

Research Article



Influence of glide path size and operating kinetics on time to reach working length and fracture resistance of Twisted File adaptive and Endostar E3 nickel-titanium file systems

Tamilkumaran Ramyadharshini , Inbaraj Anand Sherwood ,
V Shanmugham Vigneshwar , Prakasam Ernest Prince , Murugadoss Vaanjay

Department of Conservative Dentistry and Endodontics, CSI College of Dental Sciences, Madurai, TN, India

OPEN ACCESS

Received: Sep 16, 2019

Revised: Oct 25, 2019

Accepted: Nov 21, 2019

Ramyadharshini T, Anand Sherwood I,
Vigneshwar VS, Ernest Prince P, Vaanjay M

*Correspondence to

Inbaraj Anand Sherwood, MDS, PhD

Professor and Head, Department of
Conservative Dentistry and Endodontics, CSI
College of Dental Sciences, 129 East Veli St,
Madurai, TN 625001, India.
E-mail: anand.sherwood@gmail.com

Copyright © 2020. The Korean Academy of
Conservative Dentistry

This is an Open Access article distributed
under the terms of the Creative Commons
Attribution Non-Commercial License ([https://
creativecommons.org/licenses/by-nc/4.0/](https://creativecommons.org/licenses/by-nc/4.0/))
which permits unrestricted non-commercial
use, distribution, and reproduction in any
medium, provided the original work is properly
cited.

Conflict of Interest

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

Author Contributions

Conceptualization: Anand Sherwood I;
Data curation: Ramyadharshini T; Formal
analysis: Anand Sherwood I; Investigation:
Ramyadharshini T; Methodology: Vigneshwar
VS; Project administration: Ernest Prince
P; Resources: Vaanjay M; Software: Anand
Sherwood I; Supervision: Anand Sherwood
I; Validation: Ernest Prince P; Visualization:

ABSTRACT

Objectives: This study investigated the influence of glide path size and operating kinetics on the time to reach the working length and the fracture resistance of Twisted File (TF) and Endostar E3 files.

Materials and Methods: A total of 120 mandibular single-rooted premolars were selected. Two methods of kinetic motion (TF adaptive and continuous rotary motion) and file systems (TF and Endostar E3) were employed. The files were used in root canals prepared to apical glide path sizes of 15, 20, and 25. The time taken to reach the working length and the number of canals used before the instrument deformed or fractured were noted. Fractured instruments were examined with scanning electron microscopy.

Results: The TF system took significantly more time to reach the working length than the Endostar E3 system. Both systems required significantly more time to reach the working length at the size 15 glide path than at sizes 20 and 25. A greater number of TFs than Endostar E3 files exhibited deformation, and a higher incidence of instrument deformation was observed in adaptive than in continuous rotary motion; more deformation was also observed with the size 15 glide path. One TF was fractured while undergoing adaptive motion.

Conclusions: No significant difference was observed between continuous rotary and adaptive motion. The TF system and adaptive motion were associated with a higher incidence of deformation and fracture. Apical glide path sizes of 20 and 25 required significantly less time to reach the working length than size 15.

Keywords: Adaptive motion; Continuous rotary motion; Cyclic fatigue; Glide path; Nickel-titanium files; Torsional fatigue

INTRODUCTION

The use of nickel-titanium (Ni-Ti) rotary files has become the standard for root canal preparation. Clinicians desire to use the Ni-Ti rotary files as a safe, efficient, and quick method for root canal preparation [1]. To meet these requirements, Ni-Ti rotary files have undergone several modifications with regard to their design and manufacture [2-5]. However,

Vigneshwar VS; Writing - original draft: Anand Sherwood I; Writing - review & editing: Anand Sherwood I, Vigneshwar VS.

ORCID iDs

Tamilkumaran Ramyadharshini 
<https://orcid.org/0000-0003-4996-4516>
Inbaraj Anand Sherwood 
<https://orcid.org/0000-0002-1261-9842>
V Shanmugham Vigneshwar 
<https://orcid.org/0000-0002-8554-7843>
Prakasam Ernest Prince 
<https://orcid.org/0000-0002-2049-420X>
Murugadoss Vaanjay 
<https://orcid.org/0000-0001-8251-6884>

one inherent drawback of these files is the risk of fracture from flexural and torsional stresses, which can cause fatigue failure and shear failure, respectively [6]. Dramatically higher torsional stresses have been associated with a wide area of contact between the canal walls and the cutting edge of the instrument, as well as situations in which the canal diameter is smaller than the non-active tip of the instrument; the latter phenomenon has been termed taper lock [7-9]. Establishment of the glide path prior to use of Ni-Ti instrumentation has been shown to reduce this stress [10,11]. However, evidence is lacking in the literature regarding the size of the glide path needed to reduce stress development.

