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Original Article

Shaping ability of rotary and reciprocating single-file systems in combination with and without different glide path techniques in simulated curved canals

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KEYWORDS
Glide path management;
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Shaping ability;
Single-file system

Abstract *Background/purpose:* Glide path management (GPM) is a consequential clinical step that serves to influence predictably successful root canal therapy. However, the effect of GPM on the shaping ability of single-file system remains controversial. This study compared the performance of rotary single-file One Curve (OC) and reciprocating single-file Reciproc Blue (RCB) in combination with/without different glide path techniques: no glide path preparation (NG), PathFile (PF), ProGlider (PG) and WaveOne Gold Glider (WOGG), respectively.
Materials and methods: 80 simulated curved canals (n = 10 canals/per group) were instrumented to an apical size of 0.25 mm using OC and RCB in combination with/without different glide path techniques, respectively. The amount of resin removal, canal transportation, and the degree of canal straightening were measured in Photoshop CS6 software. Statistical analysis of the data was performed by using Kruskal–Wallis test, followed by Dunn's post hoc test with Bonferroni correction ($\alpha = 0.05$).
Results: Post–glide path analysis found that WOGG and PG produced less canal transportation and curvature straightening than PF ($P < 0.05$). Post-shaping analysis showed that OC groups removed significantly less resin than RCB groups ($P < 0.05$). The PG and WOGG subgroups in both OC groups and RCB groups produced less transportation and curvature straightening than NG and PF subgroups ($P < 0.05$). OC + PG subgroup and OC + WOGG subgroup yielded the least canal transportation and curvature straightening ($P < 0.05$).
Conclusion: PG and WOGG can improve the shaping ability of OC and RCB instrument. OC, especially when combined with PG and WOGG, has a less aggressive dentin cutting and more centered preparation than the RCB instrument.

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Introduction

Ever since their introduction, nickel-titanium (Ni—Ti) alloys have continued to revolutionize the field of endodontics.[1] It has been shown that root canal preparation with engine-driven Ni—Ti endodontic instruments results in significantly less canal transportation and fewer preparation errors compared with stainless steel hand instruments.[2] Despite the numerous advantages of Ni—Ti rotary instruments, these instruments present a risk of fracture associated with increased instrument fatigue caused by the repeated use and the possibility of cross-contamination associated with the inability to adequately clean and sterilize endodontic instruments.[3] Besides, as these techniques require the use of numerous instruments to enlarge the canal to an adequate size and taper, they are relatively time consuming. Therefore, Yared reported a novel canal preparation technique using only one Protaper F2 file (Tulsa Dentsply, Tulsa, OK, USA) in reciprocating motion (the clockwise (CW) rotation of 4/10 circle and the counter-clockwise (CCW) rotations of 2/10 circle) in 2008.[3] Heat-treated Ni—Ti alloy (i.e. M-wire, Gold or Blue-wire) used as the raw material for making endodontic files facilitates the realization of this new technique in clinical practice. Ever since, many single-file Ni—Ti systems with different designs, i.e. cross section, taper, alloy, movement kinemics, have been introduced to the market.

Based on the type of their motions, single-file rotary systems can be classified to two groups: continuous rotating and reciprocating files. Reciproc Blue files (RCB, VDW GmbH, Munich, Germany), operated in 150°CCW and 30°CW directions, are manufactured through a complex heating—cooling proprietary treatment resulting in a visible titanium oxide layer on the surface, which imparts a gold/blue color to the alloy depending on the thickness of the titanium oxide layer.[1] The Gold/Blue-wire instruments differ from M-wire systems as they are ground before they undergo the post-machining heat treatment.[1] This process renders the file more flexible and more resistant to cyclic fatigue compared with conventional Ni—Ti and M-wire alloys.[4] The One Curve (OC, Micro-Mega, Besançon, France) is a single-use, continuous rotary file manufactured from heat-treated Ni—Ti alloy C. Wire with the property of controlled memory, which is a proprietary process, exclusively developed and implemented by Micro-Mega for OC. The manufacturer states that patented variable cross-section all along the blade ensure a centering ability in the apical third and an excellent debris removal up to the medium and coronal parts.

