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ORIGINAL ARTICLE

Shaping Ability of Different Rotary and Reciprocating File Systems in Simulated S-Shaped Root Canals

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ABSTRACT

Objective: This study aimed to examine the shaping ability of six rotary and reciprocating file systems, as well as hybrid techniques in simulated S-shaped root canals.

Methods: A hundred and twenty S-shaped radiopaque thermosetting epoxy resin blocks were grouped according to the system used for biomechanical preparation. Six groups of 15 canals each were prepared using TruNatomy, Procodile, VDW Rotate, Hyflex CM, OneCurve, and WaveOne Gold, respectively. Two additional hybrid (Procodile/Hyflex CM and Procodile/TruNatomy) groups (n=15 each) were added after evaluating the results of individual systems. All canals were enlarged to 0.25 mm apically. Canal transportation, centering ability, diameter increase, and iatrogenic errors were assessed by superimposed pre-operative and post-operative images. AutoCAD was used for data analysis. All groups were statistically compared with analysis of variance and Tukey honest significant difference test ($p<0.05$).

Results: Hyflex CM resulted in the most conservative diameter increase in all thirds (coronal, middle, and apical; $p<0.001$). Procodile showed the best ($p<0.001$) centering ability in the coronal and middle thirds, while TruNatomy resulted in the least canal transportation and most centering preparation in the apical third ($p<0.001$). Hybridisation of Procodile and Hyflex CM produced the least canal transportation and best centering ability in the middle third ($p<0.001$). No instrument breakage occurred, and no ledge, elbow, or apical zip formation was observed during canal preparation.

Conclusion: Hybridisation of Procodile and Hyflex CM showed remarkable results in preserving the canal diameter in all thirds and resulted in the least canal transportation and best centering ability in the middle third of the canal. However, when treatment cost and duration limit the clinical applicability of the hybrid technique, clinicians can use a single file system (Hyflex CM or TruNatomy) since it shows satisfactory results in all parameters when compared with a hybrid system.

Keywords: Hybrid technique, rotary files, S-shaped canal, shaping ability

HIGHLIGHTS

- This study aims to help clinicians select the most suitable NiTi rotary system for treating S-shaped root canals in their specific context and setting.
- Using Procodile/Hyflex CM as a hybrid system showed a clear advantage over other rotary systems and could improve the quality of mechanical preparation and avoid aberrations in S-shaped root canals.
- Clinicians can still use a single file system (Hyflex CM or TruNatomy) since it shows satisfactory results in all parameters compared to a hybrid system.
- No iatrogenic errors (ledge, apical zip, elbow, or broken instrument) were observed during root canal preparation in all rotary systems used in this study.

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INTRODUCTION

Successful root canal treatment depends on the establishment of an accurate diagnosis and a detailed treatment plan. Having adequate and meticulous knowledge of root canal anatomy and morphology is essential for performing correct and sufficient biomechanical preparation (1). Biomechanical preparation aims to eliminate bacteria and debris from the root canal system while considering the canal's original shape and morphology (1). This objective is best achieved by avoiding the production of canal aberrations including transportation, zip, ledge, elbow, and canal straightening and over-instrumentation of the root canal (2).

S-shaped or double curve canals, also known as bayonet-shaped root canals (3), are found in 30–40% of clinical cases and are commonly present in the mesial root of mandibular molars and in the distobuccal canals of maxillary molars (4). Owing to their complexity and vast morphological variability, S-shaped canals are very difficult to appropriately shape without the iatrogenic production of previously mentioned aberrations (5).

Unlike stainless steel instruments, canal preparation using rotary nickel-titanium (NiTi) instruments leads to faster and more predictable preparation. NiTi instruments can preserve the original shape of the canal and minimize procedural errors such as ledges, zip, or perforations, especially in complex canal morphologies. Despite these advantages, unexpected fractures of NiTi instruments are possible, especially in narrow or highly curved canals (6).

The recently developed NiTi files are identified by distinctive design characteristics in terms of taper, cross-section, and number and angle of flutes. These instruments are believed to reduce the occurrence of canal aberrations and fractures as well as the number of procedural steps (7, 8).

Owing to the vast diversity of cases, anatomies, and canal characteristics, there is no "one ideal" rotary NiTi system for the entire root canal treatment. Moreover, NiTi systems have diverse properties that can be used in a "hybrid" concept (9). The principle of the hybrid technique is to combine individual files of different systems to achieve an optimal biomechanical cleaning and shaping result while creating the least number of aberrations. Hybrid technology incorporates the best elements of various file systems for efficient and predictable results. When instrumenting using a hybrid method, the biomechanical preparation should be performed using the crown-down technique, which involves establishing a glide path, shaping the body of the canal until the middle of the first curvature, and then preparing the root canal in the apical third (9).

This study aimed to (a) determine the best shaping protocol of different NiTi rotary and reciprocating systems in simulated S-shaped canals, (b) measure and compare a variety of parameters and iatrogenic aberrations (diameter increase, canal transportation, and centric ability), and (c) analyse the results of individual file systems to construct and design a hybridized system.

The null hypothesis tested in this study is that there are no significant differences in diameter increase, canal transportation, and centric ability among the different file systems that were used.

