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Effect of large instrument use on shaping ability and debris extrusion of rotary and reciprocating systems

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Abstract

Aim: The aim of the present study was to evaluate the effect of large instrument use on the shaping ability and apical debris extrusion of rotary and reciprocating systems in oval-shaped root canals.

Methods: Forty-five mandibular premolars, with an 18-mm long, oval-shaped single canal, and apical diameter ranging from 300 to 350 μm, were separated into three groups (n=15), according to the system used: ProTaper Universal group, F5 (0.50/0.05); ProTaper Next (PTN group), X5 (0.50/0.06); and Reciproc (RC group), R50 (0.50/0.05). Cone-beam computed tomography was performed before and after preparation to analyze apical transportation (AT), centering ability (CA), and change in root canal diameter (CRCD). For evaluating apical debris extrusion, the roots were coupled to pre-weighed glass receptacles to collect the extruded debris during preparation.

Results: All systems promoted AT and apical debris extrusion; the latter was higher for the PTN group ($P<.05$). No system presented perfect CA. The RC group demonstrated the largest CRCD ($P<.05$).

Conclusions: As consequences of their use, the large instruments promoted undesirable AT and debris extrusion, irrespective of the system used to perform root canal preparation. Moreover, no system was able to remain perfectly centralized within the root canal.

KEYWORDS

endodontic, large instrument, mandibular premolar, root canal preparation, tomography

1 | INTRODUCTION

Instruments with different kinematics can be used for root canal preparation.[1,2] Irrespective of the system used, all promote extrusion of microorganisms, contaminated dentin, irrigant solutions, and remaining pulp tissue beyond the apical foramen, causing postoperative complications, such as periapical inflammation and pain.[3,4] However, studies have pointed out that there are differences in the amount of debris extruded, depending on the system used for root canal preparation.[5,6]

Several instruments have been developed over the past few years, with the purpose of diminishing the morphological changes caused during root canal preparation, such as zip formation and apical transportation (AT), in addition to debris extrusion into the periapical region.[6,7]

The Reciproc (RC; VDW GmbH, Munich, Germany) and ProTaper Next (PTN) systems (Dentsply-Maillefer, Ballaigues, Switzerland) are among the latest innovations.[7] Both systems are manufactured with M-Wire alloy, which provides the instruments with greater flexibility, diminishing the incidence of fracture due to cyclic fatigue or torsion.[8,9]

The PTN system has an innovative design, with progressive and regressive taper in a single instrument, diminishing the risk of screw-in force occurring, due to less contact of the instrument with the root canal walls.[8,9] In addition, the cross-section and asymmetrical rotation axis of the PTN system instruments, enable them to cut a larger amount of dentin than instruments of the conventional ProTaper Universal (PTU; Dentsply-Maillefer, Switzerland) and RC systems.[9-11] Therefore, the combination of distinct characteristics, such as kinematic motion, type of alloy, and cross-section of the instruments, plays a fundamental role in their shaping ability.[2,7,8]

Studies have demonstrated how controversial the topic of apical enlargement still is.[1,5] Many researches have pointed out that a restricted apical enlargement is fundamental for conserving the tooth structure and promoting less debris extrusion.[9,12] However, most researchers attest that a minimum enlargement performed with three instruments, starting with one that has a diameter equivalent to that of the initial root canal diameter, is necessary for achieving adequate circumferential dentin removal.[13-15]

Thus, the aim of the present ex vivo study was to evaluate the effect of using large instruments on the shaping ability and apical debris extrusion of rotary and reciprocating systems in oval-shaped root canals.

2 | MATERIALS AND METHODS

2.1 | Selection of teeth

The sample size was calculated to determine the number of root canals necessary to detect a statistically-significant difference of 5% among groups. A minimum number of 15 repetitions for each variable was established with the aid of GMC 8.1 software (http://143.107.206.201/restauradora/gmc/gmc.html) in order to obtain a reasonable error distribution for statistical analysis.

With prior approval from the research ethics committee of the Federal University of Amazonas (Manaus, Amazonas, Brazil; no. 39415014.9.0000.5020) 45 recently-extracted mandibular premolars were selected for this research. The selected teeth had to be uniradicular, with completely formed root and closed apex, and an 18-mm long, oval-shaped, single canal, based on the ratio between the buccolingual and mesiodistal canal diameter, according to the criteria of Wu et al.[14] Furthermore, the teeth had to have an apical diameter ranging from 300 to 350 μm. Anatomical features were confirmed by means of cone-beam computed tomography (CBCT) (i-CAT Cone Beam 3D Dental Imaging System; Imaging Sciences International, Hatfield, PA, USA).[16] Teeth that did not meet these criteria were excluded from the final sample.

