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Keywords: instrumentation, M-Wire, reciprocation, shaping ability, simulated canals, single-file

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Conclusions: Under the conditions of this study, all single-file instruments were safe to use and were able to prepare the canals efficiently. However, single-file systems that are less tapered seem to be more favourable when preparing S-shaped canals.

.Title Page (Only file with author names)

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Acknowledgments

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

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Abstract

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Introduction

The single-file root canal preparation was first introduced by Yared in 2008 (1), who proposed the use of only one ProTaper F2 file (Tulsa Dentsply, Tulsa, OK, USA) in a reciprocating motion for the preparation of curved root canals. Shortly thereafter, a number of manufacturers adopted this technique and introduced different files with a unique flute design, cross sectional shape, alloy, and working motion to the market. Canal preparation is faster with the single-file technique (2). In addition, this technique may reduce the treatment cost compared to full-sequence systems because only one file is required for root canal preparation. The single use of files reduces the risk of file separation and prevents possible cross-contamination among patients (3).

Currently, two reciprocating single-file systems are available: Reciproc (VDW, Munich, Germany) and WaveOne (Dentsply Maillefer, Ballaigues, Switzerland). The reciprocation working motion consists of a counter-clockwise (cutting direction) and a clockwise motion (release of the instrument), while the angle of the counter-clockwise cutting direction is greater than the angle of the reverse direction. These instruments are manufactured from M-Wire, which is created by an innovative thermal-treatment process of nickel-titanium (NiTi) alloy. This process has been proven to increase the flexibility and resistance of the NiTi alloy to cyclic fatigue (4). The Reciproc system consists of 3 files: R25, R40, and R50. The R25 file has a taper of 0.08 over its first 3mm, followed by a regressive taper of 0.043, and is characterised by an S-shaped cross-section. The WaveOne system also consists of three files with tip sizes of 21, 25, and 40. The primary WaveOne file has a tip size of 25 with a constant taper of 0.08 over the first 3mm from the tip, followed by a regressive taper of 0.055. The cross-sectional design has a modified triangular convex cross-section at the tip region of the instrument that changes to a convex triangular cross-section near the shank.

Two other recently introduced single-file systems, the OneShape (Micro Méga, Besançon, France) and F360 (Komet Brasseler, Lemgo, Germany), are made from traditional NiTi alloy and work in a continuous clockwise rotational motion. The respective recommended speeds with torque settings are 400 rpm with 4 Ncm for OneShape and 250–350 rpm with 1.8 Ncm for F360. The F360 files are available in four different sizes (25, 35, 45, and 55) with a constant taper of 0.04. The cross-section of the files is a modified S-shaped design, which resembles the laterally reversed cross-section of Reciproc (2). Unlike the other three systems, the OneShape system consists of only one file of size 25 with a constant taper of 0.06. The file has three cutting edges at its tip region, which progressively changes to an S-shaped cross-section near the shaft, resembling the design of Reciproc and F360.

The shaping ability of these single-file systems has been compared with full-sequence rotary systems both in extracted teeth and in resin blocks with encouraging results. Yoo and Cho reported that both Reciproc and WaveOne respected the canal curvature better than full-sequence systems in simulated curved canals (5). In a study by Bürklein *et al*. using extracted teeth, Reciproc and WaveOne prepared severely curved canals significantly faster than full-sequence systems, with no difference regarding the maintenance of the original canal curvature (2). In another study by the same authors, the single-file systems (F360, OneShape, and Reciproc) showed promising results in comparison with the full-sequence Mtwo system (VDW, Munich, Germany) (6). However, only sparse information is currently available regarding the shaping ability of these single-file systems when used in S-shaped canals.

Therefore, the aim of this study was to compare the shaping ability of these four different single-file systems in simulated S-shaped canals. The null hypothesis tested was that there is no difference between the single-file systems regarding the preparation of simulated S-shaped canals.

Materials and Methods

Simulated Canals

Sixty-four simulated S-shaped canals (Endo Training Block-S; Dentsply Maillefer, Ballaigues, Switzerland) with a taper of 0.02, an apical diameter of 0.15 mm, and a length of 16 mm were prepared. The respective angles and radii of the curvatures were 30° and 5 mm for the coronal curvature and 20° and 4.5 mm for the apical curvature. The patency of the canals was confirmed by passing a size 10 K-file just beyond the apex; subsequently, the resin blocks were randomly divided into four groups (n =16 canals/group) and were numbered.

