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Original Article

Shaping ability of ProTaper Gold and WaveOne Gold nickel-titanium rotary instruments in simulated S-shaped root canals

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Abstract *Background/purpose:* Gold metal technology improves flexibility and the resistance to cyclic fatigue of the endodontic mechanical files. This study compared the performance of ProTaper Gold (PTG) multiple file system and WaveOne Gold (WOG) single file system in simulated S-shaped root canals, which represents one of the most challenging root canal morphology.
Materials and methods: Forty S-shaped canals (n = 20 canals/per group) in resin blocks were instrumented to an apical size of 0.25 mm using PTG and WOG Primary, respectively. The total amount of resin removal, canal transportation, centering ratio, and the degree of canal straightening were measured in Photoshop CS6 software. Statistical analysis was performed by using Mann—Whitney U-test (α = .05).
Results: None of the files fractured during the instrumentation. The WOG group removed significantly less amount of resin at 0, 3, 6, 7 and 9 mm from the apex ($P < .05$). The WOG group remained more centered in canals at 0 mm from the apex ($P < .05$). The PTG group showed a better centering ability and less canal transportation at 4, 5 and 6 mm from the apex ($P < .05$). In the coronal curvature portion, the use of WOG Primary significantly decreased curvature angle and increased radius compared with PTG instruments ($P < .05$). There was no significant difference between the two groups in terms of the apical curvature angle and radius change ($P > .05$).

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Conclusion: The WOG Primary file has a less aggressive dentin cutting and more centered apical preparation. The PTG system is more advantageous in shaping the coronal curvature of S-shaped canal.

Introduction

In the past decades, several proprietary processing procedures for NiTi alloy were developed to improve the mechanical properties of NiTi endodontic instruments, including thermal, mechanical, electropolishing, and electric discharge machining.[1] Gold heat-treated instruments, possessing a distinctive gold color, were introduced by Dentsply Tulsa Dental (Tulsa, OK, USA) in 2012. The instruments were repeatedly heat-treated and then slowly cooled after they have been manufactured, which resulted in a special surface color corresponding to the thickness of the layer of titanium oxide. The manufacturer claims that the new heat treatment increases the flexibility of the files. There are now two Gold heat-treated NiTi shaping systems available, WaveOne Gold and ProTaper Gold (both manufactured by Dentsply Maillefer, Ballaigues, Switzerland), with different geometry design and movement kinematics.

WaveOne Gold (WOG) is a single-file and single-use technique used in reciprocating motion, which is developed from M-wire WaveOne instrument (Dentsply Maillefer).[2] Four WaveOne Gold files are available, termed Small (tip size/taper:#20/0.07), Primary (tip size/taper: #25/0.07), Medium (tip size/taper: #35/0.06), and Large (tip size/taper: #45/0.05). Each file has an alternating offset parallelogram-shaped cross-section and a semi-active guiding tip. Another unique design feature is that each file has a fixed taper from D1-D3, yet a progressively decreasing percentage tapered design from D4-D16, which serves to preserve dentin.[2] Differently, ProTaper Gold (PTG) is a multi-file system and comprised of 3 shaping files (SX, S1, and S2) and 5 finishing files (F1-5) used in continuous motions. PTG has the exact geometries as ProTaper Universal (PTU; Dentsply Maillefer), like multiple changing tapers over each file's cutting blades, convex triangular cross section and modified guiding tip, etc.[3]

When compared with their respective predecessors, WaveOne and ProTaper Universal, both of the Gold-wire files exhibited higher cyclic fatigue and torsional resistance.[4,5] However, regarding the root canal transportation and centering ability, the use of WOG was not associated with an improved shaping ability when compared with WaveOne instrument in severely curved canals (angles of curvatures ranging between 25° and 35° and radii ranging between 3.1 and 8.5 mm) and in mandibular premolars.[6,7] Meanwhile, the results of the comparison of the shaping ability of PTG and PTU are quite different. In mesial root canals of mandibular first molars with curvature angles of 35°—70° and radii of 2—6 mm, root canal transportation and the centering ratio with the PTG were similar to those obtained with the PTU.[8] However, PTG was better than the PTU at maintaining the centralization of the shape in the cervical portion of straight mesial root canals of mandibular molars.[9]

