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ORIGINAL RESEARCH

Flute and Shank Dimensions of Reciprocating Instruments before and after Simulated Root Canal shaping

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ABSTRACT

Aim: This study analyzed the effect of the dimensions of the flute and shank in the first 4 mm of instrument tips on the deformation and dimensional changes of reciprocating instruments after root canal shaping (RCS).

Materials and methods: The reciprocating instruments used were Reciproc® R25, R40, and R50; WaveOne® Small, Primary, and Large; and Unicone® #20, #25, and #40. Scanning electron microscopy images of the first 4 mm of the tip were acquired at 30× magnification before and after simulated curved root canals were shaped. Each instrument was used only once. The images were transferred to the AxioVision® software to measure the flute area (μm^2), shank area (μm^2), flute length (μm), and cross-sectional diameter (μm). Student's t test for paired samples was used to compare differences before and after RCS, and analysis of variance followed by the Tukey test, to compare differences between instruments of similar sizes. The instruments were classified according to deformations after RCS.

Results: Reciproc® instruments had larger flutes and smaller shanks. The Reciproc® R40 had significant differences in cross-sectional diameter at 0.5 mm from the tip. Reciproc® had no plastic deformations. Unicone® #20 instruments had significant differences in cross-sectional diameter at 1.5 and 3.0 mm from the tip, and #25 instruments had differences at 1.5 and 3.0 mm and in length of the second and third flutes. One #20 and three #40 instruments had plastic deformations. The differences in length of the first and fourth flutes of WaveOne® Primary and in cross-sectional diameter at 2.0 mm from the tip of WaveOne® Large were significant. Two of three WaveOne® Large instruments had plastic deformations.

Conclusion: Reciproc® instruments had greater flute areas and lengths and smaller shanks than Unicone® and WaveOne® instruments of similar sizes. Reciproc® instruments had a greater flute-to-shank ratio. WaveOne® instruments had the lowest flute-to-shank ratio. Unicone® instruments had the most plastic deformations. Instruments with larger flutes and smaller shanks had fewer plastic deformations after curved RCS.

Clinical significance: The knowledge of mechanical behavior before choosing the endodontic instrument may avoid fracture, regardless of the clinical condition, and it is essential to the success of root canal treatment.

Keywords: Endodontic instruments, Flute, Laboratory research, Plastic deformation, Reciprocating instruments, Root canal shaping.

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INTRODUCTION

The control of microorganisms depends on effectiveness of root canal, regardless of the clinical condition of the pulp.[1] Cleaning and shaping should include irrigation strategies and the mechanical action of endodontic instruments. A perfectly shaped root canal is a refined standard for optimal endodontic and coronal sealing.[2]

The choice of instrument for root canal shaping (RCS) may be a challenge for endodontists. The preservation of the original shape and position of the apical foramen when using a nonflexible instrument for curved RCS is complex and often difficult, especially during canal enlargement, which should respect root canal anatomy.[3,4] Therefore, several studies have evaluated the use of new nickel–titanium (NiTi) instruments and found that they are much more flexible than stainless steel instruments.[5] They are safe for RCS using continuous rotation because of their advanced manufacturing process and characteristics of use.[6] However, they may undergo plastic deformation during RCS, which may lead to instrument fracture, one of the major problems during RCS.[7] To avoid deformation, different morphological characteristics, such as cross-sections,[8] surface treatment,[9] and thermal treatments,[10] have been developed.

Reciprocating NiTi instruments[11] are currently used for RCS. A handpiece for reciprocation was invented in the 1960s,[12] but did not add any greater benefit to manual RCS for the instruments available at the time.[13]

The reciprocating motion, which consists of a counterclockwise movement followed by a shorter clockwise movement before the complete rotation, reduces NiTi instrument fracture.[11,14] It enhances cyclic fatigue resistance because it avoids bending of the instrument tip against root canal walls, which results in better resistance to torsional fracture.[14-22] Moreover, their thermal treatment during manufacture due to chemical composition changes improves their mechanical properties. The most reciprocating instruments are manufactured at the martensite phase, which improves flexibility and reduces instrument failure.[23]

Despite these advantages, reciprocating instruments also undergo deformation and fracture. In a study that evaluated 1,696 Reciproc® instruments used clinically only once, a few R25 instruments separated (0.47%) or underwent deformation (0.35%).[24] Another clinical study evaluated 2215 WaveOne® instruments used only once and found that three instruments separated in the apical third.[25]

The mechanical behavior of instruments during RCS may affect the prognosis of endodontic treatments. Several studies found microcracks after RCS using reciprocating instruments, most of them in the apical third.[22-25] The morphological features of their working area may affect their resistance and mechanical behavior.[26-29] Biz and Figueiredo[30] evaluated the association between flute and shank dimensions in the area of the first, third, and fifth flute of ProFile .04, ProFile .06, Pow-R .02, Pow-R .04, and Quantec 2000 instruments and found that shank-to-flute ratios were proportional for all the instruments. Quantec 2000 had larger flutes compared with the other instruments, which may reinforce their structure in this area of the instruments.