Instrumentation of S-shaped canals

A new instrument was used for each canal in all groups. Glyde-Prep (Dentsply Maillefer, Ballaigues, Switzerland) was used as a lubricant before the utilization of each instrument and distilled water was used for irrigation during preparation. The canals were instrumented by using the single-file systems described in the following sections without glide path preparation or additional use of hand files.

Group A:

The WaveOne Primary file (tip size, 25; apical taper, 0.08) was used in a programmed reciprocating motion generated by the WaveOne motor (Dentsply Maillefer, Ballaigues, Switzerland) in “WAVEONE ALL” mode. The files were used in a pecking motion (amplitude less than 3 mm, three pecks) according to manufacturer’s instructions. The flutes of the instrument were cleaned after three in-and-out-movements (pecks).

Group B:

The R25 Reciproc file (tip size, 25; apical taper, 0.08) was used in a programmed reciprocating motion generated by the VDW SILVER motor (VDW, Munich, Germany) in “RECIPROC ALL” mode. The files were used in a pecking motion (amplitude less than 3 mm, three pecks) according to the manufacturer’s instructions. The flutes of the instrument were cleaned after three in-and-out-movements (pecks).

Group C:

The OneShape file (tip size, 25; taper, 0.06) was used in full clockwise rotation with a rotational speed of 400 rpm generated by the X-Smart motor (Dentsply Maillefer, Ballaigues, Switzerland), and the torque was adjusted to 4 Ncm. The files were used in a slight pecking motion according to the manufacturer’s instructions.

Group D:

The F360 file (tip size, 25; taper, 0.04) was used in full clockwise rotation with a rotational speed of 300 rpm generated by the X-Smart motor (Dentsply Maillefer, Ballaigues, Switzerland), and the torque was adjusted to 1.8 Ncm. The files were used in a slight pecking motion according to the manufacturer's instructions.

All canals were prepared by an experienced operator, and a total of 64 S-shaped canals were prepared. Canals were irrigated during preparation by using saline. A new instrument was used for preparation of each canal and the flutes of all instrument were cleaned after retrieval of the instruments from the canals during instrumentation or after three pecks.

Image analysis and assessment of canal preparation

All canals were injected with black ink (Parker Quink, Parker, France) to obtain a clear pre-operative image. The canals were photographed by using a digital camera (Sony Alpha DSLR-A100 camera with DSLR-A100 macro lens, Sony, Japan) on a fixed stand with constant settings. The canals were rinsed with distilled water before and after instrumentation. The canals were subsequently filled with red ink (Parker Quink, Parker, France) and were photographed again under identical conditions.

The pre- and post-instrumentation images were superimposed into a composite image by using a computer software program (Adobe Photoshop Elements 7.0, Adobe Systems Incorporated, San Jose, CA, USA). A measuring template was superimposed on the composite images. The amount of resin removal as a result of instrumentation was measured by using ImageJ 1.46r software (Wayne Rasband, National Institutes of Health, USA) in a perpendicular manner to the surface of the canal at 22 measuring points (11 on each side of the canal). The measurement points (MP) were arranged in 1-mm steps: points 0 to 3 corresponded to the apical curve, points 3 to 7 to the coronal curve, and points 7 to 10 belonged to the straight portion of the canal. A second examiner who was blinded to all experimental groups carried out the assessments of the canal shapes prior to and after instrumentation.

The time for canal preparation, which included total active instrumentation, cleaning of the flutes of the instruments, and irrigation, was recorded. Canal aberrations were determined by two clinicians blinded to the canal preparation instruments by using composite images. Assessments were performed based on the presence of an apical zip, narrowing, ledge, and danger zone. The canal aberrations were defined according to Ersev et al. (7).

Statistical analysis

Statistical evaluations were performed with SPSS software (IBM SPSS Statistics 21, SPSS Inc., Chicago, USA). The normality of the data was verified for each set of measurements by using the Kolmogorov-Smirnov test. The results were statistically analysed by using one-way analysis of variance (ANOVA) and the post-hoc Tukey test. ANOVA and the post-hoc Tukey were also used to analyse the preparation times, and the Chi-square test was used to analyse the incidence of canal aberrations. The significance level was set at $P<0.05$.

