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Research Article

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Comparison of shaping ability of the Reciproc Blue and One Curve with or without glide path in simulated S-shaped root canals

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ABSTRACT

Objectives: This study aimed to assess the impact of a glide-path on the shaping ability of 2 single-file instruments and to compare the centering ability, maintenance of original canal curvatures and area of instrumentation in simulated S-shaped root canals.
Materials and Methods: Forty simulated S-shaped root canals were used and were prepared with One Curve (group OC), One G and OC (group GOC), Reciproc Blue (group RB) and R-Pilot and RB (group PRB) and scanned before and after instrumentation. The images were analyzed using AutoCAD. After superimposing the samples, 4 levels (D1, D2, D3, and D4) and 2 angles (Δ1 and Δ2) were established to evaluate the centering ability and modification of the canal curvatures. Then, the area of instrumentation (ΔA) was measured. The data were analyzed using 2-way analysis of variance and Tukey's test for multiple comparisons ($p < 0.05$).
Results: Regarding the centering ability in the apical part (D3, D4), the use of the glide-path yielded better results than the single-file groups. Among the groups at D4, OC showed the worst results ($p < 0.05$). The OC system removed less material (ΔA) than the RB system, and for Δ1, OC yielded a worse result than RB ($p < 0.05$).
Conclusions: The glide-path improved the centering ability in the apical part of the simulated S-shaped canals. The RB system showed a better centering ability in the apical part and major respect of the canal curvatures compared with OC system.

Keywords: Centering ability; Glide-path; Instrumentation; Root canal preparation

INTRODUCTION

The introduction of nickel-titanium (NiTi) rotary instruments has improved root canal preparation. NiTi alloy has the advantages of super-elasticity and shape memory effects, which allows the maintenance of the original canal curvature and creates a tapered root canal shape [1]. The reciprocating motion and single-file NiTi systems allow root canal preparation to be developed by using a single instrument, thereby requiring less time than full-sequence

Conflict of Interest
No potential conflict of interest relevant to this article was reported.

Author Contributions
Conceptualization: Marigo L, Grande NM, Biasillo V, Castagnola R. Data curation: Biasillo V, Castagnola R., Minciacchi I, Colangeli M, Panzetta C. Formal analysis: Colangeli M, Panzetta C. Investigation: Biasillo V, Grande NM. Methodology: Grande NM, Marigo L, Biasillo V. Resources: Staffoli S, Grande NM. Supervision: Marigo L, Grande NM. Validation: Staffoli S, Minciacchi I. Writing - original draft: Biasillo V, Castagnola R. Writing - review & editing: Plotino G.

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rotary systems [2]. The reciprocating motion of these NiTi systems relieves stress on the instrument by counter-clockwise (cutting action) and clockwise (release of the instrument) movements, thereby extending their durability and increasing their resistance to cyclic fatigue in comparison with systems that use continuous rotation motion [3].

A large percentage of root canals can be prepared with one instrument and without a preliminary glide-path [4,5]. In barely curved root canals or S-shaped canals, root canal preparation can be a difficult task [6,7]. During the shaping of curved root canals, especially double curved canals, several procedural errors can occur, including apical transportation, zips, ledges, root perforations, loss of working length, straightening of the root canal, or deviation from the original path [8]. In particular, regarding apical transportation, the use of increasingly greater diameter files decreases the angle of curvature, owing to the tendency to move towards the outer wall of the root canal and leading to a non-instrumented inner dentin wall in the apical third, which may result in a worse prognosis for treatment [9,10].

The glide-path is usually formed manually with stainless-steel instruments, but in recent years, NiTi mechanical instruments have been created dedicated exclusively to this task [11]. Compared to manual preparation, the mechanical glide-path technique has been shown to significantly reduce the procedural time, decreasing post-operative pain and flare-ups, while preserving the morphology of the original root canal [12-14].