With the introduction of reciprocating motion for Ni-Ti files [12], several reports have concluded that the cutting efficiency of reciprocating motion is similar to a full rotation of the instrument and that the lifespan of Ni-Ti files is extended by using reciprocating motion [13]. In 2013, Sybron Endo (Orange, CA, USA) introduced an adaptive motion technology that aimed to combine the benefits of rotary and reciprocating motion [13]. When the instrument is not (or is minimally) stressed, its motion is exerted as a rotation of 600° in the clockwise direction, a stop, and then a restart in the clockwise direction. When the instrument engages dentin or the root canal filling, the motion of the instrument becomes reciprocal due to the increased stress [13]. This asymmetrical rotational motion has been associated with improved cyclic and torsional fatigue resistance, and its cutting efficiency has been shown to be similar to that of rotary motion [13]. To the best of the authors' knowledge, the influence of glide path establishment on the development of stress for Ni-Ti files that are subjected to this asymmetric rotation has not yet been investigated. It is recommended to use adaptive motion with the Twisted File (TF) to attain the best results, according to the manufacturer's instructions. Endostar E3 (Poldent Co., Warsaw, Poland) has a similar 3-file sequence to TF files and has matching tapers of 8%, 6%, and 4%.

The current investigation was conducted to investigate the influence of glide path size and operating kinetics on the time to reach the working length and the fracture resistance of TF and Endostar E3 files. The null hypothesis for the current investigation was that there would be no differences in the efficiency and fracture resistance of Twisted and Endostar E3 files of different glide path sizes and utilizing different operating kinetics.

MATERIALS AND METHODS

After institutional ethical committee approval (CSICDSR/IEC/0039/2017) was obtained, a total of 120 canals of freshly extracted single-canal intact human mandibular premolars scheduled for orthodontic extraction were included in the study. The angles of curvature of the canals were determined using periapical radiographs, and all teeth selected had angles of curvature of no more than 8° [14]. The teeth were stored in 0.25% sodium hypochlorite for the disinfection and dissolution of soft tissue debris present on the root surface. The teeth were examined for cracks, fractures, and resorption, and the presence of any of these defects warranted exclusion from the study. All teeth were sectioned at the crown root junction with a size 15 K-file (Mani, Utsunomiya, Japan) with snug apical canal fit so as to have a uniform root length of 16 mm.

The 2 methods of motion employed for this study were continuous 360° rotary and adaptive motion (Elements Motor; Kavo Kerr, Brea, CA, USA). The 2 file systems used with these 2 different forms of motion were TF (medium/large canals) (Kavo Kerr) and Endostar

E3 (Basic). Both file systems have 3 file sequences. In the TF system, the 3 file sequences are file number 1 (ISO apical size 25 and an 8% taper), file number 2 (ISO apical size 35 and a 6% taper), and file number 3 (ISO apical size 50 and a 4% taper). In Endostar E3, the sequences are file number 1 (ISO apical size 30 and an 8% taper), file number 2 (ISO apical size 25 and a 6% taper), and file number 3 (ISO apical size 30 and a 4% taper).

The 3 different apical glide path sizes prepared were 15, 20, and 25. An apical glide path size of 25 was included to observe whether a medium or large canal requires further enlargement before the usage of rotary files, as well as to check whether an apical glide path size larger than 20 is required. Ten teeth were randomly allotted to each of the 3 apical glide path sizes of 15, 20, and 25 (Figure 1). The glide path sizes were manually prepared utilizing K-files (Mani) in a push-pull movement with a watch-winding motion. The estimation of working length was accomplished using a size 10 K-file inserted 1 mm beyond the root apex, and 1 mm was then subtracted from the obtained length. This measurement was confirmed using a periapical radiograph. Canal lubrication was performed using ethylenediaminetetraacetic acid (10%) with carbamide peroxide (15%) (EndoPrep RC; Anabond Stedman Pharmaceuticals, Chennai, India), and irrigation was conducted using 3% sodium hypochlorite (Parcan; Septodont, Raigad, India) with a 27-gauge conventional needle and syringe (Dispovan, Faridabad, India). Each randomly-allotted tooth was finished to the determined apical glide path size.

