Kataia *et al. Bull Natl Res Cent (2021) 45:42*
https://doi.org/10.1186/s42269-021-00499-w

Bulletin of the National Research Centre

RESEARCH Open Access

Shaping ability of two heat treated rotary NiTi instruments using different kinematics/in vitro study

Engy M. Kataia[1*], Mohamed Mokhtar Nagy[2], Mohamed M. Kataia[3] and Hala Fayek Khalil[3]

Abstract

Background: Comparing shaping ability of Azure and Fanta AF One in rotation and reciprocation. This study was conducted on 40 resin blocks, having canal curvatures 30°-angle and of 16-mm length. The blocks were assigned to 4-groups according to the instrument and motion used: Azure/Rotation (A/Rt), Fanta AF one/Rotation (F/Rt), Azure/Reciprocation (A/Rec) and Fanta AF one/Reciprocation (F/Rec). For both systems single file 25, taper 0.06 were used. Digital images were taken before and after instrumentation. Adobe Photoshop was used to overlap post and pre-instrumentation images to assess canal transportation at 1, 4, 7-mm; representing apical, middle and cervical levels respectively. Stopwatch was used to document the time taken for canal preparation. One-way ANOVA followed by Tukey post hoc test, used to compare between more than two groups in non-related samples.

Results: At the apical level, no statistically significant difference was found between both files in either rotation or reciprocation. However, reciprocation motion showed significantly lower transportation levels in both files. No significant difference was found among groups at the middle and cervical levels. Regarding preparation time, Reciprocation in both groups was significantly longer.

Conclusions: The use of reciprocation motion showed minimized apical canal transportation in both files however in longer preparation time.

Keywords: Rotation, Reciprocation, Shaping ability, Heat treatment

Background

One of the most crucial principles of shaping the root canal system is maintaining the original canal anatomy by consistently preparing all surfaces of the canal to prevent procedural errors such as zipping, ledging, perforations, and apical transportation (Elsherief et al. 2013). Canal transportation also weakens the root and compromises obturation, leading a poor apical seal (Franco et al. 2011).

Many techniques for canal preparation along with rotary nickel–titanium (NiTi) systems and various kinematics aroused to conquer these problems, preserve the original canal shape and to provide a better canal centralization (Vallaeys et al. 2016; Schäfer and Florek 2003; Weine 1996).

Centric rotary motion, developed at the end of the 1980s, is still used with most of the mechanical preparation systems available today. However, the Reciprocating motion, has been proposed in a trial to decrease the risk of instruments fracture, as it is declared to relieve stress on the instrument, minimize the risk of fracture, and improve cyclic fatigue resistance and lifespan of NiTi instruments (Bürklein et al. 2012; Plotino et al. 2012).

Reciprocal motion compromises a larger counterclockwise rotating angle, which allows the instrument to cut the dentin and a smaller clockwise angle to disengage; due to the greater counterclockwise angle,

*Correspondence: dr_engykataia@yahoo.com; anouja2@hotmail.com
[1] Restorative and Dental Materials Department, National Research Centre, Cairo, Egypt
Full list of author information is available at the end of the article

the file continuously advances toward (Bürklein et al. 2012; Plotino et al. 2012; Kim et al. 2012).

Yared (2008), carried out a study where all the canals were prepared by single F2 ProTaper file, reciprocating, with varying angles. This milestone study was an evolution in instrument kinematics, proving that sequential filing is not essential for achieving a tapered canal, thus, late reciprocating instruments were invented for single-file preparation.

During the last decade, dental companies manufactured different NiTi rotary instruments with different designs, cross sections and varying tapers aiming at improving their performance thus simplifying the preparation procedure (Cohen 1994). In 2010, controlled memory wire instruments, manufactured by thermal treatment technology were introduced. This heating and cooling process allows the pre-bending of the instruments and it also gives it a greater fatigue resistance (Pereira et al. 2015) and flexibility (Testarelli et al. 2011; Zinelis et al. 2010), allowing for a more centered canal preparation and less transportation (Pinheiro et al. 2017). Recently thermal treatments are being used to improve instrument properties (Miyazaki et al. 1982; Frick et al. 2004) rather than undergoing changes in the geometry of the instruments (Zinelis et al. 2010).