Reciproc Blue (RB; VDW, Munich, Germany) is a single-file that employs reciprocating motion and kinematics identical to those of Reciproc M-wire but uses an innovative heat treatment that transforms its molecular structure [15]. Thus, this novel system is much more flexible than its predecessor [16]. R-Pilot files (VDW), which are made of M-wire alloy, are engine-driven files for glide-path preparation and designed for use with reciprocating motion [17]. One Curve (OC; Micro Mega, Besancon, France) is a single-use, rotary file that enables shaping of the full length of the canal with a single instrument directly to the apex, manufactured from heat-treated NiTi alloy and characterized by a variable blade shape along its axis [18]. One G (Micro Mega) is a mechanical glide-path instrument with an asymmetrical cross-section. The 3 cutting edges are situated on 3 different radiuses relative to the canal axis with space for debris elimination, cutting action for the pre-enlargement of the canal and snake-like behavior [19].

Similar characteristics of the alloy (heat-treated NiTi alloy) and being single instrument but with different motions (reciprocating and rotating) make these instruments very suitable for comparison. The purpose of this study was to assess the effect of a preliminary glide-path formed by mechanical instruments (R-Pilot and One G) on the shaping ability (centering ability, maintenance of the original canal curvatures and area of instrumentation) of 2 single-file systems (RB and OC) in artificial root canals with double curvature.

MATERIALS AND METHODS

Forty simulated S-shaped root canals made of clear resin were used for this study, with an apical diameter of 0.10 mm and taper 0.00 (Endo training Blocks, VDW). The artificial canal had 2 curvatures, with a coronal angle of 30° and an apical angle of 20°. A size K-file was inserted inside the artificial canal until the tip was visible at the apex and the working length was determined. The artificial canals were prepared with OC (group OC), One G and OC (group GOC), RB (group RB), R-Pilot and RB (group PRB). The instruments were used by a single operator for canal preparation following the indications of the manufacturers, specific for each type of file used. The Reciproc Gold Motor was used (VDW) in reciprocating movement for the RB and R-pilot instruments and in continuous rotation (300 RPM, Torque 2,5 N/cm^2) for the OC and One G instruments. Saline solution was used as an irrigant during instrumentation. Then, the artificial canals were scanned using the Epson Perfection V330 photo scanner at times T0 and T1, before and after instrumentation, respectively. The scans were saved in JPEG format at 4,800 × 8,600 pixels and 12,800 dpi resolution.

AutoCAD analysis

The images were analyzed using the AutoCAD program (version 23.0, 2018). Four levels were defined (D1, D2, D3, and D4), drawn along the entire length and perpendicular to the root canal, at the beginning of the canal (D1), in the center of the first curvature (D2, 7 mm from the apex), in the center of the second curvature (D3, 2 mm from the apex) and at the apex (D4, 0 mm from the apex) (**Figure 1**). For each scan, the contours of the canal were traced and a line was made through the center to indicate the central axis. After superimposing the sample image before instrumentation (T0) and after instrumentation (T1), the distance was measured between the center of the root canal in T0 and the center of the canal in T1 of all samples (centering ability). The distance was taken in the 4 levels already defined (D1, D2, D3, and D4) (**Figure 2**).

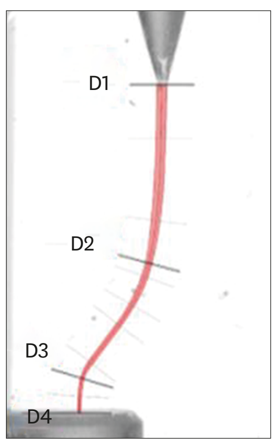

Figure 1. The 4 levels defined in the artificial canals: The beginning of artificial canal (D1); the center of the first curvature (D2); the center of the second curvature (D3); apex level (D4).

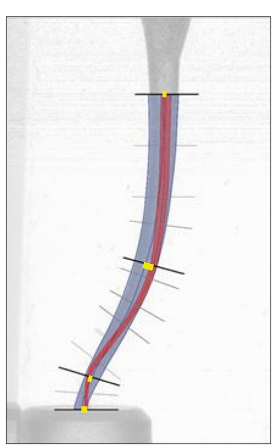

Figure 2. Superimposition of the artificial canal before (red) and after shaping (blue) and the measurement of centering ability (yellow line).