Results

No instrument fractured during instrumentation of the resin blocks.

The mean amounts of resin removed at the different measuring points are presented in Table 1. At all measuring points representing the apical (MP 0–3) and the coronal curvature (MP

3–7), no significant differences were found between Reciproc and WaveOne ($P > 0.05$). The F360 removed significantly less amounts of resin compared to the Reciproc and WaveOne at eight out of 11 measuring points at the inner side and at seven out of 11 measuring points at the outer side of the canals ($P < 0.05$). OneShape removed significantly less resin compared to Reciproc and WaveOne at three out of 11 measuring points at the inner side and at five out of 11 measuring points at the outer side of the canals ($P < 0.05$; Table 1).

Regarding the total width of the canals after preparation, the canals prepared with F360 were significantly narrower than were those prepared with the other three systems at measuring points 1 to 11 ($P < 0.05$). The OneShape prepared significantly narrower canals compared to the Reciproc and WaveOne at measuring points 2 to 7 ($P < 0.05$; Table 2).

Canal aberrations

The results of the canal aberrations are presented in Table 3. No statistically significant differences were found between the different instruments regarding the incidence of canal aberrations (Chi-square test, $P > 0.05$).

Centring ability

The centring ability of the files is shown in Figure 1. The maintenance of both canal curvatures was better with F360 and OneShape compared to Reciproc and WaveOne, which removed more material from the outer side of both the coronal and apical curvatures, leading to canal straightening that was more pronounced.

Preparation time

The mean times taken to prepare the canals with the different instruments are shown in Table 4. OneShape and Reciproc prepared the canals significantly faster than did WaveOne and F360 ($P < 0.05$).

Discussion

The aim of this study was to compare the shaping ability of two reciprocating single-file systems, WaveOne and Reciproc, and two full-rotation single-file systems, OneShape and F360, in simulated S-shaped canals. The shaping ability of different rotary files has been investigated by using extracted human teeth and simulated canals. Simulated canals in resin blocks were used in this study because standardization of experimental conditions is mandatory when comparing the shaping ability of different instruments. The use of simulated canals is particularly important when investigating S-shaped canals because it is nearly impossible to select human teeth with S-shaped canals that have similar parameters in terms of the canal length, degree and radius of both curvatures, and diameter. These simulated canals can be easily photographed, measured, and evaluated before and after canal preparation (8, 9). However, the results of studies using simulated canals must be extrapolated cautiously to clinical conditions because of the differences that exist between resin and dentin (10).

S-shaped root canals are not rare in clinical practice. The frequencies of S-shaped canals are reported to be 30–40% and 35–59% in the disto-buccal root of maxillary molars and in the mesial root of mandibular molars, respectively (10). However, these S-shaped canals might not always be detected in radiographs under clinical conditions (11, 12).

Size 25 files were selected for all systems in this investigation according to the recommendations of the manufacturers because this size is designated for narrow and curved canals. Although increasing the apical preparation size may improve the cleaning efficiency and irrigation of the apical portion of the root canals, the risk of canal transportation also increases because the flexibility of the root canal instruments decreases. These aspects must be considered when preparing S-shaped canals (13, 14).

A glide path was not created prior to instrumentation of the S-shaped canals because all canals had an initial diameter compatible with ISO-size 15.

Amount of resin removed

The main findings of the present study were that less tapered instruments caused less canal transportation compared with more tapered single-file instruments and that the taper of the instruments is the predetermining factor regarding the shaping ability of the tested instruments in S-shaped canals (Tables 1 and 2, Figures. 1 and 2). The F360 and the OneShape instruments have a taper of 0.04 and 0.06, respectively, whereas the two reciprocating instruments (WaveOne and Reciproc) are characterized by a taper of 0.08 over the first 3mm from the tip. Thus, the findings that Reciproc and WaveOne removed more resin compared to F360 and OneShape and that the resulting canal widths were wider after preparation with these reciprocating single-files can be explained by the increased taper at the tip region of these two instruments. These files appear to be less flexible compared to other files of the same tip-size because of their greater taper over the first 3mm (15). This observation is in agreement with previous studies that compared the shaping effects of different instruments in S-shaped canals (16, 17).