MATERIALS AND METHODS

Simulated Canals

One-hundred-twenty simulated S-shaped resin blocks with 2% taper, apical diameter of 0.15 mm, and 16 mm working length were used (Endo Training Block-S, Dentsply Sirona, Switzerland). The angle of coronal curvature of the simulated canal was 30 degrees with a 5 mm radius, whereas the apical curvature angle was 20 degrees with a 4.5 mm radius (Fig. 1). The patency of all resin blocks was checked using k-file size 10 to eliminate any blockage with a manufacturing defect. The resin blocks were randomly divided into the following six groups (n=15) based on the individual NiTi systems used for their biomechanical preparation: Group 1, TruNatomy (Dentsply, Switzerland); Group 2, Procodile (Komet, Germany); Group 3, VDW Rotate (VDW, Germany); Group 4, Hyflex CM (Coltene, Switzerland); Group 5, OneCurve (Micro-Mega, Germany); and Group 6, WaveOne Gold (Dentsply, Switzerland). According to the results of the individual systems, two additional groups were constructed (n=15); the first group (Group 7, Procodile/TruNatomy) combined the use of Procodile and TruNatomy systems, while the second group (Group 8, Procodile/Hyflex CM) combined the use of Procodile and Hyflex CM systems.

Instrumentation of the Simulated Canals

A resin block holder was used to secure all resin blocks in a fixed position to maximize standardization and minimize both operational and procedural errors. The entire experiment was conducted under a microscope at a magnification of 10X (Extaro 300, Zeiss, Germany). A stainless steel K-file size 10 was used in pecking motion twice or thrice to assure a patent canal and facilitate irrigation to the apical region. An ethylenediaminetetraacetic acid (EDTA) 17% (Glyde, Dentsply) was used as a lubricant during instrumentation. Copious irrigation using normal saline (10 mL) was used at 37°C after every file using a side-vented irrigation needle (TruNatomy irrigation needle, Dentsply). All preparations were performed by a single operator, and one rotary file was used for every three resin blocks. All groups' files were used as per the manufacturer's instructions using X-smart Plus Motor (Dentsply Sirona, Switzerland).

The list below describes the steps undertaken for instrumentation in each group.

Group 1: The initial glide path was achieved to the full working length of 16 mm using a size 10 K-file. The TruNatomy Glider (17/02) and TruNatomy orifice modifier were used up to the coronal third of the canal. The glider was introduced again to the full working length followed by the Small (20/04) and Prime (26/04) files in that order. All files were used in a programmed continuous motion with a torque of 1.5 Ncm and speed of 500 RPM using 2–3 mm amplitudes, with two pecking motions in and out of the canal. The flutes of the files were cleaned after every two pecks.

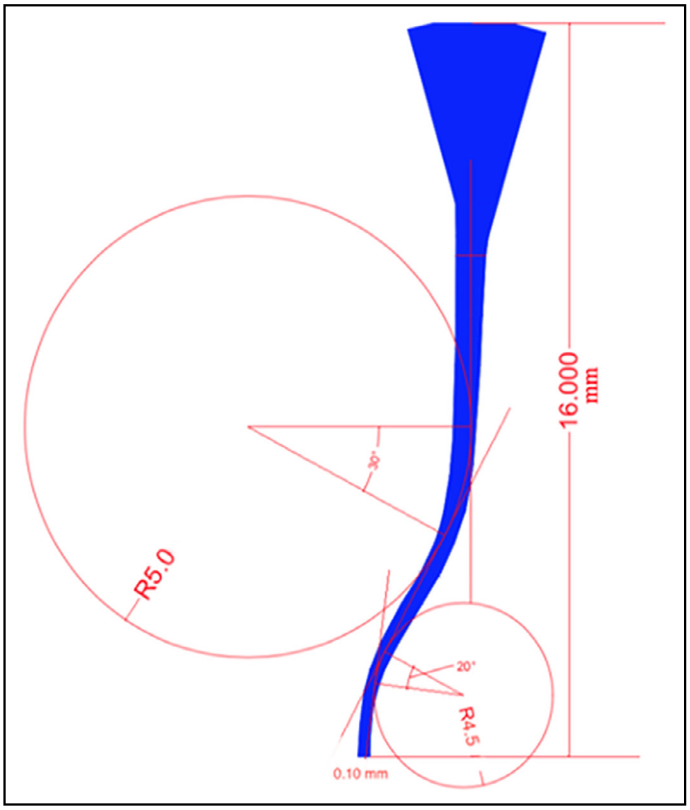

Figure 1. Dimensions of a simulated S-shaped canal

Group 2: A manual glide-path to the working length of 16 mm was achieved by a size 10 and 15 K-file since no rotary glide path file was available in this system. The size 20/06 Procodile file was used first followed by the size 25/06 Procodile file; both files were utilized according to the manufacturer's instructions in a reciprocating programmed motion. The pecking motion (amplitude less than 3 mm, two pecks) was used until the full working length. The flutes of the instruments were cleaned after every two pecks.

Group 3: The initial glide path was achieved to the full working length of 16 mm using a size 10 K-file. The VDW Rotate glide path file (15/04) was used at torque of 1.3 Ncm and advanced to two-thirds of the canal in gentle amplitudes. Subsequently, size 20/05 files with a torque of 2.1 Ncm followed by size 25/04 files at a torque of 2.3 Ncm were used with two in-and-out pecks to the full working length. All files were used in a programmed continuous motion with a speed of 300 RPM.

Group 4: The initial glide path was achieved to the full working length of 16 mm using a size 10 K-file. The Hyflex CM was used in two gentle in-and-out pecks with a rotational speed of 500 RPM and with continuous motion; the torque was 2.5 Ncm. Files were operated in the following sequence: (a) A size 25/08 file was used up to two-thirds of the working length to prepare the coronal third, (b) a size 15/04 file was inserted till the full working length to achieve the glide path, and (c) size 20/04 and 25/04 files prepared the entire canal.

Group 5: The initial glide path was achieved to the full working length of 16 mm using a size 10 K-file. A glide path was achieved with the One G (14/03) file. Thereafter, the OneCurve file (25/06) was used in a programmed continuous motion with 2.5 Ncm and 300 RPM. The pecking motion was performed (amplitude less than 3 mm, two pecks) following the manufacturer's instructions up to the full working length. The flutes of the instruments were cleaned after every two pecks.

