Micro-CT Study of Oval-Shaped Canals Prepared With SAF, Reciproc, WaveOne and ProTaper Systems

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Aims

The introduction of nickel-titanium (NiTi) rotary file systems in endodontics has resulted in a markedly progress on the mechanical preparation of the root canal space (1). However, the current technology for mechanical preparation has failed in debriding oval-shaped canals, leaving untouched fins or recesses on the buccal and/or lingual extensions (2-4). These untouched recesses may harbor unaffected residual bacterial biofilms and serve as a potential cause of persistent infection and poor treatment outcome (5).

ProTaper Universal is a multiple-file system and represented a revolutionary generation of instruments for shaping root canals (1). Self-Adjusting File (SAF), a hollow file composed of 120-µm-thick NiTi lattice, and the reciprocating files Reciproc and WaveOne, made of a special NiTi alloy (M-Wire), were introduced with a concept of a single instrument to prepare the entire root canal. Previous studies have shown that SAF system was particularly advantageous in promoting cleaning, shaping, and disinfection of oval-shaped canals compared to rotary files (2-3).

Several methodologies were developed to evaluate the shaping ability of NiTi systems, including simulated root canal models, serial sectioning technique, and radiographic comparison (1). These methodologies have been successfully used for many years; however, some inherent limitations encouraging the search for new methods able to produce improved results. The development of X-ray micro-computed tomography (µCT) has gained increasing significance in the study of dental tissues as it is a noninvasive reproducible technique that can be applied both quantitatively and qualitatively assessment (6-11).

The purpose of this study was to evaluate the preparation of oval-shaped root canals of extracted mandibular canines using the three single-file systems SAF, Reciproc and WaveOne compared with the rotary full-sequence ProTaper Universal system, using three-dimensional µCT analysis.

Method

One hundred straight single-rooted human mandibular canine teeth with fully formed apices and a single root canal were randomly selected from a pool of extracted teeth, decoronated slightly above the cementoenamel junction and stored in labeled individual plastic vials containing 0.1% thymol solution. All teeth presenting isthmus, apical curvature or more than one root canal were excluded.

After being washed in running water for 24 h, each tooth was dried, mounted on a custom attachment, and scanned in a µCT scanner (SkyScan 1174v2; Bruker-microCT, Kontich, Belgium) at an isotropic resolution of 19.6 µm. Images of each specimen were reconstructed with dedicated software (NRecon v.1.6.3; Bruker-

microCT) providing axial cross sections of the inner structure of the samples. For each tooth, evaluation was done for the full canal length in approximately 600-800 slices per specimen. CTAn v.1.12 software (Bruker-microCT) was used for the bi-dimensional (area, perimeter, roundness, major diameter, and minor diameter) and three-dimensional (volume, surface area, and structure model index) evaluation of the root canal.

Area and perimeter were calculated using the Pratt algorithm. The cross-sectional appearance, round or more ribbon-shaped, was expressed as roundness. Roundness of a discreet 2D object is defined as 4.A/(π.(dmax)2), where "A" is the area and "dmax" is the major diameter. The value of roundness ranges from 0 to 1, with 1 meaning the perfect circle. The major diameter was defined as the distance between the two most distant pixels in that object. The minor diameter was defined as longest chord through the object that can be drawn in the direction orthogonal to that of the major diameter. Volume was calculated as the volume of binarized objects within the volume of interest. For the measurement of the surface area of the 3D multilayer dataset, two components to surface measured in 2D were used; first the perimeters of the binarized objects on each cross-sectional level, and second, the vertical surfaces exposed by pixel differences between adjacent cross-sections. Structure model index (SMI) involves a measurement of surface convexity in a 3D structure. SMI is derived as 6.(S'.V)/S2, where S is the object surface area before dilation and S' is the change in surface area caused by dilation. V is the initial, undilated object volume. An ideal plate, cylinder and sphere have SMI values of 0, 3 and 4, respectively. CTVol v.2.2.1 software (Bruker-microCT) was used for visualization and qualitative evaluation of the specimens.

