http://dx.doi.org/10.17159/2519-0105/2022/v77no1a2

Shaping ability of WaveOne Gold reciprocating instruments compared to two analogous counterparts

SADJ February 2022, Vol. 77 No. 1 p12- 17

C Victor[1], P J van der Vyver[2], F Paleker[3], M Vorster[4], Z I Vally[5]

ABSTRACT

Introduction

The aim of this study was to evaluate and compare canal centering ability and transportation of three analogous reciprocating shaping instruments after glide path preparation.

Methods

Radiographs were used to select sixty untreated mesiobuccal canals with curvatures of 25° to 35° from extracted, human, mandibular molars. The canals were randomly divided into three groups for glide path preparation and shaping (n = 20): Group TWOG (WaveOne Gold Glider + Primary WaveOne Gold); Group TEF (Edge GlidePath + Primary EdgeOne Fire); and Group TOFG (One File G Reciprocating Glide Path File + Primary Shaping file). Pre- and post-preparation micro-CT scans were compared at levels 7 mm (coronal), 5 mm (midroot), and 3 mm (apical) from the apex to evaluate transportation and centering ratios.

Results

There were no significant differences in centering ratios at the coronal and midroot levels ($P > 0.05$). Transportation values were similar at the coronal level and for the combined mean values ($P > 0.05$). Transportation values for TEF and TWOG were similar ($P = 0.98$) at the midroot level but significantly lower than TOFG ($P = 0.04$). Apically, TEF remained significantly more centered with significantly lower transportation values than TWOG and TOFG ($P < 0.05$). Combined results showed that TEF was significantly more centered than TWOG but similar to TOFG ($P = 0.017$).

Conclusions

Centering ratios and transportation values were more favorable in the apical region after use of TEF. All three groups evaluated in this study proved to be safe for the preparation of moderately curved root canals.

Author affiliations:

1. Christiaan Victor: *BChD, PG Dip Dent (Endo)(Pret), PG Dip Dent (Impl), MSc (Pret).* Department of Odontology, School of Dentistry, University of Pretoria, Pretoria, South Africa. ORCID Number: 0000-0003-1279-7101.
2. Peet J van der Vyver: *BChD, PG Dip Dent (Endo), PG Dip Dent (Aesthet Dent), MSc, PhD (Pret).* Department of Odontology, School of Dentistry, University of Pretoria, Pretoria, South Africa. ORCID Number: 0000-0003-1951-6042.
3. Martin Vorster: *BChD, PG Dip Dent (Endo), MSc (Pret).* Department of Odontology, School of Dentistry, University of Pretoria, Pretoria, South Africa. ORCID Number: 0000-0003-4470-1530.
4. Farzana Paleker: *BChD (Stell), Dip Odont (Endo), MSc (Pret).* Department of Odontology, School of Dentistry, University of Pretoria, Pretoria, South Africa. ORCID Number: 0000-0002-5446-309X
5. Zunaid I Vally: *BDS, MDent (Prosthodontics)(Wits).* Department of Odontology, School of Dentistry, University of Pretoria, Pretoria, South Africa. ORCID Number: 0000-0002-2718-4706.

Corresponding author:
Peet J van der Vyver
Department of Odontology, School of Dentistry, University of Pretoria, Gauteng, South Africa.
Email: peetv@iafrica.com

Author contributions:

1. Christiaan Victor: Contributed to the data collection and analysis, scientific writing, and proofreading of the manuscript - 30%
2. Peet J van der Vyver: Contribute to the data analysis, scientific writing and proofreading of the manuscript - 20%
3. Farzana Paleker: Contribute to the data analysis, scientific writing and proofreading of the manuscript - 20%
4. Martin Vorster: Contribute to the scientific writing and proofreading of the manuscript - 20%
5. Zunaid I Vally: Contribute to the scientific writing and proofreading of the manuscript - 10%