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.[5] Glide path management (GPM) is considered a consequential clinical step that serves to influence predictably successful endodontics. Breakdowns in GPM encourage preparation errors such as blocks, ledged, perforations, and broken instruments.[6] An established glide path may prolong the life of rotary shaping instruments to prepare more canals, give preparation safety in severely curved canals by decreasing the torsional stress generated in the shaping by Ni—Ti rotary instruments and reduce postoperative pain by diminishing the amount of debris extruded apically.[7,8]

The three-file rotary Ni—Ti system PathFile (PF, Dentsply Sirona, York, PA,USA), manufactured with a conventional austenite Ni—Ti alloy, was the first specifically designed in intermediate sizes (size/taper: #13/0.02, #16/0.02, #19/0.02) for the purpose of preparing the glide path.[9] Each file has a square cross-section and non-cutting tip. These features, according to the manufacturer, ensure flexibility, improved cutting efficiency, more resistant to cyclic fatigue and reduce the risk of ledge formation. The ProGlider (PG, Dentsply Sirona) is a single mechanical glide path file manufactured from M-wire and has increasing tapers from 2% to over 8% along its active portion. The file has a square cross section with a diameter of 0.16 mm at D0 and 0.82 mm at D16. These design features result in a file that safely pre-enlarges the glide path in a controlled, smooth, inward cutting action with significantly improved flexibility and 400% greater resistance to cyclic fatigue.[6,10] In 2017, another dedicated single-use glide path file, termed WaveOne Gold Glider (WOGG, Dentsply Sirona) manufactured with Gold-wire was marketed. The WOGG, working in reciprocating motion (150° CCW and 30° CW), has an ISO #15 tip size with a variable taper of between 2% (D0) and 6% (D16) and a parallelogram shaped cross sectional design. The tip of the file is semi-active and the active cutting flute length is 16 mm.

The role of a glide path prior to engine-driven canal instrumentation has been emphasized in endodontic literature; however, basic research studies offered mixed conclusions.[11] In root canals of mandibular molars (curvature angles ranging from 0° to 20°), using PF before RCB resulted in less root canal transportation and better centering ability.[12] However, other studies reported that a glide path had no impact on canal straightening.[13] In addition, according to the literature, there is no study that compares the shaping ability of the OC and RCB in combination with/without different glide path system. Thus, the aims of this ex vivo study was to compare the effects of different glide path techniques on the shaping ability of rotary and reciprocating single-file systems, OC and RCB, in simulated curved canals. The null hypothesis was that there would be no differences among the groups in amount of resin removal, canal transportation, and changes in canal curvature after shaping of curved root canals.

Materials and methods

Specimen grouping

80 ISO #15, 0.02-tapered, J-shaped endo training blocks (Dentsply Sirona) with length of 16 mm were randomly distributed into two experimental groups according to the shaping system adopted: OC group (tip size/taper: #25/0.06) and RCB group (tip size/taper: #25/0.08). Subsequently, each group was further divided into 4 subgroups according to the path finding system employed: no glide path preparation (NG), PF, PG, and WOGG. Therefore, 8 test groups were established (n = 10).

Root canal instrumentation

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

Subsequently, root canals were instrumented by the same operator to a working distance of 16 mm. All the instruments were introduced into the canals using in-and-out motions of 3- to 4-mm amplitude with light apical pressure.[12] The files were driven by an X-Smart Plus motor with a 6:1 reduction ratio contra-angle handpiece (Dentsply Sirona) according to the manufacturers' recommendations as follows: PF #13/0.02, #16/0.02 and #19/0.02 were successively introduced to the working length at 300 rpm and 4 Ncm torque; PG at 300 rpm and 4 Ncm torque; OC at 300 rpm and 2.5 Ncm torque, respectively. The RCB was operated in pre-programmed "Reciproc" mode and WOGG in "Waveone Gold" mode.

Copious irrigation with 3% NaOCl, 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.

Photographs were taken as described above after glide path preparation and final instrumentation, respectively. Therefore, each sample had 3 images: initial, after glide path preparation (except OC + NG subgroup and RCB + NG subgroup), and after final instrumentation.