The various NiTi file systems commercially available have different characteristics in terms of geometry design, the working motion (rotary or reciprocation) and specific alloy-all these conditions may affect file behavior. One frequently assessed parameter is cyclic fatigue resistance. Hyflex EDM files (CM-wire, Coltène/Whaledent, Altstätten, Switzerland) exhibited a significantly increased cyclic fatigue resistance compared with PTG and WOG.[1] The XP-endo Shaper (MaxWire, FKG Dentaire, La Chaux-de-Fond, Switzerland) instruments showed a significantly higher number of cycles to fracture than PTG.[10] Due to the heterogeneity of the methodology and characteristics of the tested instruments, the results on the comparison of Gold-wire instruments with Blue-wire, R-phase, M-wire or electropolished instruments are inconsistent.[11—13] Regarding the canal transportation, limited to the instruments studied in the literatures, the results of Blue-wire, R-phase, MaxWire and CM-wire instruments were better than or similar to that of WOG and PTG; while, WOG and PTG showed better or similar results when compared with M-wire and electropolished instruments.[14—17]

Previous studies also compared the performance of PTG and WOG and the results were inconsistent. PTG produced significantly more dentin removal and canal transportation than WOG in mandibular first molar teeth with root curvature ranging from 25° to 30°.[18] While, PTG produced the lowest canal transportation values in mandibular premolars.[7] In mesial root canals of mandibular first molars having moderate curvature (10°—20° curvature angle), both PTG and WOG transported toward the mesial wall at the apical third and no significant differences in apical transportation were found between the groups.[19] Another study was conducted in mesial root canals of mandibular first molars with a curvature radius greater than 4 mm and shorter than 8 mm.[17] In mesiodistal direction, both PTG and WOG transported toward the mesial wall without statistically significant differences. While in buccolingual direction, PTG had a greater transportation toward the buccal direction than WOG at 4 mm below furcation.[17]

Canals with double curvatures, also named as S-shaped canals, represent one of the most challenging canal configurations regarding preservation of the integrity of the root canal anatomy and maintenance of the location of the apical foramen. The frequencies of S-shaped canals are reported to be 30%—40% and 35%—59% in the distobuccal root of maxillary molars and in the mesial root of mandibular molars, respectively.[20] Therefore, it is demanded to utilize efficient instruments to treat this particular canal configuration. There is limited information regarding the outcome of shaping S-shaped root canals with Gold-wire Ni—Ti rotary instruments. Previous study showed that WOG removed a statistically significantly less amount of resin from all the simulated S-shaped canal regions when compared with Reciproc (VDW, Munich, Germany) and no canal aberrations were observed in WOG group.[21] The comparison of both WOG and PTG systems in a single study is rare, especially in S-shaped root canal. Al-Dhbaan and colleagues found that WOG produced relatively less canal aberrations in both L-and S-shaped root canals than PTG. PTG/S-shaped root canals were wider at the beginning of the first curve of the prepared canal.[22] Nonetheless, the performance of these Gold-wire instruments in S-shaped root canal deserves to be further investigated. The purpose of the present study is to compare the shaping ability of PTG and WOG in simulated root canals having S-shaped curves.

Materials and methods

Specimen grouping and preparation

Forty ISO #15, 0.02-tapered S-shaped endo training blocks (Dentsply Maillefer) were equally divided into two groups ($n = 20$) according to the rotary instruments: ProTaper Gold (PTG) group and WaveOne Gold (WOG) group. The canal curvature and the radius of curvature were measured as follows (Fig. 1).[20,23] A straight line a was drawn parallel to the long axis of the coronal straight portion of canal. The point where the canal deviated from this line to begin the coronal curvature was marked as point A. Point B was defined as the most apical extent of the coronal curve prior to the deviation away from the arc to begin the apical curve. The apical foramen was labeled as point C. The angle formed by the intersection of the line a and line AB was measured as

