Micro–computed Tomographic Evaluation of the Shaping Ability of WaveOne Gold, TRUShape, EdgeCoil, and XP-3D Shaper Endodontic Files in Single, Oval-shaped Canals: An *In Vitro* Study

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SIGNIFICANCE

Micro-CT analysis of canal geometry before and after instrumentation revealed that WaveOne Gold, TRUShape, EdgeCoil, and XP-3D Shaper all had similar abilities to shape single, oval-shaped canals.

ABSTRACT

Introduction: This study evaluated and compared the shaping ability of the WaveOne Gold (Dentsply/Tulsa Dental Specialties, Tulsa, OK), TRUShape 3D Conforming File (Dentsply/Tulsa Dental Specialties), EdgeCoil (EdgeEndo, Albuquerque, NM), and XP-3D Shaper (Brasseler USA, Savannah, GA) endodontic file systems on oval-shaped canals using micro–computed tomographic (micro-CT) technology. **Methods:** Thirty-two oval-shaped, single-canal extracted human teeth were decoronated 1 mm coronal to the cementoenamel junction and scanned via a micro-CT scanner (μCT100; Scanco Medical, Bassersdorf, Switzerland). Teeth were divided into 4 groups ($n = 8$) and instrumented according to the manufacturer's instructions. Coregistered images, before and after root canal preparation, were evaluated for morphometric measurements of the surface area, volume, structure model index (SMI), conicity, and percent of walls untouched using the manufacturer's evaluation software (IPL Register, Scanco Medical). Data were statistically compared between groups using 1-way analysis of variance and within groups using a paired sample *t* test. **Results:** Instrumentation with all file types increased the surface area, volume, and conicity between and within groups. There was no statistically significant difference between the groups for any of the rotary instruments used ($P < .05$). **Conclusions:** Instrumentation of oval-shaped canals with WaveOne Gold, TRUShape, EdgeCoil, and XP-3D Shaper rotary endodontic instruments similarly increase the volume, surface area, and conicity. None of the file systems were capable of contacting all of the surface area in any canal. *(J Endod 2020;46:244–251.)*

KEY WORDS

3-dimensional analysis; EdgeCoil; micro–computed tomography; TRUShape 3D; WaveOne; XP-3D Shaper

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One of the primary goals of effective root canal instrumentation is to maintain the original shape of the canal configuration[1]. Currently, nickel-titanium (NiTi) rotary file systems are able to act mechanically on the central body of the canal space. Oval-shaped canals pose a unique challenge during cleaning and shaping procedures. The majority of micro–computed tomographic (micro-CT) studies found that 59.6%–79.9% of the dentinal walls remain untouched during root canal preparation of oval-shaped canals[2–5]. Metallurgic advancements in NiTi rotary files over the last 2 decades have led to endodontic preparations that may be accomplished more predictably and with reduced iatrogenic risk[6]. However, a limitation remains when using round cross-sectional–shaped rotary files to prepare oval-shaped canals in meeting 2 primary objectives: removing adequate circumferential dentin from all areas of the root canal and avoiding overpreparation of root canal dentin. Attempting to overcome these limitations may lead to multiple instrumentation errors, including the risk of weakening the tooth structure by overinstrumentation, perforation, and canal transportation[7]. These procedural errors have been shown to decrease treatment outcome[8].

Instrumentation of oval-shaped canals often results in uninstrumented recesses[9]. It is noteworthy that recent endodontic trends focus on preservation of the tooth structure with increased emphasis on chemical disinfection despite numerous studies supporting mechanical debridement of the canal system as being paramount in biofilm removal[10–12]. Untouched portions of the canal space may harbor microbial biofilms that serve as a persistent source of infection[13,14]. Biofilms are widely recognized to cause an increased antigenic host response and have decreased susceptibility to the immune system and chemotherapeutics[15]. Novel file designs aim to provide greater contact to canal walls and improve apical cleaning while preserving the original root canal shape and cervical dentin[16]. Recently, using heat treatment technology, several manufacturers have produced rotary file shapes with corkscrew-like or S-shaped geometry as well as reciprocating action to accomplish these objectives[17–20].

Potential advantages of using files with a flexible and expandable profile are

1. improved adaptation to irregular canal geometries,
2. a reduced risk of overenlarging narrow portions of the root canal, and
3. improved cyclic fatigue resistance through modified file geometries and metallurgies[21–23]. NiTi endodontic files currently on the market that implement a profile-based geometry, as opposed to a predefined fixed shape, include the TRUShape (Dentsply/Tulsa Dental Specialties), EdgeCoil (EdgeEndo, Albuquerque, NM), and XP-3D Shaper (Brasseler USA, Savannah, GA).