Image analysis and assessment of canal preparation

Initial and after glide path preparation images were superimposed in Adobe Photoshop CS6 imaging analysis software (Adobe Systems Inc, San Jose, CA, USA) and saved in tiff format. Similarly, initial and after final instrumentation images were also superimposed and saved.

Three measuring points were determined on each canal by using a method described by Calberson et al.: point BC, the beginning of the curve; point AC, the apex of the curve of the original canal, determined by the intersection of two lines (one along the coronal aspect of the central line, and the second along the apical portion of the central line); point EP, end point of preparation (Fig. 1A).[14] The difference of canal at a point in the inner side was denoted as X1, and the difference of canal in the opposite side was denoted as X2 (Fig. 1B). The canal curvature was measured according to the Schneider method and recorded as α (Fig. 2).[15] The radius of curvature (r) was calculated according to the formula suggested by Schäfer.[16] In brief, if the length of the chord between the beginning of the curve and the apical foramen was measured as S (Fig. 2), then $r = S/2\sin\alpha$. Therefore, each simulated canal had an initial 35°curvature and 5 mm radius.

Using the following equations, the shaping ability of the path finding systems and single-file systems were evaluated quantitatively: (1) amount of resin removal, X1+X2; (2) amount and direction of transportation, X1−X2.[17] A positive result indicated transportation toward the inner side of the root, whereas a negative result indicated transportation toward its outer side; (3) the degree of canal straightening, determined by the change of curvature angle and radius of pre- and post-instrumentation: $\Delta\alpha = \alpha$-35°, $\Delta r = r$-5mm, respectively. The assessment of the canal preparation was performed by an examiner who was blinded to all the experimental groups.

Statistical analysis

Statistical analysis was performed by using the SPSS 21.0 software (IBM, Armonk, NY, USA). The data were analyzed with Kruskal–Wallis test followed by Dunn's post hoc test with Bonferroni correction. The testing was performed at $\alpha = 0.05$ ($P < 0.05$).

Results

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

Amount of resin removal

Post–glide path analysis found that WOGG (0.074 ± 0.020 mm) and PG (0.063 ± 0.020 mm) removed significantly more resin than PF (0.056 ± 0.015 mm) at point BC ($P < 0.05$) with no significant difference between the former two

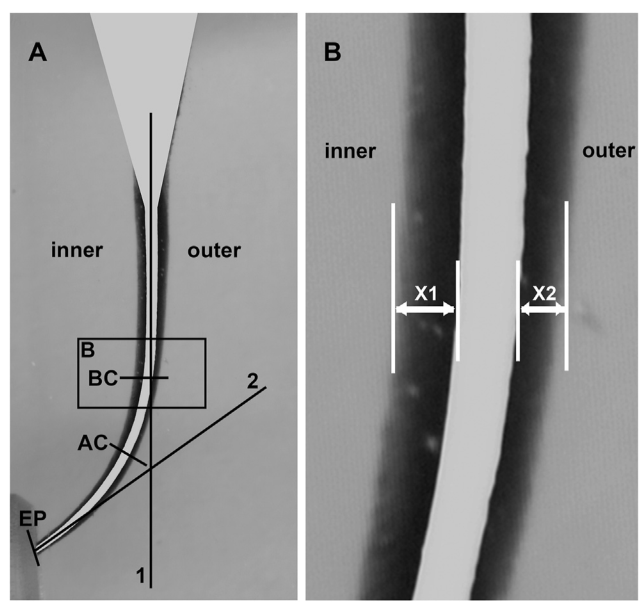

Figure 1 Pre- and post-instrumentation images were superimposed and measured. A, determination of the measuring points. B, measurement of the amount of resin removal. Line 1, the central line of the coronal portion. Line 2, the central line of the apical portion. BC, the beginning of the curve. AC, the apex of the curve of the original canal, determined by the intersection of line1 and line 2. EP, end point of preparation. X1, the difference of canal at a point in the inner side. X2, the difference of canal in the outer side.