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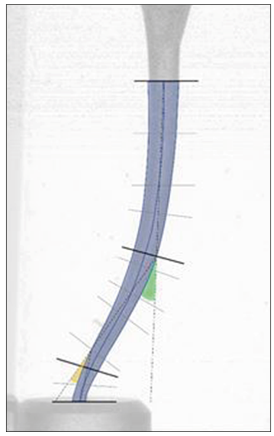

Figure 3. The angles of the 2 curvatures (angle 1, green; angle 2, blue).

The area of the canal (mm^2) from D1 to D4 was measured at T0 and T1 and the difference of the 2 measurements was calculated (ΔA). Then, the angles of the 2 curvatures of the artificial canal were measured before and after instrumentation (Δ1, Δ2), following the Cunningham and Senia method to evaluate the curvature modifications (**Figure 3**) [20]. A file was inserted inside simulated S-shaped root canals. Four points were determined: point 'a' at canal orifice, point 'b' and 'c' where the instrument deviated from the straight edge, point 'd' at apical foramen. Three lines were drawn and the angles formed by the intersection of the 3 lines were measured as the canal curvature.

Statistical analysis

The data were analyzed using 2-way analysis of variance (ANOVA) and Tukey's test for multiple comparisons. The level of statistical significance was set at $p < 0.05$.

RESULTS

The results are shown in **Tables 1** and **2**. Regarding centering ability, the 2-way ANOVA test for D1 showed the use of a single-file technique without glide-path preparation (RB and OC groups) yielded better performance than the use of the glide-path file before the single-file

Table 1. Centering ability

Resin block levels	OC	RB
D1		
Without glide-path	143.46 ± 83.04	122.36 ± 103.36
With glide-path	238.96 ± 121.50	196.18 ± 100.97
D2		
Without glide-path	146.72 ± 94.65	191.36 ± 66.69
With glide-path	165.66 ± 112.85	250.32 ± 102.39
D3		
Without glide-path	109.94 ± 78.52	155.52^B ± 43.87
With glide-path	89.74 ± 83.21	56.04^A ± 34.19
D4		
Without glide-path	451.22^B ± 220.72	184.92^A ± 118.81
With glide-path	158.16^A ± 144.91	167.22^A ± 33.78

Means (μm) ± standard deviation at D1, D2, D3, and D4 after preparation with RB and OC with or without glide-path. The data were analyzed using the 2-way analysis of variance test ($p < 0.05$) and the Tukey-test for multiple comparisons. Different upper case letters denote a statistically significant difference obtained with the Tukey-test. OC, One Curve; RB, Reciproc Blue.

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Table 2. Deviation of original canal curvatures (°) and area of instrumentation (mm^2)

Resin block area and angles	OC	RB
ΔA		
Without glide-path	$4.103^A \pm 0.310$	$5.489^B \pm 0.383$
With glide-path	$4.066^A \pm 0.209$	$5.174^B \pm 0.342$
Δ1		
Without glide-path	$5.0^B \pm 1.76$	$3.0^A \pm 0.67$
With glide-path	3.4 ± 1.71	3.6 ± 0.84
Δ2		
Without glide-path	5.4 ± 3.98	2.6 ± 1.43
With glide-path	3.8 ± 2.44	5.0 ± 2.75

Mean ± standard deviation after instrumentation with RB and OC with or without glide-path. The data were analyzed using the 2-way analysis of variance test ($p < 0.05$) and the Tukey-test for multiple comparisons. Different upper case letters denote a statistically significant difference obtained with the Tukey-test.
OC, One Curve; RB, Reciproc Blue; ΔA, area of the instrumentation; Δ1, angle of the first curvature after instrumentation (green angle in **Figure 3**); Δ2, angle of the second curvature (blue angle in **Figure 3**).

(PRB and GOC groups) ($p < 0.05$), and for D2, there was a statistically better result for the OC system (OC and GOC groups) than the RB system (RB and PRB groups) in terms of centering ability ($p < 0.05$).