INTRODUCTION

Micro computed tomography (micro-CT) studies produce the most accurate and non-invasive 3D images that allow researchers to examine the effects of endodontic instruments within root canal systems.[1–4] The interaction of three main instrument factors can have an effect on the preservation of the original canal anatomy during endodontic treatment: the cross-sectional design of the file, kinematics, and the alloy of the nickel-titanium (NiTi) instrument.[5] Several kinematic studies have examined shaping ability following the use of instruments in either a rotational or a reciprocal motion and concluded that reciprocation results in superior shaping and fewer transported canals.[6–9] Thermomechanical processes have resulted in the development of NiTi endodontic glide path and shaping files with increased flexibility and fatigue resistance compared to their predecessors. Companies are now developing analogous instrumentation systems that are similar in form and function to their competitors' but are constructed from differing proprietary heat-treated NiTi.

The WaveOne Gold Glider (Dentsply Sirona, Ballaigues, Switzerland), a single glide path file, and WaveOne Gold (Dentsply Sirona) shaping files are reciprocating systems manufactured from Gold wire. The Edge GlidePath file (EdgeEndo, Albuquerque, New Mexico, USA) is a variable tapered single rotary glide path file and EdgeOne Fire (EdgeEndo) is a reciprocating shaping system similar to WaveOne Gold. Both systems are manufactured from a proprietary heat-treated NiTi known as "FireWire".[10,11] The One File G Reciprocating File System (Pac-Dent, Brea, CA, USA) consists of a single glide path file and four shaping

files. One File Shaping files (Pac-Dent) are used with the same handpiece settings as WaveOne Gold. The One File Glide Path- and Shaping files are constructed from a proprietary heat-treated NiTi wire.[12]

Root canal transportation is assessed by measuring the amount of dentine remove (in millimetres) from the outside wall of the canal due to the tendency of root canal shaping instruments to restore to their original shape.[13] This procedural error may lead to ledge formation or even strip perforation. Centering ability is defined as how well the shaping instrument preserved the original canal anatomy when equal amounts of transportation occur in all directions relating to the original canal anatomy. Centering ability is measured as a ratio of transportation and a measurement closest to 1, indicates a more centered root canal preparation.[14] The purpose of this *ex vivo* study was to use micro-CT to compare canal centering ability and transportation of three reciprocating shaping instruments after glide path preparation: WaveOne Gold Glider combined with the Primary WaveOne Gold; Edge GlidePath followed by the Primary EdgeOne Fire; and One File Glide Path file combined with the Primary One File Shaping file. The null hypothesis tested was that there are no differences in canal centering ability and canal transportation values between the three groups. Currently, there are no published studies comparing canal centering ability and transportation of these analogous shaping systems.

MATERIALS AND METHODS

Specimen preparation

Mandibular first molar teeth extracted for reasons unrelated to this study were used in accordance with approval from the local ethics committee. Radiographs (Carestream Health Inc., NY State, USA) were taken to select sixty previously untreated, curved, separate mesiobuccal canals, each with a curvature of 25° to 35° according to the Schneider method.[15] Immature molars with open apices, and resorption was excluded from this study. Molars with sclerosed mesio-buccal canals was also eliminated from the study during the preparation stage.

Specimens were engraved from 1 to 60 before being randomly divided into three experimental instrumentation groups of 20 canals each (Research Randomizer version 4.0).[16]

A pre-instrumentation scan of each selected tooth was carried out using a XTH 225 ST micro-focus X-ray CT system (Nikon Metrology, Leuven, Belgium). The micro-CT system was used at settings of 100 kV, 100 mA and an isotropic resolution of 22 µm. The roots of each tooth were placed in a polystyrene platform (2.5 x 2.5 x 2.5 cm) and aligned perpendicular to the scanning beam. VGStudioMax visualization software (Volume Graphics GmbH, Heidelberg, Germany) was used to confirm the curvatures of the mesiobuccal canals.

After access cavity preparation using and Endo Access Bur (size 2) (Dentsply, Mailefer), each mesiobuccal canal was located and patency was confirmed with a size 08 K-file. Working length (WL) was determined by deducting 0.5 mm from the length of the canal measured to the major apical terminus under 10 times magnification using a surgical microscope (Zumax Medical Co. Ltd, Suzhou, China). An initial manually reproducible micro-glide path was prepared by negotiating size a 08 K-file, followed by a size 10 K-file, to WL with increasing amplitudes of 1–3 mm.