In each group of apical glide path sizes, 1 set of each file system was used. Thus, 6 sets of each TF and Endostar E3 file system were used. The files were utilized according to the instructions regarding the torque and speed settings set forth by Elements Motor, and TFs were used according to the preset settings available from Elements Motor itself. Each file set was designated to be used in a maximum of 10 canals. The time taken for each file to reach the working length, in seconds, was measured using a digital stopwatch. After each use, the files were wiped with gauze and inspected for any deformation or separation with the operating microscope under $\times 2.5$ magnification, and the number of canals used was recorded. If any instrument separation occurred, the file was discarded and was not used further, and the number of canals for which the instrument was used was noted. All canal preparations were performed by a single endodontist.

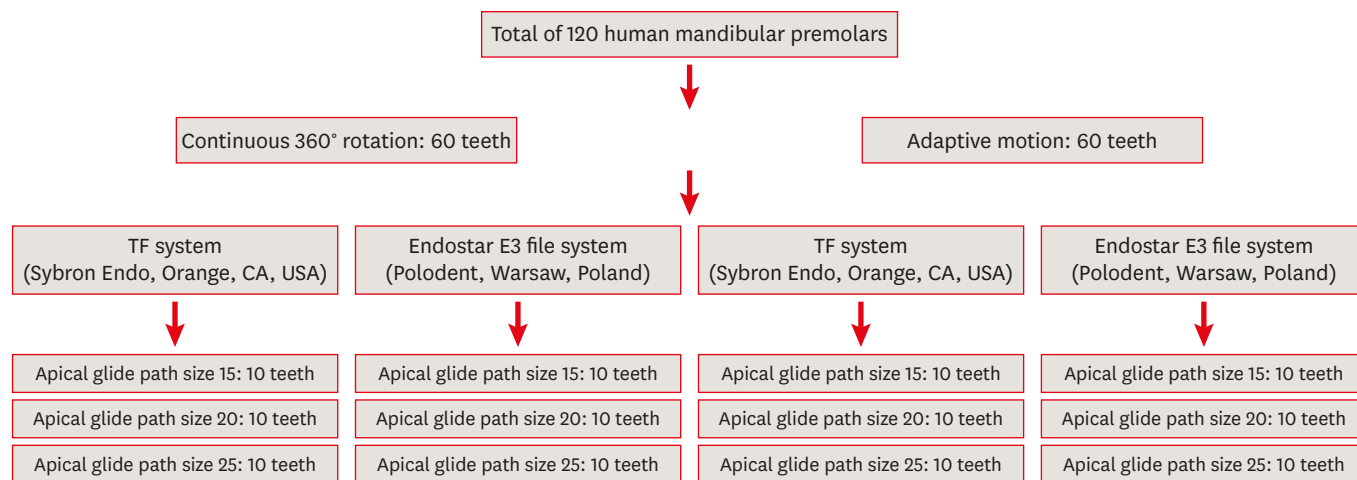


Figure 1. Flowchart representing the experimental procedure. TF = Twisted File.

The fractured instruments were cleaned with absolute alcohol and were also ultrasonically cleaned for 90 seconds; they were then analyzed using a scanning electron microscope (SEM) (VEGA3; TESCAN, Brno-Kohoutovice, Czech Republic) to determine the type of fracture. At $\times 41$ magnification in the lateral view and at $\times 650$ and $\times 1,500$ magnification in the cross-sectional view, each fractured instrument was classified by an independent examiner as exhibiting either torsional failure (associated with instrument elongation) or a flexural failure, according to the description given by Sattapan *et al.* [15].

Data were analyzed using univariate analysis of variance with the *post hoc* Tukey honest significant difference test. SPSS version 23.0 software (IBM Corp., Armonk, NY, USA) was utilized, and p values < 0.05 were considered to indicate statistical significance.