Evaluation of the instrumented canal wall surface contacted by rotary files can be accurately measured using micro-CT 3-dimensional scanning. Micro-CT analysis is currently considered the gold standard, which permits noninvasive analysis of changes in canal morphology, surface area, and volume and identification of unprepared areas[4,24–26]. A morphometric parameter of canal geometric convexity can be measured through a structure model index (SMI) with values ranging from 0–4. This 3-dimensional (3D) scoring system assigns a plate a score of 0, a cylinder a score of 3, and a sphere a score of 4[27]. The SMI represents surface convexity of a 3D structure evaluated with Scanco evaluation software (Scanco Medical, Bassersdorf, Switzerland) evaluation software. The goals of this study were to use micro-CT scanning and software analysis to evaluate and compare the percent of untreated surface area and the volumetric and geometric change of instrumented oval-shaped canals of the 4 selected rotary systems. The null hypothesis was that no significant difference exists in morphometric parameters of the instrumented oval-shaped canals using WaveOne Gold (Dentsply Tulsa Dental Specialties, Tulsa, OK), TRUShape, EdgeCoil, and XP-3D Shaper files.

A pilot study was conducted to validate the methodology of Scanco evaluation software (Scanco Medical, IPL Register l). A scanning mounting jig was printed from stereolithography (.stl) files provided by the University of Michigan School of Dentistry MicroCT Core (μCT100, Scanco Medical) to secure specimens within the micro-CT unit. Each jig held 5 teeth, whereas the Scanco micro-CT scanner is able to accommodate several jigs per scan. Five oval-shaped premolar teeth were collected, mounted in the scanning jig using Aquasil VPS bite registration material (Dentsply Caulk, Milford, DE), and scanned at the University of Michigan School of Dentistry MicroCT Core laboratory. Teeth were then instrumented with ProTaper S2 rotary files (Dentsply/Tulsa Dental Specialties) irrigated with tap water, and rescanned. Scanco evaluation software was used for analysis of morphometric changes via superimposition of the preinstrumented and postinstrumented root canals. The use of micro-CT scans before and after instrumentation allowed superimposition with Scanco evaluation software. The analysis was able to provide the volumetric and geometric change, SMI values, and color renderings pre- and postinstrumentation.

MATERIALS AND METHODS

After approval of the Institutional Review Board at the University of Detroit Mercy School of Dentistry, deidentified straight single-rooted maxillary and mandibular human premolar teeth were selected from a pool of extracted teeth. Extracted teeth were stored in saline at 25°C and evaluated using 2-dimensional Schick CMOS digital radiography (Dentsply Sirona, York, PA) in both a buccolingual and mesiodistal dimension to identify single-rooted teeth with oval canals. Teeth that had buccolingual dimension 2 times greater than the mesiodistal dimension were considered oval canals[9] (Supplemental Fig. S1 is available online at www.jendodon.com). The exclusion criteria were teeth with 2 or more root canals, nonoval canals, gross caries, severe root curvatures, and immature apices.

Thirty-two teeth passed the inclusion/exclusion criteria and were randomly assigned to 1 of 4 ($n = 8$) experimental groups: WaveOne, TRUShape, EdgeCoil, and XP-3D Shaper. Teeth were sectioned 1 mm coronal to the cementoenamel junction, washed with running tap water, air-dried at room temperature, and scanned on a custom mounting attachment in a micro-CT scanner (μCT100) (Supplemental Fig. S2*B* is available online at www.jendodon.com).

Specimens were placed in a 48-mm diameter specimen holder and scanned over the entire length of the tooth using the Scanco micro-CT system. The scan settings were as follows: voxel size of 25 μm, 90 kVp, 155 μA, 0.1-mm Cu filter, and integration time of 500 milliseconds. Scans were performed both before and after instrumentation. The volume of interest was defined as an 8-mm-long region ending 1 mm from the root apex (D1–D9). Analysis was performed using the manufacturer's evaluation software (IPL Register) to calculate root superimposition after instrumentation, enabling the visualization and 3D quantification of uninstrumented areas.

Images of each specimen were reconstructed (Scanco manufacturer's micro-CT software) to provide axial cross sections of their canal structure, and each canal was evaluated over the predetermined volume of interest (8-mm canal length) with approximately 600–800 slices/specimen. Scanco micro-CT software was used for 3D volume, surface area, and SMI evaluation.