From the initial sampling (n=100), 72 teeth were matched to create 18 foursomes based on the morphological dimensions of the root canal assessed in the initial μCT evaluation. One tooth from each foursome was randomly assigned to one of the 4 experimental groups (n=18) for this study. After checking the normality assumption (Shapiro-Wilk test), the degree of homogeneity (baseline) of the four groups with respect to the working length, and the aforementioned two- and three-dimensional parameters, was assessed using one-way analysis of variance (ANOVA) with a confidence interval of 95%.

After the groups were established, a flip of a coin was used to define which group of teeth would be treated with each of the following root canal preparation techniques: Self-Adjusting File, WaveOne, Reciproc, or ProTaper Universal systems. Root canal preparations were performed according to the manufacturer's guidelines. The instruments used in this experiment were 25 mm long and were used to enlarge two canals only. All canal preparations were completed by one operator (MAV) with clinical and laboratorial experience with all systems. After biomechanical preparation, the canals were dried with paper points, and the roots were submitted to a postoperative μCT scan and reconstruction applying the initial parameter settings.

Three-dimensional root canal models were reconstructed on the basis of μCT scans and the superimposition of pre- and post-preparation images was ensured with by means of a previously validated registration software (Mosaic 0.05; Institute of Communication and Computer Systems, Athens, Greece). CTVol v.2.2.1 (Bruker-microCT) was used for qualitative evaluation of the pre- and post-instrumented canals. Color-coded root canal models (green indicates preoperative, red postoperative canal surfaces) enabled qualitative comparison of the matched root canals before and after shaping. CTAn v.1.12 (Bruker-microCT) was used for measuring area, perimeter, roundness, major diameter, minor diameter, volume, surface area, and SMI. Mean increase (Δ) of each analyzed parameter was calculated by subtracting the scores for the treated canals from those recorded for the untreated counterparts. Two-dimensional evaluation (area, perimeter, roundness, major diameter, and minor diameter) was done for the full canal length in all sample

in a total of 14,142 (SAF), 14,145 (WaveOne), 14,295 (Reciproc), and 14,325 (ProTaper Universal) cross-sections.
Because normality assumptions could be verified (Shapiro-Wilk test), the mean increase (Δ) of each parameter were compared by using one-way analysis of variance (ANOVA) with *post hoc* Tukey test between groups and paired-sample *t* test within group using SPSS v17.0 for Windows with the level of statistical significance set at 5%.

Results

Initial Parameters of the Experimental Groups

No statistical differences were found between the experimental groups with respect to working length, bi-dimensional (area, perimeter, roundness, major diameter, and minor diameter) and three-dimensional (volume, surface area, and structure model index) analyzed parameters. It confirmed that the experimental groups were previously well-balanced from an anatomical standpoint, either considering the entire root canal (Table 1) ($P > .05$).

Qualitative Assessment of Root Canal Preparation

Preoperatively (Figure 1A), root canal presented significantly flatter and irregularly tapered by either in the mesiodistal or the buccolingual views (Figure 1B and C). However, preparation led to substantial changes in its geometry. After instrumentation, the outline of the canals was larger and showed a smooth taper in all experimental groups (Figure 1D). Figures 1E and 1F shows representative examples of superimposed root canals before and after canal instrumentation in each group. Changes in canal shape are shown as superimpositions of unprepared (green) and prepared (red) areas. Red demonstrates overlapping areas. All groups showed more untouched areas mainly on the lingual side of the middle third of the canal. However, superimposed μCT reconstructions in all thirds demonstrated that the use of SAF resulted in a more uniform dentin removal along the perimeter of the canals than reciprocating or rotary instrumentation.

Quantitative Assessment of Root Canal Preparation

The results of two- and three-dimensional analysis are detailed in Table 1.
Paired-samples *t* test revealed that preparation significantly increased all analyzed parameters in either reciprocating or rotary groups ($P < .05$), indicating larger and more rounded canals after preparation. On the other hand, SAF group presented no significance difference before and after preparation considering the perimeter ($P > .05$). Overall, comparison between groups revealed that SAF presented the lowest while WaveOne and ProTaper Universal showed the highest mean increase in most of the analyzed parameters ($P < .05$), and Reciproc showed intermediate results in some parameters. SMI analysis revealed no statistical significant difference between groups ($P > .05$).