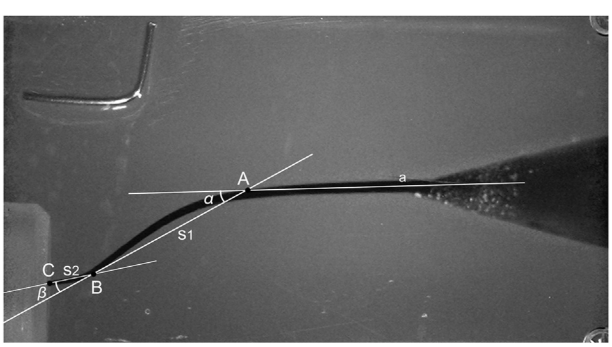

Figure 1 Techniques used for determining angle and radius of curvature. Line a represented the long axis of the coronal straight portion of canal. Point A: the beginning point of the coronal canal curvature, Point B: the ending point of the coronal canal curvature, Point C: the apical foramen, α: the angle of coronal curvature formed by the intersection of the line a and line AB, β: the angle of apical curvature formed by the intersection of the line AB and line BC, S1: length of the chord AB, S2: length of the chord BC.

the coronal canal curvature α. The angle of curvature formed by lines AB and line BC was measured as the apical curvature β. The length of the chord AB and the chord BC was measured as S1 and S2, respectively. Then, the coronal radius (r_c) and the apical radius (r_a) were calculated according to the following formula: $r_c = S1/2\sin\alpha$, $r_a = S2/2\sin\beta$, respectively. Therefore, each simulated canal had an initial 30°coronal curvature (5 mm radius), 20°apical curvature (3.5 mm radius), and a 16 mm canal length.

After the canal patency was confirmed using an ISO standard size #10 K-file (Dentsply Maillefer), black ink was injected into the canal with the 1 ml syringe. Perpendicular to the objective lens of the dental operating microscope (Zeiss OPMI PROergo, Carl Zeiss Meditec AG, Oberkochen, Germany), the resin block was mounted on the table consisting of a rectangular slot of block size. Pre-instrumentation images were taken with 10 × magnification and saved in jpeg format.

Root canal instrumentation

All the instruments were driven using the X-Smart Plus motor with a 6:1 reduction ratio contra-angle handpiece (Dentsply Maillefer) according to the manufacturers' recommendations. Copious irrigation with 3% NaOCl was performed repeatedly after each instrument was used. Glyde file prep root canal conditioner (Dentsply Maillefer) containing ethylene diamine tetraacetic acid (EDTA) and urea hydrogen peroxide was used as lubricant during preparation.

A glide path was created with ProGlider instrument (tip size/taper: #16/0.02) (Dentsply Maillefer) at 300 rpm and a torque of 4.0 N/cm to full working length (WL). Then the following procedures were initiated.

The PTG system was operated with X-Smart Plus (Dentsply Maillefer) motor in "PROTAPER" mode with the manufacturer's recommendations as follows: SX at 250 rpm and 3 N/cm torque, S1 at 250 rpm and 3 N/cm torque, S2 at 250 rpm and 1 N/cm torque, F1 at 250 rpm and 1.5 N/cm torque, and F2 at 250 rpm and 2 N/cm torque. The SX was introduced into the canal and passively followed the glide path. The file was utilized with an outward brushing motion to enlarge the coronal two-thirds of the root canal.[2,24] Then the S1, S2, F1 and F2 were used exactly as described for SX in sequence until each instrument reached to the full working length in one or more passes. However, for the shaping and finishing files, the outstroke brushing motion was only used before the second curve of the S-shaped canal. Irrigation, recapitulation with #10 K-file, and re-irrigation were performed after removing each rotary file, or if the file bogged down and ceased to passively advance.