The selected teeth were disinfected by immersion in 0.5% chloramine T solution (4°C/48 hours), followed by washing in running water for 24 hours. After disinfection, the tooth crowns were sectioned to standardize the size of samples, followed by root canal access performed with a spherical diamond bur (no. 1014; KG Sorensen, Cotia, SP, Brazil) coupled to a high-speed motor (Extra Torque 605C; Kavo, Joinville, SC, Brazil) under abundant water cooling. After this, a size 15 K-type file (Dentsply-Maillefer, Switzerland) was inserted in the apical direction, until the instrument tip was visualized in the apex, and then withdrawing it 1 mm to determine the real working length.

2.2 | Biomechanical preparation

To standardize the root canal position during instrumentation, and enable the later collection of apically-extruded debris (AED), the roots were inserted into rubber stoppers –longitudinally in relation to their long axis - coupled to glass receptacles containing 10 mL distilled water. A layer of cyanoacrylate ester (Super Bonder; Loctite, Aachen, Germany) was applied on each root surface to ensure they were fixed to the rubber stoppers coupled to the receptacles, and to avoid extravasation of the irrigant solution through the orifice that held the roots in position. A needle was inserted into the rubber stopper, parallel to the root long axis, to balance the internal and external pressure of the receptacle. After this, the specimens were randomly distributed into three groups (n=15), according to the different instrumentation systems used.

2.2.1 | ProTaper Universal group

For the PTU group, root canal preparation was done with the PTU system, following the sequence S1 (0.18/0.02), S2 (0.20/0.04), F1 (0.20/0.07), F2 (0.25/0.08), F3 (0.30/0.09); F4 (0.40/0.06), and F5 (0.50/0.05) to the working length. The instruments were coupled to a 6:1 contra-angle (VDW Silver Reciproc; Sirona Dental Systems GmbH, Bensheim, Germany) powered by an electric motor (VDW Silver Reciproc Motor; Sirona Dental Systems GmbH, Germany), at a constant speed of 7 *g*, in accordance with the manufacturer's instructions. Each instrument was introduced into the root canal using back-and-forth movements until the working length was reached. On reaching the working length, the next instrument was used.

2.2.2 | ProTaper Next group

For the PTN group, root canal preparation was done with the PTN system, following the sequence X1 (0.17/0.04), X2 (0.25/0.06), X3 (0.30/0.07), X4 (0.40/0.06), and X5 (0.50/0.06) to the working length. As for the previous group, the instruments were coupled to a 6:1 counter-angle, at a constant speed of 7 *g*, in accordance with the manufacturer's instructions. The instruments were also used in back-and-forth movements until the real working length was reached, after which the change of instruments was made.

2.2.3 | Reciproc group

For the RC group, root canal preparation was done with the RC system using the R50 (0.50/0.05) instrument in all root canal thirds, with small pecking movements of 3-mm amplitude, until the desired length was reached in the different thirds (cervical, middle, and apical). Between the instrumentation of the different root thirds, the instrument was removed and cleaned with sterile gauze. The instrument was coupled to a 6:1 contra-angle, powered by an electric motor (VDW Silver Reciproc Motor), in RECIPROC ALL mode, in accordance with the manufacturer's instructions.

At each change of instrument, 2 mL of 2.5% NaOCl (Fórmula e Ação, SP, Brazil) was applied as irrigating solution, with a 30-gauge needle (Navitip, Ultradent Products, South Jordan, UT, USA), 1 mm short of the working length. The smear layer resulting from instrumentation was removed by applying 1 mL of 17% ethylenediaminetetraacetic acid solution (Biodinâmica, Ibiporã, PR, Brazil) for 3 minutes, followed by final irrigation with 5 mL of 2.5% NaOCl. The procedures described were performed by a single operator, who is a specialist in endodontics.