In this study the shaping ability of the newly introduced, heat-treated E3 Azure and Fanta AF one was compared in both rotation and reciprocation motions, using a single file 25 taper 0.06.

The E3 Azure has a modified S-shape cross section (decreasing the core of the file so allowing for better debris removal and greater flexibility), a variable pitch and a safe cutting tip, whereas the AF F-One file has a unique cross sectional design; two active cutting points and a flat side-cut design, a non-cutting tip and developed with a CM wire combined with a titanium oxide surface treatment, allowing for better flexibility, hardness and resistance to fracture (Shangahai Fanta catalogue 2018–2019.pdf).

Our null hypothesis is; there'll be no difference in canal shaping capacity among the file systems, regarding the two types of kinematics. This is according to the claims of the manufacturer that both files have similar properties in design and metallurgy.

Methods

Two files were used in this study, both having same size, 25/06, the E3 Azure BASIC (Poldent Co. Ltd., www.endostar.eu) and the Fanta AF One File (Shanghai Fanta Dental Materials Co., LTD).

Sample selection

Based on data from a previous study (Mittal et al. 2017), a power calculation was performed using G*Power 3.1 software (Heinrich Heine University, Dusseldorf, Germany). The calculation indicated that the sample size for each group should be a minimum of 10 files. The study was carried out on 40 simulated curved canals in clear resin blocks (Endo Training Bloc, Dentsply, Maillefer, Tulsa, OK, USA) with 30° angle of curvature and 16 mm canal length. All simulated canals had diameter and taper equivalent to an ISO standard size 15 with a 2% taper root canal instrument. For all the canals, working length was set to the level of the apical foramen using a #15 hand K-file (Dentsply Maillefer, Ballaigues, Switzerland). All canals were checked for patency and canals regulated with glide path up to size #20 hand K-file taper 2%.

These clear resin blocks were then randomly assigned into four equal experimental groups (n = 10) according to the instrument and motion used: E3 Azure/Rotation (A/Rt group; Azure file 25 taper 0.06 was used in continuous rotation), Fanta AF one/ Rotation group (F/Rt group: Fanta AF one file 25 taper 0.06 was used in full rotation), E3 Azure/Reciprocation Group (A/Rec; Azure file 25 taper 0.06 was used in Reciprocation motion 270/90) and Fanta AF one/Reciprocation Group (F/Rec: file AF2 (25 taper 0.06) was used in Reciprocation motion 270/90).

A metal pin was used to code each resin block by engraving a number on the outer surface of the block to be assigned for each canal, and four vertical orientation grooves were also carved away from the canal, to act as identification point for subsequent image analysis.

Before experimental instrumentation of the resin blocks, all simulated canals were stained with India blue ink (Faber-Castell, Stein, Germany) using a 30-gauge insulin syringe. K-file no. 8 (Dentsply, Maillefer, Tulsa, OK) was inserted into the canal to allow uniform penetration of the ink within the simulated canal system and to prevent air bubble formation.

A stable platform for mounting camera was prepared at a fixed distance and at an angle of 90° to the resin block. All the images were captured using a digital camera (D 3300, Nikon, Tokyo, Japan). In this way, pre- and post-canal preparation images could be superimposed. Fixed distance of the camera also eliminated the doubt of distortion and magnification of the subsequent images and guaranteed image standardization.

All the resin blocks were stored for 48 h to air dry the India blue ink. A special holder was prepared to hold and cover each resin block using vinyl polysiloxane impression material to facilitate blind preparation of the canals to mimic the clinical setup during canal instrumentation.

All samples were prepared by the same operator using a gentle pecking up and down motion with an electric and torque-controlled endodontic motor (X-Smart plus Dual, Dentsply Maillefer) adjusted manually according to manufacturer's specifications to speed 350 rpms and 2.5 Ncm torque for the 4 groups.