Several instrument types are available in the market, and dentists should consider each instrument characteristics and how these characteristics affect their mechanical behavior before choosing the instrument for each clinical condition. The flute and shank designs and dimensions of endodontic reciprocating instruments differ, and it is therefore, important to evaluate the association of these parameters with instrument plastic deformation. This study evaluated the effect of the dimensions of the first 4 mm of the flute and shank on the occurrence of plastic deformations and dimensional changes in reciprocating instruments used for RCS.

MATERIALS AND METHODS

Sample Selection

Reciprocating instruments of different tapers and origins were used for the evaluation of flute and shank dimensions: Reciproc® R25 #25/.08, R40 #40/.06, and R50 #50/.05 (VDW GmbH, Munich, Germany); Unicone® #20/.06, #25/.06, and #40/.06 (Medin, Nové Město na Moravě, Czech Republic); WaveOne® Small #21/.06, Primary #25/.08, and Large #40/.08 (Dentsply Maillefer, Ballaigues, Switzerland). Three instruments of each type were used (n = 27).

Image Acquisition before RCS

The reciprocating instruments were fixed in 5.5 cm diameter stubs before use. The surface images of each instrument were acquired using a scanning electron microscopy (SEM) unit (Jeol; JSM 6610, Tokyo, Japan). The images of the first 4 mm of the tip of the instruments were acquired at 30× magnification and 7 kV tension in two positions: (A) Flat surface (concave) of the attachment section and (B) convex surface of the attachment section (LabMic, Federal University of Goiás, Goiania, Brazil).

Root Canal Shaping

The instruments were rinsed under running water, placed in the ultrasonic cleaning unit for 3 minutes, and then dried with sterile gauze. For RCS, 27 simulated and standardized curved root canals (0.18 mm of apical limit diameter and 15 mm long) (IM do Brasil Ltda., São Paulo, Brazil) were used. The simulated root canals were irrigated with 5 mL of 2.5% sodium hypochlorite during RCS. Root canals were prepared with a single instrument and an electric motor (X-Smart® Plus; Dentsply Maillefer, Ballaigues, Switzerland). The Reciproc program was used for Reciproc® instruments, and the WaveOne program for WaveOne® and Unicone® instruments. The WaveOne program was selected for Unicone® instruments because Unicone® instrument numbers are similar to those of the WaveOne® system and because there is no specific program for Unicone® instruments in X-Smart® Plus. After RCS, the instruments were cleaned as described earlier.

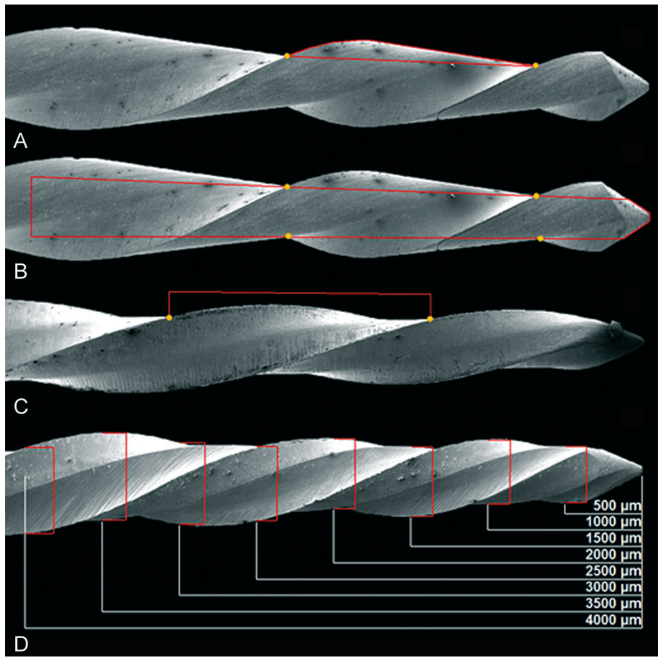
Image Acquisition after RCS

The instruments were fixed in stubs, and images of their tips were acquired using SEM at 30× magnification and 7 kV tension (LabMic, UFG) as previously described.