The WaveOne Gold Primary was operated with the X-Smart Plus motor (Dentsply Maillefer) in "Waveone Gold" mode. In brief, the Primary file was passively progressed 3—4 mm along the confirmed glide path with gentle inward pressure. A brushing motion on the outstroke was utilized to enlarge the coronal two-thirds of the canal.[3,24] Then the file was carried to the full working length in one or more passes. The outstroke brushing motion was only used before the second curve of the S-shaped canal. The irrigation strategies were performed as mentioned above.

After the instrumentation, the block was put back in the slot and the final photograph was taken as described for initial one with the ink re-filled in the canal. All simulated root canals were prepared by same experienced operator. Each instrument was used for preparation of a single block.

Image analysis and assessment of canal preparation

The pre- and post-instrumentation digital images were superimposed in imaging analysis software (Adobe Photoshop CS6, Adobe Systems Inc. San Jose. CA. USA) and saved in tiff format.10 consecutive points positioned perpendicularly to the long axis of resin blocks in 1 mm steps were defined as measurement points (Fig. 2). Thus, the S-shaped root canal was divided into three portions: points 0 to 3 corresponded to the apical curve, points 3 to 7 corresponded to the coronal curve, and points 7 to 10 belonged to the straight portion of the canal.[25] A total of 20 measurements were made from the 2 sides of the canal, the left side corresponding to the inner aspect of the apical curve and the outer aspect of the coronal curve and the right side corresponding to vice versa (Fig. 2).

The following parameters were measured (Figs. 1 and 2): (1) X1, the difference of canal at a point in the inner side; (2) X2, the difference of canal in the opposite side; (3) Y, the final diameter of prepared canal; (4) α_f, the final coronal curvature; β_f, the final apical curvature; r_{fc}, the final coronal radius and r_{fa}, the final apical radius.

Using the following equations, the shaping ability of the two systems were evaluated quantitatively and qualitatively: (1) total amount of resin removal, X1+X2; (2) amount and direction of transportation, X1−X2.[26] A positive result indicated transportation toward the inner side of the root, whereas a negative result indicated transportation toward its outer side; (3) centering ratio (X1−X2)/Y.[27] The centering ability is the capacity of an instrument to stay centered in root canal while performing its enlargement. Centering ratio value comes near to zero if X1 and X2 is closer to the center of the canal. For an instrument to be centered, it should obtain the lower centering ratio. Thus the lesser the centering ratio value, the better is the centering ability of the instruments; (4) the degree of canal straightening, determined by the change of curvature angle and radius of pre- and post-instrumentation. $\Delta\alpha = 30^\circ\text{-}\alpha_f$, $\Delta\beta = 20^\circ\text{-}\beta_f$, $\Delta r_c = 5\text{ mm-}r_{fc}$, $\Delta r_a = 3.5\text{ mm-}r_{fa}$, respectively.

An examiner who was blinded to all experimental groups performed the assessments of the canal shapes before and after instrumentation.

Statistical analysis

Statistical analysis was performed by using the SPSS software (IBM SPSS Statistics 21, SPSS Inc. Chicago. IL. USA). The data were analyzed by the Mann—Whitney U-test, Statistical significance level of 5% ($P < .05$) was established for all analyses.

Results

No instrument separation occurred. Therefore, all of the canals were used for evaluation and statistical analyses.

Total amount of resin removal

A steady and increasing amount of resin was removed from apex to orifice along the canal in both groups. In general,