Decoronated teeth were stored in sterile physiologic saline before instrumentation and instrumented in a heated water bath maintained at body temperature (37°C) to hydrate dentin and perform instrumentation at body temperature. Teeth were individually mounted in a tooth securing device (Panavise, Sparks, NV), and all hand and rotary file instrumentation was performed under surgical operating microscopes (Global Surgical Corporation, St Louis, MO) (Supplemental Fig. S2*A* is available online at www.jendodon.com). Root canals were negotiated with size #10 and #15 K-files (Dentsply Tulsa Dental Specialties) to establish a glide path. The working length was determined by inserting a size #10 K-file until it was visible at the tip and subtracting 1 mm from the patency length. After length determination, each rotary system was used to the manufacturer's guidelines to the full working length. A single operator with experience in all systems performed all canal preparations and was blinded to the virtual 3D models of the teeth before preparation of the root canals to prevent bias. The instrumentation groups were as follows:

1. WaveOne Gold: instrumentation was performed with light pecking and outstroke brushing motions according to the

manufacturer's directions for use. Canals were instrumented using a single-file technique with reverse reciprocating motion to size 25/07. WaveOne Gold is marketed as a "single-file system" and is available in the following sizes/tapers: 20/07, 25/07, 35/06, and 45/05. WaveOne Gold files have an offset rectangular shape, have a variable taper, and are manufactured with "gold" thermal treatment used in a reverse reciprocating motion that is aimed to be fatigue resistant and maximize cutting efficiency.

2. TRUShape: canals were instrumented using size 25/06 at 300 rpm and 3 Ncm torque with a light pecking and brushing motion against the buccal and lingual canal walls until the working length was reached. The TRUShape Conforming File is available in the following sizes/tapers: 20/06, 25/06, 30/06, and 40/06; the .06 taper occurs in the apical 2 mm, and the remainder of the instrument shaft has a variable taper so that the maximum shaft width is no more than .80 mm. The file has a symmetric triangular cross section and is operated at 300 rpm and 3 Ncm torque. The manufacturer claims that this file promotes greater dentin preservation than classic rotary files.
3. EdgeCoil: Canals were instrumented using a single-file technique with reverse reciprocating motion and short-amplitude inward-outward motions. EdgeCoil was used with a brushing motion on the outstroke with 1 or more passes to reach the working length. EdgeCoil is a heat-treated FireWire NiTi single-file shaping protocol stated to be capable of negotiating 90° curves. It has a reverse-reciprocating rectangular cross section that can expand and contract from 20/04 to 50/06 because of its flexible profile.
4. XP-3D Shaper: canals were instrumented using a single-file technique at 800–1000 rpm at 1 Ncm torque. Long gentle strokes were used until the file reached the full working length. XP-3D Shaper is an adaptive core design that is able to clean from a #30 to a size #90 apical size and can range from a .02 to .08 taper. This is made possible by MaxWire (Brasseler USA) technology, providing a superelastic, cyclic fatigue resistance alloy. MaxWire is predominantly in a martensitic phase at 68°F (20°C) and transforms to an austenitic phase at 95°F (35°C). The Booster Tip (Brasseler USA) is designed to have a #15 size tip that transitions to a #30 within 1 mm, which facilitates simultaneous scouting and canal preparation.

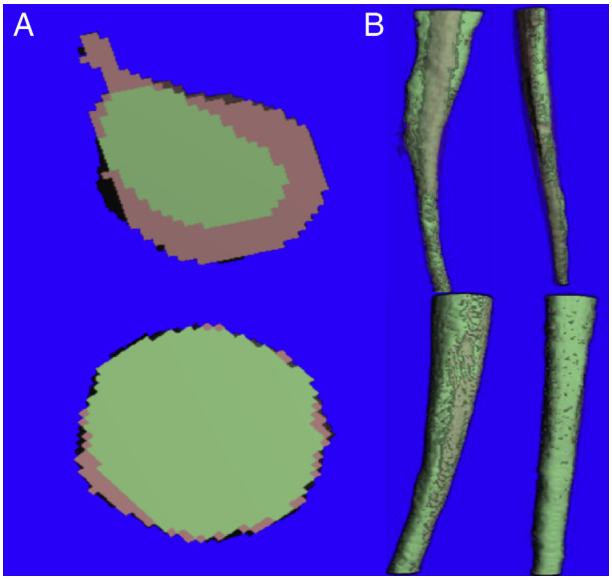

FIGURE 1 – Reconstructed micro-CT images of the (*A*) axial views at the midroot level and (*B*) lateral views of superimposed canals before instrumentation (*green*) and after instrumentation (*red*) with the WaveOne Gold rotary file system.