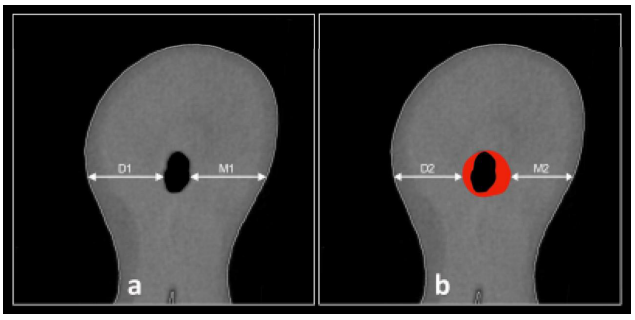

Figure 1. Pre-instrumentation (a) and post-instrumentation (b) micro-CT images in the axial plane showing the effects of instrumentation (red), and points of measurements used for determination of centering ability and canal transportation.

Glide path preparation and root canal shaping

Glide path preparation and root canal shaping were carried out by the same operator and new files were used for each tooth. RC Prep (Premier, Pennsylvania, USA) was used as a lubricating agent during glide path enlargement and canal shaping. The mesiobuccal canals were irrigated with 2 ml of 3.5% sodium hypochlorite following the use of each instrument. Patency was maintained throughout the glide path and root canal preparations with a size 08 K-file.

Group TWOG (n=20)

The X-Smart IQ endodontic motor (Dentsply Sirona) was used in reciprocation mode for both glide path preparation with the Wave One Gold Glider (WOGG), and shaping with the Primary Wave One Gold (WOG). This was done on the WaveOne (Dentsply Sirona) setting, according to the manufacturer's instructions.

Group TEF (n=20)

The Edge GlidePath File (EGP), according to the manufacturer's instructions, was used to prepare glide paths using the X-Smart IQ endodontic motor in rotation mode on the ProGlider (Dentsply Sirona) setting at a speed of 350 rpm. Root canal shaping in this group was carried out as per the manufacturer's guidelines, using the same motor in reciprocation mode on the WaveOne setting with the Primary EdgeOne Fire file (EOF).

Group TOFG (n=20)

The X-Smart IQ endodontic motor (Dentsply Sirona) was used in reciprocation mode for both glide path preparation with the One File Glide Path file (OFGP), and shaping with the Primary One File Shaping file (OFS). This was done on the WaveOne setting according to the manufacturer's instructions.

The teeth were scanned again to generate a post-instrumentation scan for each specimen. Using VGStudioMax software (Volume Graphics GmbH), specimen images from the pre- and post-instrumentation scans were identified by their engraved numbers and aligned according to the Cemento Enamel Junction (CEJ). This enabled superimposition of each mesiobuccal canal and allowed for pre- and post-instrumentation analyses.

Data collection and measurements

Cross-sections of each mesiobuccal canal at levels: 7 mm (coronal), 5 mm (midroot), and 3 mm (apical) from the anatomical apex were evaluated. The three levels chosen to evaluate file system performance and canal preservation represent the apical, middle and coronal aspects of the curvature, where the

root is most susceptible to iatrogenic aberrations.[17,18] The shortest distance from the prepared canal to the mesial or distal wall of the tooth at these levels were measured to determine the centering ratio and canal transportation values according to the formulae set out below.[14,18–20]

Canal transportation = (M1-M2) – (D1-D2). A transportation value closest to 0 indicated that no transportation occurred. Canal centering ratio = (M1-M2)/(D1-D2) where (D1-D2 > M1-M2) or (D1-D2)/(M1-M2) where (M1-M1) > (D1-D2). A value closest to 1 indicated a perfect centering ability.[14] M1 is the shortest distance from the mesial margin of tooth measured to the mesial margin of uninstrumented canal and M2 is the shortest distance from mesial margin of tooth measured to the mesial margin of the instrumented canal. Similarly, D1 is the shortest distance from the distal margin of tooth measured to the distal margin of the uninstrumented canal and D2 is the shortest distance from the distal margin of tooth measured to the distal margin of the instrumented canal (Fig. 1).