Group 6: The initial glide path was achieved using K-file size 10 to the full length. The WaveOne Gold Glider file was passively inserted to the full working length with gentle inward pressure and then used in two pecking motions. Thereafter, the WaveOne Gold Small file (20/07) and followed by the WaveOne Gold Primary file (25/07) were utilized up to the full length. All files were operated in a programmed reciprocating motion, i.e., in a pecking motion (amplitude less than 3 mm, two pecks). The flutes of the instrument were cleaned after every two pecks.

Group 7: The initial glide path was achieved using K-file size 10 to the full length. After patency check, a glide path using K-file size 15 was negotiated to two thirds of the canals (12 mm). The size 20/06 Procodile file was used, followed by the size 25/06 Procodile file, for up to 12 mm of the canal and in a programmed reciprocating motion. Thereafter, TruNatomy Glider was introduced to the full working length followed by the Small (20/04) and Prime (25/04) files in that order. The TruNatomy files were used in a programmed continuous motion (torque=1.5 Ncm, speed=500 RPM; two pecks). The amplitude of the pecking motion for both file systems was less than 3 mm.

Group 8: The patency of the canal was checked using K-file size 10. A manual glide path up to two-thirds of the canal (12 mm) was achieved using a size 15 K-file. The 20/06 Procodile file was used, followed by the 25/06 Procodile file, up to 12 mm of the root canal and in a programmed reciprocating motion generated by the X-Smart motor.

Thereafter, size 15/04, 20/04, and 25/04 Hyflex files were used in this sequence up to the full working length. The instruments were used in two gentle in-and-out motions with a programmed continuous motion with a rotational speed of 500 RPM; the torque was altered to 2.5 Ncm.

The procedures/techniques utilised for all groups tested in this study have been summarised in a flowchart as shown in Figure 2. The flowchart provides a comprehensive overview of the various steps followed during this study.

Image Analysis and Assessment of Canal Preparation

All canals were filled with blue ink to obtain a pre-operative image. The canals were photographed using a microscope (Extaro 300, Zeiss, Germany) with 10X magnification and a fixed reproducible position with constant settings. The canals were rinsed with saline before and after instrumentation, and later filled with red ink and photographed once again under similar conditions.

The pre and post-instrumentation images were superimposed using AutoCAD (Autodesk, 2018). The amount of removed resin after instrumentation was measured with AutoCAD at 11 measuring points and in a perpendicular manner to the surface of the canal. The measurement points were arranged in

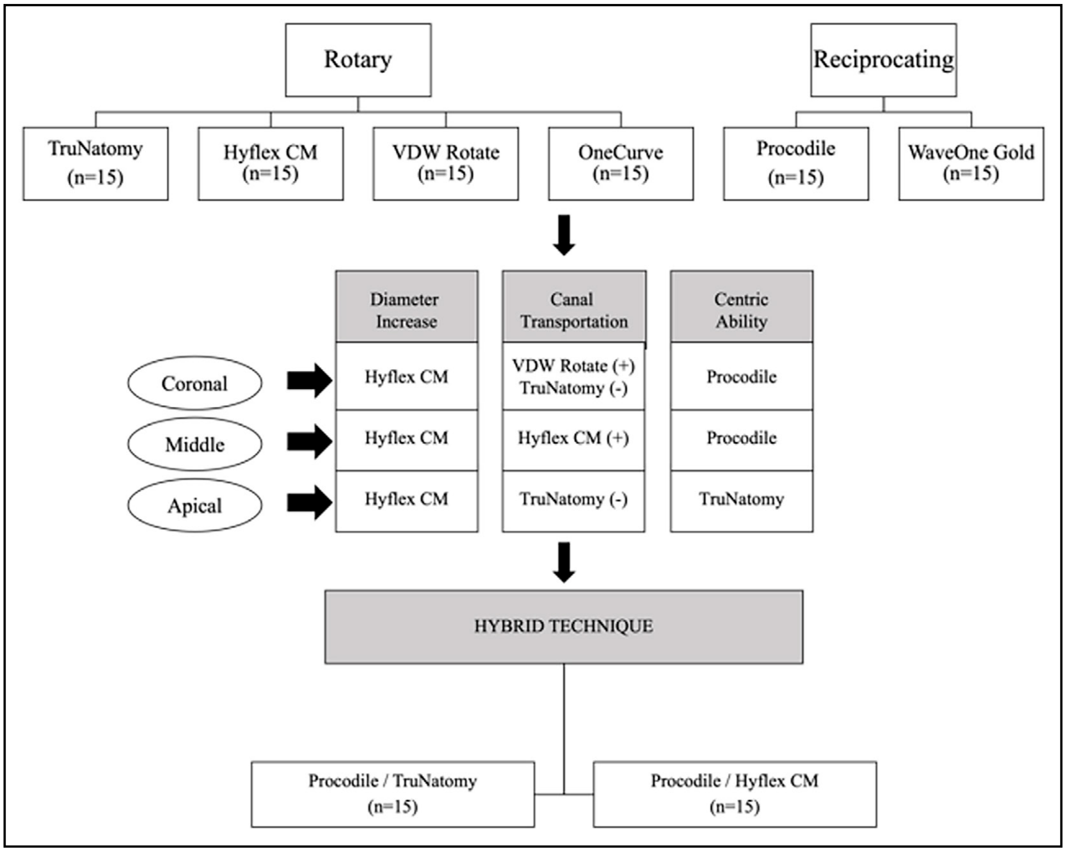

Figure 2. Flowchart which summarises all procedures/techniques used in this study, providing a comprehensive overview across all groups

1-mm increments; 0 to 3 represented the apical curve, 3 to 7 the middle curve, and points 7 to 11 the coronal part of the canal (Fig. 3). A blinded examiner to all experimental groups assessed the diameter increase, canal transportation and centric ratio before and after instrumentation.