In the present study, WaveOne and Reciproc removed comparable amounts of resin at most of the measurement points, and this can be attributed to their common features such as the reciprocating working motion, the taper of 0.08 at their tip region, and the fact that both files are manufactured from M-Wire alloy. The results obtained for the Reciproc are consistent with those of a previous study by Yoo and Cho, who suggested careful preparation of severely curved canals with Reciproc to avoid danger zone formation (5). However, the results obtained with the WaveOne are not consistent with another study in which good shaping effects were obtained when this instrument was used to prepare both L- and S-shaped simulated canals (18).

Preparation time

The preparation time is dependent on the technique, the number of instruments used, operator experience, and other details regarding the study design (9). In the present study, the preparation time included active instrumentation as well as the time required for cleaning the flutes of the instruments and irrigation. OneShape and Reciproc were significantly faster compared to WaveOne and F360 (Table 4). This observation is consistent with a previous study that investigated the shaping ability of different single-file systems in severely curved root canals in extracted teeth (6). In general, all single-file systems were able to prepare the canals relatively fast; thus, from a clinical perspective, the obtained differences might be of subordinate importance.

File separation and canal aberrations

In the present study, all instruments prepared the canals to the full working length and no instrument fractured. However, it should be noted that the instruments were used to prepare only one canal in this study. OneShape and F360 files are made of conventional austenite 55-NiTi alloy, which has been reported to have less resistance to cyclic fatigue compared to M-Wire alloy (19). However, in other studies, these single-file systems were used to prepare four severely curved canals in extracted teeth, and no file separation was reported (2, 6). Thus, the present results suggest that the use of M-Wire alloy is not a prerequisite for single-file systems in terms of avoiding instrument fracture.

Although the use of Reciproc and WaveOne resulted in danger zone formation in four canals (Table 3), no statistically significant difference was found between the different instruments regarding the incidence of canal aberrations.

Conclusions

According to the results of the present investigation, the null hypothesis was rejected because significant differences were obtained between the four single-file systems regarding their shaping ability in S-shaped canals.

Within the parameters of this study, all single-file systems performed well and were safe. Single-files that are less tapered should be preferred when preparing S-shaped canals as they maintain the original canal curvatures better than files having greater tapers.

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Figure Legends:

Figure 1: Direction and amount of canal transportation (mm) after instrumentation with the different instruments at the different measurement points. Values were calculated by subtracting the amount of resin removed at the inner side of the simulated canal from the amount removed at the outer side.

(Inner refers to the concavity of the apical curvature)

Figure 2: Representative images of simulated canals instrumented by using (A) F360, (B) OneShape, (C) Reciproc and (D) WaveOne.

