and R3 (30/0.04) files. Root canals were finished with the BR4 (35/0.04) and BR5 (40/0.04) BioRaCe files. In G3 (instrumentation with the Reciproc reciprocating system) and G4 (instrumentation with the WaveOne reciprocating system), root canal was instrumented with the R40 file (40/0.06) and the Large file (40/0.08), respectively. These files were used in a pecking motion (forward and backward), one millimeter at a time, pressing the instrument gently against the walls with slight apical pressure for each third of the root canal.

Following instrumentation, the canals were irrigated with 17% EDTA solution and ultrasonically activated for one min. Final irrigation of the root canals was performed with 10 mL of 2.5% NaOCl, and the canals were dried with absorbent paper points.

The root canals were filled using a single cone technique as recommended by the manufacturer (compatible with taper and type of each instrument), except the iRaCe system with which it was used a standard 40/0.04 cone and AH-Plus endodontic sealer (Dentsply, Tulsa Dental, Tulsa, OK, USA). The crowns were sealed with Filtek Z350 XT composite resin (3M ESPE, St Paul, MN, USA). Micro-CT scans were obtained to assess the quality of the root canal fillings and to confirm compliance with the technical requirements. Specimens were stored at approximately 37°C in a biological incubator (002CB Model; Fanem LTDA, São Paulo, Brazil) with 100% humidity for 30 days.

Micro-CT scanning

Micro-CT analysis was performed using the SkyScan 1172 micro-CT equipment (Bruker, Kontich, Belgium) operating at 100 kV and 100 uA, using a copper-aluminum filter, rotation step of 0.6, resolution of 27 µm, 360° rotation, and frame average of 4. All specimens were imaged three times: (1) at baseline, following initial treatment and obturation, (2) following retreatment instrumentation (Phase 1), and (3) after retreatment obturation (Phase 2). Prior to scanning, each tooth was positioned with the crown upwards and fixed in wax for insertion into a metallic support which allowed reproducible positioning of the tooth for all images. NRecon software (Bruker, Kontich, Belgium) was used for image reconstruction with the following parameters: smoothing of 4, beam hardening correction of 30%, and ring artifact correction of 10.

The CTAn software (Bruker, Kontich, Belgium) allowed a quantitative 3D assessment of the images; for measuring desired outcomes at each phase the volume was obtained in mm^3.

The measurement of selected outcomes (volume in mm^3) was performed with standardized regions of interest and grays level values (required for binarization) for all samples at each study phase. The diameter of the instrumented root canal was quantified at an anatomical site located 3 mm from the apex, both after phase 1 and phase 2.

Endodontic retreatment

Following the removal of temporary material at the entrance of the canals with a 1014 HL round diamond bur (KG Sorensen, São Paulo, Brazil) by a high-speed dental handpiece, root canals were retreated. The filling material was removed according to the recommended techniques of each system. The total time to remove the filling material was measured in seconds.

In the ProTaper Universal rotary system for retreatment + ProTaper Next group (PTUR-PTN), the filling material was removed with the D1, D2, D3, X3, and X4 ProTaper Universal Retreatment (PTR) files. All files were used at 500 rpm and 0.5 N/cm torque. The initial instrument, D1 (30/.09), was used to remove the coronal filling. The D2 file (25/0.08) was used to remove the filling material from the middle third, and the D3 instrument (20/0.07) was used to remove the filling material from the apical third. The X3 and X4 instruments were used for final canal preparation.

In the iRaCe group, the retreatment was performed with the D-RaCe retreatment files (D-RaCe group) (DR1 30/0.10, DR2 25/0.04, 35/0.04 and 40/0.04). The first instrument

(DR1) was used up to the cervical third at 1000 rpm and torque of 1.5 N/cm. The second instrument, DR2, was used to remove the filling of the middle and apical thirds at 600 rpm, with a torque of 0.7 N/cm. At the end, 35/0.04 and 40/0.04 files were used to prepare the root canal space to an apical diameter of 0.40 mm.

In the WaveOne Large (40/0.08) and Reciproc R40 (40/0.06) retreatment groups, the filling material was removed with the same instruments that had carried out endodontic treatment, following the same protocol used in a recent study [17]. The WaveOne large single use instrument was used in reciprocating rotation and it was introduced into the root canal in a crown down fashion with slight apical pressure until resistance was found; at that very moment, a pecking motion was performed with the handpiece. This was followed by a new introduction of rotary files until the work length was reached. The Reciproc R40 instruments followed the same methodology.

For all experimental groups, treatment was considered complete once the dentin walls were smooth and gutta-percha was not seen in the instrument flutes. Micro-CT scanning was performed after endodontic filling material removal.