2.3 | Apical debris extrusion

To evaluate apical debris extrusion, the glass receptacles were individually weighed three consecutive times on a precision analytical balance (model AB204, Mettler-Toledo, Barueri, SP, Brazil) before root canal instrumentation, and the mean weight was calculated. After this, the glass receptacles were filled with 10 mL distilled water, and the roots were positioned in the set as previously described. After instrumentation of all root canals, they were removed from the sets, and the glass receptacles were stored in an oven at 70°C for 5 days until the liquid had completely dried (distilled water + residual irrigant solution). Afterwards, the glass receptacles were individually weighed again, as described earlier. The amount of AED was calculated by the difference in weight of the glass receptacles using the formula: AED=Fw−Iw, where Fw was the mean final weight of the receptacles after root canal instrumentation, and Iw was the mean initial weight of the receptacles before root canals instrumentation.

2.4 | Apical transportation

AT is characterized by a change in the original root canal trajectory in the apical third.[7] To evaluate the AT and its direction, an initial tomographic analysis of the root canals was performed for image acquisition before instrumentation. The roots were positioned in a polystyrene sample holder and placed on the CBCT scanner, in accordance with the following specifications for image acquisition: voltage: 120 kvp, current: 3-7 mA, and focal point: 0.5 mm. The protocol - M and 6 cm, 40 seconds, 0.2 voxel MaxRes - was used to obtain the images.[7]

The second, third, and fourth millimeters were selected for analyzing AT and its direction, totaling six axial images of 1 mm. AT was calculated in two directions: buccolingual and mesiodistal, with the aid of the OxiriX Imaging Software program (www.osirix-viewer.com). The pre-instrumentation and post-instrumentation images were analyzed by a single, blinded, previously-calibrated examiner, using the following formulae: AT=$(B_1-B_2)-(L_1-L_2)$ and $(M_1-M_2)-(D_1-D_2)$, where B_1 and B_2 represent the values of the buccal root canal walls of the instrumented and uninstrumented root canals, respectively; L_1 and L_2, the lingual root canal walls before and after instrumentation; M_1 and M_2, the mesial root canal walls; and D_1 and D_2, the distal root canal walls of the instrumented and uninstrumented root canals, respectively (Figure 1A). When the result of the equation was equal to zero, no AT had occurred; when negative, transportation occurred in the lingual or distal directions, and when there was a positive value, the transportation occurred in the buccal or mesial directions.[7]

2.5 | Centering ability

The centering ability (CA) could be considered the instrument capacity to remain centralized within the root canal axis during its preparation.[7] The CA was calculated in two directions (buccolingual and mesiodistal) in the second, third, and fourth apical millimeters, using the values obtained during the AT analysis and the following formulae as reference: CA=B_1-B_2/L_1-L_2 or L_1-L_2/B_1-B_2 and M_1-M_2/D_1-D_2 or D_1-D_2/M_1-M_2.

The formula to be used for CA evaluation depended on the values obtained in the enumerator, which always had to be the lower value obtained by the difference.[7] Values obtained equal to one meant perfect CA of the instrument, and the values equal to zero meant that the instrument used had low CA.

2.6 | Change in root canal diameter

To calculate the CRCD by the different instrumentation systems, the images obtained with the OxiriX Imaging Software were used, outlining the root canals areas before and after instrumentation (Figure 1B). The following formula was then used to determine the area of wear: CRCD=Fa−Ia, where Fa represented the final area, and Ia the initial area.

2.7 | Statistical analysis

The data obtained were submitted to test of normality (Kolmogorov-Smirnov test), and were subsequently statistically analyzed (Kruskal-Wallis, the Dunn multiple comparisons test, $P<.05$ for apical debris extrusion, AT, and CA; one-way analysis of variance, Tukey-Kramer multiple comparisons test, $P<.05$ for CRCD) using Graphpad InStat for Windows 8 program (GraphPad Software, La Jolla, CA, USA). Statistical difference among groups was considered when $P<.05$.

3 | RESULTS

3.1 | Apical debris extrusion

The median, minimum, and maximum values of apical debris extrusion (g) are shown in Table 1. All systems promoted apical debris extrusion, and these values were higher for the PTN group, which demonstrated a statistically-significant difference in comparison with the RC and PTU groups ($P<.05$). There was no significant difference between the RC and PTU groups ($P>.05$).

3.2 | Apical transportation

The median, minimum, and maximum values (mm) of AT are shown in Table 2. The different systems presented similar AT values, without significant difference between them, irrespective of the factors evaluated (apical distance and direction of AT, $P>.05$).

