Original Article

HEALTH SCIENCES
MEDICINE

DOI: 10.32322/jhsm.1315227
J Health Sci Med. 2023;6(4):826-832

Evaluation of shaping performance and surface changes of two different minimally invasive shaping file systems used in resin blocks

Merve Yeniçeri Özata[1], Seda Falakaloğlu[2], Mehmet Eskibağlar[3]

[1]Department of Endodontics, Faculty of Dentistry, Dicle University, Diyarbakır, Turkey
[2]Department of Endodontics, Faculty of Dentistry, İstanbul Health and Technology University, İstanbul, Turkey
[3]Department of Endodontics, Faculty of Dentistry, Firat University, Elazığ, Turkey

Cite this article as: Yeniçeri Özata M, Falakaloğlu S, Eskibağlar M. Evaluation of shaping performance and surface changes of two different minimally invasive shaping file systems used in resin blocks. *J Health Sci Med.* 2023;6(4):826-832.

Received: 15.06.2023 ◆ **Accepted**: 19.07.2023 ◆ **Published**: 30.07.2023

ABSTRACT

Aims: This study aimed to compare the shaping ability of T-endo MIS and TruNatomy (TRN) file systems in J-shaped resin root canals and to investigate the deformation of the files after two acrylic block preparation and two sterilization cycles.

Methods: Forty acrylic blocks were numbered, then four file groups (n=10) were established: T-endo MIS glider (15.04) + T-endo MIS Finisher (25.04) (first and second usage) and TRN Glider (17.02) + TRN Prime (26.04) (first and second usage). Preoperative and postoperative images after the root canal preparation of simulated acrylic blocks were taken for each sample, and superimposed. The amount of resin removed from both the inner and outer walls of the canal to the level of 3, 5, and 7 mm from the apical point was measured, and the amount of transportation was calculated. Additionally, the deformation of the files was examined under a scanning electron microscope before and after usage and sterilization process.

Results: Tip deformation of TRN files increased with the number of uses (p=0.007). With the second use, the surface deformation of the MIS files increased (p=0.015). There was no difference in cutting-edge deformation in either file type according to the number of uses (p>0.05). There was no difference in transportation values between the MIS and TRN file systems at any level (p>0.05). The file systems did not show a significant difference in the amount of transportation between first and second use (p>0.05).

Conclusion: When TRN (26.04) and MIS (25.04) NiTi rotary files were used twice on acrylic blocks, the amount of deformation did not differ. Both file types were similar in terms of transportation values.

Keywords: Acrylic block, canal transportation, file deformation, minimally invasive shaping

INTRODUCTION

Root canal instruments are commonly reused in clinical conditions to achieve economic benefits. However, the repeated usage of these instruments, coupled with increased mechanical stresses encountered within the root canals, as well as exposure to irrigation solutions, sterilization, and disinfection procedures, can lead to file deformation.[1] An increase in the number of autoclave sterilizations increases the surface roughness of the file and thus increasing the likelihood of file separation.[2] The increased working time of the instrument inside the root canal due to multiple uses may increase the risk of instrument fracture.[3] The precursors of the start of this process are the tip, cutting edge, and surface deformations that occur in the file.[4] The presence of a broken file in the root canal can impede access to the apical portion of the canal, posing challenges for effective treatment.[5]

Minimally invasive endodontics (MIE) aims to preserve as much tooth structure as possible and apply MIE principles to all root canal treatments. These principles encompass various objectives, ranging from the preparation of a smaller access cavity to the use of instruments with smaller tapers and tip diameters, and the utilization of instruments with different geometric designs and metallurgical properties.[6-8] Endodontic instruments conforming to this concept are designed to exhibit less taper, greater flexibility, and improved cyclic fatigue resistance than conventional instruments.[9]

Earlier research indicated that conducting minimally invasive root canal preparation with NiTi files having a smaller taper might result in the preservation of root dentin tissue to a greater extent than larger-tapered NiTi

Corresponding Author: Merve Yeniçeri Özata, merveyeniceri05@hotmail.com

files.[10] Therefore, the introducing new rotary files to the dental market, which adheres to the principles of MIE and possesses the capability to shape root canals, has increased interest in conservative preparation.[11] One of these files is TruNatomy (TRN; Dentsply Sirona, Maillefer, Ballaigues, Switzerland), produced from a thin NiTi wire with a diameter of 0.8 mm and a unique off-centered square cross-sectional design. TRN is a multiple file system consisting of an orifice modifier (20.08), a glider (17.02), Small (20.04), Prime (26.04,) and Medium (36.03) shaping files.[11] Studies conducted on TRN have demonstrated its ability to preserve root canal dentin and respect the natural anatomy of the canal during instrumentation.[12] Another file introduced for conservative shaping is T-endo MIS multiple file system (Dentac, İstanbul, Türkiye), a rectangular-sectioned file with a high martensitic crystal content, providing it with the feature of memory control.[13] This system consists of four files and they are as follows: Orificer (25.09), Glider (15.04), Shaper (20.05), and Finisher (25.04) files. The taper of the main shaping file of both TRN and MIS is 4%.[13,14] Both file system movement kinematics are rotation.[11,13]