Analysis of SEM Images

The SEM images were transferred to the software AxioVision® (Carl Zeiss Microscopy GmbH, Jena, Germany) to measure instrument dimensions and analyze deformations after use, defined as shape changes in the working area of the instrument and deformation of instrument flutes, and to compare them with the images acquired before use. First, flute areas (μm^2) were measured between the points where the flute met the upper and lower helical grooves (Fig. 1A). The flutes were always positioned in the upper part of the image to standardize measurements, and each had to be fully seen in the 4 mm from the tip of the instrument. The shank area was 4 mm from the tip, and the lateral limits for measurement were the same points used to determine flute area. The lower limit was the tip and the upper limit was the point 4 mm from the tip (Fig. 1B).

In addition, flute length was measured from the upper to the lower points where the flute met the helical grooves (Fig. 1C). Measurements were recorded in micrometers (μm). Diameter was measured at 0.5, 1, 1.5, 2, 2.5, 3, 3.5, and 4 mm from the tip (μm) (Fig. 1D).



Figs 1A to D: (A) Flute area. Yellow points, at intersection of flute and helical groove, are upper (farthest from tip) and lower (closer to tip) limits; (B) shank area. Yellow points used for flute measurements are also lateral limits for shank measurement. Shank was measured from tip to 4 mm (area under study); (C) flute length. Yellow points, at intersection of flute and helical groove, are upper (farthest from tip) and lower (closer to tip) limits; and (D) cross-sectional diameters measured at each 0.5 mm (500 μm) from tip. A reference ruler was developed from scale on SEM image to determine measurement area and points where diameters should be measured

Statistical Analysis

The data about the plastic deformation of instrument surfaces were descriptively analyzed using frequency tables and including only the number of instruments with plastic deformation, not the number of deformations or their characteristics.

Student's t test for paired samples was used to compare measurements before and after use.

Instruments numbers #25 (Reciproc R25, Unicone #25, and WaveOne Primary) and #40 (Reciproc R40, Unicone #40, and WaveOne Large) were compared between systems using analysis of variance and the Tukey test.

RESULTS

The SEM images revealed that there were plastic deformations in the flutes of one Unicone® #20, three Unicone® #40, and two WaveOne® Large instruments. The measurements confirmed structural changes after RCS. Reciproc® instruments had larger flutes and smaller shanks. Only Reciproc® R40 instruments had significant differences in cross-sectional diameter at 0.5 mm from the tip ($p < 0.05$). Unicone® #20 instruments had significant differences ($p < 0.05$) in cross-sectional diameter at 1.5 and 3 mm from the tip and in the length of the second and third flutes. Shank area after use was significantly different in Unicone® #25. The lengths of the first and fourth flutes were significantly different in WaveOne® Primary instruments. Significant differences were also found in the cross-sectional diameter at 2 mm from the tip of the WaveOne® Large instruments. The other measurements had no significant differences. There were also no significant differences in the cross-sectional diameter at 1.0, 2.5, and 4 mm from the tip between Reciproc® R25, Unicone® #25, and WaveOne® Primary before and after RCS (Table 1). The differences of cross-sectional diameter at 1.5, 2.5, and 4 mm from the tip between Reciproc® R40, Unicone® #40, and WaveOne® Large before and after RCS were also not statistically significant (Table 2).

DISCUSSION

The reciprocating instruments included in this study, Reciproc®, WaveOne®, and Unicone®, have different diameters, taper, and cross-sections. These differences

Table 1: Reciproc® R25, Unicone® #25, and WaveOne® Primary before and after RCS

Variable	*Reciproc® R25 before*	*Reciproc® R25 after*	*Unicone #25 before*	*Unicone #25 after*	*WaveOne primary before*	*WaveOne primary after*
Flute area 1	34871.30A	34498.15A	17780.56BC	19802.78C	11400.00BD	10145.37D
Flute area 2	52392.59A	52155.55A	26574.08BC	30200.00C	16420.37D	16930.56BD
Shank area	976682.41A	973281.48A	1102911.11B	1086040.74B	1259451.85C	1264200.00C
Diameter 0.5 mm	187.00A	182.52A	268.80B	272.80B	263.81B	266.02B
Diameter 1.0 mm	299.51A	294.53A	291.76A	287.32A	287.80A	284.46A
Diameter 1.5 mm	247.18A	254.41A	301.12B	303.90B	329.50C	328.37C
Diameter 2.0 mm	357.28A	333.66A	320.53B	319.42B	363.66A	366.43A
Diameter 2.5 mm	365.02A	374.43A	348.47A	351.25A	391.75A	391.74A
Diameter 3.0 mm	365.31A	364.57A	369.19A	370.85A	413.81B	418.27B
Diameter 3.5 mm	483.86A	473.77A	397.25B	394.50B	438.80C	437.69C
Diameter 4.0 mm	401.23A	419.02A	423.88A	425.55A	453.31A	451.62A
Flute length 1	1059.89A	1048.20A	938.98B	925.89B	725.87C	742.89C
Flute length 2	1242.84A	1226.44A	1098.74B	1094.84B	890.55C	895.26C