The parameters at 11 levels from the apex at 1-mm intervals were calculated using the following formulas:

Diameter increase = (X2–X1) + (Y2–Y1)

Canal transportation = (X2–X1) – (Y2–Y1)

Centring ratio = (X2–X1) / (Y2–Y1) if (Y2–Y1) > (X2–X1)

or Centring ratio = (Y2–Y1) / (X2–X1) if (X2–X1) > (Y2–Y1)

Transportation of the inner wall of the canal curvature was indicated by a positive number, while a negative number was given when transportation was toward the outer wall.

The closer the centring ratio was to 1, the better the ability of the instrument to remain centered. Any additional iatrogenic errors, such as ledge, apical zip, or elbow formation; canal straightening; and instrument breakage were subjected to standard scoring if observed.

Statistical Analysis

The raw data collected from AutoCAD was entered and analysed using the Statistical Package for the Social Sciences Statistics Desktop version 26.0 (IBM Corp., Chicago, USA). Collected data were organized and tabulated as descriptive results and included the mean (mm) and standard deviations for each file and the combined values for each parameter (diameter increase, canal transportation, and centric ability) in all thirds of each group. After that, the assumption of normality was confirmed to check the validity of the parametric test using the Shapiro–Wilk test with an p-value set at <0.05.

Furthermore, one-way ANOVA was used to determine the level of difference between the groups with the dependent variables, while *post-hoc* comparison tests (LSD) were used to determine the significant difference of the various rotary file systems between every two groups. Statistical significance was set at 0.05 (p=0.05) with 95% confidence.

RESULTS

Individual Systems

The results showed no formation of ledge, apical zip, or elbow and no instrument breakage; therefore, all cases (100%) were assigned a standard score of zero for these errors.

Diameter increase

The results in the coronal (7–11), middle (3–7), apical (0–3) thirds showed the least diameter increase when the Hyflex CM file system was used. The increase in diameter significantly differed between the groups in all thirds (p<0.001) (Table 1).

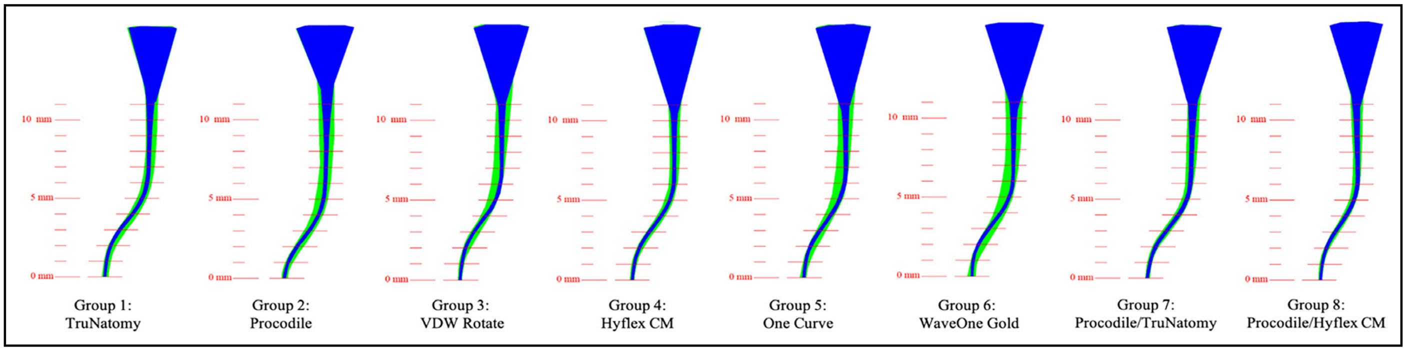

Figure 3. Superimposed pre-instrumentation and post-instrumentation images prepared using AutoCAD

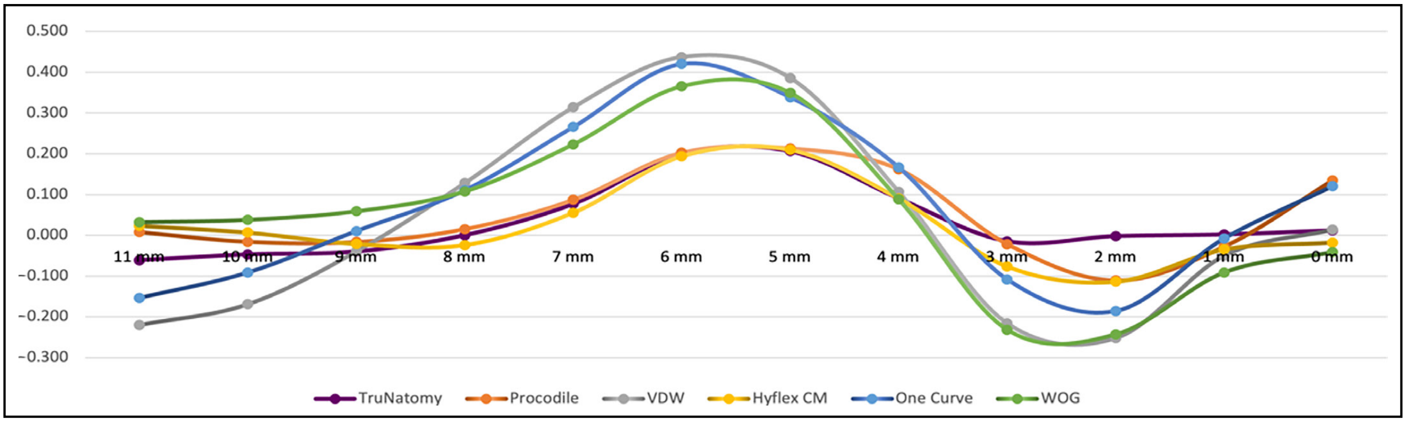

Figure 4. Canal transportation within each mm of S-shaped canals caused by different rotary systems