During the shaping of curved root canals, it is necessary to preserve the original canal curvature and to prevent the tendency to flatten in the apical region, which may disrupt the canal integrity in the inner part of the root curvature.[15] Evaluation of the performance of endodontic files is often associated with their ability to shape curved root canals and preserve the original anatomy.[16,17] However, our knowledge about the tendency to preserve or disrupt this anatomy as a result of multiple uses of files is limited. Contrary to a study stating that the repeated use of files increases the transportation rate,[3] there is also a study in which no significant difference in transportation was observed between the first and sixth use of files.[18]

To our knowledge, no study has yet compared the T-endo MIS file system with TRN regarding deformation and transportation. Therefore, this study aimed to examine the deformation, before use in J-shaped resin canals, after first and second usage, and post-sterilization, of T-endo MIS and TRN, which are newly developed heat-treated NiTi rotary file systems. Moreover, evaluation of transportation occurring at 3, 5, and 7 mm in acrylic blocks after the first and second usage was intended. The null hypotheses of this study can be listed as follows:

$H0_1$: There is no difference within and between the file systems in terms of the amount of transportation that occurs in the acrylic blocks after the first and second use.

$H0_2$: There is no difference within and between the file systems in terms of the deformation that occurs in the files after the first and second use.

METHODS

A selection of 40 J-shaped resin canals (Dentsply Maillefer, OK, USA) with a taper of 2% and a single-direction curvature of 40 degrees, measuring 17 mm in length, was chosen. The resin block images were captured using a Canon EOS 60D digital camera equipped with a Sigma 105 mm 1:2.8 DG macro-lens (Sigma Corp., Fukushima, Japan) under standardized conditions before canal preparation. The images were saved as JPEG files for further analysis and documentation. Then, all blocks were concealed with black adhesive tape, masking the root canals, and randomly divided into four groups. The working length was determined using a #10K type file. A single endodontist performed all procedures. Irrigation was conducted using a 30-G IrriFlex needle (Produits Dentaires SA, Switzerland) with 20 mL of distilled water. The same endo motor (VDW Gold, VDW, Munich, Germany) was used for all instruments.

Group 1 (n=10): For the resin canal preparation, the TRN Glider (17.02) and Prime (26.04) files were used for the first time at 500 rpm and 1.5 Newton-centimeter (N-cm) torque. Then the files were then sterilized for the first time.

Group 2 (n=10): For the resin canal preparation, the TRN Glider (17.02) and Prime (26.04) files were employed for the second time at the same rpm and torque values. Then the files were then sterilized for the second time.

Group 3 (n=10): For the resin canal preparation, the MIS Glider (15.04) and Finisher (25.04) files were used for the first time at 300 rpm and 2.5 N/cm torque. Then the files were then sterilized for the first time.

Group 4 (n=10): For the resin canal preparation, the MIS Glider (15.04) and Finisher (25.04) files were employed for the second time at the same rpm and torque values. Then the files were then sterilized for the second time.

Since both file systems underwent sterilization during packaging, no additional sterilization was performed before their use. Following the first and second use, all files were cleaned using a sponge and immersed in an ultrasonic bath (Ege Eagle Ultrasonic, Bornova, İzmir, Türkiye) for 15 minutes. After drying, each file was individually sealed in a sterilization package and autoclaved (Getinge Quadro Avanti, Getinge, Sweden) at 134°C under 30 psi for 20 minutes.

Following preparation, the black tape on the blocks were removed. Images of the prepared acrylic block were taken and recorded after the first and second usage of the file.

Scanning Electron Microscopy (SEM) Analysis and Assessment of Deformation

All deformation evaluations were performed on the main shaping files. The first SEM examination was conducted before using the files, right after they were removed from their packaging. After the first and second usage, once sterilized, the files were placed into the SEM apparatus without any contact with the surfaces to be examined. Examination of file deformation was carried out using SEM (FEI, Quanta 250 FEG, Eindhoven, Netherlands) before use, after the first and second use, and after the sterilization process. To ensure consistent examination of the file surfaces, a holder was used to position the files in a standardized manner for each examination. High-resolution SEM microphotographs were captured for each instrument and its 5 mm tip, magnified at 1500× and 5000×. In this study, the physical and visual changes in MIS and TRN files caused by mechanical stress and sterilization processes during canal preparation were evaluated according to the following parameters (Figure 1):[4]

Tip deformation: Flattening and distortion at the tip of the files,

Cutting edge deformation: Notching, waviness, and/or deterioration of the original helical structure on the cutting edges of the files,

Surface deformation: Micro-level surface separations.