Table 1. Morphometric data (mean ± standard deviation) of the root canal of one-rooted mandibular canines before and after preparation with SAF, Reciprocating, and Rotary Systems.

	Experimental Groups			
	SAF (n=18)	**WaveOne (n=18)**	**Reciproc (n=18)**	**ProTaper (n=18)**
Working Length (mm)	15.50 ± 1.32	15.67 ± 1.13	15.68 ± 1.18	15.61 ± 1.18
Area (mm^2) (Initial)	0.84 ± 0.26	0.86 ± 0.36	0.86 ± 0.17	0.86 ± 0.37
After Preparation	1.01 ± 0.26	1.23 ± 0.33	1.16 ± 0.18	1.21 ± 0.26
Δ	0.17 ± 0.07^{A}	0.38 ± 0.11^{B}	0.30 ± 0.10^{B}	0.35 ± 0.21^{B}
Perimeter (mm) (Initial)	**3.78 ± 0.63**	3.48 ± 0.78	3.79 ± 0.71	3.68 ± 0.85
After Preparation	**3.84 ± 0.58**	4.04 ± 0.64	4.08 ± 0.66	4.09 ± 0.62
Δ	0.06 ± 0.17^{A}	0.56 ± 0.26^{C}	0.29 ± 0.20^{B}	0.40 ± 0.39^{C}
Roundness (Initial)	0.56 ± 0.10	0.60 ± 0.11	0.58 ± 0.11	0.61 ± 0.09
After Preparation	0.63 ± 0.09	0.82 ± 0.04	0.78 ± 0.08	0.82 ± 0.04
Δ	0.07 ± 0.10^{A}	0.21 ± 0.08^{B}	0.20 ± 0.06^{B}	0.21 ± 0.06^{B}
Major Diam. (mm) (Initial)	1.41 ± 0.23	1.28 ± 0.34	1.41 ± 0.34	1.33 ± 0.32
After Preparation	1.44 ± 0.24	1.43 ± 0.29	1.50 ± 0.32	1.47 ± 0.29
Δ	0.04 ± 0.03^{A}	0.15 ± 0.09^{B}	0.09 ± 0.04^{C}	0.15 ± 0.06^{B}
Minor Diam. (mm) (Initial)	0.70 ± 0.14	0.73 ± 0.15	0.72 ± 0.09	0.73 ± 0.16
After Preparation	0.80 ± 0.12	1.01 0.08	1.03 ± 0.21	0.95 ± 0.08
Δ	0.10 ± 0.06^{A}	0.28 ± 0.11^{B}	0.31 ± 0.23^{B}	0.22 ± 0.09^{B}
Volume (mm^3) (Initial)	13.17 ± 4.48	13.56 ± 6.96	13.85 ± 3.02	12.99 ± 4.85
After Preparation	15.76 ± 4.81	19.29 ± 5.75	18.15 ± 3.14	18.97 ± 4.60
Δ	2.58 ± 1.33^{A}	5.73 ± 1.42^{B}	4.31 ± 1.54^{C}	5.98 ± 1.51^{B}
Surface Area (mm^2) (Initial)	63.86 ± 13.32	60.80 ± 15.34	65.40 ± 12.63	62.85 ± 14.56
After Preparation	66.69 ± 13.81	70.11 ± 13.16	70.78 ± 11.41	71.15 ± 12.65
Δ	2.83 ± 2.01^{A}	9.31 ± 4.71^{B}	5.38 ± 2.57^{C}	8.31 ± 3.63^{B}
SMI (Initial)	2.21 ± 0.45	2.58 ± 0.32	2.34 ± 0.57	2.27 ± 0.55
After Preparation	2.64 ± 0.29	2.88 ± 0.13	2.73 ± 0.34	2.80 ± 0.29
Δ	0.43 ± 0.31	0.30 ± 0.24	0.39 ± 0.44	0.53 ± 0.48

Two-dimensional evaluation (area, perimeter, roundness, major diameter, and minor diameter) was done for the full canal length in all sample in a total of 14,142 (SAF), 14,145 (WaveOne), 14,295 (Reciproc), and 14,325 (ProTaper Universal) cross-sections. Different superscript letters in the same line indicate statistical significant difference between groups (ANOVA *post hoc* Tukey test, $P<.05$); Δ: mean increase (± SD) of the analyzed parameter; within group, values with bold letters in the same column were not statistically different (Paired *t*-test, $P>.05$).