Statistical analysis

Canal transportation and centering ratio values were compared between the three groups by a one-way analysis of variance (ANOVA). Comparison among groups was also done using the non-parametric Kruskal-Wallis H test.

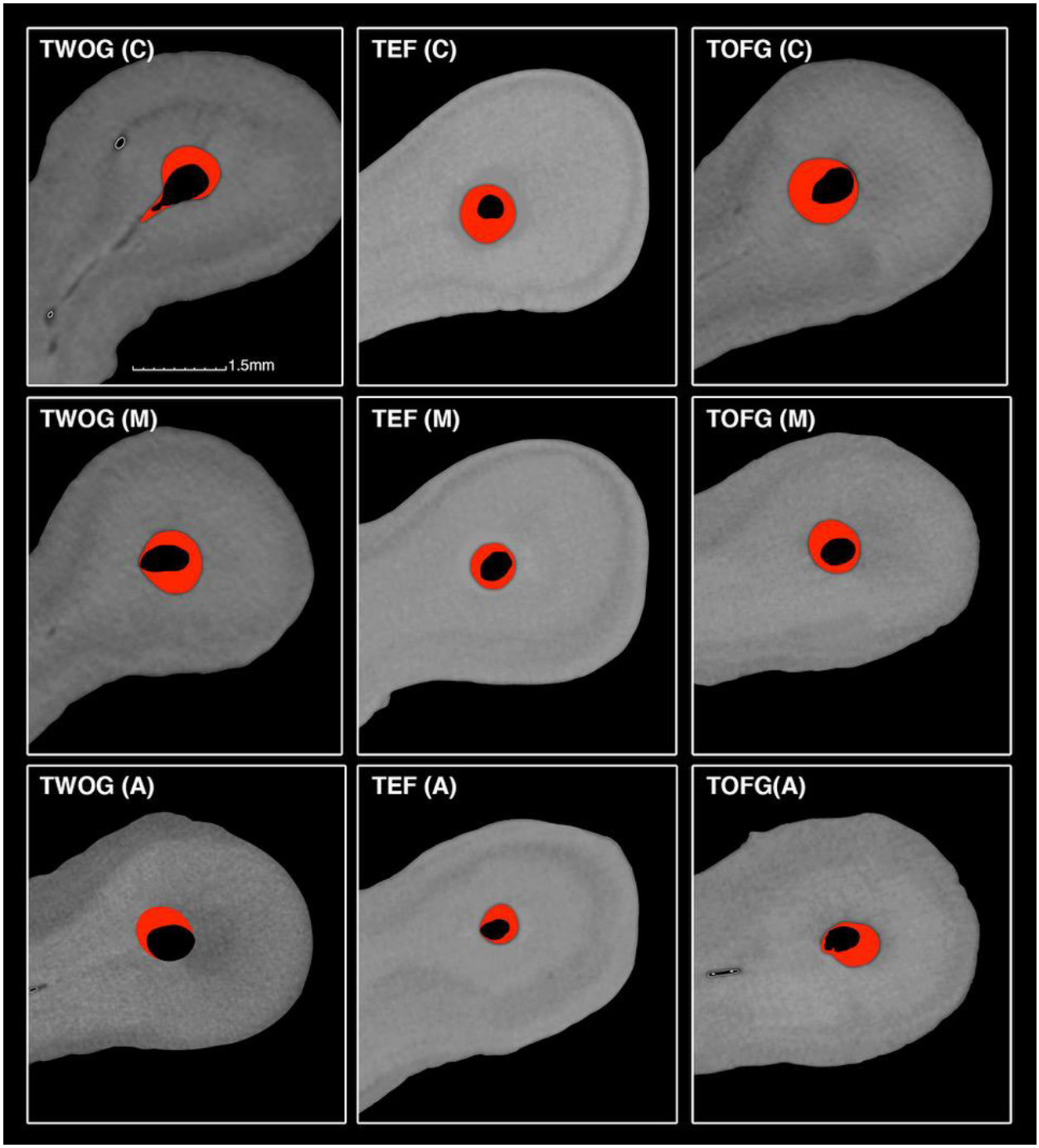

Figure 2. Representative cross sections of the superimposed root canals before and after final shaping (red) at the: coronal (C), middle (M), and apical (A) thirds.