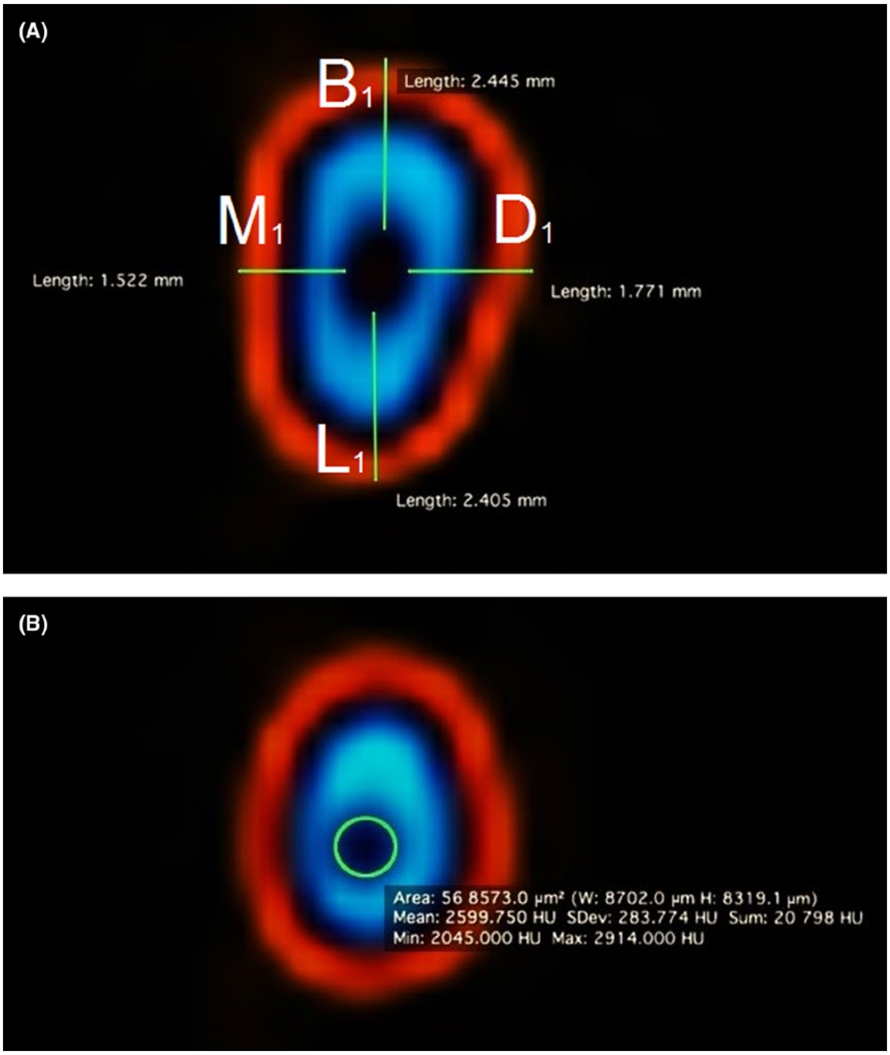

FIGURE 1 Representative cone-beam computed tomography images of pre-instrumented canals visualized in the Osirix MD software. (A) Apical transportation (AT) measurement made before root canal preparation to be applied in the following formulae: AT=(B_1−B_2)−(L_1−L_2) and (M_1−M_2)−(D_1−D_2), where B_1 and B_2 represent the values of the buccal root canal walls of the instrumented and uninstrumented root canals, respectively; L_1 and L_2, the lingual root canal walls before and after instrumentation; M_1 and M_2, the mesial root canal walls; and D_1 and D_2, the distal root canal walls of the instrumented and uninstrumented root canals, respectively (B) Root canal area outlined in green to determine its limit. Change in root canal diameter (CRCD) measurement made before root canal preparation to be applied in the formula: CRCD=Fa−Ia, where Fa represented the final area, and Ia the initial area

Regarding the direction of AT, when evaluated in the buccolingual direction, the tendency toward transportation was in the lingual direction (n=58), except at the second apical millimeter, where the tendency was greater in the buccal direction (n=28). In the mesiodistal direction, all the systems presented a tendency to transportation in the distal direction, irrespective of the apical distance evaluated (n=90).

3.3 | Centering ability

The median, minimum, and maximum CA values are shown in Table 3. None of the tested systems had perfect CA of the instrument in relation to the central axis of the root canal (=1.0). There was no statistical difference among the groups (P>.05).