In general, for D3 and D4 the 2-way ANOVA test showed the use of the glide-path improved the centering of the shaping ($p < 0.05$), moreover in D4, the RB system (RB and PRB groups) showed a better canal centering ability than the OC system (OC and GOC groups) ($p < 0.05$). Moreover, according to the 2-way ANOVA test, the final area after instrumentation (ΔA) showed that the OC system removed less material than the Reciproc system ($p < 0.05$).

Regarding centering ability, the Tukey-test for D1 and D2 showed no statistically significant differences among the groups ($p > 0.05$). In D3, among the groups, PRB yielded better results than RB ($p < 0.05$). Among the groups in Δ1, RB showed better results than OC while in Δ2, no differences were found in the 2 systems used ($p > 0.05$).

DISCUSSION

In endodontics, considerable attention has always been paid to the phase of obtaining the glide-path as a mandatory clinical step to improve the safety and efficiency of NiTi instruments and to increase the life of the instrument by decreasing the fracture rate and preventing inaccurate shaping [21-23]. Many authors, especially in the past, have emphasized the idea that coronal enlargement and preliminary manual preflaring are fundamental to obtain the glide-path and therefore allow safer use of NiTi rotating instruments [21,22,24,25]. However, the entry into the world of "single-file" endodontics as well as having produced the enormous advantage of simplifying the operating sequence, reducing the number of steps for root canal preparation and, therefore, working times [2,26]. According to some authors, made the creation of a preliminary glide-path unnecessary to avoid screwing and torsional fracture of the instruments for root canal preparation [4,27].

As already done in many previous studies, simulated canals were used to standardize the experimental conditions [13,28,29]. The S-shaped canals, which present a greater difficulty for instrumentation, were used to highlight the differences in the performance of the instruments. However, the use of resin blocks is a limitation of this study. In fact, differences in the hardness of artificial resin and dentinal walls can affect the results. The microhardness of resin materials used for artificial canals is included in a range from 20 to 22 kg/mm^2, while the hardness of dentin is 35-40 kg/mm near the pulp space. In this respect, the force applied to remove dentin of natural teeth is double that for the resin. Moreover, the size of resin chips may be different from natural dentin chips by determining difficulties to remove the debris in the resin canal and so, blockages of the apical root canal space [30]. Zhang *et al.* [31] also described in resin blocks the heat generation during instrumentation can soften the resin material and binding of instrument cutting blades.

The analysis of the samples using AutoCAD software allowed to accurately evaluate the anatomy of the artificial canals before and after instrumentation and to superimpose them to precisely measure the differences between the 2 times (T0 and T1) at which the samples were analyzed (**Figure 4**). Better centering abilities were evident for the single-file instruments (OC and RB groups) in D1 compared to the glide-path groups (RPB and GOC groups). The use of a preliminary glide-path in the coronal part of the artificial canal probably caused major deviation from the center of the canal. The brushing motion of the glide-path instrument performed by operator may not have been homogeneous throughout the circumference of the coronal part of the artificial canal. Regarding D3 and D4, the glide-path groups (GOC and PRB groups) showed a better centering ability than the groups without a preliminary glide-path (OC and RB respectively). Keskin *et al.* [32] affirmed that glide-path preparation with a Proglider instrument improved the shaping ability of the RB R25 instrument. In contrast with our results, Bürklein *et al.* [33] reported that glide-path preparation had no impact on the centering ability of rotary and reciprocation systems in resin blocks double curved. In the apical part of the canal (D4), the RB system had a better performance than the OC system. This result is confirmed by several studies that have reported that instruments with reciprocating motion have better centering ability than those with continuous rotation motion [34-37].