Table 1 Descriptive statistics of the mean centering ratio values for the tested groups (n=20)

Group	Coronal		Midroot		Apical		Combined	
	Mean ± SD	Min-Max	Mean ± SD	Min-Max	Mean ± SD	Min-Max	Mean ± SD	Min-Max
TWOG	0.39a ± 0.27	0.07 – 0.97	0.42a ± 0.26	0.03 – 0.84	0.38b ± 0.28	0.03 – 1.00	0.40b,c ± 0.27	0.03 – 1.00
TEF	0.44a ± 0.25	0.07 – 0.92	0.56a ± 0.27	0.01 – 0.98	0.63a ± 0.31	0.02 – 1.00	0.54a ± 0.29	0.01 – 1.00
TOFG	0.51a ± 0.27	0.08 – 0.97	0.42a ± 0.25	0.09 – 0.83	0.41b ± 0.32	0.02 – 0.94	0.44a,c ± 0.28	0.02 – 0.97

Different superscript letters in the same column indicate a significant difference at $P < 0.05$.

Table 2 Descriptive statistics of the transportation values (mm) for the tested groups (n=20)

Group	Coronal		Midroot		Apical		Combined	
	Mean ± SD	Min-Max	Mean ± SD	Min-Max	Mean ± SD	Min-Max	Mean ± SD	Min-Max
TWOG	0.19a ± 0.18	0.01 – 0.87	0.09a ± 0.07	0.01 – 0.26	0.13b ± 0.07	0.02 – 0.25	0.14a ± 0.12	0.01 – 0.87
TEF	0.19a ± 0.14	0.00 – 0.52	0.09a ± 0.08	0.01 – 0.27	0.06a ± 0.06	0.00 – 0.24	0.11a ± 0.07	0.00 – 0.52
TOFG	0.14a ± 0.14	0.01 – 0.66	0.19b ± 0.24	0.02 – 0.77	0.16b ± 0.20	0.00 – 0.74	0.16a ± 0.20	0.01 – 0.77

Different superscript letters in the same column indicate a significant difference at $P < 0.05$.

Statistical significance was set at $P < 0.05$. All statistical procedures were performed on SAS (SA Institute Inc, Carey, NC, USA), release 9.4, or higher running under Microsoft Windows (Redmond, WA, USA).

RESULTS

Following instrumentation, all the canals remained patent without any loss of working length. No instrument fracture or deformation was noted. Figure 2 represents cross sections of the superimposed root canals before and after final shaping at the coronal (C), middle (M), and apical (A) thirds levels of analysis for each of the three groups.

Centering ratio

The results for canal centering are summarized in Table 1. Centering ratios for TEF were the highest at each level. However, no statistically significant differences between the three groups were found at the coronal and midroot levels. The TEF group displayed significantly better centering ratio values at the apical level. When all the results were combined, TEF was shown to be significantly more centered than TWOG but similar to TOFG. TWOG and TOFG displayed similar apical and combined centering ratios.

Canal transportation

Canal transportation results are summarized in Table 2. No statistically significant differences between the three groups were found at the coronal level. At the midroot level, transportation values for TEF and TWOG were the same. Both these groups performed significantly better than TOFG at this level. TEF performed significantly better at the apical level than the other two groups, which were found to be statistically similar. No significant differences were observed when the results were combined.