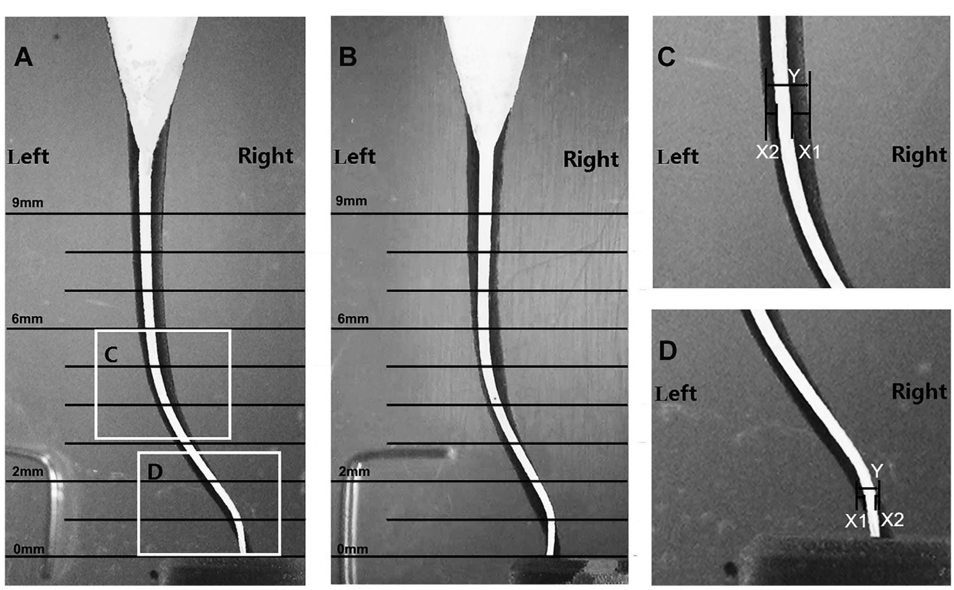

Figure 2 Pre- and post-instrumentation images were superimposed and measured. A: ProTaper Gold, B: WaveOne Gold, C: the coronal canal curvature, D: the apical curvature. Measurement points positioned perpendicularly to the long axis of resin blocks in 1 mm steps. X1: the difference of canal at a point in the inner side, X2: the difference of canal in the outer side, Y: the final diameter of prepared canal.

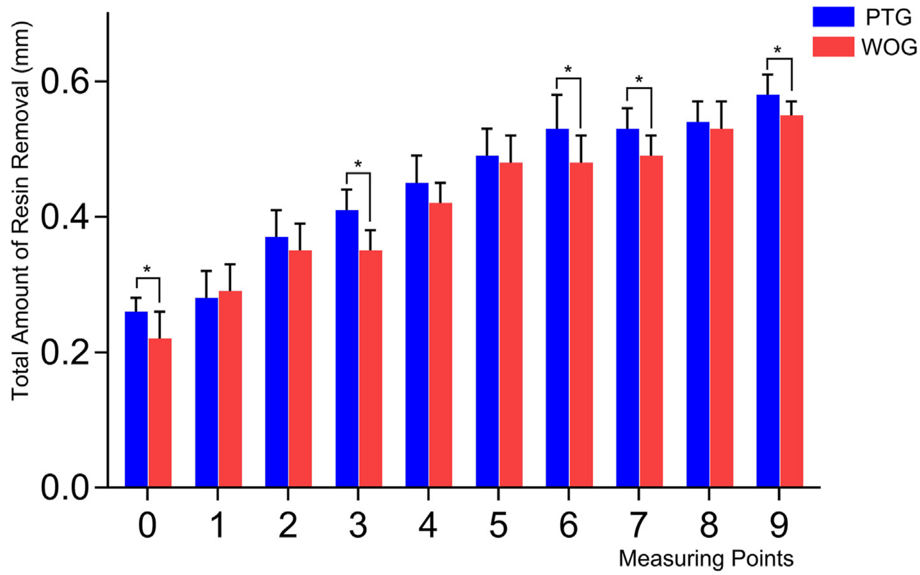

Figure 3 The total amount of resin removal. PTG: ProTaper Gold; WOG: WaveOne Gold, *: significantly different according to Mann–Whitney U-test ($P < .05$).

the PTG group showed a greater amount of resin removal than the WOG group at all measurement points except at 1 mm from the apex, and significant differences were found at 0, 3, 6, 7 and 9 mm from the apex ($P < .05$) (Fig. 3).