RESULTS

Time taken to reach the working length (efficiency)

Table 1 presents the mean time taken by the 2 file systems (TF and Endostar E3) to reach the working length, and the TF system took a significantly longer time (5.71 seconds) ($p < 0.05$). For each of the 2 file systems, there was a significant difference in the time taken among the 3 file sequences to reach the working length, with file number 3 in the TF system (8.27 seconds) and file number 2 (6.70 seconds) in the Endostar E3 system requiring the longest times (**Table 2**). The least time taken for each file system was observed with file numbers 2 (3.74 seconds) and 1 (2.10 seconds) in the TF and Endostar E3 systems, respectively. The file systems tested showed no significant difference regarding the time taken between the 2 forms of kinetic motion ($p > 0.05$) (**Table 3**). The TF system took a longer time for both forms of kinetic motion than the Endostar E3 system.

Apical glide path size had a significant influence on the time taken by the files to reach the working length. Both file systems required significantly more time with the size 15 glide path ($p < 0.05$), but *post hoc* analysis showed no significant difference between the size 20 and 25 apical glide paths ($p > 0.05$) (**Table 1**). To a significant extent, file sequence numbers 3 and 2 with the TF and Endostar E3 systems, respectively, required the longest time when using the size 15 apical glide path (**Table 2**).

No significant difference was observed in the time to reach the working length according to the form of kinetic motion and the apical glide path size while adaptive motion took more time (5.33 seconds) than rotary motion (4.83 seconds) ($p > 0.05$) (**Table 3**). With both forms

Table 1. Mean time taken in seconds to reach the working length for the different types of file systems

File system name	Glide path size	Working time (sec)
TF	15	5.92 \pm 4.02 ^a
	20	5.88 \pm 2.68 ^b
	25	5.35 \pm 3.37 ^b
	Total	5.71 \pm 3.36 ^A
Endostar E3	15	6.13 \pm 5.56 ^a
	20	4.18 \pm 3.49 ^b
	25	3.12 \pm 1.80 ^b
	Total	4.47 \pm 4.10 ^B

Data are shown as mean \pm standard deviation.

The same lower case letters indicate no significant difference between the different glide path sizes of each file system ($p > 0.05$). The same upper case letters indicate no significant difference between the 2 file systems ($p > 0.05$).

TF = Twisted File.

Table 2. Mean time taken in seconds to reach the working length for the different sizes of files in different glide path sizes

File system name	File sequence	Glide path size	Working time (sec)
TF	File No. 1	15	4.11 ± 1.45
		20	5.70 ± 2.90
		25	5.70 ± 3.96
		Total	5.17 ± 3.03 ^a
	File No. 2	15	3.59 ± 1.18
		20	4.15 ± 1.93
		25	3.50 ± 0.76
		Total	3.74 ± 1.79 ^b
	File No. 3	15	10.18 ± 4.39
		20	7.80 ± 1.77
		25	6.85 ± 3.60
		Total	8.27 ± 3.58 ^c
Endostar E3	File No. 1	15	2.25 ± 1.07
		20	2.00 ± 0.56
		25	2.05 ± 0.76
		Total	2.10 ± 0.81 ^a
	File No. 2	15	9.30 ± 7.00
		20	6.65 ± 4.86
		25	4.15 ± 2.52
		Total	6.70 ± 5.46 ^b
	File No. 3	15	6.85 ± 4.37
		20	3.90 ± 1.55
		25	3.15 ± 0.88
		Total	4.63 ± 3.12 ^c

Data are shown as mean ± standard deviation.

The same lower case letters indicate no significant difference between the file sequences ($p > 0.05$).

TF = Twisted File.

Table 3. Mean time taken in seconds to reach the working length for the different types of kinetics

Operating kinetics	Glide path size	Working time (sec)
Continuous rotation	15	5.83 ± 4.73 ^a
	20	5.02 ± 3.11 ^a
	25	3.65 ± 1.59 ^a
	Total	4.83 ± 3.49 ^a
TF adaptive motion	15	6.27 ± 5.10 ^a
	20	5.05 ± 3.35 ^a
	25	4.82 ± 3.73 ^a
	Total	5.33 ± 4.09 ^a

Data are shown as mean ± standard deviation.

The same lower case letters indicate no significant difference between the different glide path sizes ($p > 0.05$).

The same upper case letters indicate no significant difference between the 2 operating kinetics ($p > 0.05$).

TF = Twisted File.

of kinetic motion, the 15 and 25 apical glide path sizes required the most and least time, respectively, to reach the working length.