Canals were instrumented with ample irrigation using the same irrigation protocol for all instrumentation groups. Canals were irrigated with 3 mm 6% sodium hypochlorite using a 30-G ProRinse needle (Dentsply Tulsa Dental Specialties) inserted 1 mm less than the binding. Teeth were subsequently rinsed with 1 mL 17% EDTA followed by 1 mL 6% sodium

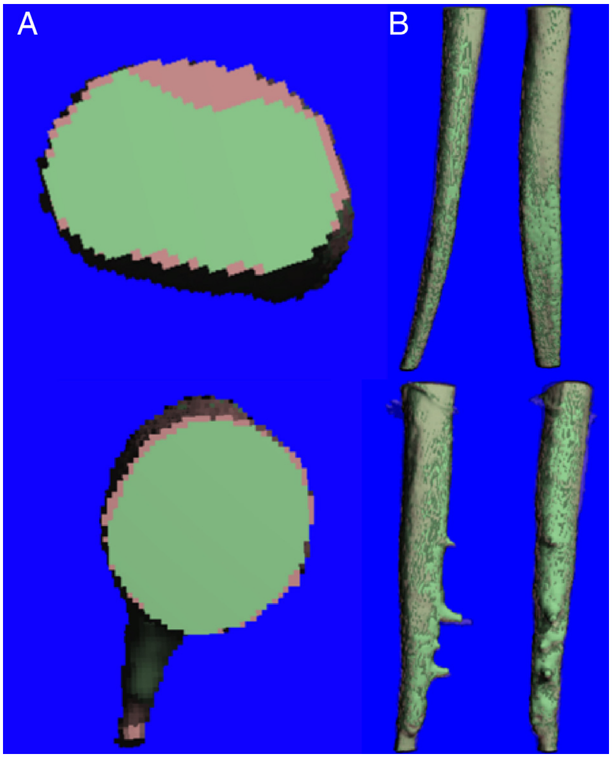

FIGURE 2 – Reconstructed micro-CT images of the (*A*) axial views at the midroot level and (*B*) lateral views of superimposed canals before instrumentation (*green*) and after instrumentation (*red*) with the TRUShape rotary file system.

hypochlorite for 1 minute each. A final 1-mL sterile water rinse was used, and the canals were dried with sterile paper points. Teeth were allowed to dry at room temperature, and postinstrumentation micro-CT scanning was completed.

A comparison was made before and after instrumentation to measure changes in surface area, volume, unprepared canal surface area, and SMI. Scanco software also allowed for computation of conicity, which is the average best-fit line slope of divergence within the canal after instrumentation. Two examiners blinded to preparation protocols performed micro-CT scanning and statistical analysis, respectively. Micro-CT images were constructed with preinstrumentation (green) and postinstrumentation (pink) geometry. Figures 1 through 4 show mesiodistal and buccolingual views as well as a single axial section 5 mm from the apex. Changes in geometric parameters were compared with preoperative values using analysis of variance ($P < .05$) between groups and a paired sample t test within groups ($\alpha = .05$).

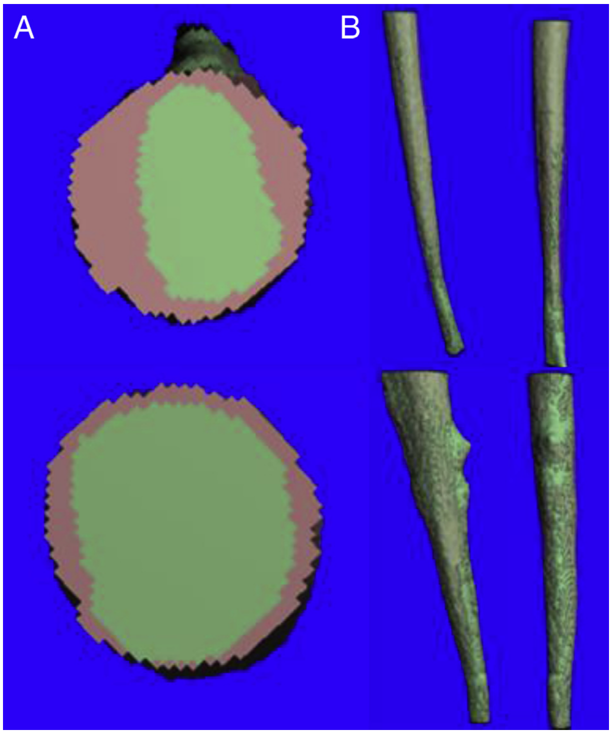

FIGURE 3 – Reconstructed micro-CT images of the (*A*) axial views at the midroot level and (B) lateral views of superimposed canals before instrumentation (*green*) and after instrumentation (*red*) with the EdgeCoil rotary file system.