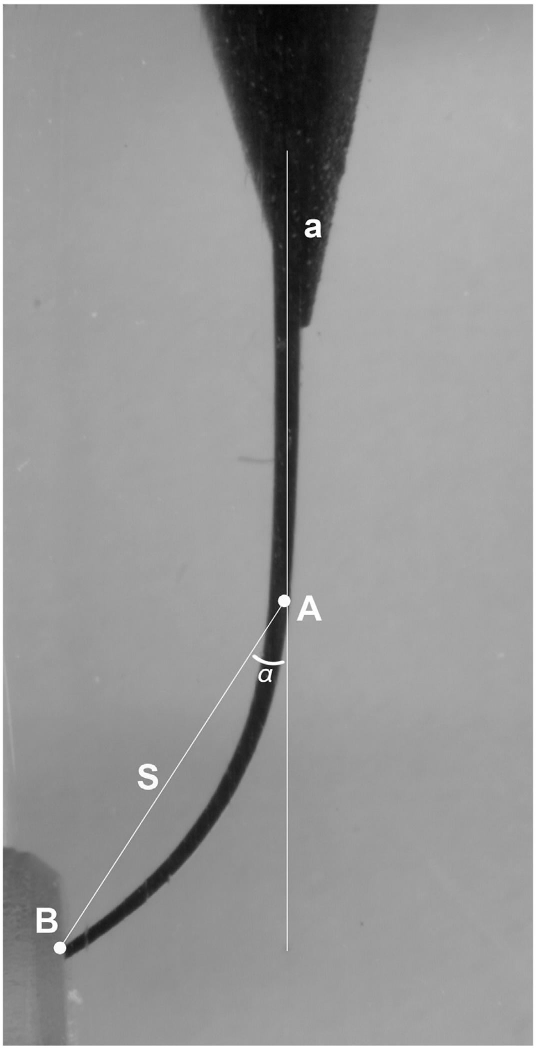

Figure 2 Illustration of the curvature angle and radius measurement. Line a: the central line of the coronal portion; point A: the beginning point of the canal curvature; point B: the apical foramen; α: the curvature angle formed by the intersection of the line a and line AB; *S*: length of the chord AB.

($P > 0.05$). At point AC, no significant difference was found among the groups: PF, 0.040 $\pm$ 0.019 mm; PG, 0.039 $\pm$ 0.013 mm; WOGG, 0.036 $\pm$ 0.016 mm ($P > 0.05$). At point EP, WOGG (0.028 $\pm$ 0.021 mm) removed significantly less resin than PF (0.043 $\pm$ 0.026 mm) ($P < 0.05$); however, there was no significant difference between PF and PG (0.037 $\pm$ 0.021 mm), nor between PG and WOGG ($P > 0.05$).

Post-shaping analysis of the amount of resin removal was illustrated in Fig. 3. No significant difference was found in respect of the comparisons of intra-group findings in all thirds ($P > 0.05$).

Inter-group comparisons showed that OC + WOGG subgroup and OC + PG subgroup produced lower values than all the RCB subgroups at BC and AC points ($P < 0.05$) (Fig. 3A and B). At EP point, RCB + NG, RCB + PF and RCB + WOGG subgroups removed significantly more resin than OC + WOGG subgroup and OC + PG subgroup (Fig. 3C) ($P < 0.05$).

Amount and direction of canal transportation

Post—glide path analysis found that at point BC, PF (0.024 $\pm$ 0.013 mm) transported significantly more than PG (0.013 $\pm$ 0.009 mm) and WOGG (0.011 $\pm$ 0.009 mm) toward