*Capital letters (A, B, C and D) indicate statistically significant differences

Table 2: Reciproc® R40, Unicone® #40, and WaveOne® Large before and after RCS

Variable	*Reciproc® R40 before*	*Reciproc® R40 after*	*Unicone® #40 before*	*Unicone® #40 after*	*WaveOne® Large before*	*WaveOne® Large after*
Flute area 1	76051.85AB	81265.74B	73115.74ABC	99125.93B	43952.78C	48920.37AC
Shank area	1111100.00A	1108128.70A	1386538.89B	1376334.26B	1490857.41C	1511757.41C
Diameter 0.5 mm	288.12A	355.35B	356.64B	354.99B	355.45B	370.44B
Diameter 1.0 mm	369.05B	321.80B	396.14A	392.83A	402.95A	404.06A
Diameter 1.5 mm	380.57A	384.95A	417.85A	418.97A	426.18A	431.73A
Diameter 2.0 mm	395.66A	443.41AB	450.46AB	439.90AB	467.03B	451.47AB
Diameter 2.5 mm	445.95A	378.76A	463.51A	461.30A	489.47A	486.80A
Diameter 3.0 mm	442.44A	444.16A	490.51AB	485.74AB	520.00B	513.85B
Diameter 3.5 mm	425.39A	517.03B	515.60B	516.72B	542.78B	543.34B
Diameter 4.0 mm	516.69A	502.79A	541.97A	523.86A	571.35A	564.45A
Flute length 1	1368.57AB	1395.60AB	1646.23BC	1959.14C	1175.57A	1756.72AB

*Capital letters (A, B, C and D) indicate statistically significant differences

may result in different resistance and mechanical behaviors. Reciproc® instruments have larger flutes and greater flute-to-shank ratios, whereas WaveOne® instruments have lower flute-to-shank ratios. None of the three sizes of Reciproc® instruments underwent any plastic deformation but they all had some changes in dimensions after RCS. These results are similar to those found in a clinical study[24] and confirm that reciprocating instruments are safe for RCS when used once.

Reciproc® instruments are S-shaped, WaveOne® instruments are triangular and have concavities near flute, and Unicone® instruments are triangular and have convex helical grooves. Schäfer and Tepel[31] evaluated the effect of cross-section and number of flutes on fracture of rotary NiTi instruments. The resistance to torsional fracture and to cyclic fatigue of S-shaped instruments increased with number of flutes, but number of flutes did not affect the resistance to fracture of triangular instruments. Our study found that Reciproc® instruments had fewer flutes, which may improve resistance to cyclic fatigue because of their S-shaped cross-section. WaveOne® and Unicone® had more flutes, but this may not affect resistance to fracture because of their triangular cross-sections. However, a greater flute area may reinforce their structure.[30] Reciproc® had greater flute areas than WaveOne® and Unicone®, which may have contributed to the fact that Reciproc® had fewer plastic deformations after curved RCS.

The evaluation of fracture resistance of Reciproc® R40 and WaveOne® Large revealed that the first had greater resistance to cyclic fatigue.[18,32] The comparison of Reciproc® R25 and WaveOne® Primary revealed that WaveOne® had worse cyclic fatigue results.[33] These results are similar to those reported in other studies:[18,32,33] WaveOne® instruments had more dimensional changes after use, and two of the three WaveOne® Large instruments had deformations.

The results of this study and the knowledge about the structure of endodontic instruments[30,31] suggest Reciproc® instruments may have higher resistance to cyclic fatigue due to their larger flute area and length and their shorter shank. The longer shank of WaveOne® may provide greater resistance to torsional fracture.

Plotino et al[34] evaluated the cutting efficiency of Reciproc® R25 and WaveOne® Primary and found that Reciproc® R25 had a greater cutting efficiency than

WaveOne® Primary. Reciproc® larger flutes may contribute to their greater cutting efficiency, especially because of their association with an S-shaped cross-section.