DISCUSSION

Assessment of centering ratios and transportation values after root canal instrumentation may reveal how effective instruments are in maintaining the original root canal anatomy and minimizing the risk of shaping errors. The present micro-CT study evaluated the ability of three different glide path files combined with their corresponding shaping systems to produce centred preparations without transportation, in curved root canals. There are no studies comparing these new analogous file systems to the existing WOG system. Although instruments of comparable diameter and taper were used for final canal preparation in the present study, there were some differences in their respective designs and alloy construction that could have influenced their shaping ability.[21] Additional factors that can affect the shaping ability of an instrument include the cross-sectional design of the file, operator technique, and canal system anatomy.[22,23] In this study a single operator instrumented all the mesiobuccal canals with similar curvatures using glide path and analogous shaping files in the same motor, according to the manufacturer's instructions.

Single glide path and root canal shaping instrument systems were used in this study to achieve final apical preparation sizes of ISO 25. The combination of EGP and EOF (TEF) performed significantly better than the other two groups when centering ability was assessed at the apical level and when the results for all three levels were combined. In the apical third, mean transportation values for TEF were significantly lower than the other two groups, which were found to be similar. TWOG and TEF exhibited the same mean transportation value in the middle third, which was significantly lower than TOFG.

The shaping performance of the TEF group at the apical level in this study could be attributed to its annealed heat-treated FireWire NiTi composition and/or the design of the EGP and EOF. EOF files have similar cross-sectional designs, three-dimensional characteristics, and tip sizes to the WOG system. Each of the three shaping files in in the current study has a parallelogram-shaped cross-section. The EOF however has a fixed taper (D1–D3) of 6% compared to WOG and OFS, which both have 7% fixed tapers (D1–D3). Only the Primary WOG has semi-active guiding tip, whereas the Primary EOF and Primary OFG tips are non-cutting. The individual tip designs could explain why TEF performed more favourably than TWOG in the apical region while transportation results in the middle third for these two groups were the same.

Each instrument was used in a reciprocating motion except for the EGP, which was used in continuous rotation before final shaping with the Primary EOF.

Recently EdgeEndo launched its reciprocating glide path file, EdgeOne Fire GlidePath, which was not available at the time this research was undertaken. EGP presents with a triangular cross-section and a progressive taper, while WOGG and OFGP each have a parallelogram-shaped cross-section with a variable and progressively decreasing taper. The WOGG was the only glide path file with a semi-active tip. Although each canal was shaped to final size of ISO 25, final glide path sizes were not equivalent. EGP has an ISO 19 tip compared to ISO 15 tip sizes of the other two glide path files. The importance of glide path preparation was reiterated in a recent review concluding that glide path preparation helps preserve the original canal anatomy.[24] It could be speculated, although this was not evaluated in this study, that use of the EGP file, in continuous rotation, prior to the EOG instrument positively influenced the favourable results ultimately delivered by the TEF group.

FireWire seems to exhibit superior cyclic fatigue resistance and flexibility to Gold/Blue heat-treated instruments. According to recent studies, these characteristics can be attributed to the "peculiar three-dimensional aspect of the crystalline matrix" of this alloy.[25,26] A study by Hasheminia *et al* (2018) compared canal transportation and centering ability of Reciproc (VDW), WaveOne (Dentsply Sirona), and EdgeFile (EdgeEndo), which is made from the same FireWire heat-treated NiTi as EdgeOne Fire. In their study, EdgeFile exhibited the lowest transportation and the best centering ability of all the groups tested.[27]

A recent study by Lee *et al.* [26] compared the mechanical properties of ProGlider (Dentsply Sirona), One G (MicroMega), and EGP. They concluded that EGP had the highest residual angle of the three systems tested. The residual angle is measured by bending a file along its main axis while it remains fixed in a jig at its apical end. This angle is defined as "the angle between the bent file and the first position where the bent file did not return to the starting position". A file with a high residual angle is able to retain its modified shape at a higher angle, which aids in maintaining the centre of the root canal.[26,28,29]

Overall, in the apical region, centering ratio and transportation values were found to be significantly more favourable after the use of TEF therefore rejecting the null hypothesis. Although significant differences in canal transportation and centering were found in the apical region, their clinical relevance remains questionable and probably has limited importance in these moderately curved canals. According to a review by Peters[30] and a recent study by Pinheiro *et al.*,[31] apical canal transportation of up to 0.15 mm may be considered acceptable. In the current study, the mean transportation value of only TOFG exceeded 0.15 mm at the apical level.