3.4 | Change in root canal diameter

The graphic representation (%) of CRCD is shown in Figure 2. There was no significant difference among the groups at the second apical millimeter (P>.05). At the third apical millimeter, the RC group had the lowest values, with a significant difference in comparison with the PTN and PTU groups (P<.05), which were statistically similar (P>.05). However, at the fourth apical millimeter, the RC group had significantly the largest area of dentin wear in comparison with the other groups (P<.05).

4 | DISCUSSION

Conservative apical enlargement compromises root canal cleaning.[13-16] Proper root canal enlargement during endodontic therapy is fundamental, because microorganisms are capable of penetrating into the dentinal tubules.[17] Furthermore, because it is highly organic, the pre-dentin layer must be completely removed during preparation to prevent the formation of empty spaces between filling material and root canal walls, due to filling material degradation over the course of time.[17] However, several studies have reported that the use of large instruments for apical enlargement compromises root canal shaping, by causing morphological changes that lead to treatment failure.[11,18]

The same could apply to apical debris extrusion.[5,9,12] Most research conducted to date have evaluated apical debris extrusion and morphological changes in root canals after preparation with the use of small-diameter instruments.[9,19,20] Thus, the effect of larger

TABLE 1 Median, minimum and maximum (g) values of apical debris extrusion

Group	Median	Minimum	Maximum
PTU	0.0056[a]*	0.0018	0.0334
PTN	0.0179[b]	0.0013	0.0305
RC	0.0056[a]	0.0008	0.0151

*P<.05. Different lowercase letters in columns indicate statistically-significant difference among groups (Kruskal-Wallis, the Dunn multiple comparisons test). N=15. PTN, ProTaper Next, PTU, ProTaper Universal, RC, Reciproc.

instruments with a shape and size compatible with their use in root canals must be assessed.[14]

Although Ni-Ti and M-Wire instruments are more flexible and resistant to cyclic and torsional fatigue, these characteristics tend to be reduced in large instruments, hindering their action in root canals with smaller diameters or accentuated curvatures.[21] Tensile stresses associated with compressive forces are alternately generated on the instrument during its action.[21] Continuous repetition of these forces during preparation can lead to instrument fracture, particularly when its diameter is inadequate for an atresic or curved root canal.[21] For this reason, oval-shaped root canals were selected for the present study, simulating the clinical situation in which greater apical enlargement can be performed without compromising the dynamics of instrument use.

In the present study, the PTN group presented higher apical debris extrusion values than the other groups. The difference between the PTN and RC systems might be explained by the use of a larger number of instruments for root canal preparation in the PTN group.[5] Moreover, the different instrumentation techniques recommended by the manufacturers of the two systems could have influenced the results observed in the present study.[5] During root canal preparation, the R50 instrument (RC) was introduced into the canal in pecking movements of small amplitude (3 mm), without being completely removed from the canal. When the instrumentation length was reached, the instrument was removed from the root canal and cleaned with gauze, thereby removing a large amount of debris from its surface.[7,22] This dynamic of instrumentation was repeated in the cervical, middle, and apical thirds, whereas in the PTN system, preparation was performed by introducing each instrument into the root canal with back-and-forth movements, advancing progressively until the real working length was reached. The complete sequence of instruments was used following this pattern, without excess of debris removal, as was done with the reciprocating instrument.[5]

In a recent study, Silva et al. reported that the PTU system produced more debris than the PTN and RC systems in root canals prepared to a large apical size.[5] These results differed from the findings of the present study, as the PTN group had higher values of AED than the PTU group. Although the PTN system presented a new, swaggering movement that minimized engagement between the instrument and dentin, and promoted root canal preparation with fewer instruments,[5] the prior cervical enlargement provided by the S1 and S2 instruments of the PTU system significantly diminished debris production during preparation of the apical third and its consequent extrusion.[12]

TABLE 2 Median, minimum, and maximum (mm) values of apical transportation

Apical distance (mm)	Group*	Direction	Median	Minimum	Maximum
2	PTU	B/L	0.034	−0.218	0.340
	PTU	M/D	0.019	−0.317	0.469
	PTN	B/L	0.033	−0.310	0.522
	PTN	M/D	0.069	−0.381	0.493
	RC	B/L	0.037	−0.310	0.798
	RC	M/D	−0.146	−0.692	0.488
3	PTU	B/L	−0.009	−0.198	0.518
	PTU	M/D	−0.036	−0.325	0.311
	PTN	B/L	0.003	−0.284	0.599
	PTN	M/D	−0.061	−0.039	0.382
	RC	B/L	−0.090	−0.809	0.609
	RC	M/D	−0.077	−0.645	0.156
4	PTU	B/L	−0.049	−0.365	0.513
	PTU	M/D	−0.048	−0.284	0.270
	PTN	B/L	−0.032	−0.339	0.341
	PTN	M/D	−0.058	−0.617	0.307
	RC	B/L	−0.110	−0.487	0.719
	RC	M/D	−0.128	−0.431	0.128