RESULTS

Visual analysis of registration alignment identified internal or external cracks in 7 of 32 teeth, which were excluded from the study. The remaining 25 teeth resulted in the following 4 experimental groups: WaveOne ($n = 4$), TRUShape ($n = 6$), EdgeCoil ($n = 7$), and XP-3D Shaper ($n = 8$). The results showed no significant difference between all experimental groups in volumetric, surface area, conicity, and percent of untreated voxels ($P < .05$). The null hypothesis was accepted because all instrument groups had similar shaping tendencies (Table 1). Although not significant, instrumented canals in the EdgeCoil group resulted in the least percent of untreated voxels (39.09%) and the greatest increase in volume (62.4%) and surface area (24.3%). Canals in the XP-3D group exhibited the greatest increase in conicity (101%) compared with the other file systems, indicating that the degree of taper within the canal increased compared with preoperative canal geometry. In contrast, canals in the TRUShape group showed very little increase in conicity (1.6%). Within the experimental groups, all file types significantly increased the surface area ($\alpha = .05$) (Table 2). Additionally, TRUShape, EdgeCoil, and XP-3D Shaper files had a significant effect on volume change. The WaveOne file group was nearly significant at a P value of .060. No file system by itself showed a significant increase of conicity. However, the overall pooled data showed a significant increase in conicity.

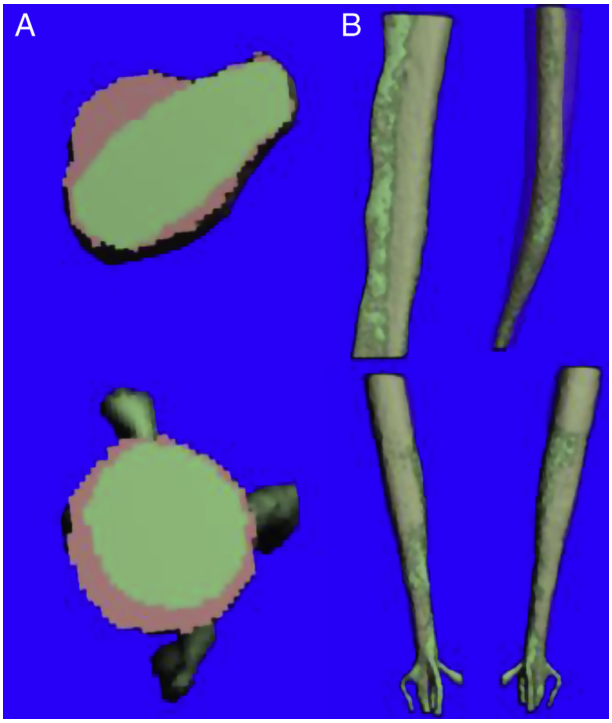

FIGURE 4 – Reconstructed micro-CT images of the (*A*) axial views at the midroot level and (*B*) lateral views of superimposed canals before instrumentation (*green*) and after instrumentation (*red*) with the XP-3D Shaper rotary file system.