The ΔA of the OC system showed that this file removed less resin compared with the RB system. The higher area could be related to the higher apical taper of the RB system. Furthermore, Özyürek *et al.* [38] found that the Reciproc 25 removed a statistically significantly higher amount of resin from every canal zones when compared with the WaveOne gold and Hyflex EDM in double curved resin block. The RB system (RPB and RB groups) better maintained the first canal curvature (Δ1) than the OC system (OC and GOC groups), but no differences were found for the apical curvature (Δ2). The reciprocating

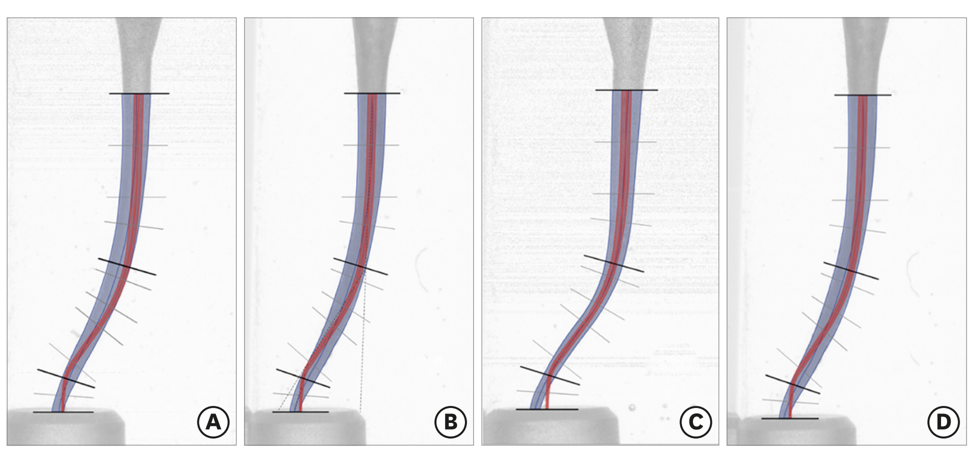

Figure 4. The 4 simulated resin blocks groups after superimposition, R-Pilot and Reciproc Blue (RPB) (A), Reciproc Blue (RB) (B), One Curve (OC) (C), One G and One Curve (GOC) (D).

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motion may have positively influenced these results. In fact, Dhingra *et al.* [39] reported that the WaveOne NiTi Primary reciprocating single-file better maintained the original canal anatomy, reducing deviations in the canal curvature compared with the OneShape continuous rotary file system.

CONCLUSIONS

Under the conditions of the present study, glide-path preparation improved the centering ability of both the single-instruments in the apical part of the canal in resin blocks with S-shaped canals, regardless of reciprocating or rotational movement. In addition, RB with or without the use of the glide-path file showed better centering ability in the apical part and higher respect of the canal curvature of the artificial canal in comparison with OC.

REFERENCES

1. Walia HM, Brantley WA, Gerstein H. An initial investigation of the bending and torsional properties of Nitinol root canal files. J Endod 1988;14:346-351.
PUBMED | CROSSREF
2. Bürklein S, Hinschitza K, Dammaschke T, Schäfer E. Shaping ability and cleaning effectiveness of two single-file systems in severely curved root canals of extracted teeth: Reciproc and WaveOne versus Mtwo and ProTaper. Int Endod J 2012;45:449-461.
PUBMED | CROSSREF
3. Plotino G, Grande NM, Testarelli L, Gambarini G. Cyclic fatigue of Reciproc and WaveOne reciprocating instruments. Int Endod J 2012;45:614-618.
PUBMED | CROSSREF
4. De-Deus G, Arruda TEP, Souza EM, Neves A, Magalhães K, Thuanne E, Fidel RAS. The ability of the Reciproc R25 instrument to reach the full root canal working length without a glide path. Int Endod J 2013;46:993-998.
PUBMED | CROSSREF
5. Zuolo ML, Carvalho MC, De-Deus G. Negotiability of second mesiobuccal canals in maxillary molars using a reciprocating system. J Endod 2015;41:1913-1917.
PUBMED | CROSSREF
6. Yun HH, Kim SK. A comparison of the shaping abilities of 4 nickel-titanium rotary instruments in simulated root canals. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2003;95:228-233.
PUBMED | CROSSREF
7. Schäfer E, Florek H. Efficiency of rotary nickel-titanium K3 instruments compared with stainless steel hand K-Flexofile. Part 1. Shaping ability in simulated curved canals. Int Endod J 2003;36:199-207.
PUBMED | CROSSREF
8. Peters OA. Current challenges and concepts in the preparation of root canal systems: a review. J Endod 2004;30:559-567.
PUBMED | CROSSREF
9. Greene KJ, Krell KV. Clinical factors associated with ledged canals in maxillary and mandibular molars. Oral Surg Oral Med Oral Pathol 1990;70:490-497.
PUBMED | CROSSREF
10. Schäfer E, Vlassis M. Comparative investigation of two rotary nickel-titanium instruments: ProTaper versus RaCe. Part 1. Shaping ability in simulated curved canals. Int Endod J 2004;37:229-238.
PUBMED | CROSSREF
11. Plotino G, Nagendrababu V, Bukiet F, Grande NM, Veettil SK, De-Deus G, Aly Ahmed HM. Influence of negotiation, glide path, and preflaring procedures on root canal shaping-terminology, basic concepts, and a systematic review. J Endod 2020;46:707-729.
PUBMED | CROSSREF
12. Ruddle CJ, Machtou P, West JD. Endodontic canal preparation: innovations in glide path management and shaping canals. Dent Today 2014;33:118-123.
PUBMED