The three combination groups evaluated in this study proved to be safe for the preparation of mesiobuccal canals of mandibular molars with moderate curvature. The limited information on EdgeEndo and One File G systems in the literature made it impossible to compare the results obtained in this study with other studies. To date, no article has been published on the shaping ability of these file combinations. It is however recommended that further studies are needed to evaluate the different performance of these endodontic glide path and shaping systems.

Acknowledgements

The authors wish to thank the South African National Centre for Radiography and Tomography, Radiation Science, South African Nuclear Energy Corp for the use of the Micro-Focus X-ray Tomography Facility, particularly Mr. Jacobus Hoffman and Ms. Clarissa Sutherland for their time and assistance with the reconstruction of micro-focus x-ray images. The authors state explicitly that there is no conflict of interest in connection with this article.

References

1. Peters OA, Laib A, Göhring TN, et al. Changes in root canal geometry after preparation assessed by high-resolution computed tomography. J Endod 2001;27(1):1–6. Doi: 10.1097/00004770-200101000-00001.
2. Versiani MA, Leoni GB, Steier L, et al. Micro-computed tomography study of oval-shaped canals prepared with the self-adjusting file, Reciproc, WaveOne, and ProTaper universal systems. J Endod 2013;39(8):1060–6. Doi: 10.1016/j.joen.2013.04.009. Epub 2013 May 22. PMID: 23880278.
3. Van der Vyver PJ, Paleker F, Vorster M, et al. Root canal shaping using nickel titanium, M-Wire, and Gold Wire: a micro–computed tomographic comparative study of One Shape, ProTaper Next, and WaveOne Gold instruments in maxillary first molars. J Endod 2019;45(1):62–7. Doi: 10.1016/j.joen.2018.09.013.
4. Paqué F, Ganahl D, Peters OA. Effects of root canal preparation on apical geometry assessed by micro-computed tomography. J Endod 2009;35(7):1056–9.
5. Plotino G, Mohamed H, Ahmed A, et al. Current assessment of reciprocation in endodontic preparation: A comprehensive review — Part II: properties and effectiveness. J Endod 2015;41:1939–50.
6. Franco V, Fabiani C, Taschieri S, et al. Investigation on the shaping ability of nickel–titanium files when used with a reciprocating motion. J Endod 2011;37:1398–401.
7. Giuliani V, Di Nasso L, Pace R, et al. Shaping ability of WaveOne primary reciprocating files and ProTaper system used in continuous and reciprocating motion. J Endod 2014;40(9):1468–71.
8. Tambe VH, Nagmode PS, Abraham S, et al. Comparison of canal transportation and centering ability of rotary protaper, one shape system and wave one system using cone beam computed tomography: an in vitro study. J Conserv Dent 2014;17:561–5.
9. Saber SE, Nagy MM, Schäfer E. Comparative evaluation of the shaping ability of WaveOne, Reciproc and OneShape single-file systems in severely curved root canals of extracted teeth. Int Endod J 2015;48:109–14.
10. EdgeEndo. EdgeGlidePath. Available at: https://www.edgeendo.com/wp-content/uploads/2019/01/DFU-EdgeGlidePath.pdf. Accessed October 15, 2019, 2016.
11. Tomer AK, Miglani A, Sahni S, et al. Comparison of efficacy of three Ni-Ti instruments in removal of gutta-percha from root canal during retreatment- an in vitro study. IOSR J Dent Med Sci 2017;16:32–7.
12. PacDent. One File G Reciprocating File. Available at: https://pac-dent.com/collections/files/products/one-file-g-reciprocating-file. Accessed October 21, 2019, 2018.
13. Glossary of endodontic terms: American Association of