Figure

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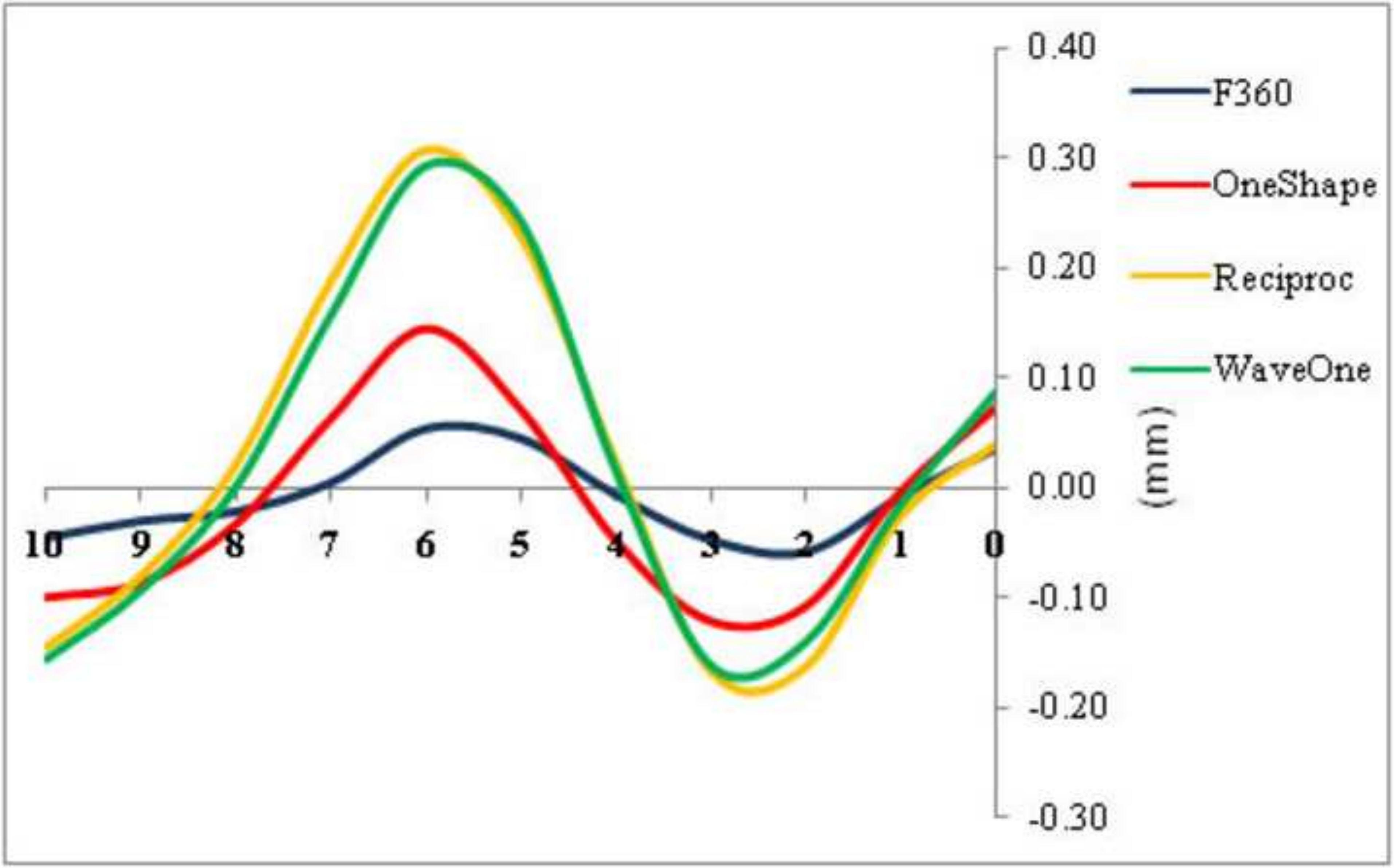