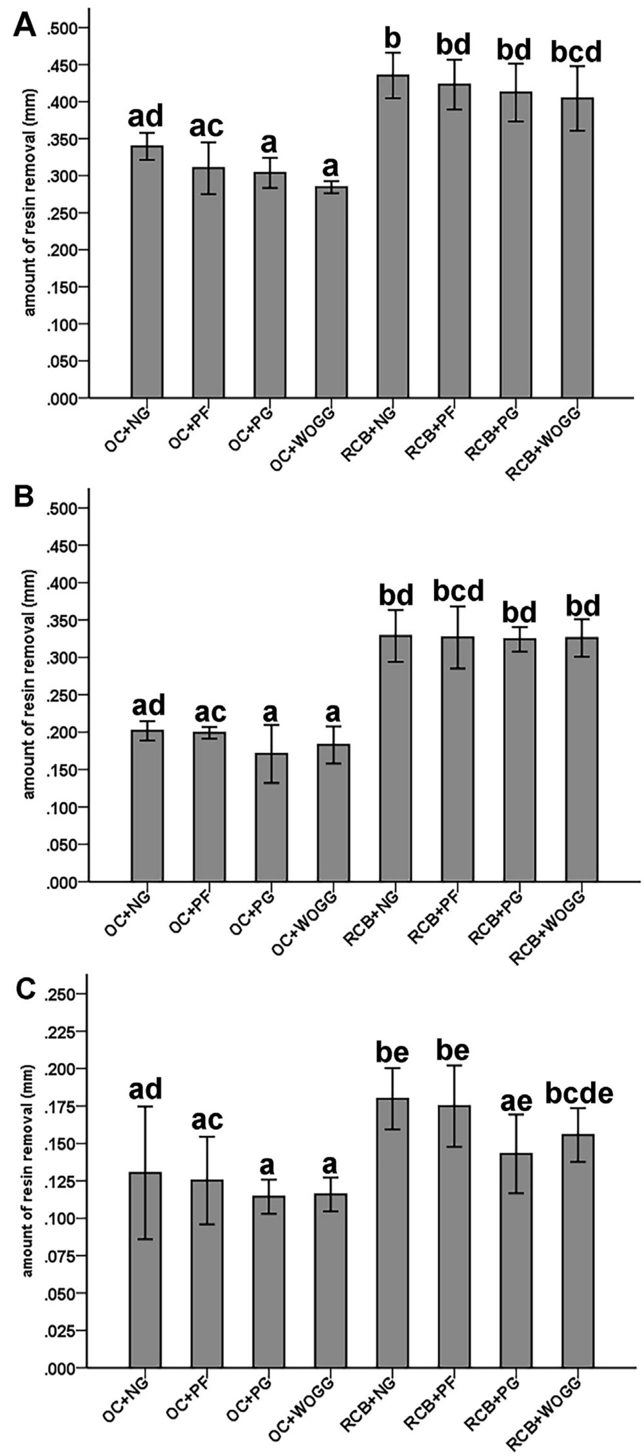

Figure 3 The amount of resin removal after final root canal preparation. Values with different superscript letters were significantly different at α = 0.05. OC, One Curve. RCB, Reciproc Blue. NG, no glide path preparation. PF, PathFile. PG, ProGlider. WOGG, WaveOne Gold Glider.

the inner side of the root canal ($P < 0.05$). At point AC, both PG (0.008 ± 0.009 mm) and WOGG (0.008 ± 0.010 mm) showed significantly less amount of canal transportation than PF (0.015 ± 0.013 mm) ($P < 0.05$), with no significant differences between the former two ($P > 0.05$). At point EP, WOGG (−0.009 ± 0.011 mm) showed significantly less amount of transportation toward the outer side of the root canal than PF (−0.014 ± 0.011 mm) and PG (−0.013 ± 0.011 mm) ($P < 0.05$), with no significant difference between the latter two ($P > 0.05$).

Post-shaping analysis of the amount and direction of canal transportation at the three measuring points was presented in Fig. 4. At BC point, all the groups transported toward the inner side of the root canal. OC + WOGG subgroup yielded less amount of transportation than OC + NG, RCB + NG, RCB + PF and RCB + PG subgroups ($P < 0.05$). OC + PG subgroup showed less transportation than RCB + NG and RCB + PF subgroups ($P < 0.05$) (Fig. 4A).

At AC and EP points, all the groups deviated to the outer canal curvature. At AC point, OC + PG subgroup showed significantly less transportation than RCB + NG subgroup ($P < 0.05$). RCB + PG subgroup produced significantly less transportation than RCB + NG and RCB + PF subgroups ($P < 0.05$) (Fig. 4B). At EP point, RCB + NG subgroup transported significantly more than OC + PF, OC + PG and OC + WOGG subgroups ($P < 0.05$). RCB + PF subgroup showed significantly more transportation than OC + PG subgroup ($P < 0.05$) (Fig. 4C).

Curvature straightening

Both post–glide path analysis and post-shaping analysis demonstrated that after the instrumentation, the curvature angle decreased and the curvature radius increased in all the groups, indicating that both glide path management and canal shaping with different regimens straightened the curvature.