All Canals were irrigated with 20 ml of 2.5% NaOCl after each instrument, delivered by means of a gauge 27 needle.

The time elapsed until the instrument reached the working length in each group was recorded as working time. This was measured with a stopwatch by two different observers at the same time.

After mechanical preparation, a final digital image was taken with the same procedure described previously.

Evaluations

An examiner who was blind to all experimental groups carried out assessment of the canal transportation. To assess transportation, the final and the initial images of each sample were superimposed using Adobe Photoshop (10 Adobe Systems, San Jose, CA, USA), then compared by ImageJ analysis software (ImageJ 1.52d, Wayne Rasband, National Institute of Health USA).

The displacement of each canal center was investigated at 3 levels; 1, 4, 7 mm from the apex along the canal. The measurements were made perpendicular to the canal at the three levels as shown in Fig. 1

An analysis of variance (ANOVA) and post hoc Tukey's test were used for comparisons of the three groups. The level of statistical significance was set at $P < 0.05$.

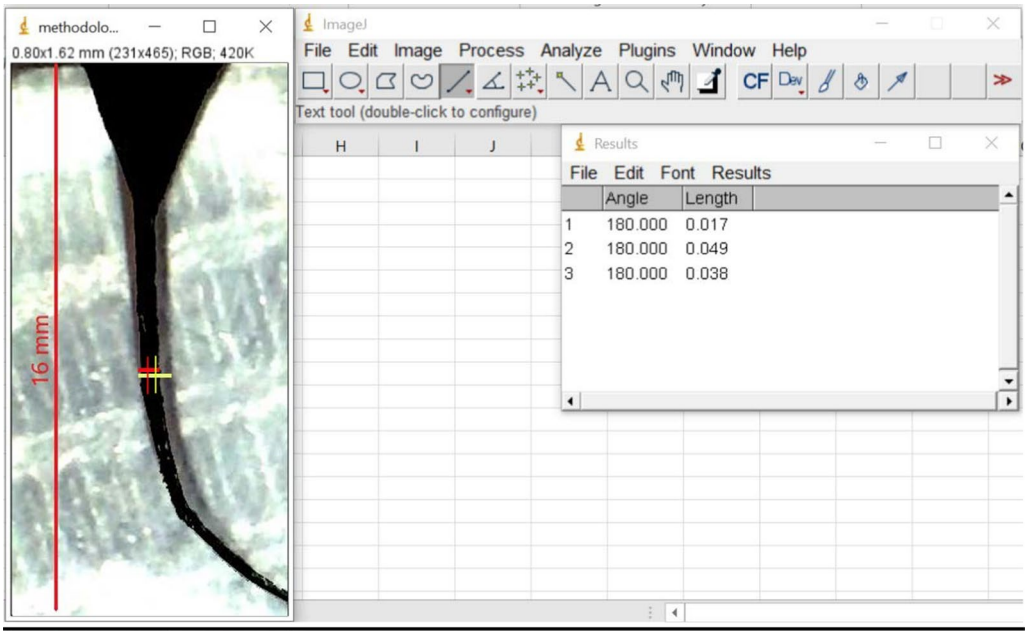

Fig. 1 Measurement of canal transportation using Image J software

Table 1 Showing transportation values in mms of the Azure and Fanta files in rotation and reciprocation motions in all levels

	A/Rot	F/Rot	A/Rec	F/Rec	*P* value
APICAL	0.067 ± 0.009^{Aa}	0.069 ± 0.004^{Aa}	0.05 ± 0.005^{Bb}	0.048 ± 0.007^{Bb}	< 0.001
MIDDLE	0.049 ± 0.008^{B}	0.052 ± 0.005^{B}	0.049 ± 0.007^{B}	0.05 ± 0.005^{B}	0.863
CORONAL	0.073 ± 0.006^{A}	0.081 ± 0.005^{A}	0.072 ± 0.006^{A}	0.082 ± 0.003^{A}	0.21
P VALUE	< 0.001	< 0.001	< 0.001	< 0.001	

P value < 0.05 is determined as significant. Different capital letters demonstrate significant difference within the same column. Different small letters represent significant difference within the same row

Results

1. Transportation: data are shown in Table 1.

Effect of file type and motion at different levels

At the apical level, no statistically significant difference was found between both files in either rotation or reciprocation. However, reciprocation motion showed significantly lower transportation levels in both files.