Table 1. Residual filling material (mm^3) in the root canal after removal of the filling material

	Groups			
	Reciproc	**WaveOne**	**D-RaCe + iRaCe**	**ProTaper + ProTaper Next**
Mean (SD)	4.990 (1.899)	3.105 (1.903)	3.617 (3.059)	2.915 (1.088)
Post hoc *t*-test				
Comparative groups	*P*-value	Hedge's g		95% CI (lower/upper)
Reciproc × WaveOne	0.0673	0.992		-0.145/ 2.128
Reciproc× D-RaCe + iRaCe	0.2990	0.539		-0.145/2.128
Reciproc×ProTaper + ProTaper Next	0.0179	1.341		0.154/2.528
WaveOne × D-RaCe + iRaCe	0.6936	0.201		-0.874/1.276
WaveOne × ProTaper + ProTaper Next	0.8097	0.123		-0.951/1.196
D-RaCe +iRaCe× ProTaper + ProTaper Next	0.550	0.306		-0.773/1.385

Table 2. Results of the difference (after retreatment minus before retreatment) in apical root canal diameter (mm) relative to root canal retreatment

	Groups			
	Reciproc	**WaveOne**	**D-RaCe + iRaCe**	**ProTaper + ProTaper Next**
Mean (SD)	0.080 (0.059)	0.1978 (0.1948)	0.1249 (0.1138)	0.087 (0.0559)
Post hoc *t*-test				
Comparative groups	P-value	Hedge's g	95% CI lower limit	95% CI upper limit
Reciproc × WaveOne	0.124	0.819	-0.297	1.936
Reciproc × D-RaCe + iRaCe	0.338	0.496	-0.593	1.585
Reciproc × ProTaper + ProTaper Next	0.799	0.129	-0.944	1.203
WaveOne × D-RaCe + iRaCe	0.376	0.457	-0.629	1.544
WaveOne × ProTaper + ProTaper Next	0.146	0.771	-0.341	1.882
D-RaCe +iRaCe ×ProTaper + ProTaper Next	0.417	0.418	-0.666	1.502

Table 3. Retreatment time (min: sec) according to the technique used

	Groups			
	Reciproc	**WaveOne**	**D-RaCe + iRaCe**	**ProTaper + ProTaper Next**
Mean (SD)	2:10 (0:44)	2:03 (0:31)	0:57 (0:13)	1:36 (0:12)
Post hoc *t*-test				
Comparative groups	P-value	Hedge's g	90% CI lower limit	90% CI upper limit
Reciproc × WaveOne	0.7338	-0.1740	0.7188	-1.067
Reciproc × D-RaCe + iRaCe	0.0019	2.2568	1.0673	3.4462
Reciproc×ProTaper + ProTaper Next	0.0668	1.0598	0.0669	2.0527
WaveOne × D-RaCe + iRaCe	0.0003	2.7903	1.5028	4.0779
WaveOne × ProTaper + ProTaper Next	0.0445	1.1663	0.1749	2.1578
D-RaCe +iRaCe × ProTaper + ProTaper Next	0.00004	3.0350	4.3334	1.7363

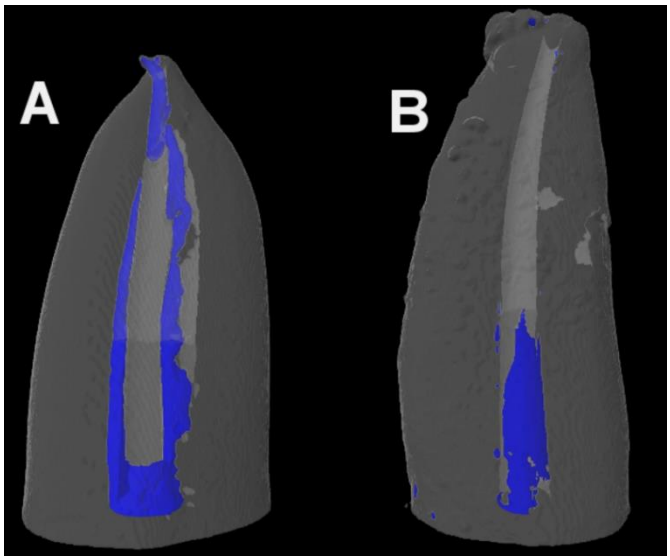

Figure 1. Examples of root canals with high; *A)* Reciproc; *B)* lowProTaper + ProTaper Next volumes with residual amount of filling material after retreatment as visualized under micro CT

Root canal refilling

The teeth were obturated in the same manner as described previously.