After the glide path management by using PG ($\Delta\alpha = -0.48 \pm 0.18°$, $\Delta r = 0.24 \pm 0.09$ mm) and WOGG ($\Delta\alpha = -0.47 \pm 0.22°$, $\Delta r = 0.23 \pm 0.11$ mm), the changes of curvature angle and curvature radius were significantly less than that of PF ($\Delta\alpha = -0.70 \pm 0.27°$, $\Delta r = 0.31 \pm 0.12$ mm) ($P < 0.05$). There was no significant difference between PG and WOGG ($P > 0.05$).

Post-shaping analysis of the changes of curvature angle and curvature radius was listed in Table 1. OC + WOGG subgroup showed the least change in angle and radius with significant difference compared with OC + NG, OC + PF, RCB + NG and RCB + PF subgroups ($P < 0.05$). RCB + NG subgroup produced the most pronounced change in angle and radius with significant difference compared to OC + PG, OC + WOGG, RCB + PG and RCB + WOGG subgroups ($P < 0.05$).

Discussion

In the present study, the shaping abilities of OC and RCB combined with/without 3 glide path systems were evaluated in simulated curved canals. Simulated canals in resin

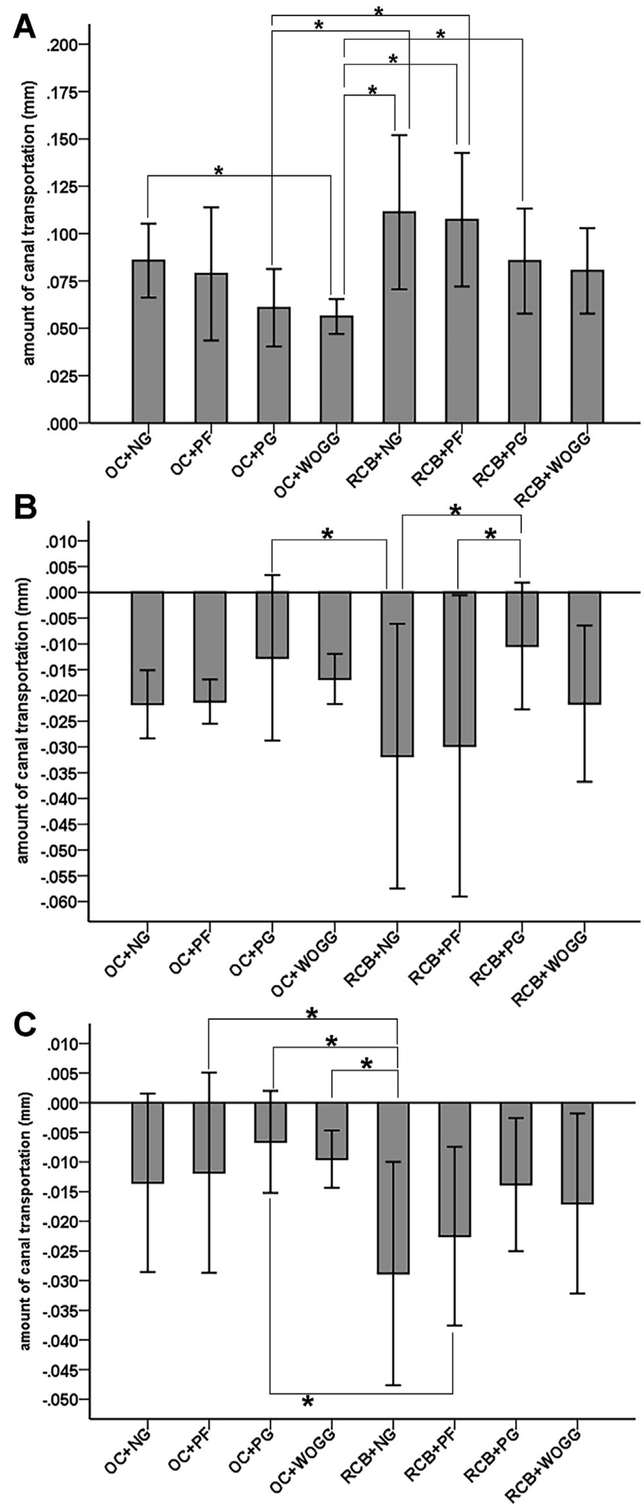

Figure 4 The amount and direction of canal transportation after final root canal preparation. A positive result indicated transportation toward the inner side of the root, whereas a negative result indicated transportation toward its outer side. *, significantly different at $\alpha = 0.05$. OC, One Curve. RCB, Reciproc Blue. NG, no glide path preparation. PF, PathFile. PG, ProGlider. WOGG, WaveOne Gold Glider.