WOG: WaveOne Gold

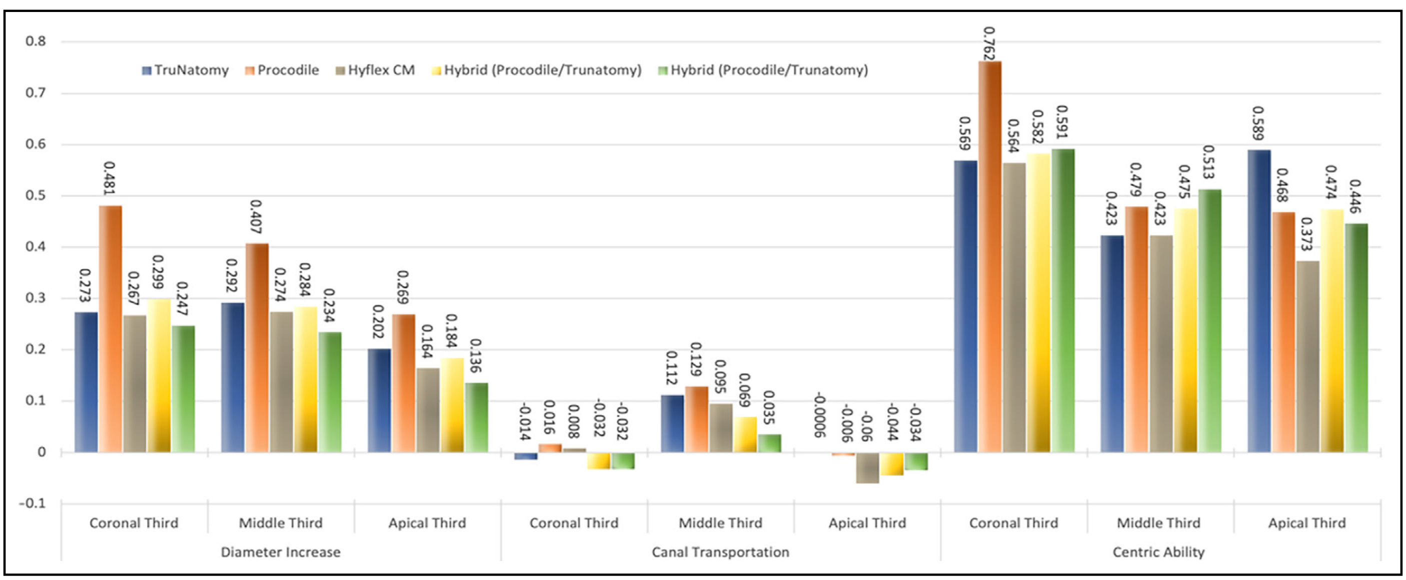

Figure 5. Overall differences in parameters of biomechanical root canal preparation by individual and hybrid rotary systems

Canal transportation

In the coronal third, the VDW file system revealed the least positive canal transportation whereas the TruNatomy system showed the least negative transportation. In the middle third, the Hyflex CM system showed the least positive transportation, whereas in the apical third, TruNatomy presented the least negative transportation. There was a significant difference between the groups in all three-thirds of the root canal: coronal ($p<0.006$), middle ($p<0.001$) and apical ($p<0.001$). The means and standard deviations for apical transportation and the p-values for statistical differences between the groups are shown in (Fig. 4).

Centric ability

The Procodile system showed the most centric ability in the coronal and middle thirds, while the TruNatomy system showed the best centric ability in the apical third. There was a significant difference between the groups in all thirds ($p<0.001$) (Table 2).

TABLE 1. Diameter change within each third of S-shaped canals using different rotary systems

Levels		Diameter increase (Mean±SD)												p	
		TruNatomy		Procodile		VDW		Hyflex CM		OneCurve		WaveOne Gold			
Coronal third (7–11 mm)	11 mm	0.15±0.07	0.27±0.03[A]	0.40±0.13	0.48±0.05[B]	0.39±0.12	0.47±0.04[B]	0.12±0.09	**0.27±0.02[A]**	0.30±0.07	0.46±0.02[B]	0.36±0.99	0.53±0.03[C]	0.00	<0.001
	10 mm	0.28±0.03		0.47±0.05		0.50±0.05		0.31±0.05		0.50±0.03		0.54±0.04		0.00	
	9 mm	0.31±0.03		0.52±0.05		0.50±0.03		0.30±0.02		0.50±0.03		0.57±0.03		0.00	
	8 mm	0.32±0.03		0.52±0.05		0.49±0.03		0.30±0.03		0.51±0.02		0.58±0.04		0.00	
Middle Third (3–7 mm)	7 mm	0.32±0.04	0.29±0.02[A]	0.49±0.06	0.41±0.06[B]	0.47±0.03	0.41±0.02B[C]	0.31±0.02	**0.27±0.01[A]**	0.51±0.02	0.44±0.04[C]	0.57±0.03	0.47±0.04[D]	0.00	0.000
	6 mm	0.32±0.04		0.46±0.06		0.50±0.06		0.32±0.03		0.51±0.04		0.52±0.04		0.00	
	5 mm	0.30±0.03		0.42±0.07		0.44±0.04		0.29±0.03		0.47±0.13		0.49±0.04		0.00	
	4 mm	0.28±0.03		0.36±0.07		0.32±0.03		0.24±0.02		0.36±0.03		0.39±0.05		0.00	
Apical Third (0–3 mm)	3 mm	0.26±0.03	0.20±0.02[A]	0.31±0.05	0.27±0.05[B]	0.34±0.04	0.26±0.05[B]	0.22±0.03	**0.16±0.02[C]**	0.33±0.02	0.27±0.01[B]	0.37±0.05	0.28±0.05[B]	0.00	0.000
	2 mm	0.21±0.04		0.29±0.05		0.36±0.10		0.20±0.05		0.33±0.05		0.34±0.08		0.0_0	
	1 mm	0.17±0.03		0.23±0.04		0.19±0.04		0.12±0.03		0.22±0.02		0.22±0.04		0.00	
	0 mm	0.17±0.03		0.25±0.06		0.15±0.05		0.12±0.05		0.20±0.04		0.21±0.05		0.00	