No significant difference existed between groups in the middle and cervical levels.

Effect of the level within different groups

For group Azure and group Fanta in rotation motion

The middle level recorded significantly reduced transportation values than at apical and coronal. No significant difference was found amongest the apical and cervical levels.

For group Azure and group Fanta in reciprocation

The coronal level recorded significantly higher transportation values than the apical and middle. No significant difference was found between the apical and middle levels.

2. Preparation time, Table 2.

Difference between both files was insignificant, in either rotation or reciprocation. However, both files operated in reciprocation recorded significantly longer time than when operated in rotation motion.

Discussion

For an endodontic file to provide good canal shaping, it is essential that it possesses a centering ability inside the root canal (Alshahrani and Al-Omari 2019) and because there is a continuous search for files with reasonable prices, recent innovations (blue heat treatment) and good mechanical properties, this work aimed at assessing the mechanical shaping ability of heat treated E3 Azure and Fanta AF one file systems in both rotation and reciprocation motions.

For standardization of groups, simulated resin canals were favored than natural teeth. Although they are short of inherent variations in hardness, water content, and smear layer formed at time of instrumentation making them not look as an ideal dentin replacement (Shen and Haapasalo 2008), these resin canals perform consistently in terms of hardness and dimensional stability, they permit high degree of reproducibility besides fixed curvature, angle, and diameter. Therefore, using simulated canals bypassed the differences seen in canal dimensions and morphology of extracted human teeth (Al-Omari et al. 1992).

Different approaches are being advocated to evaluate the final shape of the root canal after mechanical preparation. These comprise using stereomicroscope for analyzing, serial sectioning technique (Bramante et al. 1987), microcomputed tomography (Deepak et al. 2015), and radiographic imaging (Bramante et al. 1987). Nonetheless, these techniques without exception have their own advantages and disadvantages. Sectioning of the teeth is sophisticated, invasive, and can lead to loss of material. Microcomputed tomography is not cost-effective as it only assesses volumetric changes, and possible geometric changes are not analyzed (Ounsi et al. 2011). Alternatively, imaging technique using Adobe Photoshop program, which is the evaluation method adopted in this study, precisely specifies the outlines of the preoperative and the postoperative canals. So, by measuring the variations in width between the pre- and postoperative images, it became achievable to compute the extent of resin material removed. Also, incorporating colored inks in pre- and postoperative imaging allowed heightened accuracy in canal width measurement without destructing the samples (Alshahrani and Al-Omari 2019).

Newly manufactured thermo-mechanically treated alloy rotary systems added special characteristics of flexibility and fatigue resistance to the files (Taha et al. 2013). Nonetheless, a small number of studies were done to evaluate the effect of these properties on shaping ability of the novel rotary files mainly due to the variation in assessment criteria. To our knowledge, this is the first study that evaluated and compared the shaping abilities of Azure files system with the Fanta AF one files system.

As claimed by the manufacturer, E3 Azure was manufactured for the three familiar types of preparation, to attain a perfect canal preparation; rotation, reciprocation and complex motions (OTR).

The Azure heat treatment technology grants it the ability for transform from martensite to austenite at body temperature. This treatment allows the pre-bending of files before their insertion inside the canal. This enables the files to easily follow the most curved canals, with little risk of perforations and ledges. This file's cross section is modified S-shape, decreasing the core of the file thus allowing for better debris removal and greater flexibility.