TABLE 1 - 1-way Analysis of Variance Comparisons of 4 File Types

Measurement	Overall		WaveOne		TrueShaped		EdgeCoil		XP-3D Shaper		1-way ANOVA
	n	Mean (SD)	*n*	Mean (SD)	*n*	Mean (SD)	*n*	Mean (SD)	*n*	Mean (SD)	*P* value
% Untreated voxels relative to before	25	49.08 ± 24.75	4	50.90 ± 37.75	6	55.26 ± 19.94	7	39.09 ± 25.61	8	52.28 ± 22.31	.671
Conicity before	25	.0653 ± .0318	4	.0500 ± .0155	6	.0728 ± .0225	7	.0677 ± .0497	8	.0653 ± .0264	.755
Conicity after	25	.0789 ± .0165	4	.0655 ± .0110	6	.0718 ± .0179	7	.0819 ± .0114	8	.0884 ± .0168	.072
Conicity change (b – a)	25	.0136 ± .0313	4	.0154 ± .0137	6	−.0009 ± .0089	7	.0142 ± 0.0498	8	.0231 ± .0284	.589
% Change conicity	25	57.7 ± 130.9	4	41.6 ± 53.6	6	1.6 ± 14.2	7	63.4 ± 85.4	8	101.0 ± 214.6	.587
Surface area before	25	19.60 ± 5.86	4	14.57 ± 3.54	6	19.92 ± 5.68	7	18.33 ± 5.66	8	22.99 ± 5.70	.105
Surface area after	25	22.70 ± 5.98	4	17.12 ± 2.45	6	22.77 ± 7.12	7	21.97 ± 4.56	8	26.07 ± 5.89	.096
Surface area change (b − a)	25	3.10 ± 1.72	4	2.55 ± 1.32	6	2.85 ± 1.76	7	3.64 ± 2.52	8	3.09 ± 1.11	.772
% Change surface area	25	17.9 ± 14.7	4	19.6 ± 13.4	6	14.0 ± 6.1	7	24.3 ± 24.4	8	14.2 ± 7.2	.535
Voxels before	25	3.66 ± 1.81	4	2.29 ± 1.01	6	3.57 ± 1.35	7	3.27 ± 1.80	8	4.76 ± 2.03	.129
Voxels after	25	4.79 ± 1.93	4	3.05 ± 0.72	6	4.65 ± 2.15	7	4.64 ± 1.66	8	5.89 ± 1.92	.105
Voxels change (b − a)	25	1.13 ± 0.74	4	0.75 ± 0.51	6	1.08 ± 0.97	7	1.37 ± 0.79	8	1.13 ± 0.64	.642
% change voxels	25	40.5 ± 42.4	4	40.7 ± 30.6	6	28.8 ± 16.3	7	62.4 ± 70.2	8	30.0 ± 25.4	.446
SMI before	25	3.12 ± 0.39	4	3.19 ± 0.21	6	3.06 ± 0.42	7	3.05 ± 0.24	8	3.19 ± 0.56	.871
SMI after	25	3.19 ± 0.32	4	3.22 ± 0.10	6	3.13 ± 0.33	7	3.16 ± 0.15	8	3.24 ± 0.48	.933
SMI change (b − a)	25	0.07 ± 0.19	4	0.02 ± 0.18	6	0.08 ± 0.16	7	0.11 ± 0.15	8	0.05 ± 0.26	.876
% change SMI	25	2.8 ± 6.6	4	0.9 ± 6.0	6	3.1 ± 6.2	7	4.1 ± 5.2	8	2.5 ± 8.8	.904

ANOVA, analysis of variance; SD, standard deviation; SMI, structure model index.

DISCUSSION

It is important to assess the shaping ability of new file designs to determine its impact on the ability to meet the objectives of instrumentation. The operator must consider biologic factors weighed against characteristics of the instrument to ensure safe preparation of the root canal and facilitate chemical disinfection[28]. This study used micro-CT technology to assess the effect of 4 endodontic file systems in altering canal morphology. To date, no article has been published on the shaping ability of the EdgeCoil file system in oval-shaped canals