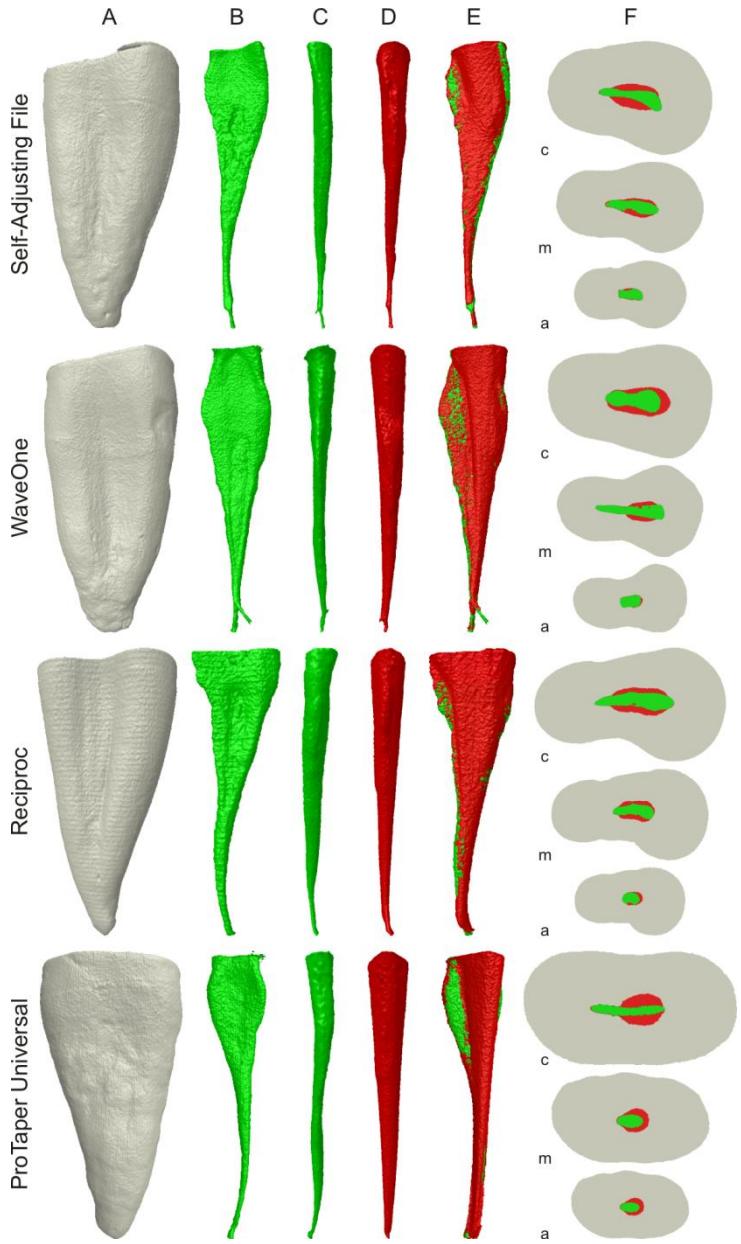

Figure 1: Representative bi- and three-dimensional reconstructions of the external and internal anatomy of mandibular canines from each experimental group, before and after root canal preparation. (A) Lateral view of the roots of four mandibular canines from each experimental group; (B and C) Mesiodistal and buccolingual views of a flatter and irregularly tapered root canals before preparation; (D) Buccolingual view of a larger and smooth tapered root canal after preparation; (E) Buccolingual view of superimposed root canals before (green) and after (red) preparation; (F) Representative cross-sections of the superimposed root canals before (green) and after (red) preparation at coronal (c), middle (m), and apical (a) thirds.

Conclusion

Within the limitations of this *ex vivo* study, it can be concluded that all systems performed similarly in terms of the amount of touched dentin walls. ProTaper Universal and WaveOne systems presented the highest changes of the basic geometric analyzed parameters (area, perimeter, roundness, major diameter, minor diameter, volume, surface area, structure model index) in comparison to Reciproc and SAF.

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