*P<.05. There was no statistically-significant difference among groups (Kruskal-Wallis, the Dunn multiple comparisons test). N=15. BL, buccolingual; M/D, mesiodistal; PTN, ProTaper Next, PTU, ProTaper Universal, RC, Reciproc.

TABLE 3 Median, minimum, and maximum values of centering ability

Apical distance (mm)	Group*	Direction	Median	Minimum	Maximum
2	PTU	B/L	0.584	0.133	0.986
	PTU	M/D	0.575	0.019	0.943
	PTN	B/L	0.570	0.090	0.920
	PTN	M/D	0.610	0.070	0.820
	RC	B/L	0.750	0.060	0.920
	RC	M/D	0.570	0.010	1.470
3	PTU	B/L	0.780	0.180	0.980
	PTU	M/D	0.800	0.100	1.000
	PTN	B/L	0.540	0.300	0.990
	PTN	M/D	0.600	0.020	0.930
	RC	B/L	0.620	0.020	0.980
	RC	M/D	0.680	0.090	0.880
4	PTU	B/L	0.750	0.450	0.980
	PTU	M/D	0.710	0.070	1.000
	PTN	B/L	0.660	0.070	0.990
	PTN	M/D	0.670	0.160	0.900
	RC	B/L	0.530	0.010	0.940
	RC	M/D	0.500	0.100	1.340

*$P<.05$. There was no statistically-significant difference among groups (Kruskal-Wallis, the Dunn multiple comparisons test). N=15. BL, buccolingual; M/D, mesiodistal; PTN, ProTaper Next, PTU, ProTaper Universal, RC, Reciproc.

It is also worth emphasizing that the results of the present study differed from those presented by Topçuoglu et al., in which the instrument of the reciprocating system (RC) promoted a higher apical debris extrusion value than those of the PTN system instruments.[23] However, in the previously-cited research, instruments of smaller diameter were used, demonstrating that instrument diameters could be a preponderant factor with respect to debris extrusion.

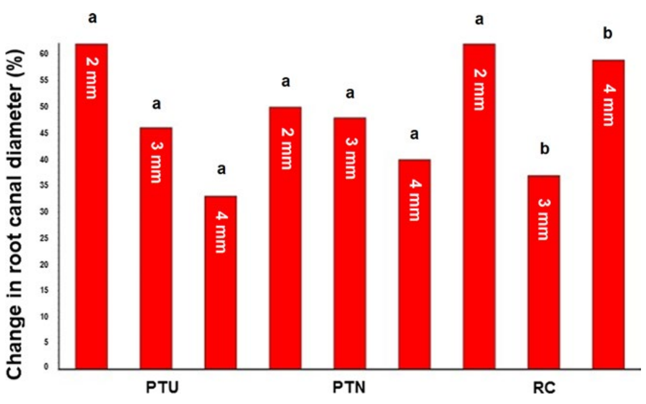

FIGURE 2 Graphic representation (%) of change in mean root canal diameter values. Different lowercase letters over bars indicate statistically-significant difference among groups at the same apical millimeter (one-way analysis of variance, Tukey-Kramer multiple comparisons test, $P<.05$). PTN, ProTaper Next, PTU, ProTaper Universal, RC, Reciproc

Several methods have been proposed to evaluate the pre- and post-preparation root canal morphology.[24] To assess the shaping ability of instruments in the present study, a CBCT analysis was performed, as it produced undistorted 3-D images of the tooth. This imaging method allowed a reliable and accurate analysis of root canal system morphology and undesirable changes in their anatomic features in comparison with radiographic examination.[7,24,25]