A, B, and C indicate a significant difference between the groups in multiple comparison test (*Tukey's* HSD for different types of rotary systems, p<0.05). SD: Standard deviation

Hybrid Systems

The Procodile/Hyflex CM hybrid system in Group 8 presented the least diameter increase in the coronal, middle, and apical thirds. There was a significant difference between the two hybrid groups in the coronal third (p<0.003) and (p<0.001) in the middle and apical thirds. Of note, the Procodile/Hyflex CM hybrid system resulted in the least positive transportation in the middle third but a negative transportation in the apical third. There was no significant difference between the groups in the coronal (p<0.97) and apical thirds (p<0.57). Although the Procodile/Hyflex CM hybrid system showed the best centric ability in both the coronal and middle thirds, the Procodile/TruNatomy hybrid system had better results in the apical third. There was no significant difference between the groups in all thirds (Table 3, Fig. 5).

DISCUSSION

Methodological Considerations

This study was carried out on simulated S-shaped canals in radiopaque thermosetting epoxy resin blocks as it is almost unfeasible to collect standardised human teeth with S-shaped canals that have indistinguishable parameters regarding canal diameter, length, degree and radius of both curvatures (10). Although resin blocks have a different microhardness than dentine and are subject to changes in resin consistency because of heat generated during instrumentation, they are still the standardised alternative to natural teeth (11–13).

AutoCAD was used in this study because, unlike Adobe Photoshop, AutoCaD can accurately scale the resin block images to the actual canal dimensions (16 mm). Another advantage of AutoCAD is that it can be utilized to superimpose pre-operative and post-operative images to provide two-dimensional quantitative measurements in an inexpensive and reproducible manner (14).

All mechanical preparations performed in this study were terminated using files of 25 ISO tip size. This was done in accordance with the manu-

TABLE 2. Centric ability of different rotary systems in S-shaped canals

Levels		Centric Ability (Mean±SD)												p	
		TruNatomy		Procodile		VDW		Hyflex CM		OneCurve		WaveOne Gold			
Coronal third (7–11 mm)	11 mm	0.38±0.30	0.57±0.12^{A}	0.66±0.22	**0.76±0.08^{B}**	0.27±0.20	0.47±0.08^{C}	0.37±0.25	0.56±0.14^{A}	0.31±0.28	0.55±0.11^{AC}	0.54±0.22	0.66±0.14^{D}	0.00	0.000
	10 mm	0.59±0.24		0.78±0.13		0.52±0.25		0.58±0.23		0.71±0.25		0.79±0.17		0.00	
	9 mm	0.68±0.22		0.83±0.11		0.77±0.19		0.62±0.20		0.80±0.20		0.79±0.18		0.02	
	8 mm	0.67±0.19		0.84±0.14		0.60±0.17		0.65±0.18		0.59±0.16		0.70±0.20		0.00	
Middle third (3–7 mm)	7 mm	0.52±0.27	0.42±0.15^{AC}	0.70±0.18	**0.48±0.12^{A}**	0.20±0.11	0.23±0.06^{B}	0.62±0.26	0.43±0.20^{AC}	0.34±0.21	0.30±0.09^{BC}	0.46±0.19	0.35±0.11^{C}	0.00	0.000
	6 mm	0.22±0.23		0.42±0.21		0.06±0.05		0.30±0.29		0.10±0.07		0.19±0.14		0.00	
	5 mm	0.20±0.21		0.22±0.14		0.07±0.07		0.20±0.23		0.14±0.21		0.18±0.10		0.21	
	4 mm	0.47±0.23		0.41±0.23		0.53±0.27		0.52±0.26		0.40±0.23		0.65±0.20		0.05	
Apical third (0–3 mm)	3 mm	0.71±0.18	**0.59±0.10^{A}**	0.66±0.23	0.47±0.13^{B}	0.28±0.26	0.32±0.16^{C}	0.50±0.25	0.38±0.17^{BC}	0.50±0.25	0.37±0.11^{C}	0.25±0.21	0.28±0.15^{C}	0.00	0.000
	2 mm	0.55±0.26		0.48±0.26		0.21±0.16		0.32±0.24		0.27±0.16		0.18±0.24		0.00	
	1 mm	0.49±0.19		0.47±0.24		0.46±0.33		0.34±0.30		0.46±0.28		0.31±0.20		0.30	
	0 mm	0.61±0.23		0.27±0.27		0.32±0.31		0.34±0.33		0.23±0.20		0.38±0.30		0.01	