Table 2 Showing means and standard deviations of preparation time in seconds for the Azure and Fanta files in rotation and reciprocation motions

	A Rot	F Rot	A Rec	F Rec	*P* value
Mean ± SD	39.65 ± 2.344625[b]	53.76 ± 1.7516[b]	82.4 ± 2.073644[a]	91 ± 1.581139[a]	< 0.001

The AF F One Rotary file is also a novel NiTi instrument designed for use in continuous rotation motion. It has two active cutting points and a flat side-cut cross-sectional design. This gives the file a higher cutting efficiency, where debris can be swept from flutes to the safe-side relief area through vertical blades, and then outside the canal. This design also provides a more efficient cutting and less stress on the file, minimizing the possibility of file separation. Moreover, the flat side-cut provides more room for irrigating solutions during instrumentation and a lower surface area contact with canal walls, which decreases the stresses falling on the file. This flat side-cut design is not deeply cut in the file, thus increasing the file's flexibility without compromising file's strength. AF F-One file has non-cutting tip, which decreases the likelihood of iatrogenic complications like perforation, zipping, ledges, and canal transportation.

For the sake of minimizing the working time, it has been recommended to use one file with different motions to prepare the whole canal (Yared 2008). Single file systems are considered a progression towards a simpler approach, when compared to systems using multiple files (Mittal et al. 2017), as they save operator's time, cost and minimize the chances of cross contamination between patients. In this study a single file was used from each system; file 25/06 at 350 rpm speed and 2.5 Ncm Torque as recommended by the manufacturers. Single file systems could be used in either continuous rotation or reciprocation motions (Kumar and Gade 2015).

The root canal preparations were performed by the same operator. Thus, the operator was not a variable (Zhao et al. 2013).

Canal transportation and centering ability are dependable methods to assess if a shaping procedure can sustain the original canal anatomy (Merrett et al. 2006). Therefore, in the current work canal transportation had been assessed as the variation in the amount of resin removed from the canals (Andrade-Junior et al. 2017) at three different positions: 1 (apical), 4 (middle) and 7 (coronal) mm from the apex. File system that produced less transportation of canal curvature in these defined positions was considered to have better shaping ability and better perseveration of the original canal anatomy (Taha et al. 2013).

Results showed no significant difference between files when compared in rotation movement and when compared in reciprocation.

However, the cervical level in both rotation and reciprocation for both files showed a significantly high transportation, this could be referred to the large taper used (0.06) which also leads to less file decreased flexibility leading to more transportation (Saberi et al. 2018).

Wu et al. (2000) claimed that transportation over 0.3 mm apically has a bad impact on the sealing capability of root filling materials. In this study, there wasn't any transportation over 0.3 mm in any of the groups, however, rotation motion with both instruments showed greater apical transportation than when the files were worked in reciprocation. These results coincide with the results of Berutti et al. (2012a), who stated that the reciprocation permits for a more centered preparation compared to continuous rotation, specifically in the apical third.

When comparing motions, reciprocation showed significantly lower transportation levels in both files. Other studies that used resin blocks to evaluate the shaping abilities of NiTi systems and the amounts of transportation caused by them have announced that reciprocating movements produced more centered preparations than continuous rotation movements (Franco et al. 2011; Berutti et al. 2012b). Cimilli and Kartal (2005) showed that the center of the preparation shifts in a clockwise direction with continuous rotation, but in reciprocation this shift is reduced.

Since engine-based root canal treatment is a valued time relief for patients and practitioners (Schäfer and Lohmann 2002). The mean time for canal preparation was, hence, noted in our work. Results showed that Reciprocation in both groups recorded significantly longer time for preparation than rotation ($P < 0.001$). This difference could be due to the number of total rotations done by the instrument during shaping; instruments undergo a 360° turn for every cycle in the continuous movement, whereas they undergo a 20° turn with the reciprocating movement in the same time span (Franco et al. 2011).

Conclusion

Within limitations in this study, we can conclude that, both files showed good shaping ability, but less canal transportation took place when they were used in reciprocating motion. Regarding the clinical significance, the azure file showed less transportation in all groups yet with no statistical significance.

Review of the research hypotheses

The pre-formulated research hypothesis was not approved, because it was found that the files showed better centering ability with reciprocating motion than with continuous rotation.

Abbreviations

A/Rt: Azure/Rotation; F/Rt: Fanta AF one/Rotation; A/Rec: Azure/Reciprocation; F/Rec: Fanta AF one/Reciprocation.