Endodontists 9th Edn. Chicarho, American Association of Endodontists.2016. Available at http://www.aae.org/speciality/clinical-resources/glossary-endodontic-terms/
14. Gambill JM, Alder M, Carlos E. Comparison of nickel-titanium and stainless steel hand-file instrumentation using computed tomography. J Endod. 1996;22(7):369-75.
15. Schneider SW. A comparison of canal preparations in straight and curved root canals. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1971;32:271–5.
16. Urbaniak GC, Pious S. Research Randomizer. Social Psychology Network. Available at: http://www.randomizer.org/form.htm%5Cnhttp://www.randomizer.org/ 2011.
17. De Oliveira Alves V, Da Silveira Bueno CE, Cunha RS, et al. Comparison among manual instruments and pathfile and mtwo rotary instruments to create a glide path in the root canal preparation of curved canals. J Endod 2012;38(1):117–20. Doi: 10.1016/j.joen.2011.10.001.
18. Elnaghy AM, Elsaka SE. Evaluation of root canal transportation, centering ratio, and remaining dentin thickness associated with Protaper NEXT instruments with and without glide path. J Endod 2014;40:2053–6.
19. Yamamura B, Cox T, Heddaya B, et al. Comparing canal transportation and centering ability of endosequence and vortex rotary files by using micro-computed tomography. J Endod 2012;38(8):1121–5. Doi: 10.1016/j.joen.2012.04.019.
20. Hashem AAR, Ghoneim AG, Lutfy RA, et al. Geometric analysis of root canals prepared by four rotary NiTi shaping systems. J Endod 2012;38(7):996–1000.
21. Shen Y, Zhou HM, Zheng YF, et al. Metallurgical characterization of controlled memory wire nickel-titanium rotary instruments. J Endod 2011;37:1566–71.
22. Capar ID, Ertas H, Ok E, et al. Comparative study of different novel nickel-titanium rotary systems for root canal preparation in severely curved root canals. J Endod 2014;40(6):852–6.
23. Zhao D, Shen Y, Peng B, et al. Micro-computed tomography evaluation of the preparation of mesiobuccal root canals in maxillary first molars with Hyflex CM, Twisted Files, and K3 instruments. J Endod 2013;39(3):385–8. Doi: 10.1016/j.joen.2012.11.030.
24. Plotino G, Nagendrababu V, Bukiet F, et al. Influence of negotiation, glide path, and preflaring procedures on root canal shaping—terminology, basic concepts, and a systematic review. J Endod 2020;46(6):707–29. Doi: 10.1016/j.joen.2020.01.023.
25. Gambarini G, Di Nardo D, Galli M, et al. Differences in cyclic fatigue lifespan between two different heat treated NiTi endodontic rotary instruments: WaveOne Gold vs EdgeOne Fire. J Clin Exp Dent 2019;11(7):e609–13. Doi: 10.4317/jced.55839.
26. Lee JY, Kwak SW, Ha JH, et al. Mechanical properties of various glide path preparation nickel-titanium rotary instruments. J Endod 2019;45(2):199–204. Doi: 10.1016/j.joen.2018.10.017.
27. Hasheminia SM, Farhad A, Sheikhi M, et al. Cone-beam computed tomographic analysis of canal transportation and centering ability of single-file systems. J Endod 2018;44(12):1788–91. Doi: 10.1016/j.joen.2018.09.011.
28. Berutti E, Paolino DS, Chiandussi G, et al. Root canal anatomy preservation of WaveOne reciprocating files with or without glide path. J Endod 2012;38(1):101–4.
29. Goo HJ, Kwak SW, Ha JH, et al. Mechanical properties of various heat-treated nickel-titanium rotary instruments. J Endod 2017;43(11):1872–7. Doi: 10.1016/j.joen.2017.05.025.
30. Peters OA. Current challenges and concepts in the preparation of root canal systems: a review. J Endod 2004;30:559–67.
31. Pinheiro SR, Alcalde MP, Vivacqua-Gomes N, et al. Evaluation of apical transportation and centering ability of five thermally treated NiTi rotary systems. Int Endod J 2018;51(6):705–13. Doi: 10.1111/iej.12881.