A, B and C indicate a significant difference between the groups in multiple comparison test (*Tukey's* HSD for different types of rotary systems, $p<0.05$)

facturer's instructions because this tip size has been selected for complex canal morphologies. Although an increase in tip size could theoretically result in enhanced cleaning and better accessibility for the irrigation material, it will also maximize the risk of canal transportation because of the decrease in the file's flexibility (15). Files with taper more than 0.04 are not recommended for apical enlargement in double curved canals. Thus, it is preferable to use a NiTi instrument with less taper and more flexibility (6). A variety of recent and common rotary systems with files of different tapers were used in this study to look over and compare their shaping abilities. Canal straightening was observed in WOG and One Curve because the taper of the files was 0.07 and 0.06, respectively. Procodile showed better results in comparison to other larger tapered files like One Curve and WOG due to its unique double S-cross section and variable tapered core with a constant tapered cutting edge. VDW rotate has an off-centric motion, consequently, it didn't respect canal anatomy and produced more resistance and debris than other file systems. As a result, the canals treated with this system showed a straightening of canal curvatures and an increase in the canal's diameter (16).

Comparing Parameters of Biomechanical Canal Preparation

Diameter increase

Dentine removal must be limited by dentists in the coronal third as this is critical to maintaining the strength of the final restorative coverage in an endodontically treated tooth (17). There have been a lot of studies done on Hyflex CM and according to literature (18, 19), Hyflex CM is more resistant to cyclic activity than other NiTi rotary instruments in simple, single canals and in canals with double curvatures (18). This provides superior preservation of the initial canal morphology and improves the efficiency of the files in endodontic preparation. According to Razcha et al. (20), the use of Hyflex CM results in minimal canal transportation and a centred preparation.

TABLE 3. Canal aberrations formed in S-shaped canals using two hybrid rotary systems

Levels		Diameter increase (Mean±SD)				p		Canal transportation (Mean±SD)				p		Centric ability (Mean±SD)				p	
		(Procodile/ Trunatomy)		(Procodile/ Hyflex)				(Procodile/ Trunatomy)		(Procodile/ Hyflex)				(Procodile/ Trunatomy)		(Procodile/ Hyflex)			
Coronal third (7–11 mm)	11 mm	0.15±0.10	0.30±0.05	0.14±0.09	**0.25±0.04**	0.74	0.00	−0.09±0.08	**−0.03±0.04**	−0.05±0.093	−0.03±0.05	0.19	0.97	0.27±0.18	0.58±0.11	0.42±0.24	**0.59±0.14**	0.08	0.857
	10 mm	0.31±0.05		0.26±0.05		0.01		−0.11±0.06		−0.07±0.077		0.12		0.50±0.22		0.55±0.27		0.55	
	9 mm	0.35±0.05		0.29±0.03		0.00		−0.06±0.05		−0.06±0.060		0.92		0.71±0.21		0.62±0.22		0.24	
	8 mm	0.36±0.05		0.29±0.03		0.00		0.01±0.08		−0.02±0.066		0.15		0.83±0.13		0.72±0.23		0.11	
Middle third (3–7 mm)	7 mm	0.33±0.04	0.28±0.03	0.27±0.02	**0.23±0.02**	0.00	0.00	0.09±0.06	0.07±0.05	0.04±0.073	**0.04±0.05**	0.04	0.05	0.60±0.20	0.48±0.07	0.65±0.23	**0.51±0.12**	0.55	0.296
	6 mm	0.30±0.05		0.24±0.03		0.00		0.19±0.07		0.11±0.056		0.00		0.24±0.13		0.40±0.24		0.04	
	5 mm	0.28±0.04		0.24±0.02		0.00		0.14±0.05		0.10±0.048		0.03		0.34±0.17		0.42±0.22		0.23	
	4 mm	0.26±0.04		0.22±0.02		0.00		0.02±0.06		0.00±0.05		0.46		0.72±0.22		0.68±0.20		0.64	
Apical third (0–3 mm)	3 mm	0.25±0.04	0.18±0.04	0.20±0.02	**0.14±0.02**	0.00	0.00	−0.10±0.07	−0.04±0.05	−0.08±0.07	**−0.03±0.03**	0.61	0.57	0.48±0.26	**0.47±0.14**	0.41±0.27	0.45±0.16	0.52	0.613
	2 mm	0.20±0.05		0.15±0.03		0.01		−0.08±0.08		−0.07±0.05		0.65		0.45±0.30		0.41±0.23		0.68	
	1 mm	0.15±0.04		0.10±0.02		0.00		−0.01±0.06		0.00±0.04		0.42		0.53±0.21		0.58±0.25		0.56	
	0 mm	0.14±0.04		0.09±0.02		0.00		0.02±0.09		0.01±0.05		0.93		0.44±0.29		0.38±0.23		0.54	

In this study, Hyflex CM and TruNatomy files showed the least diameter increase in all thirds of the canal, this could be attributable to the controlled memory characteristic wherein the file can be pre-curved just like conventional stainless-steel files, this aids in conformance to the canal anatomy and preservation of the canal curvatures.

Hyflex CM NiTi files have a triangular cross section with three cutting edges in contrast to other files of taper 0.04 that have a square cross section with four blades and four flutes. Therefore, the triangular cross section of Hyflex CM NiTi files avoids engaging the canal walls with excessive resistance by straightening the spirals of the files (18, 21), and the small size of the metal core in the cross section minimises the amount of resin removed from the entire canal. Furthermore, the elongation of the pitch between the cutting flutes of the file under compression and tensile stresses contributes to the conservative cutting design of Hyflex CM, resulting in minimum enlargement of the canal from 0 to 11 mm (17).