13. Berutti E, Cantatore G, Castellucci A, Chiandussi G, Pera F, Migliaretti G, Pasqualini D. Use of nickel-titanium rotary PathFile to create the glide path: comparison with manual preflaring in simulated root canals. J Endod 2009;35:408-412.
PUBMED | CROSSREF

14. Pasqualini D, Bianchi CC, Paolino DS, Mancini L, Cemenasco A, Cantatore G, Castellucci A, Berutti E. Computed micro-tomographic evaluation of glide path with nickel-titanium rotary PathFile in maxillary first molars curved canals. J Endod 2012;38:389-393.
PUBMED | CROSSREF

15. Plotino G, Grande NM, Testarelli L, Gambarini G, Castagnola R, Rossetti A, Özyürek T, Cordaro M, Fortunato L. Cyclic fatigue of reciproc and reciproc blue nickel-titanium reciprocating files at different environmental temperatures. J Endod 2018;44:1549-1552.
PUBMED | CROSSREF

16. De-Deus G, Silva EJNL, Vieira VTL, Belladonna FG, Elias CN, Plotino G, Grande NM. Blue thermomechanical treatment optimizes fatigue resistance and flexibility of the reciproc files. J Endod 2017;43:462-466.
PUBMED | CROSSREF

17. Özyürek T, Uslu G, Gündoğar M, Yılmaz K, Grande NM, Plotino G. Comparison of cyclic fatigue resistance and bending properties of two reciprocating nickel-titanium glide path files. Int Endod J 2018;51:1047-1052.
PUBMED | CROSSREF

18. Staffoli S, Grande NM, Plotino G, Özyürek T, Gündoğar M, Fortunato L, Polimeni A. Influence of environmental temperature, heat-treatment and design on the cyclic fatigue resistance of three generations of a single-file nickel-titanium rotary instrument. Odontology 2019;107:301-307.
PUBMED | CROSSREF

19. Yılmaz K, Uslu G, Gündoğar M, Özyürek T, Grande NM, Plotino G. Cyclic fatigue resistances of several nickel-titanium glide path rotary and reciprocating instruments at body temperature. Int Endod J 2018;51:924-930.
PUBMED | CROSSREF

20. Cunningham CJ, Senia ES. A three-dimensional study of canal curvatures in the mesial roots of mandibular molars. J Endod 1992;18:294-300.
PUBMED | CROSSREF

21. Berutti E, Negro AR, Lendini M, Pasqualini D. Influence of manual preflaring and torque on the failure rate of ProTaper rotary instruments. J Endod 2004;30:228-230.
PUBMED | CROSSREF

22. Patiño PV, Biedma BM, Liébana CR, Cantatore G, Bahillo JG. The influence of a manual glide path on the separation rate of NiTi rotary instruments. J Endod 2005;31:114-116.
PUBMED | CROSSREF

23. D'Amario M, Baldi M, Petricca R, De Angelis F, El Abed R, D'Arcangelo C. Evaluation of a new nickel-titanium system to create the glide path in root canal preparation of curved canals. J Endod 2013;39:1581-1584.
PUBMED | CROSSREF