Table 1 The changes of curvature angle (°) and radius (mm) of simulated root canals after final root canal preparation.

Groups (n = 10)	angle		radius	
	mean ± SD	95%CI	mean ± SD	95%CI
OC + NG	−1.880 ± 0.052[ac]	−1.918;-1.842	0.939 ± 0.083[bd]	0.880; 0.998
OC + PF	−1.788 ± 0.042[aef]	−1.818;-1.758	0.886 ± 0.080[bcd]	0.829; 0.943
OC + PG	−1.573 ± 0.056[bf]	−1.613;-1.533	0.717 ± 0.052[ac]	0.680; 0.754
OC + WOGG	−1.336 ± 0.168[b]	−1.339;-1.216	0.537 ± 0.179[a]	0.409; 0.665
RCB + NG	−1.914 ± 0.039[a]	−1.942;-1.886	1.017 ± 0.045[be]	0.985; 1.049
RCB + PF	−1.844 ± 0.027[ad]	−1.863;-1.825	0.990 ± 0.069[bd]	0.941; 1.039
RCB + PG	−1.689 ± 0.118[bcde]	−1.773;-1.605	0.853 ± 0.082[ade]	0.794; 0.912
RCB + WOGG	−1.592 ± 0.041[be]	−1.621;-1.563	0.810 ± 0.117[ad]	0.726; 0.894

Values with different superscript letters were significantly different at $\alpha = 0.05$. SD, standard deviation. CI, confidence interval. OC, One Curve. RCB, Reciproc Blue. NG, no glide path preparation. PF, PathFile. PG, ProGlider. WOGG, WaveOne Gold Glider.

blocks provided the standardized conditions in terms of diameter, length and angle of curvature of the original canal shape for instruments tested, avoiding the large variations in the root canal morphology in extracted human teeth. However, heat generated during the instrumentation might soften the resin material, which may lead to binding of cutting blades, and separation of the instrument.[18] In this study, irrigation, recapitulation with a 10# K-file and re-irrigation after removing each rotary file were performed to minimize the heat generation and clean up the resin debris. Three measuring points were determined according to the method described by Calberson et al., because this is the area where transportation may potentially occur.[14,19]

After the glide path management, PF removed significantly more resin than WOGG at EP point; while, PG and WOGG removed significantly more resin than PF at BC point. This may be related to the geometric designs of the files. The PF series has a traditional, fixed tapered design over the length of its active portion, with D0 tip diameters of 0.13 mm, 0.16 mm and 0.19 mm, respectively. Alternatively, PG and WOGG possess progressively tapered design, which is 2—8% and 2—6%, respectively. The PG file has a diameter of 0.16 mm at D0 and the WOGG file has a diameter of 0.15 mm at D0. Therefore, PG and WOGG will create a significantly larger, smoothly tapered pathway than PF multi-file sequence. Moreover, because of the progressively tapered design, the instruments also provide a preliminary preflaring of the middle and coronal portions of the canal, which is necessary to minimize the torsional stresses along on the file when engaging into the canal, thus decreasing and the risk of instrument failure.[20] Berutti et al. confirmed that PG appears to perform more efficiently than PF in decreasing electric power consumption of ProTaper Next X1 (Dentsply Sirona) to reach the full working length.[21] Regarding the canal transportation and curvature straightening, PG and WOGG produced less amount of deviation and the changes of curvature angle and radius than PF. Similarly, Alovisi et al. reported that PG had a better centering ability and caused less transportation than the PF and K-file systems in maxillary first molar teeth's mesiobuccal canals with moderate curvature after using micro-CT analysis.[22] This may be attributed to the differences in properties of the alloy used. The PG and WOGG, manufactured from M-wire alloy and Gold-wire alloy, respectively, had enhanced mechanical properties, including higher flexibility, higher resistance to cyclic fatigue and torsional stress compared with PF instrument made of conventional Ni—Ti alloy.[23] Flexibility may influence the instrument's ability to properly shape curved root canals. More flexible instruments produce more centered preparations.[24] At EP point, WOGG showed less canal transportation than PG. Similar to the present study, Aydın et al. reported that in moderately curved (10°—20°) mesial canals of mandibular first molar, although no significant differences in root canal transport in the apical third was found between PG and WOGG, the WOGG showed better centering abilities at all thirds compared with the PG file system.[24] This may arise from the more flexible alloy adopted by WOGG, and the smaller size/taper of the WOGG compared with the PG.[24]