The recently manufactured TruNatomy files are made from heat-treated NiTi alloys that are meant to increase fatigue resistance and flexibility of the files. The new instruments have a parallelogram cross-sectional design. A TruNatomy file can preserve structural dentine to help maintain the strength of the tooth; therefore, these files use 0.8 mm NiTi wires instead of 1.2 mm. The file's geometry allows a slim-flexible design and regressive taper root canal treatment in cases of curved canals (22). TruNatomy files remove as minimal dentine as is clinically needed to provide adequate irrigation to the canal. For the above reasons, there was no significant difference between Hyflex CM and TruNatomy regarding diameter increase, as both files produced conservative and less aggressive results.

The Hyflex CM system's shaping ability in S-shaped canals is well established and is proven to have outstanding results (18). However, the shaping ability of WaveOne Gold and One Curve in double curved canals is controversial (12, 23). Furthermore, VDW showed significant increase in the volume and area of the root canals which in agreement with this study (16).

Canal transportation

According to the American Association of Endodontics, transportation of the canal can be considered as the removal of dentine from the outer wall of the canal in the apical third (24). This can occur because of the affinity of the file to go back to its original shape during instrumentation of the canal, this results in canal aberrations, such as ledge and probable perforation, which are common complications of endodontic preparation and especially occur in multirooted teeth (20). Transportation can act as a harbour for microorganisms, residual dentine, and pulpal tissue. Another predisposing factor to canal transportation is an active file tip. New and improved instrumentation systems are being developed to minimise such complications (20). In this study, the TruNatomy system showed the least canal transportation towards the outer wall in the apical third which is in agreement with (Kim et al., (25)) who found that TruNatomy system preserved the original anatomy of the apical curvature when compared to ProTaper GOLD and WaveOne Gold. This could be because the semi-active tip reduces the risk of canal transportation and subsequent aberration apically to a greater extent than other file systems do (26). Interestingly, in the middle third critical area of the first curvature (3–7 mm), the hybrid technique combining Procodile/Hyflex CM systems revealed the best results because initiative flaring by Procodile resulted in less engagement of the successor file.

Centric ability

It is important to maintain the centric ability of rotary files to avoid canal zipping, ledging, or perforations (17). NiTi heat-treated wires are characterised by their special flexibility, aiding the file to pre-curve when adapting to the canal's anatomy, and thus making the file more centred. This effect could explain why the TruNatomy system showed the best results in the apical third.

Reciprocating systems are known to reduce canal transportation and improve centring ability in comparison to continuous rotary systems (19, 27, 28). However, a systematic review stated that both movements showed similar results regarding canal transportation and centring ability (29). Procodile (a reciprocating system) showed consistent results for centric ability in both coronal and middle thirds whereas other systems did not. This due to the double s-cross section design of the file and variably tapered core which will safely prepared curved canals without alterations to the canal anatomy (30). However, Procodile did not preserve the best centric ability in the apical third of the canal. This could be because the Procodile files has a large (0.06) taper that is not recommended in double curved canals apically (6, 31).

Hybrid technique

There are several possible combinations of systems that can be utilised when applying the hybrid technique. The most accepted and efficient combinations include coronal flaring succeeded by other sequences of apical preparations. It is crucial that the clinician is aware of the different possible canal morphologies before selecting the systems and file sequences to be used. The goal of hybridising NiTi rotary techniques is to enlarge the apical size using an efficient and effective clinical procedure. The trick is for the selected instruments of different file systems to be used in a sequence that promotes their individual advantages and avoids their limitations.

Most cases that require root canal therapy allow the clinician to prepare the canal using a variety of endodontic file systems. The clinician's strategy to clean and shape the canals depends on the canals' unique morphology, and thus can vary considerably. An example can be seen in the mesio-buccal roots of the maxillary molars that can exhibit considerable complexities; in such cases, rotary instrumentation or hybridisation of techniques allows for the preservation of the curvatures and permits optimal shaping and cleaning.

Hand instruments have also been used instead of ISO-normed files to ensure a smooth tapering of the canal apically and to minimise chances of ledge occurrence (32). However, this study did not include a control that consists of conventional stainless-steel K-files or NiTi hand instruments. The justification behind this decision lies in the fact that the superiority of NiTi instruments over K-files in maintaining the original canal anatomy is already well established (33). In addition, NiTi rotary files have gained more popularity over the years and are being used more often for canal instrumentation than conventional hand files are therefore, this study focused exclusively on the newer generations of endodontic file systems (34).

The hybrid technique (Procodile/Hyflex CM) showed remarkable results for diameter increase in all thirds of the S-shaped canal; this could be explained by the preliminary coronal enlargement that was facilitated by the higher tapered instrument (Procodile), which created a path for the less tapered file (Hyflex CM) to make more apical enlargement (35).

Based on the findings of this study, it can be concluded that there are significant variations in diameter increase, canal transportation, and centric ability among the different file systems tested.

Therefore, the null hypothesis tested in this study has been rejected.

Several limitations should be acknowledged in this study. The use of simulated resin canals, while useful, does raise concerns regarding their hardness, anatomical fidelity, and their divergence from the clinical reality of file handling. Additionally, it is important to note that image superimpositions employed here are two-dimensional, which can be susceptible to human errors. Future studies could benefit from employing micro-computed tomography, which can offer more accurate three-dimensional results, potentially enhancing the precision of our findings. These considerations pave the way for future research, allowing for a more comprehensive exploration of the topic and further refining our understanding of file performance that can be eventually conducted on randomised control trials, which would further substantiate our results.

CONCLUSION

Hybridisation of Procodile and Hyflex CM showed remarkable results in preserving the canal diameter in all thirds and resulted in the least canal transportation and best centering ability in the middle third of the canal. However, when treatment cost and duration limit the clinical applicability of the hybrid technique, clinicians can use a single file system (Hyflex CM or TruNatomy) since it shows satisfactory results in all parameters when compared with a hybrid system.

Disclosures

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