Instrument deformation

1. TF system

The first- and second-sequence files exhibited deformation when undergoing both continuous and adaptive motion (**Figure 2A**). In continuous motion, both files displayed deformation after 10 canal uses, and in adaptive motion, they became deformed after 6 and 4 canal uses for the first- and second-sequence files, respectively. In the size 25 apical glide path, the first-sequence file displayed deformation after 10 canal uses when subjected to adaptive motion. Five TFs were observed to undergo deformation; of these, 3 files were used with adaptive motion.

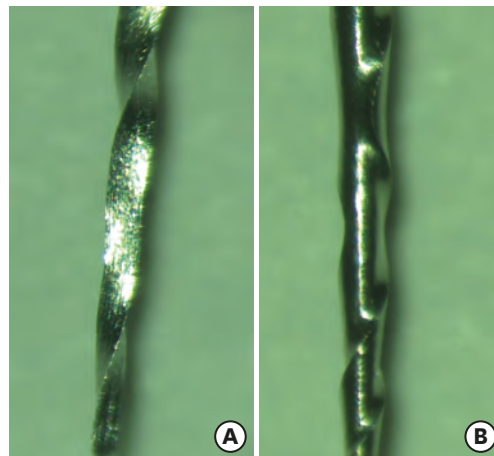


Figure 2. (A) Deformation of a Twisted File visualized under $\times 2.5$ magnification. (B) An Endostar E3 file displaying deformation viewed under $\times 2.5$ magnification.

2. Endostar E3

When subjected to adaptive motion, only 2 third-sequence files displayed deformation in the size 15 and 25 apical glide path sizes, after 9 and 10 canal uses, respectively (**Figure 2B**). No files were deformed after undergoing continuous rotary motion.

In both file systems, adaptive motion was associated with a higher incidence of deformation and at an earlier stage than continuous rotary motion. Of the total of 7 files that were deformed, 5 deformations occurred in size 15 apical glide paths.

SEM analysis of the fractured instrument

Only 1 first-sequence file in the TF system was fractured in adaptive motion in the size 15 apical glide path, during its eighth use. Under low-power magnification of $\times 41$ in the lateral view, the instrument exhibited unwinding, showing characteristics of torsional failure according to the classification by Sattapan *et al.* [15] (**Figure 3**). However, under higher-powered magnification settings of $\times 650$ and $\times 1,500$ in the cross-sectional view, the fractured surfaces showed features of fatigue failure (shear fracture), such as fatigue striations (**Figure 4A**) and skewed dimple marks in the center of rotation of the instrument (**Figure 4B**).

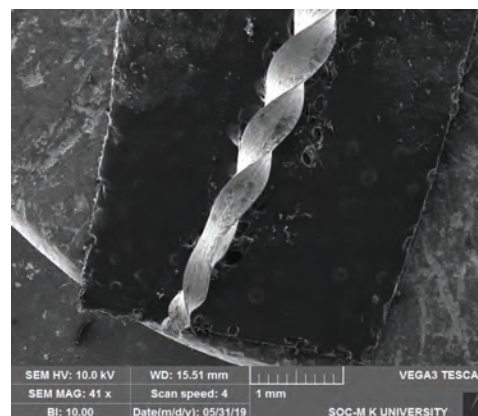


Figure 3. Scanning electron microscopic image of Twisted File exhibiting unwinding, which is characteristic of torsional failure, under low-power ($\times 41$) magnification.

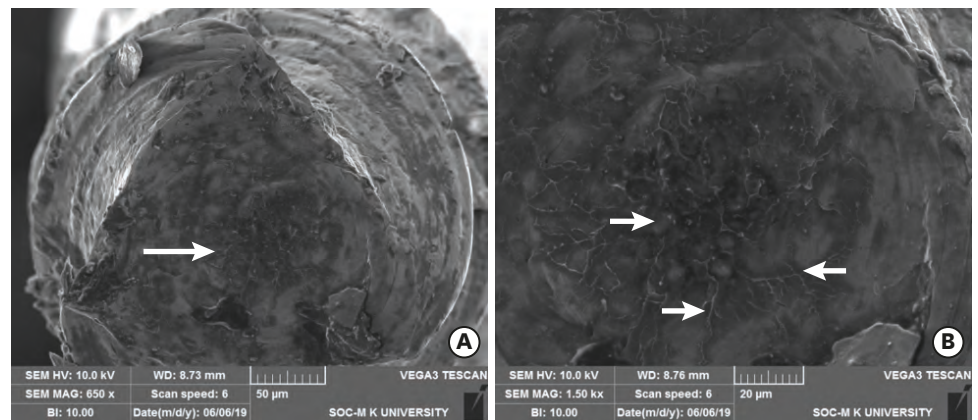


Figure 4. Scanning electron microscopic images under higher magnification: (A) $\times 650$, showing fatigue striations and (B) $\times 1,500$, showing skewed dimple marks at the center of rotation. Arrows indicate fatigue striations and skewed dimple marks.