These results may define the choice of an instrument for each type of root canal. Endodontists should understand how the morphological characteristics of an instrument may affect its properties so that they make the best choice for each clinical case. Reciproc® seems to be a safer choice for a highly curved root canal, whereas WaveOne® may provide better results for a straighter canal. Unicone® instruments may be more susceptible to failure due to more deformations and dimensional differences and of all the instruments analyzed should not be the first choice.

However, any adequate choice of endodontic instruments should consider all other characteristics that may affect resistance and be associated with root canal morphology, operator experience, instrument cross-section, and kinematics.[35-37] The number of uses should not be a key factor in instrument choice because despite the effect of use on plastic deformation and fractures, sterilization and reuse of the instruments are not recommended for two of the systems under evaluation, Reciproc® and WaveOne®.

The NiTi alloy currently used has minor variations in chemical composition and undergoes different heat treatments to improve its mechanical properties. For example, the alloy in the martensite reorientation stage, called M-Wire, has greater flexibility under stress and is less likely to fracture.[23] The Reciproc® and WaveOne® instruments are manufactured using M-Wire. Unicone® also undergoes heat treatment, but the manufacturer does not specify the stage. The use of M-Wire should provide a safer RCS with reciprocating systems.

The root canal should be enlarged within anatomical limits, regardless of instrument properties or technique applied. The greatest diameter of the apical third at 1 mm from the apex of the root canals of permanent premolars is 0.18 to 0.37 mm, and of molars, 0.19 to 0.45 mm.[38] Ran et al[39] evaluated the penetration of *Enterococcus faecalis* in dentinal tubules of single-rooted teeth prepared to #30 instruments under different conditions. The microorganisms penetrated 435 µm into the dentin of the apical third, 322 µm at low-alkaline pressure (pH = 9.0) and 100 µm at pH 10. Anatomical and microbiological features should be considered to define the minimal enlargement of the apical third with instruments of a higher diameter than the one specified by the manufacturer for reciprocating instruments (D_0 = 0.25 mm).

This study found that all the instruments underwent dimensional changes after shaping of a root canal of D_0 = 0.18 mm, although some of these changes were not statistically significant. The instruments were used in curved root canals of the same D_0 (0.18 mm) to evaluate and understand the dimensional changes of these instruments after RCS. Although used in root canals different from those recommended, instruments #50 did not have plastic deformations. WaveOne® and Unicone® #40 instruments had more plastic deformations than the other instruments of the same systems. Because of this need to enlarge the root canal to a size greater than the one recommended by the manufacturer, as explained above, and the high number of microfractures, more than one instrument of the reciprocating system, in increasing sizes, should be used to ensure greater safety and avoid plastic deformations and fractures, as well as to achieve optimal RCS. This study evaluated the area of the instrument closer to the tip (4 mm) because this is where most instrument fractures[25] and dentinal microcracks[26-29] occur.

The simulated root canals were used to standardize the diameter along the entire length of the canals. The results of this study are similar to those of previous studies, despite the limitations of simulated root canals.[18,24,31-37,40,41]

The method used in this study successfully detected plastic deformations of endodontic instruments. Some plastic deformations were not detected by measuring the dimensions because of the position of the external surface, but were visible under SEM magnification. At the same time, measurements were useful to detect morphological changes that are less evident to the eye.

The AxioVision® software was used in a previous study[42] for the accurate external delimitation of areas. The 30× magnification ensured that measurements were accurate and that instrument plastic deformations were visualized. Biz and Figueiredo[30] found that 60× magnification was accurate for measurements of abraded surfaces of flute and shank, and this method was effective to calculate the shank-to-flute ratio at the flute site. The structures in the first 4 mm from the tip were accurately measured at 30× magnification.

Instrument structures should be carefully evaluated because they may directly affect mechanical behavior during shaping of the complex root canal system. The characteristics under evaluation in this study suggest that Reciproc® has greater flexibility and resistance to cyclic fatigue. WaveOne® has less flexibility and greater shank resistance and resistance to torsional fracture. Studies should further investigate the mechanical behavior of reciprocating instruments and how their design and dimensions may affect their properties during use.

CONCLUSION

Reciprocating instruments had dimensional changes after curved RCS. Reciproc® instruments had a greater flute area and length and a shorter shank than Unicone®

and WaveOne® instruments of similar sizes. Unicone® instruments had a greater number of plastic deformations detected under SEM. Greater flute dimensions and smaller shank dimensions were associated with fewer plastic deformations after RCS.

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