The second part of the present study examined shaping ability of OC and RCB after the different glide path preparation techniques and without any glide path preparation. To our knowledge, there are currently no existing studies that compared the shaping ability of OC with RCB files, making it difficult to compare the current study's results directly with another study. Regarding the amount of resin removal, there was no significant difference among the OC subgroups or among the RCB subgroups in all thirds, indicating that the GPM had no statistically significant influence on the cutting efficacy of instruments. However, the comparisons between the OC groups and RCB groups revealed that RCB removed significantly more resin than OC in all thirds. Several interrelated parameters define the cutting ability of root canal instruments, including cross-sectional area and design, helical and rake angle, debris removal capacity, surface treatment, metallurgical properties and movement kinematics.[25,26] The greater cutting efficacy of the Reciproc instrument (VDW) is likely related to its S-shaped cross section having a double-cutting edge.[26] Except the Ni—Ti alloy, Reciproc and RCB have exactly the same geometric characteristics (cross section, taper and tip). The OC has a variable cross-sectional design with a triple helix cross-section in the apical area and an S-shaped design in the medium and coronal parts. Moreover, the final taper might influence the removal of material from the canal walls.[27] The OC has constant taper of 6% throughout its length; while, RCB has an 8% tip taper and regressive taper design in the medium and coronal parts.

With respect to canal transportation and curvature straightening, the comparisons of intra-group findings demonstrated that the PG and WOGG subgroups in both OC groups and RCB groups produced less transportation and curvature straightening than NG and PF subgroups. As mentioned above, PG and WOGG produced a larger, tapered pathway than PF, which may make the root canal preparation more gradual leading to a better respect of the original anatomy. Similarly, a study by Keskin et al. found that glide path preparation using PG rotary instrument improved the shaping ability of RCB instrument by leading to less transportation and maintaining centering ability in simulated S-shaped root canals.[28]

Inter-group comparisons revealed that the OC groups yielded better results than RCB groups, especially when OC combined with PG and WOGG. The canal transportation results from the tendency of the instrument to return to its original straight shape when introduced into a curved root canal. OC is controlled memory file. RCB also exhibits a controlled memory effect and can be deformed.[29] However, depending on the modification of the heat treatment protocols, the degree of the controlled memory effect might vary.[30] Previous studies showed that the Blue treatment did not produced statistically significant differences regarding the shaping capability of curved root canals or canal transportation in relation to instruments manufactured from Gold-wire.[31,32] On the other hand, OC rotary file showed less canal transportation and better canal centering ability than WaveOne Gold file (Dentsply Sirona) during the preparation of severely curved canals.[33,34] Furthermore, the variable cross-sections of OC with a triangular-shaped at the tip of the instrument and S-shaped near the shaft are claimed to allow effective cutting and centered trajectory.[35] Concerning the influence of kinematic characteristics on the shaping ability of instruments, conflict results were obtained from previous studies. A systematic review of in vitro studies stated that instruments with reciprocating motion seemed to have better resistance to cyclic fatigue with less canal transportation tendency than the instruments with continuous rotating motion.[36] However, recent studies demonstrated that the similarities and differences regarding shaping ability between the files could be more related to their characteristics in alloy, taper and design than with their kinematic characteristics.[37,38]

Taken together, within the parameters of the present study, the performance of OC and RCB might be enhanced by the creation of a glide path by using PG or WOGG before final shaping with the OC and RCB. OC has a less aggressive dentin cutting and more centered preparation than the RCB instrument.

Declaration of competing interest

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

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