With regard to the CRCD promoted by the different systems, we observed that, irrespective of the apical distance evaluated, the reciprocating system (RC group) had a larger mean wear area (52.5%) than those of the rotary systems (PTN group: 45.7%, and PTU group: 47%), despite the R50 instrument having a smaller taper (0.50/0.05) than the respective instrument of the PTN system (X5) (0.50/0.06). These results corroborate the findings of Moura-Netto et al. and Busquim et al.[24,26] This difference could be explained by the reciprocating kinematics of the R50 instrument, which involved cutting large amounts of dentin in a counter-clockwise direction, and in the clockwise direction relieved stress on the instrument as it advanced into the root canal.[27] The PTN system had a rectangular cross-section with decentralized rotation in relation to its long axis.[20] Due to its design, only two cutting blades of the instrument touched the root canal walls simultaneously, while the other two remained free.[20] Therefore, a smaller amount of dentin was cut during preparation.[20]

All samples evaluated in the present study had AT, irrespective of the system used to perform root canal preparation, as reported by De Carvalho et al.[7] in their recent research. However, transportation mean values were lower than 0.300 mm, which, according to Fan et al., was not clinically relevant.[28] In a similar study, Moura-Netto et al. also reported a low tendency toward transportation of reciprocating systems.[24] However, it is worth emphasizing that although the root canals selected for the present study were straight and wide, the systems tested caused a certain level of AT, although this was practically insignificant from a clinical point of view.[28]

Previous studies have demonstrated that apical enlargement with instruments with a diameter of 0.40 in curved root canals must be avoided due to the significant morphological changes that can be produced.[29-31] Based on the results of the present study, this factor must also be taken into consideration for preparing straight and wide canals, as all the tested systems produced a certain level of AT in the samples, despite the initial favorable morphology of root canals. In addition, all the systems tested presented a greater trend toward transportation in the lingual and distal directions, which could be explained by the absence of a radial guide on the instruments assessed.[7]

Regarding the CA of the instruments, none of the systems were capable of maintaining the instrument perfectly centralized within the root canals during biomechanical preparation. Although the root canals used in the present study were straight and wide, it is more difficult to maintain the long axis of large instruments centralized along the root canal due to their large taper/conicity and lower degree of flexibility.[7]

4.1 | Conclusions

Despite the limitations of the present ex vivo study, we believe that the use of large instruments promoted undesirable levels of AT and apical debris extrusion. Apical debris extrusion was significantly higher for PTN compared with PTU and RC. RC promoted greater dentin wear than the other systems, and no system was able to remain perfectly centralized within the root canal.