Acknowledgements

Not applicable.

Authors' contributions
MMK, and HFK conducted the practical work, MMN, did the result analysis and statistics and EMK, the corresponding author, wrote the manuscript, did the plagiarism adjustments needed and is undergoing the submission steps. All authors read and approved the final manuscript.

Funding
This research did not receive any fund from any organization.

Availability of data and materials
The authors declare that the data supporting the findings of this study are available within the article.

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
We declare that there is no competing interest.

Author details
[1] Restorative and Dental Materials Department, National Research Centre, Cairo, Egypt. [2] Endodontics Department, Faculty of Dentistry, Ain Shams University, Cairo, Egypt. [3] Endodontic Department, The British University in Egypt, Cairo, Egypt.

Received: 6 January 2021 Accepted: 4 February 2021
Published online: 16 February 2021

References

Al-Omari MA, Dummer PM, Newcombe RG, Doller R (1992) Comparison of six files to prepare simulated root canals 2. Int Endod J 25:67–81
Alshahrani MO, Al-Omari M (2019) Shaping ability of ProTaper next and navigator EVO rotary nickel–titanium file systems in simulated L-shaped and S-shaped root canals. Saudi Endod J 9:161–168
Andrade-Junior CV, Neto ND, Rodrigues RCV, Santos Antunes HD, Porpino MTM, Carvalha JCA, Armada L (2017) Transportation assessment in simulated curved canals after preparation with twisted file adaptive and BT-race instruments. J Clin Exp Dent 9(9):e1136–e1140
Berutti E, Paolino DS, Chiandussi G, Alovisi M, Cantatore G, Castellucci A et al (2012a) Root canal anatomy preservation of WaveOne reciprocating files with or without glide path. J Endod 38:101–104
Berutti E, Chiandussi G, Paolino DS, Scotti N, Cantatore G, Castellucci A et al (2012b) Canal shaping with WaveOne primary reciprocating files and ProTaper system: a comparative study. J Endod 38:505–509
Bramante CM, Berbert A, Borges RP (1987) A methodology for evaluation of root canal instrumentation. J Endod 13:243–245
Bürklein S, Hinschitza K, Dammaschke T, Schäfer E (2012) 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 45:449–461
Cimilli H, Kartal N (2005) Shaping ability of rotary nickel–titanium systems and nickel–titanium k-files in separable resin blocks. G Ital Endod 19:159–161
Cohen SBR (1994) PathwaysofthePulp, 6th edn. Mosby-YearBook, Louis, MO
Deepak J, Ashish M, Patil N, Kadam N, Yadav V, Jagdale H et al (2015) Shaping ability of 5(th) generation Ni–Ti rotary systems for root canal preparation in curved root canals using CBCT: an in vitro study. J Int Oral Health 7:57–61
Elsherief SM, Zayet MK, Hamouda IM (2013) Cone-beam computed tomography analysis of curved root canals after mechanical preparation with three nickel–titanium rotary instruments. J Biomed Res 27:326–335
Franco V, Fabiani C, Taschieri S, Malentacca A, Bortolin M, Del Fabbro M (2011) Investigation on the shaping ability of nickel–titanium files when used with a reciprocating motion. J Endod 37:1398–1401
Frick CP, Ortega AM, Tyber J et al (2004) Thermal processing of polycrystalline NiTi shape memory alloys. Mater Sci Eng A 405(1–2):34–49
Kim HC, Kwak SW, Cheung GS, Ko DH, Chung SM, Lee W (2012) Cyclic fatigue and torsional resistance of two new nickel–titanium instruments used in reciprocation motion: Reciproc versus WaveOne. J Endod 38:541–544
Kumar SR, Gade V (2015) Single file NiTi-rotary systems. Int J Med Dent Sci 4(1):701–707
Merrett SJ, Bryant ST, Dummer PM (2006) Comparison of the shaping ability of RaCe and FlexMaster rotary nickel–titanium systems in simulated canals. J Endod 32:960–962