Figure 2
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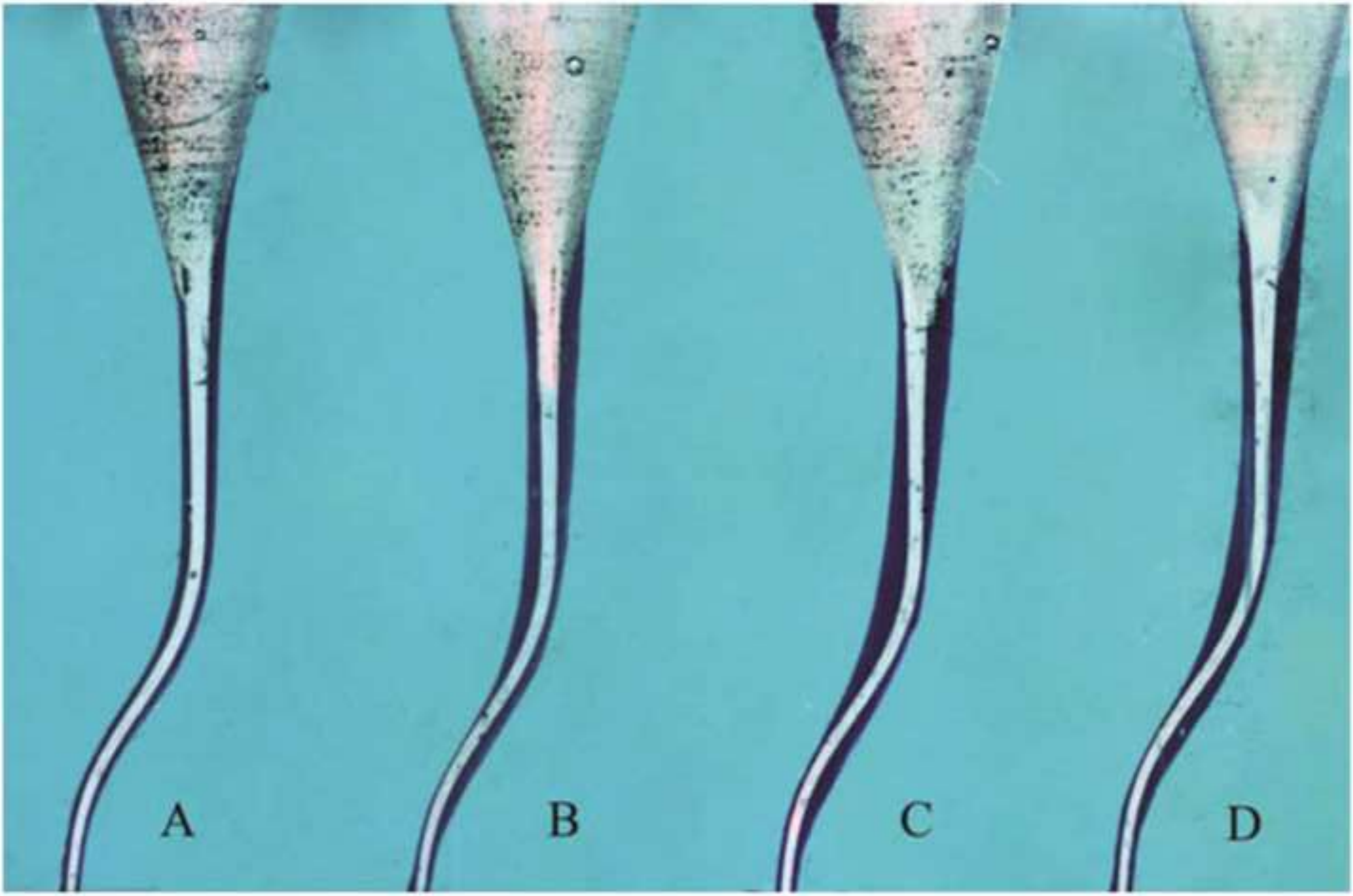

Table 1

Table 1: Means of removed resin (mm) and standard deviations (SD) at both sides of the canals at the different measurement points after root canal preparation.

	Inner Canal Wall (mm from the apex)											Outer Canal Wall (mm from the apex)										
	0	1	2	3	4	5	6	7	8	9	10	0	1	2	3	4	5	6	7	8	9	10
F360																						
Mean	0.06^{a}	0.09^{a}	0.13^{a}	0.13^{a}	0.12^{a}	0.12^{a}	0.12^{a}	0.15^{a}	0.17^{a}	0.18^{a}	0.18^{a}	0.09^{a}	0.08^{a}	$0.07^{a,b}$	0.08^{a}	0.12^{a}	0.16^{a}	0.17^{a}	0.16^{a}	0.15^{a}	0.15^{a}	0.13^{a}
SD	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.01	0.02	0.02	0.02	0.04	0.03	0.02	0.01	0.02	0.03
OneShape																						
Mean	0.05^{a}	$0.10^{a,b}$	0.18^{b}	0.20^{b}	0.18^{b}	0.15^{b}	0.14^{a}	0.20^{b}	0.27^{b}	0.30^{b}	0.31^{b}	$0.13^{a,b}$	$0.10^{a,b}$	0.07^{a}	0.07^{a}	0.13^{a}	0.22^{b}	0.28^{b}	0.26^{b}	0.23^{b}	0.22^{b}	0.21^{b}
SD	0.02	0.04	0.03	0.03	0.03	0.02	0.04	0.03	0.03	0.03	0.04	0.07	0.04	0.02	0.03	0.05	0.04	0.04	0.04	0.03	0.03	0.03
Reciproc																						
Mean	0.07^{a}	0.12^{b}	0.24^{c}	0.26^{c}	0.19^{b}	0.14^{b}	0.12^{a}	0.18^{b}	0.26^{b}	0.32^{b}	0.35^{c}	$0.11^{a,b}$	$0.10^{a,b}$	$0.07^{a,b}$	0.09^{a}	0.21^{b}	0.36^{c}	0.43^{c}	0.37^{c}	0.28^{c}	0.24^{b}	0.20^{b}
SD	0.03	0.05	0.05	0.02	0.02	0.02	0.01	0.03	0.02	0.03	0.05	0.05	0.02	0.01	0.02	0.04	0.04	0.03	0.03	0.03	0.03	0.03
WaveOne																						
Mean	0.06^{a}	0.12^{b}	0.23^{c}	0.26^{c}	0.20^{b}	$0.13^{a,b}$	0.13^{a}	0.20^{b}	0.26^{b}	0.33^{b}	0.38^{c}	0.15^{b}	0.11^{b}	0.09^{b}	0.09^{a}	0.21^{b}	0.38^{c}	0.42^{c}	0.36^{c}	0.26^{c}	0.23^{b}	0.22^{b}
SD	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.01	0.02	0.02	0.03	0.03	0.04	0.05	0.03	0.03	0.03
P-value		*	***	***	***	**		***	***	***	***	*	**	*		***	***	***	***	***	***	***