Amount and direction of canal transportation

The PTG group yielded significantly more transportation at 0 mm from the apex ($P < .05$). The WOG group showed significantly more transportation at 4, 5, 6 mm from the apex ($P < .05$). As regards transportation direction, both files deviated to the outer canal curvature at 0 and 3 mm from the apex. At other measuring points (except 9 mm from the apex) both files deviated to the inner canal curvature. At 9 mm from the apex, the PTG group transported to the inner canal curvature, while the WOG group transported to the opposite direction (Fig. 4).

Centering ratio

Consistent with the findings of canal transportation, the WOG group showed a more centered shaping at 0 mm from the apex ($P < .05$); and the PTG group showed a better

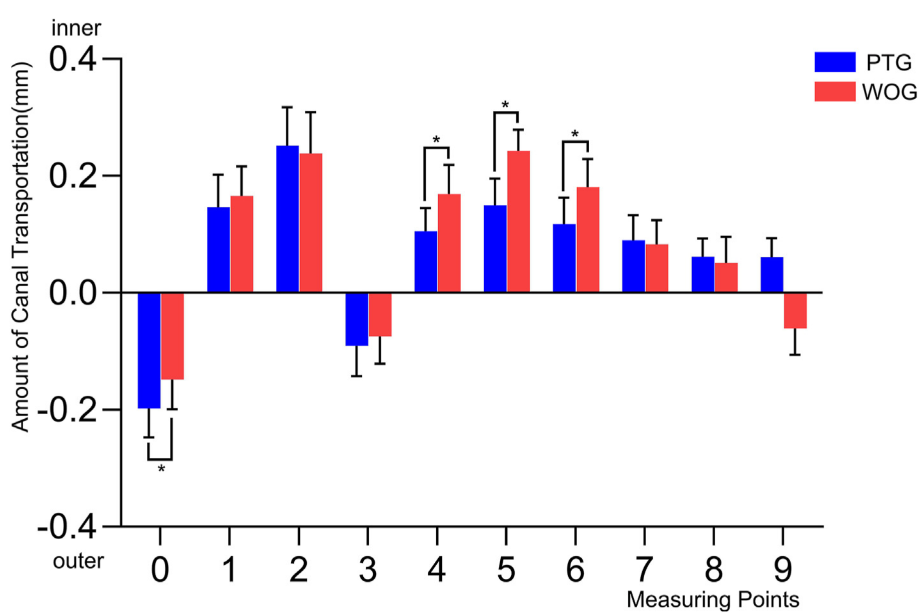

Figure 4 The amount and direction of canal transportation. PTG: ProTaper Gold, WOG: WaveOne Gold, inner: the inner side of the canal, outer: the outer side of the canal, *: significantly different according to Mann–Whitney U-test ($P < .05$).