DISCUSSION

The results of the present study partially refute the null hypothesis, which was that no difference in efficiency and fracture resistance would exist between the TF and Endostar E3 systems. Since there was no statistically significant difference between the 2 forms of kinetic motion in the time taken to reach the working length in either of the 2 file systems, the null hypothesis must be partially accepted. However, there was a significant difference in the time taken to reach the working length between the file systems and between the apical glide path sizes. The Endostar E3 file system was used for this investigation, as it is a 3-file system similar to the TF system and with matching tapers of its 3 instruments. The TF and Endostar E3 file systems utilize an equilateral triangle-shaped cross-section and a modified S-shaped cross-section, respectively. No significant difference between adaptive and continuous rotary motion was seen in the present study, with adaptive motion taking the most time to reach the working length for the TF system. To the best of the authors' knowledge, no other study has been performed on the speed at which adaptive motion can be used to reach the working length, so a direct comparison with previous studies was not feasible. A review article by Plotino *et al.* [16] concluded that a reciprocating single-file system was able to reduce the canal shaping time compared to a rotary full-sequence system; this observation is contradictory to the present results. However, the results of the present investigation are in agreement with an earlier report that showed no significant difference in shaping time between reciprocating and continuous rotary motion [17,18]. The explanation given for continuous rotary motion lacking a faster shaping time was that, unlike reciprocation, continuous rotary motion does not include a process of instrument release. Additionally, in our study, the time taken to reach the working length was significantly influenced by the file system, but not by the method of kinetic motion of the files. Reducing the shaping time allows clinicians to focus more of their time on irrigation activation, improving the potential for cleaning and disinfection [19]. Additionally, reduced time in contact with the canal walls is associated with less stress buildup in the files, as shown in our finding that the TF system, which is associated with more canal contact time, had a higher incidence of instrument deformation and separation.

Evidence in the literature supports the use of rotary file systems such as ProFile (Denstply Maillefer, Ballaigues, Switzerland) [19], ProTaper (Denstply Maillefer) [20], Mtwo (VDW,

Munich, Germany) [17], RaCe (FKG, La Chaux-de-Fonds, Switzerland) [19], and FlexMaster (VDW) [21], which have reciprocating motion and show improved performance. In the present investigation, the Endostar E3 file system took less time to reach the working length using adaptive motion than using continuous rotary motion. However, this file system exhibited instrument deformation with adaptive motion, but not with continuous rotary motion; this aligns with an observation made under SEM in which a rotary instrument automated for reciprocation showed gross morphological deformations, most likely because of fatigue due to the periodic changes in direction [16]. Moreover, a report on the cyclic fatigue resistance of adaptive motion compared to continuous motion revealed that the TF system performed better under continuous motion. A plausible explanation for this could be the lower speed setting of 300 revolutions per minute, compared to 440 revolutions per minute with adaptive motion [22]. TF used with adaptive motion has also been shown to display significantly lower cyclic fatigue resistance in S-shaped canal preparation [23]. These observations are in agreement with the present results. In disagreement with the present observations, a report on cyclic fatigue showed that the TF system subject to adaptive motion had better performance in artificial canals with a 60° angle of curvature [24]. In this investigation, however, continuous rotary motion was not evaluated [24]. The TF system is a newer-generation file system with R-phase heat-treated Ni-Ti technology [25], whereas the Endostar E3 file system consists of older-generation Ni-Ti files. However, in terms of the time taken to reach the working length and resistance to instrument deformation, the Endostar E3 file system was found to be superior to the TF system in the present report.