TABLE 2 - *t* Test Analysis Comparing Instrumentation within Groups and Overall

Measurement	Overall		WaveOne		TrueShaped		EdgeCoil		XP-3D Shaper	
	N	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SD	*n*	Mean ± SD
Conicity before	25	.0653 ± .0318	4	.0500 ± .0155	6	.0728 ± .0225	7	.0677 ± .0497	8	.0653 ± .0264
Conicity after	25	.0789 ± .0165	4	.0655 ± .0110	6	.0718 ± .0179	7	.0819 ± .0114	8	.0884 ± .0168
Conicity change (a − b)	25	.0136 ± .0313	4	.0154 ± .0137	6	−.0009 ± .0089	7	.0142 ± 0.0498	8	.0231 ± .0284
% Change conicity	25	57.67 ± 130.9	4	41.65 ± 53.61	6	1.65 ± 14.24	7	65.37 ± 85.40	8	100.98 ± 214.58
P value (before vs after)		.040		.110		.805		.481		.055
Surface area before	25	19.60 ± 5.86	4	14.57 ± 3.54	6	19.92 ± 5.68	7	18.33 ± 5.66	8	22.99 ± 5.70
Surface area after	25	22.70 ± 5.98	4	17.12 ± 2.45	6	22.77 ± 7.12	7	21.97 ± 4.56	8	26.07 ± 5.89
Surface area change (a − b)	25	3.10 ± 1.72	4	2.55 ± 1.32	6	2.85 ± 1.76	7	3.64 ± 2.52	8	3.09 ± 1.11
% Change surface area	25	17.88 ± 14.68	4	19.65 ± 13.43	6	14.05 ± 6.06	7	24.34 ± 24.44	8	14.23 ± 7.21
P value (before vs after)		<.001		.031		.011		.009		<.001
Volume before	25	3.66 ± 1.81	4	2.29 ± 1.01	6	3.57 ± 1.35	7	3.27 ± 1.80	8	4.76 ± 2.03
Volume after	25	4.79 ± 1.93	4	3.05 ± 0.72	6	4.65 ± 2.15	7	4.64 ± 1.66	8	5.89 ± 1.92
Volume change (a − b)	25	1.13 ± 0.74	4	0.75 ± 0.51	6	1.08 ± 0.97	7	1.37 ± 0.79	8	1.13 ± 0.64
% Change volume	25	21.63 ± 15.62	4	22.44 ± 12.92	6	19.69 ± 7.56	7	27.31 ± 26.57	8	17.71 ± 8.11
P value (before vs after)		<.001		.060		.041		.004		.002
SMI before	25	3.12 ± 0.39	4	3.19 ± 0.21	6	3.06 ± 0.42	7	3.05 ± 0.24	8	3.19 ± 0.56
SMI after	25	3.19 ± 0.32	4	3.22 ± 0.10	6	3.13 ± 0.33	7	3.16 ± 0.15	8	3.24 ± 0.48
SMI change (a − b)	25	0.07 ± 0.19	4	0.02 ± 0.18	6	0.08 ± 0.16	7	0.11 ± 0.15	8	0.05 ± 0.26
% Change SMI	25	2.82 ± 6.57	4	0.91 ± 5.95	6	3.13 ± 6.25	7	4.06 ± 5.24	8	2.48 ± 8.80
P value (before vs after)		.073		.830		.287		.083		.592

SD, standard deviation; SMI, structure model index.
Instrumentation significantly increased surface area, volume, and conicity overall. TRUShape, EdgeCoil, and XP-3D Shaper increased the surface area and volume within groups, whereas WaveOne increased the surface area only. No statistically significant difference was observed in SMI after instrumentation for any group or overall.

using the Scanco software technology. The current research showed no significant difference of morphometric measurements between the experimental groups.

No file system tested was capable of completely preparing the oval shaped canals, leaving areas of untouched canal walls. This is in agreement with other studies that evaluated other rotary systems[29–32]. The statistical analysis did not show a significant difference in surface area and volume increase between the evaluated file systems. Although statistically not significant, the EdgeCoil did show a greater percent increase in surface area (24.3%) and volume (62.4%) compared to the other file systems tested. In addition, the EdgeCoil also resulted in the least untouched voxels (39.09%) in oval-shaped canals, indicating more surface area was contacted by this newly introduced rotary file system.

The current findings also showed no significant difference in conicity, surface area, and SMI between WaveOne and EdgeCoil reciprocating files compared with TRUShape and XP-3D continuous rotary motion files. This is in agreement with other studies[32] that found no significance difference between root canal volume, surface area, and SMI between WaveOne, ProTaper Universal, and ProTaper Next file systems (Densply/Tulsa Dental Specialties) and no difference in terms of shaping ability when evaluating reciprocating and continuous rotating motion of the Mtwo file compared with Reciproc reciprocating file systems (VDW, Munich, Germany).[33]

The XP-3D Shaper had a nearly significant conicity ($P = .055$) in the *t* test, suggesting the XP-3D rotary system effectively produced an increased canal taper. This finding is in agreement with Versiani et al[27], who found that the XP-endo Shaper (FKG Dentaire SA, La Chaux-de-Fonds, Switzerland) significantly altered the overall geometry of the root canal to a more conical shape. The EdgeCoil had the least untreated voxels while only having moderate increases in conicity. This may suggest that the EdgeCoil is more efficient in contacting more surface area in oval-shaped canals. Clinically, this may translate into more complete instrumentation without increasing the coronal shape of the canal as exhibited by the XP-3D Shaper. Further studies with larger sample sizes are needed to confirm such effectiveness.