24. Roland DD, Andelin WE, Browning DF, Hsu GHR, Torabinejad M. The effect of preflaring on the rates of separation for 0.04 taper nickel titanium rotary instruments. J Endod 2002;28:543-545.
PUBMED | CROSSREF

25. Peters OA, Peters CI, Schönenberger K, Barbakow F. ProTaper rotary root canal preparation: effects of canal anatomy on final shape analysed by micro CT. Int Endod J 2003;36:86-92.
PUBMED | CROSSREF

26. Abu Haimed A, Abuhaimed T, Dummer P, Bryant S. The root canal shaping ability of WaveOne and Reciproc versus ProTaper Universal and Mtwo rotary NiTi systems. Saudi Endod J 2017;7:8-15.
CROSSREF

27. Yared G. Canal preparation with only one reciprocating instrument without prior hand filing: a new concept. Peterborough: Quality Endodontic Distributors Ltd; 2010. p1-8.

28. Uslu G, Özyürek T, Yılmaz K, Gündoğar M. Cyclic fatigue resistance of R-Pilot, HyFlex EDM and PathFile nickel-titanium glide path files in artificial canals with double (S-shaped) curvature. Int Endod J 2018;51:584-589.
PUBMED | CROSSREF

29. Topçuoğlu HS, Düzgün S, Aktı A, Topçuoğlu G. Laboratory comparison of cyclic fatigue resistance of WaveOne Gold, Reciproc and WaveOne files in canals with a double curvature. Int Endod J 2017;50:713-717.
PUBMED | CROSSREF

30. Hulsmann M, Peters OA, Dummer PMH. Mechanical preparation of root canals: shaping goals, techniques and means. Endod Topics 2005;10:30-76.
CROSSREF

31. Zhang L, Luo HX, Zhou XD, Tan H, Huang DM. The shaping effect of the combination of two rotary nickel-titanium instruments in simulated S-shaped canals. J Endod 2008;34:456-458.
PUBMED | CROSSREF
32. Keskin C, Sarıyılmaz E, Demiral M. Shaping ability of Reciproc Blue reciprocating instruments with or without glide path in simulated S-shaped root canals. J Dent Res Dent Clin Dent Prospect 2018;12:63-67.
PUBMED | CROSSREF
33. Bürklein S, Poschmann T, Schäfer E. Shaping ability of different nickel-titanium systems in simulated S-shaped canals with and without glide path. J Endod 2014;40:1231-1234.
PUBMED | CROSSREF
34. Navós BV, Hoppe CB, Mestieri LB, Böttcher DE, Só MVR, Grecca FS. Centering and transportation: *in vitro* evaluation of continuous and reciprocating systems in curved root canals. J Conserv Dent 2016;19:478-481.
PUBMED | CROSSREF
35. Jain A, Asrani H, Singhal AC, Bhatia TK, Sharma V, Jaiswal P. Comparative evaluation of canal transportation, centering ability, and remaining dentin thickness between WaveOne and ProTaper rotary by using cone beam computed tomography: an *in vitro* study. J Conserv Dent 2016;19:440-444.
PUBMED | CROSSREF
36. Yao J, Sun Y, Yang M, Duan Y. Chemistry, physics and biology of graphene-based nanomaterials: New horizons for sensing, imaging and medicine. J Mater Chem 2012;22:14313-14329.
CROSSREF
37. Elashiry MM, Saber SE, Elashry SH. Comparison of shaping ability of different single-file systems using microcomputed tomography. Eur J Dent 2020;14:70-76.
PUBMED | CROSSREF
38. Özyürek T, Yılmaz K, Uslu G. Shaping ability of reciproc, waveone gold, and hyflex edm single-file systems in simulated s-shaped canals. J Endod 2017;43:805-809.
PUBMED | CROSSREF
39. Dhingra A, Kochar R, Banerjee S, Srivastava P. Comparative evaluation of the canal curvature modifications after instrumentation with One Shape rotary and Wave One reciprocating files. J Conserv Dent 2014;17:138-141.
PUBMED | CROSSREF