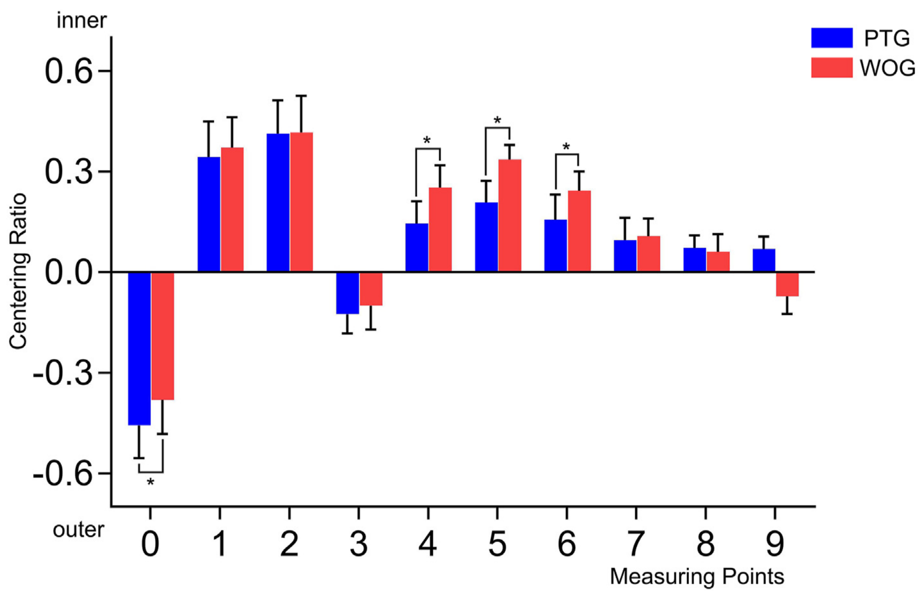

Figure 5 The results of centering ratio. PTG: ProTaper Gold, WOG: WaveOne Gold, inner: the inner side of the canal, outer: the outer side of the canal, *: significantly different according to Mann—Whitney U-test ($P < .05$).

centering ability at 4, 5 and 6 mm from the apex ($P < .05$) (Fig. 5).

Curvature straightening

After the instrumentation, the apical and coronal curvature angle decreased and the apical and coronal radius increased in both groups, indicating that both files straightened the apical and coronal curvature. PTG maintained the coronal curvature better than WOG ($P < .05$). No significant differences were found at the apical curvature ($P > .05$) (Table .1).

Discussion

In the present study, S-shaped simulated canals in resin blocks were used to compare the performance of two commercial Gold heat-treated NiTi systems, named WaveOne Gold and ProTaper Gold. Although the plastic blocks lack the qualities of human dentin, especially with respect to hardness and thermal properties,[28] the validity of using resin simulated canals (RSCs) as substitutes for extracted human teeth has been verified by many instrumentation studies.[21,22] The advantages of RSCs include the possibility of standardizing the shape, curvature, and dimension of the canal, and the fact that there are no infection control concerns.[28] Other possible side effects related to the resin blocks were created by heat generation during instrumentation which may soften the resin material and binding of instrument cutting blades.[29] Thus, copious irrigations were used to minimize the side effects caused by the heat generation.

The endodontic glide path is defined as a smooth radicular tunnel from the canal orifice to the physiological terminus of the root canal facilitating the shaping files to follow the pathway.[30] The size of the glide path created by small-sized and slightly tapered NiTi rotary instruments has been shown to decrease the torsional stress generated in the shaping by NiTi rotary instruments.[31] Besides the inherent difficulties in preparing canals with 2 curvatures, S-shaped canals also influence the cyclic fatigue of rotary NiTi instruments, with the number of cycles to fracture being statistically lower in double-curved canals when compared with single-curved canals.[32] Therefore, although the original root canal employed in this study was ISO #15, 0.02-tapered, the ProGlider was used to pre-enlarge the body of the canal. No instrument fracture occurred in the present study.

In accordance with other studies,[21,22] the WOG was found to cause a lower level of resin removal than the PTG system. This could be attributed to their variable tapered designs. Many studies have compared the shaping ability of root canal instruments with different tapers, indicating that the final taper might influence the removal of material from the canal walls.[33,34] The final taper is 0.08 at the apical 3 mm for PTG and 0.07 for WOG. Moreover, the S1 and S2 files have D0 diameters of 0.17 mm and 0.20 mm, respectively, and a progressively increasing percentage tapered design over their active portions. The S1 dominantly prepares the coronal one-third, whereas the S2 prepares the middle one-third of a canal. F1 and F2 have a decreasing taper. They are designed to prepare the apical one-third and further enlarge

Table 1 The changes of curvature angle (°) and radius (mm) of S-shaped root canals (mean ± standard deviation).

group	Coronal curvature		Apical curvature	
	Angle	Radius	Angle	Radius
ProTaper Gold	5.07 ± 1.12	−1.97 ± 0.33	4.58 ± 1.76	−0.86 ± 0.52
WaveOne Gold	8.12 ± 1.94	−3.98 ± 1.29	5.37 ± 1.29	−0.82 ± 0.35
P value	<0.05*	<0.05*	>0.05	>0.05

*Significantly different at P < .05.

the middle one-third of root canals.[3] For WOG, the WOG Primary file has a progressively decreasing percentage tapered design from D4-D16, which conserves remaining dentin in the body of the prepared canal.[2]