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$(analysis of variance and post-hoc Tukey test)

Values with the same superscript letters were not statistically different at $P < 0.05$.

Inner side of a canal is defined as the concavity of the apical curvature

Table 2

Table 2: Canal width following preparation with the different instruments. Given are the means (mm) and standard deviations (SD) at the different measurement points.

		Prepared Canal Width (mm from the apex)										
		0	1	2	3	4	5	6	7	8	9	10
F360												
	Mean	0.29^{a}	0.33^{a}	0.39^{a}	0.40^{a}	0.45^{a}	0.50^{a}	0.53^{a}	0.56^{a}	0.60^{a}	0.64^{a}	0.69^{a}
	SD	0.06	0.02	0.03	0.03	0.02	0.04	0.03	0.02	0.02	0.02	0.02
OneShape												
	Mean	$0.34^{a,b}$	0.37^{b}	0.43^{b}	0.48^{b}	0.52^{b}	0.60^{b}	0.67^{b}	0.72^{b}	0.78^{b}	0.83^{b}	0.89^{b}
	SD	0.07	0.02	0.02	0.02	0.03	0.03	0.02	0.03	0.02	0.02	0.03
Reciproc												
	Mean	$0.33^{a,b}$	$0.39^{b,c}$	0.50^{c}	0.55^{c}	0.62^{c}	0.73^{c}	0.79^{c}	0.79^{c}	0.81^{c}	$0.85^{b,c}$	0.91^{b}
	SD	0.07	0.05	0.05	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.03
WaveOne												
	Mean	0.38^{b}	0.41^{c}	0.50^{c}	0.55^{c}	0.62^{c}	0.73^{c}	0.80^{c}	0.80^{c}	$0.79^{b,c}$	0.86^{c}	0.96^{c}
	SD	0.02	0.02	0.02	0.02	0.03	0.04	0.04	0.04	0.03	0.03	0.02
P-value		**	***	***	***	***	***	***	***	***	***	***

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$(analysis of variance and post-hoc Tukey test)

Values with the same superscript letters were not statistically different at $P < 0.05$

Table 3

Table 3: Incidence of aberrations

	F360	OneShape	Reciproc	WaveOne
Ledge	0	1	0	0
Danger Zone	0	0	2	2
Narrowing	0	0	1	1
Zip and Elbow	0	1	0	0

Chi-square test, no significant difference (*P* > 0.05).

Table 4

Table 4: Mean preparation time (s) and SD with different instruments

	Mean	SD
F360	72.7[a]	7.4
OneShape	58.4[b]	12.5
Reciproc	64.2[b]	5.2
WaveOne	72.4[a]	6.3

Values with the same superscript letters were not statistically different at $P < 0.05$

Highlights:

- We evaluated shaping ability of four single-file systems in simulated S-shaped canals

- Files that are less tapered seem to be more favourable

- OneShape and Reciproc showed to be faster than WaveOne and F360

- WaveOne and Reciproc should be used with care in canals with severe curvature