An earlier investigation of the TF system in the context of retreatment published by the authors' department also revealed that the performance of this system was not better when under adaptive motion [26]. These findings suggest that adaptive motion technology could be utilized in a better way in conjunction with instrument design specifically adapted to this movement. Files with S-shaped cross-sections have been shown to have better fatigue resistance and flexibility than triangular-based cross-section files in continuous rotary motion [23,27,28]. Similarly, in this study, the Endostar E3 files (which also have an S-shaped cross-section) showed better resistance to deformation than a triangular-based TF system in both rotary and adaptive motion. Reciproc Blue, which has an S-shaped cross-section, and WaveOne Gold, which has a rectangular cross-section, are other files recommended for automated reciprocating movement. The performance of these cross-section files in adaptive motion must be evaluated to better understand the optimum cross-section and taper suitable for adaptive motion. Other evidence in the literature contains conflicting reports regarding the performance of reciprocating files [24].

In the present study, glide path analysis revealed that a size 15 apical glide path enlargement required significantly more time for the files to reach the working length than was the case for size 20 and 25 apical glide paths; additionally, the instruments deformed at an earlier stage and were more likely to fracture in the size 15 apical glide path. This conclusion—that a minimum apical size of 20 was required to significantly reduce the time to reach the working length and that an apical size of 15 was associated with more deformation—aligns with an earlier experiment on continuous rotary motion files [29]. Larger files in the sequence of the TF system required significantly more time to reach the working length; in Endostar E3, the second-sequence file required more time, since the first file sequence is an orifice opener with reduced cutting length, and canal preparation was not done using this instrument. Larger files require more time because they must remove more dentin to reach the working length. Further research is necessary to investigate the

performance of root canal files of different cross-sections and Ni-Ti material treatments in adaptive motion. Glide path establishment with rotary files should also be studied in the context of TF adaptive motion technology.

CONCLUSIONS

Within the limitations of this study, the TF system required significantly more time to reach the working length. The TF system and adaptive motion displayed a higher incidence of deformation and instrument separation. No significant difference was demonstrated between continuous rotary and adaptive motion. An apical glide path size of 20 required significantly less time than the other sizes to reach the working length. An apical glide path size of 15 was associated with a higher number of instrument deformations.

REFERENCES

1. Park SK, Kim YJ, Shon WJ, You SY, Moon YM, Kim HC, Lee W. Clinical efficiency and reusability of the reciprocating nickel-titanium instruments according to the root canal anatomy. *Scanning* 2014;36:246-251. [PUBMED](#)
2. Peters OA. Current challenges and concepts in the preparation of root canal systems: a review. *J Endod* 2004;30:559-567. [PUBMED](#) | [CROSSREF](#)
3. Schäfer E, Oitzinger M. Cutting efficiency of five different types of rotary nickel-titanium instruments. *J Endod* 2008;34:198-200. [PUBMED](#) | [CROSSREF](#)
4. Bui TB, Mitchell JC, Baumgartner JC. Effect of electropolishing ProFile nickel-titanium rotary instruments on cyclic fatigue resistance, torsional resistance, and cutting efficiency. *J Endod* 2008;34:190-193. [PUBMED](#) | [CROSSREF](#)
5. Fayyad DM, Elhakim Elgendy AA. Cutting efficiency of twisted versus machined nickel-titanium endodontic files. *J Endod* 2011;37:1143-1146. [PUBMED](#) | [CROSSREF](#)
6. 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](#)
7. Blum JY, Cohen A, Machtou P, Micallef JP. Analysis of forces developed during mechanical preparation of extracted teeth using Profile NiTi rotary instruments. *Int Endod J* 1999;32:24-31. [PUBMED](#) | [CROSSREF](#)
8. Peters OA, Peters CI, Schönenberger K, Barbakow F. ProTaper rotary root canal preparation: assessment of torque and force in relation to canal anatomy. *Int Endod J* 2003;36:93-99. [PUBMED](#) | [CROSSREF](#)
9. Yared GM, Bou Dagher FE, Machtou P. Influence of rotational speed, torque and operator's proficiency on ProFile failures. *Int Endod J* 2001;34:47-53. [PUBMED](#) | [CROSSREF](#)
10. 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](#)
11. 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](#)
12. Yared G. Canal preparation using only one Ni-Ti rotary instrument: preliminary observations. *Int Endod J* 2008;41:339-344. [PUBMED](#) | [CROSSREF](#)