REFERENCES

1. Fornari VJ, Silva-Sousa YT, Vanni JR, Pécora JD, Versiani MA, Sousa-Neto MD. Histological evaluation of the effectiveness of increased apical enlargement for cleaning the apical third of curved canals. *Int Endod J*. 2010;43:988-994.
2. Ferrara G, Taschieri S, Corbella S, Ceci C, Del Fabbro M, Machtou P. Comparative evaluation of the shaping ability of two different nickel-titanium rotary files in curved root canals of extracted human molar teeth. *J Investig Clin Dent*. 2017;8:e12187.
3. Alves VO. Endodontic flare-ups: A prospective study. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2010;110:e68-e72.
4. Parirokh M, Jalali S, Haghdoost AA, Abbott PV. Comparison of the effect of various irrigants on apically extrude debris after root canal preparation. *J Endod*. 2012;38:196-199.
5. Silva EJ, Carapiá MF, Lopes RM, et al. Comparison of apically extruded debris after large apical preparations by full-sequence rotary and single-file reciprocating systems. *Int Endod J*. 2016;49:700-705.
6. Ciçek E, Akkocan O, Furuncuoglu F. Comparison of apically extruded debris associated with several nickel-titanium systems after determining working length by apex locator. *J Conserv Dent*. 2016;19:68-71.
7. De Carvalho GM, Sponchiado Junior EC, Garrido AD, Lia RC, Garcia LF, Marques AA. Apical transportation, centering ability, and cleaning effectiveness of reciprocating single-file system associated with different glide path techniques. *J Endod*. 2015;41:2045-2049.
8. Ruddle CJ, Machtou P, West JD. The shaping movement: Fifth-generation technology. *Dent Today*. 2013;32:94-96-9.
9. Capar ID, Arlan H, Akcay M, Ertas H. An in vitro comparison of apically extruded debris and instrumentation times with ProTaper Universal, ProTaper Next, Twisted File Adaptive, and HyFlex instruments. *J Endod*. 2014;40:1638-1641.
10. Weiger R, Elayouti A, Löst C. Efficiency of hand and rotary instruments in shaping oval canals. *J Endod*. 2002;28:580-583.
11. Ahn SY, Kim HC, Kim E. Kinematic effects of nickel-titanium instruments with reciprocating or continuous rotation motion: A systematic review of in vitro studies. *J Endod*. 2016;42:1009-1017.
12. Koçak MM, Çiçek E, Koçak S, Saglam BC, Yilmaz N. Apical extrusion of debris using ProTaper universal and ProTaper next rotary systems. *Int Endod J*. 2015;48:283-286.
13. Pécora JD, Capelli A, Guerisoli DM, Spanó JC, Estrela C. Influence of cervical preflaring on apical file size determination. *Int Endod J*. 2005;38:430-435.
14. Wu MK, R'Oris A, Barkis D, Wesselink PR. Prevalence and extent of long oval canals in the apical third. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2000;89:739-743.
15. Wu MK, Barkis D, Roris A, Wesselink PR. Does the first file to bind correspond to the diameter of the canal in the apical region? *Int Endod J*. 2002;35:264-267.
16. Paqué F, Ganahl D, Peters OA. Effects of root canal preparation on apical geometry assessed by micro computed tomography. *J Endod*. 2009;35:1056-1059.
17. Hecker H, Bartha T, Löst C, Weiger R. Determining the apical preparation size in premolars: Part III. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2010;110:118-124.
18. Bartha T, Kalwitzki M, Lost C, Weiger R. Extended apical enlargement with hand files versus rotary NiTi files. Part II. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2006;102:692-697.
19. Koçak S, Koçak MM, Saglam BC, Tüker AS, Sagsen B, Er Ö. Apical extrusion of debris using self-adjusting file, reciprocating single-file, and 2 rotary instrumentation systems. *J Endod*. 2013;39:1278-1280.
20. Koçak MM, Çiçek E, Koçak S, Saglam BC, Furuncuoglu F. Comparison of ProTaper Next and HyFlex instruments on apical debris extrusion in curved canals. *Int Endod J*. 2016;49:996-1000.
21. da Frota MF, Espir CG, Berbert FL, et al. Comparison of cyclic fatigue and torsional resistance in reciprocating single-file systems and continuous rotary instrumentation systems. *J Oral Sci*. 2014;56:269-275.
22. Bürklein S, Benter S, Schäfer E. Quantitative evaluation of apically extruded debris with different single-file systems: Reciproc, F360 and OneShape versus Mtwo. *Int Endod J*. 2014;47:405-409.
23. Topçuoglu HS, Zan R, Akpek F, et al. Apically extruded debris during root canal preparation using Vortex Blue, K3XF, ProTaper Next, and Reciproc instruments. *Int Endod J*. 2016;49:1183-1187.
24. Moura-Netto C, Palo RM, Pinto LF, Mello-Moura AC, Daltoé G, Wilhelmsen NS. CT study of the performance of reciprocating and oscillatory motions in flattened root canal areas. *Braz Oral Res*. 2015;29:1-6.
25. Patel S, Durack C, Abella F, Shemesh H, Roig M, Lemberg K. Cone beam computed tomography in endodontics – a review. *Int Endod J*. 2015;48:3-15.
26. Busquim S, Cunha RS, Freire L, Gavini G, Machado ME, Sants MA. Micro-computed tomography evaluation of long-oval canal preparation using reciprocating or rotary systems. *Int Endod J*. 2015;48:1001-1006.
27. Yared G. Canal preparation using only one Ni-Ti Rotary instrument: Preliminar observation. *Int Endod J*. 2008;41:339-344.

28. Fan B, Wu MK, Wesselink PR. Leakage along warm gutta-percha filling in the apical canals of curved roots. *Endod Dent Traumatol*. 2000;16:29-33.
29. López FU, Fachin EV, Camargo Fontanella VR, Barletta FB, Só MV, Grecca FS. Apical transportation: A comparative evaluation of three root canal instrumentation techniques with three different apical diameters. *J Endod*. 2008;34:1545-1548.
30. Kunert GG, Camargo Fontanella VR, de Moura AA, Barletta FB. Analysis of apical root transportation associated with ProTaper Universal F3 and F4 instruments by using digital subtraction radiography. *J Endod*. 2010;36:1052-1055.
31. Zanette F, Grazziotin-Soares R, Flores ME, Camargo Fontanella VR, Gavini G, Barletta FB. Apical root canal transportation and remaining dentin thickness associated with ProTaper Universal with and without PathFile. *J Endod*. 2014;40:688-693.

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