Mittal A, Dadu S, Singh NS, Singh S, Gupta B, Abraham A, Yendrembam B, Kumari S (2017) Comparative assessment of canal transportation and centering ability of Reciproc and one shape file systems using CBCT-an in vitro study. J Clin Diagn Res 11(4):1231–1234
Miyazaki S, Ohmi Y, Otsuka K, Suzuki Y (1982) Characteristics of deformation and transformation pseudoelasticity in Ti–Ni alloys. J Phys Colloq 43(C4):C4-255-C4-260. https://doi.org/10.1051/jphyscol:1982434.jpa-00222148
Ounsi HF, Franciosi G, Paragliola R et al (2011) Comparison of two techniques for assessing the shaping efficacy of repeatedly used nickel–titanium rotary instruments. J Endod 37:847–850
Pereira ÉS, Viana AC, Buono VT, Peters OA, Bahia MG (2015) Behavior of nickel–titanium instruments manufactured with different thermal treatments. J Endod 41(1):67–71. https://doi.org/10.1016/j.joen.2014.06.005
Pinheiro SR, Alcalde MP, Vivacqua-Gomes N, Bramante CM, Vivan RR, Duarte MA et al (2017) Evaluation of apical transportation and centring ability of five thermally treated NiTi rotary systems. Int Endod J. https://doi.org/10.1111/iej.12881
Plotino G, Grande NM, Testarelli L, Gambarini G (2012) Cyclic fatigue of Reciproc and WaveOne reciprocating instruments. Int Endod J 45:614–618
Saberi EA, Mollashahi NF, Farahi F (2018) Canal transportation caused by one single-file and two multiple-file rotary systems: a comparative study using cone-beam computed tomography. G Ital Endod 32:57–62
Schäfer E, Florek H (2003) 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 36:199–207
Schäfer E, Lohmann D (2002) Efficiency of rotary nickel–titanium flexmaster instruments compared with stainless steel hand K-Flexofile–part 1. Shaping ability in simulated curved canals. Int Endod J 35:505–513
Shangahai Fanta catalogue 2018–2019.pdf.
Shen Y, Haapasalo M (2008) Three-dimensional analysis of cutting behavior of nickel–titanium rotary instruments by microcomputed tomography. J Endod 34:606–610
Taha N, Maghaireh G, Sadek D, Bagheri R, Al-Omari M (2013) Shaping ability of thermomechanically treated files in simulated S-shaped root canals. Open J Stomatol 3:386–391
Testarelli L, Plotino G, Al-Sudani D, Vincenzi V, Giansiracusa A, Grande NM et al (2011) Bending properties of a new nickel–titanium alloy with a lower percent by weight of nickel. J Endod 37(9):1293–1295. https://doi.org/10.1016/j.joen.2011.05.023
Vallaeys K, Chevalier V, Arbab-Chirani R (2016) Comparative analysis of canal transportation and centring ability of three Ni–Ti rotary endodontic systems: Protaper, MTwo and Revo-S, assessed by micro-computed tomography. Odontology 104(1):83–88
Weine FS (1996) The use of non-ISO-tapered instruments for canal flaring. Compend Contin Educ Dent 17(7):651–656 (**quiz 664**)
Wu M-K, Fan B, Wesselink PR (2000) Leakage along apical root fillings in curved root canals. Part I: effects of apical transportation on seal of root fillings. J Endod 26(4):210–216
Yared G (2008) Canal preparation using only one Ni–Ti rotary instrument: preliminary observations. Int Endod J 41(4):339–344
Zhao D, Shen Y, Peng B, Haapasalo M (2013) Micro-computed tomography evaluation of the preparation of mesiobuccal root canals in maxillary first molars with Hyflex CM, TwistedFiles, and K3 instruments. J Endod 39:385–388
Zinelis S, Eliades T, Eliades G (2010) A metallurgical characterization of ten endodontic Ni–Ti instruments: assessing the clinical relevance of shape memory and superelastic properties of Ni–Ti endodontic instruments. Int Endod J 43(2):125–134. https://doi.org/10.1111/j.1365-2591.2009.01651.x

Publisher's Note