13. Çapar ID, Arslan H. A review of instrumentation kinematics of engine-driven nickel-titanium instruments. *Int Endod J* 2016;49:119-135.
[PUBMED](#) | [CROSSREF](#)
14. Schneider SW. A comparison of canal preparations in straight and curved root canals. *Oral Surg Oral Med Oral Pathol* 1971;32:271-275.
[PUBMED](#) | [CROSSREF](#)
15. Sattapan B, Nervo GJ, Palamara JE, Messer HH. Defects in rotary nickel-titanium files after clinical use. *J Endod* 2000;26:161-165.
[PUBMED](#) | [CROSSREF](#)
16. Plotino G, Ahmed HM, Grande NM, Cohen S, Bukiet F. Current assessment of reciprocation in endodontic preparation: a comprehensive review--part II: properties and effectiveness. *J Endod* 2015;41:1939-1950.
[PUBMED](#) | [CROSSREF](#)
17. Hwang YH, Bae KS, Baek SH, Kum KY, Lee W, Shon WJ, Chang SW. Shaping ability of the conventional nickel-titanium and reciprocating nickel-titanium file systems: a comparative study using micro-computed tomography. *J Endod* 2014;40:1186-1189.
[PUBMED](#) | [CROSSREF](#)
18. Gu LS, Kim JR, Ling J, Choi KK, Pashley DH, Tay FR. Review of contemporary irrigant agitation techniques and devices. *J Endod* 2009;35:791-804.
[PUBMED](#) | [CROSSREF](#)
19. Jin SY, Lee W, Kang MK, Hur B, Kim HC. Single file reciprocating technique using conventional nickel-titanium rotary endodontic files. *Scanning* 2013;35:349-354.
[PUBMED](#) | [CROSSREF](#)
20. Kim HC, Hwang YJ, Jung DW, You SY, Kim HC, Lee W. Micro-computed tomography and scanning electron microscopy comparisons of two nickel-titanium rotary root canal instruments used with reciprocating motion. *Scanning* 2013;35:112-118.
[PUBMED](#) | [CROSSREF](#)
21. Franco V, Fabiani C, Taschieri S, Malentacca A, Bortolin M, Del Fabbro M. Investigation on the shaping ability of nickel-titanium files when used with a reciprocating motion. *J Endod* 2011;37:1398-1401.
[PUBMED](#) | [CROSSREF](#)
22. Marks Duarte P, Barcellos da Silva P, Alcalde MP, Vivan RR, Rosa RA, Duarte MA, Só MV. Canal transportation, centering ability, and cyclic fatigue promoted by Twisted File Adaptive and Navigator EVO instruments at different motions. *J Endod* 2018;44:1425-1429.
[PUBMED](#) | [CROSSREF](#)
23. Al-Obaida MI, Merdad K, Alanazi MS, Altwajry H, AlFaraj M, Alkhamis AA, Al-Madi EM. Comparison of cyclic fatigue resistance of 5 heat-treated nickel-titanium reciprocating systems in canals with single and double curvatures. *J Endod* 2019;45:1237-1241.
[PUBMED](#) | [CROSSREF](#)
24. Higuera O, Plotino G, Tocci L, Carrillo G, Gambarini G, Jaramillo DE. Cyclic fatigue resistance of 3 different nickel-titanium reciprocating instruments in artificial canals. *J Endod* 2015;41:913-915.
[PUBMED](#) | [CROSSREF](#)
25. Zupanc J, Vahdat-Pajouh N, Schäfer E. New thermomechanically treated NiTi alloys - a review. *Int Endod J* 2018;51:1088-1103.
[PUBMED](#) | [CROSSREF](#)
26. Meena D, Ramyadharshini, Nivedha V, Sherwood A, Kumar S. Influences of continuous rotation and TF adaptive motion on the resistance of different retreatment file systems to deformation and fracture: an *in vitro* study. *J Oper Dent Endod* 2018;3:71-78.
27. Kim HC, Kim HJ, Lee CJ, Kim BM, Park JK, Versluis A. Mechanical response of nickel-titanium instruments with different cross-sectional designs during shaping of simulated curved canals. *Int Endod J* 2009;42:593-602.
[PUBMED](#) | [CROSSREF](#)
28. Gündoğar M, Özyürek T. Cyclic fatigue resistance of OneShape, HyFlex EDM, WaveOne Gold, and Reciproc Blue nickel-titanium instruments. *J Endod* 2017;43:1192-1196.
[PUBMED](#) | [CROSSREF](#)
29. Ha JH, Park SS. Influence of glide path on the screw-in effect and torque of nickel-titanium rotary files in simulated resin root canals. *Restor Dent Endod* 2012;37:215-219.
[PUBMED](#) | [CROSSREF](#)