Statistical analysis

For each study phase, the tested null hypothesis was that the specific retreatment did not affect the outcomes (3 dependent variables). All groups were tested statistically regarding normality by calculating kurtosis and skewness, and those with a variation of ±2 from the optimal value (-2 to 2 in skewness; 1 to 5 in kurtosis) were considered normally distributed [18]. When evaluating assumptions for ANOVA, homogeneity of variances was not tested because ANOVA is only slightly affected by heterogeneous variances when groups have equal sample size as it was here [19]. One-way ANOVA and post hoc T tests for comparisons between pairs of groups were performed with a 5% significance level (2-tailed for T tests), and the effect size, 95% confidence interval, were calculated [20]. Bonferroni correction for type I error was not performed because all tests were planned in advance, during study design [21]. Post hoc pairwise comparisons were not performed with Tukey's honestly significant difference (HSD) test because it increases the false negative error rate (false acceptance of the null hypothesis) [18]. Even when One-Way ANOVA had $P>0.05$, post hoc tests were performed because One-Way ANOVA might mask some pairwise differences when most (but not all) of the groups have similar effects [22].

Results

Phase 1

For this phase, the tested null hypothesis was that the retreatment system did not change the amount of residual filling material in the root canal. We did not reject ($P= 0.216$) the null hypothesis, with a low ETA-squared effect size of 0.145. Though the omnibus null hypothesis was not rejected ($P> 0.05$), pairwise comparisons were performed because high *P*-values from ANOVA do not preclude the existence of statistical differences for all pairwise comparisons [22]. The results of pairwise comparisons are shown in Table 1. The ProTaper systems group presented the lowest volume of residual filling material, and it differed from the Reciproc group with a large effect size (1.341) [20].

Examples of root canals with high and low residual filling material volume are shown in Figure 1.

Phase 2

Our null hypothesis assumed that the technique used for filling material removal did not affect the diameter of the instrumented canal in the apical third (3 mm away from the apical foramen). However, the null hypothesis was not rejected ($P>0.05$) by ANOVA, with a low effect magnitude (0.148 ETA-squared). Omnibus null hypothesis was not rejected ($P=0.207$), never the less, pairwise comparisons were performed (as done before in Phase 1) for statistical reasons stated above. The Reciproc group had the lowest alteration of the apical third root canal diameter, but all groups presented with very close values ($P>0.05$; Table 2).

Endodontic retreatment time

In this case, the null hypothesis was rejected ($P = 6.08\times10^{-5}$), *i.e.* there would no difference in time, with high effect size (Eta-squared of 0.54) and power (99.98%). The results of the pairwise comparisons between groups are shown in Table 3. The DR+iR group had the shortest retreatment time compared to all the other groups, followed by the PTUR-PTN group. Reciproc and WaveOne groups had the longest times and did not differ from each other.

Discussion

Our study illustrated that the type of endodontic instrument and kinematics affected the removal of endodontic root canal filling material, root canal diameter at the apical third post-retreatment as well the retreatment time. This has important implications for endodontic retreatment of flat-oval root canals. The present study used flat root canals due to their complex anatomy, which makes it difficult for endodontic instruments to get to all the walls during biomechanical preparation [23, 24].

All the specimens were filled with their respective gutta-percha cones according to their instrumentation systems and the manufacturer's guidelines, except for the iRaCe system. That system obturated with gutta-percha cone that matched the size and taper of the last instrument used. For groups treated with PTUR +PTN, REC, and WO systems, their respective cones were used.

The PTUR+PTN system presented with the lowest residual filling material volume after retreatment. Other studies have shown good PTR results for the removal of gutta-percha [4, 25, 26]. The fact that the PTN rotary files were complemented with asymmetric rotary motion of PTN instruments, may have resulted in their superior performance compared to the others systems with symmetrical rotary motion. None of the retreatment techniques were entirely effective in removing the filling material from the root canals, concurring with previous studies [17, 27, 28]. Although the two assessed reciprocating systems (REC and WO) are not specifically developed for root canal *re*treatment- in contrast to as PTUR+PTN and DR retreatment systems- the former instruments are generally used for this purpose [17, 29].

The studies that assessed the effectiveness of the Reciproc system in root filling material removal have shown their excellent performance [30, 31] when compared to conventional rotary systems. Our results disagree: the ProTaper rotary retreatment system had superior performance compared to the REC and WO reciprocating systems. There is evidence indicating that the sectioning capability of the WaveOne system is lower than the Reciproc system [32]. The increased sectioning ability of the Reciproc system should have resulted in a higher efficiency in the removal of root filling material [13]. Interestingly, the present study results showed the opposite. In this context, we must emphasize that no study has evaluated the effectiveness of the association of retreatment instruments with a root canal preparation instrument during retreatment of flat-oval root canals.

Micro-CT analysis was chosen because it is an excellent non-invasive and non-destructive method for the quantitative and qualitative assessment of the root canal [33]. It allows both two-dimensional and three-dimensional analyses without destroying the specimens [17]. Few studies in the literature have assessed the performance of endodontic instrumentation techniques for retreatment with micro-CT [17, 34-36]. The small pool studies available investigating flat-oval root canals of lower incisors [34-36], do not assess all the parameters we have looked into in this study; *i.e.* the combined assessment of residual filling material volume, root canal diameter at the apical third after endodontic retreatment and obturation, as well as retreatment time.