Statistical *t* test results comparing instrumentation within groups are significant for volume, with the exception of the WaveOne Gold ($P = .060$). The nonsignificant value may be attributed to a reduced sample size of this group resulting from an unexpected cracking complication, perhaps caused by desiccation of the teeth, which affected coregistration and analysis. The analysis of variance test showed none of the file systems tested resulted in significant conicity change. However, the overall pooled data represented a statistically significant increase in conicity. This finding may similarly be attributed to the lack of the sample size of certain groups caused by the previously mentioned technical difficulties. Further studies with increased sample sizes are suggested to confirm the current findings and take into consideration homogeneity of tooth anatomy. An alternative suggestion to control some of these limitations is to use 3D-printed teeth with similar canal anatomy and dentinlike hardness.

CONCLUSION

Within the limitations of this study, it can be concluded that the WaveOne Gold, TRUShape, Edge Coil, and XP-3D Shaper file systems increase volume, surface area, and conicity of instrumented root canals. No file system was capable of contacting all of the surface area in any canal, but EdgeCoil attained the greatest increase in volume and surface area as well as the least amount of untreated voxels among all of the file systems tested.

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The authors deny any conflicts of interest related to this study.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found in the online version at www.jendodon.com (https://doi.org/10.1016/j.joen.2019.11.001).

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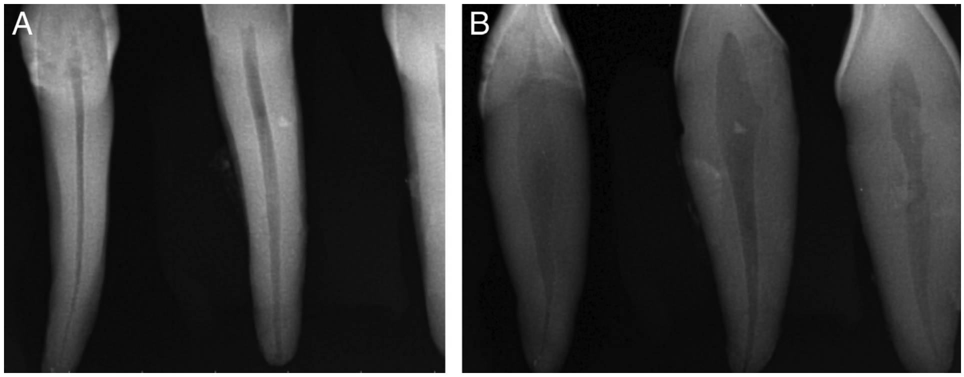
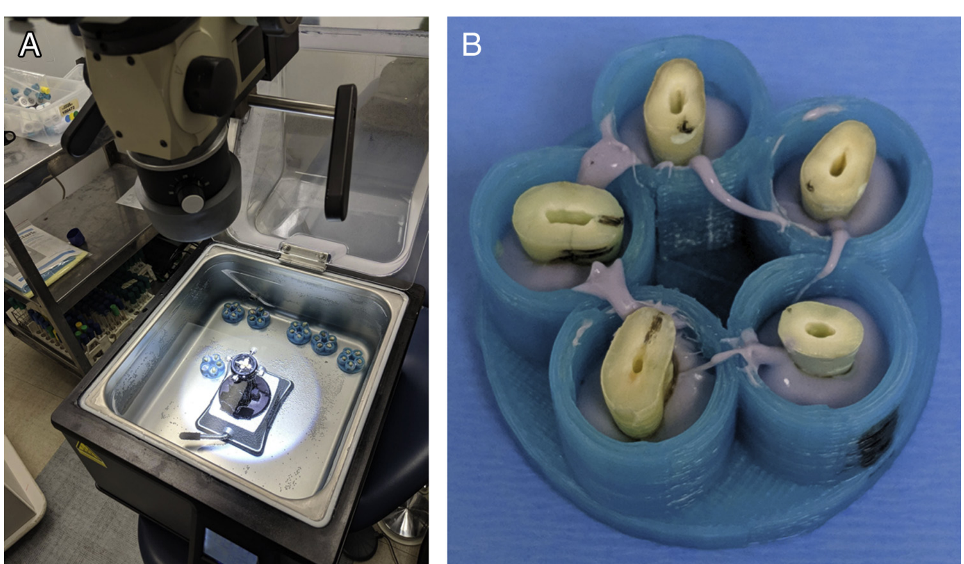


SUPPLEMENTAL FIGURE S1 – Radiographic identification of oval-shaped single-rooted teeth during screening evaluation in a (*A*) buccolingual and (*B*) proximal view.



SUPPLEMENTAL FIGURE S2 – The experimental setup for teeth and micro-CT preparation. (*A*) Mounted teeth in the experimental instrumentation setup held at 37°C within a secured device under a surgical operating microscope. (*B*) A close-up of teeth secured in a micro-CT mounting jig.