Canal transportation corresponds to a deviation of the prepared canal from its natural axis after instrumentation when compared with pre-treatment measurements.[7] Elastic memory provides the file with a restoring force that straightens it when it has been deformed by curvature. The restoring force underlies canal transportation and prevents the instrument from remaining perfectly centered within the canal.[35] Previous study reported that apical transportation of more than 0.3 mm could negatively affect the sealability of filling material.[36] In the present study, we observed both files transported toward the outside of the curve at 0 mm from the apex, yet none of the rotary systems used reached apical transportation greater than 0.2 mm. Besides, WOG demonstrated a better centering ability with less canal transportation than PTG group at apical level. Both WOG Primary file and all PTG finishing files have a fixed taper from D1-D3.[2,3] The semi-active guiding and less tapered tip of the WOG Primary file enable the file to more readily follow and safely progress along manually reproduced and secured canals.[2] The greater taper of PTG finishing file F2 may be responsible for transportation and straightening effect in severely curved canals. PTG showed a better result in maintaining the coronal curvatures than WOG. As mentioned above, because of the considerable heterogeneity in the methodologies, including types of root canal system, canal models (real teeth or model teeth) and outcome measurements, the outcomes of in vitro studies comparing the shaping ability of PTG and WOG were conflict.[7,17,19] Al-Dhbaan et al. found that the WOG system showed fewer canal aberrations (danger zones) than the PTG system in S-shaped canals.[22] Many factors have been identified that exert an impact on the incidence of canal transportation, such as geometry design features, kinematics, and metallurgical properties.[1] These aspects require further investigations, in which some attempts should be made to standardize as many design features of different instruments as possible to assess solely the impact of the alloy on the shaping ability.

Under the conditions of the present study, PTG and WOG removed relatively more amount of material from the inner aspects than they removed from the outer aspects of both apical and coronal curvatures and tended to deviate from the original axis, indicating that these instruments had tendencies to straighten the canals. This is further supported by the statistical comparisons of the change of curvature angle and radius. Excessive removal of dentin from the inner side of the curvature can potentially weaken the root structure that consequently leads to root fracture or strip perforation. Thus, anticurvature debridement of the root canal should be performed toward the outer side of the curvature.[24,37] Both PTG and WOG were recommended to be used with a brushing action on the outstroke.[2,3] A brush-cutting action creates lateral space and allows the bigger, stronger, and more efficient blades to passively run deeper into the canal.[38] Endodontic file has the tendency to straighten up in the canal, and hence it is difficult to control removal of dentine along the entire length of file. Flare the coronal part of the canal and anticurvature filing can be conducive to reducing the incidence of procedural errors in S-shaped root canal.[24] The outward action also resulted in significantly lower torque, hence, less torsional stresses were elicited and it might be considered as a clinical procedure to increase debridement safely.[39] However, it should be noted that multiplying the number of brushing strokes will lead to significant cutting of the canal wall in all directions. This would lead to unnecessary root canal enlargement and shaping mishaps.[40] In the present study, each file was carried to the established working length in one or more passes with a brushing action on the outstroke to avoid aggressive removal of dentin. However, the outstroke brushing motion was only used before the second curve of the S-shaped canal in the present study. The double curvatures of S-shaped root canal are in opposite directions and the file undergoes a more severe elastic deformation in S-shaped root canal. Theoretically, brushing on the outer wall of the second curve may lead to excessive removal of dentin from the inner side of the coronal curve and apical transportation. Despite the thorough literature, information about the impact of instrumentation techniques on the performance of endodontic instruments in S-shaped root canal is insufficient, which deserves further investigation to define the best strategy for achieving an optimal prepared shape of canal.

Taken together, within the parameters of the present study, the WOG Primary file has a less aggressive dentin cutting and more centered apical preparation than the PTG instruments. Whereas PTG files produced less canal transportation in the coronal curved portion of the simulated S-shaped canal.

Declaration of competing interest

The authors have no conflict of interest relevant to this article.

Acknowledgments

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