Our research showed that DR+iR groups had higher amounts of remaining root canal filling material compared to the PTUR+PTN group. Another research also found D-RaCe instrument to be ineffective when compared with the ProTaper universal retreatment and Mtwo retreatment instruments. Authors concluded that the percentage of residual material was lowest in the PTUR group and was statistically significant only when compared to the D-RaCe system root filling remnants [7].

We also found that D-RaCe instruments left significantly more residual filling material in root canals than the PTUR+PTN instruments, however, this contradicts the findings of Rödig *et al.* [37]. This result may be related to the different diameters of the instruments (taper 40/0.04 in iRaCe and taper 40/0.06 in ProTaper Next), and, therefore, during the apical preparation, gutta-percha might have been removed simultaneously with the re-preparation of the root canal, what reinforces the importance of enlarging the apical third after removing gutta-percha. Dhaimy *et al.* [38] despite their good results for D-RaCe primary retreatment, concluded that all systems left some debris inside the root canal and classical removal of canal filling material may not be sufficient for root canal disinfection. A complementary finishing approach to improve results has been recommended.

No procedural failures, such as instrument fractures, occurred in the PTUR+PTN, WO, and DR+iR groups. In the Reciproc group, two instruments presented separation of parts at the cervical third of the root canal. This might be explained by the fact that Reciproc instruments were not designed for retreatment. Reciproc has the smallest core mass when compared to the other rotary files we utilized. Therefore, the active part of the instrument may have buckled during contact with the root canal filling material, contributing to the fracture of the instruments. Furthermore, in order to remove the filling material from the canal, by forcing the instrument in the apical direction, the elasticity limit of the instrument may be exceeded. One study has shown that reciprocating motion, when subjected to repetitive torsional loading, significantly reduces torsional strength compared to continuous rotating motion [39].

During the removal of the filling material, endodontic instruments might simultaneously prepare the root canal. We can verify that in our study none of the systems affected the diameter of the instrumented root canal in the apical third, during the removal of the filling material, similar to another study [40].

The diameter of the instrumented canal was assessed at 3 mm away from the apical foramen. This part was chosen because: (*i*) it has been shown that the more apically located 4

mm are the most contaminated after endodontic treatment [41]; and (*ii*) baseline X-ray tomographic analysis showed that the most oval part was located 3 mm away from the apical foramen. The Reciproc system presented the lowest change in root canal diameter in the apical third, while it presented the highest residual filling material volume after retreatment.

The results indicated that all instruments showed similar changes in the diameter of the root canal in the apical third. This might be explained by the last instrument tip diameter used to prepare the canals was the same as the one used at the end of retreatment. Other studies investigated the effect of additional apical preparation using systems larger than 40/0.08 tip and lower taper and concluded that an additional apical preparation with instruments such as 50/0.01, for endodontic retreatment, improved filling material removal in the apical third, while maintaining the dentine in the cervical and middle thirds with low risk of fracture [42]. Therefore, it is important that the apical diameter be enlarged beyond a size 40 file so that dentine can be removed, decreasing the potential for remaining infection of the root canal after endodontic retreatment.

If we analyze the time averages of each system, the Reciproc and WaveOne systems required a longer treatment time compared to the D-RaCe group, despite the differences in the number of files for each system. The continuous and reciprocating instruments differ in terms of movement kinematics, with the continuous instruments using only clockwise rotation and the reciprocating instruments using both clockwise and counterclockwise rotations to complete a full 360° rotation in the root canal [43]. As material removal from the root canal and its walls occurs during clockwise movement, continuous instruments tend to be faster than reciprocating ones.

De Campos Fruchi *et al.* [28]; however, observed that reciprocating systems are faster at removing filling material, conflicting with the results of the present study. This might be explained by the use of curved mesio-buccal root canals of permanent molar teeth in their study, which require several continuous instruments to be completely shaped [43]; while in the present study we tested lower incisors with straight canals. Retreatments of root canals are tricky dental operations, with each tooth having its challenges. Our study can be a base for further analysis of incisor retreatment procedures.

Conclusion

Endodontic retreatment is a difficult procedure. We can conclude that the type of endodontic retreatment system did not affect the diameter of the root canal in the apical third in this *in vitro* study. The PTUR+PTN system created the lowest residual filling material volume, a large change in root canal diameter in the apical third, and a relatively low retreatment time in the oval shaped incisor root. The above-mentioned system may be recommended for use in endodontic retreatments; however, it could not be considered gold standard. Further research and investigations are nevertheless necessary to better the endodontic treatment outcomes of flat-oval root canals.

Conflict of Interest: 'None declared'.

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