The images were then evaluated based on criteria, by two endodontists who were not involved in the preparation process. Deformation parameters were scored as either present or absent.

Image Analysis and Assessment of Transportation

The Adobe Photoshop CS6 Extended program (Adobe Systems Inc., San Jose, CA, USA) was utilized to overlay the pre- and post-preparation images of the blocks (Figure 2). Three measurement zones were identified at the apical foramen levels of 3, 5, and 7 mm, and the images were analyzed using AutoCAD 2021 (Autodesk Inc., San Jose, CA, USA). After the superposition, the amount of resin removed from each canal's inner and outer walls at the 3, 5, and 7 mm levels was measured (Figure 3). Positive values indicate that transportation occurs at the inner surface of the canal curvature, and negative values indicate that transportation occurs mainly at the outer surface of the canal curvature.18 A difference of 0 indicated no transportation on the inner and outer wall.

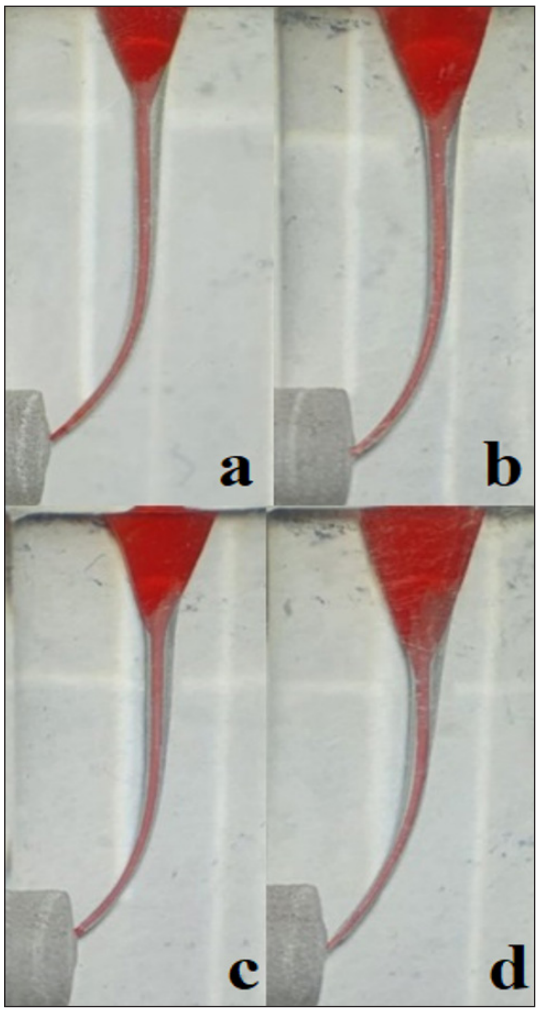

Figure 2. Superimposition of pre- and post-preparation block images a, MIS – first usage; b, MIS – second usage; c, TRN – first usage; d, TRN – second usage.

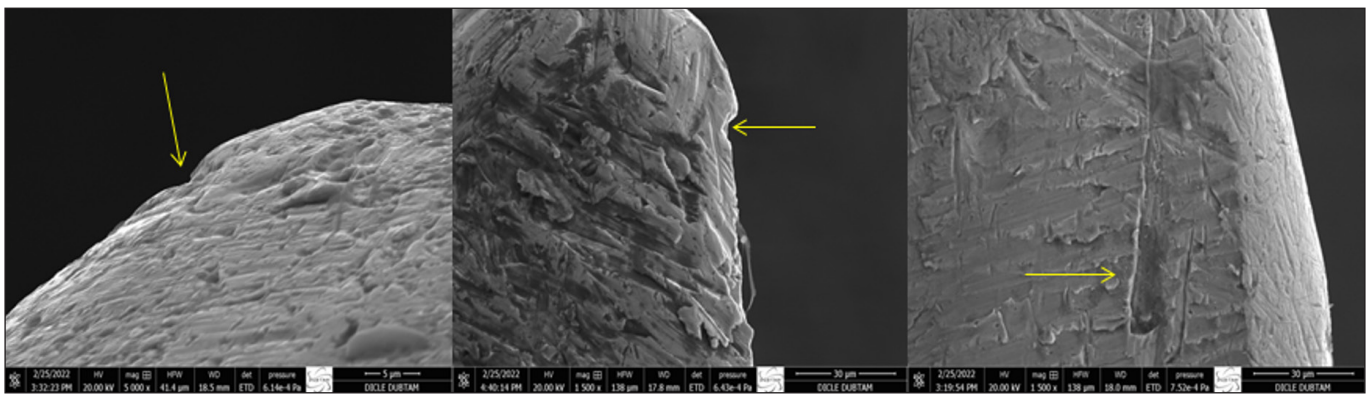

Figure 1. Tip, cutting edge, and surface deformation in file systems

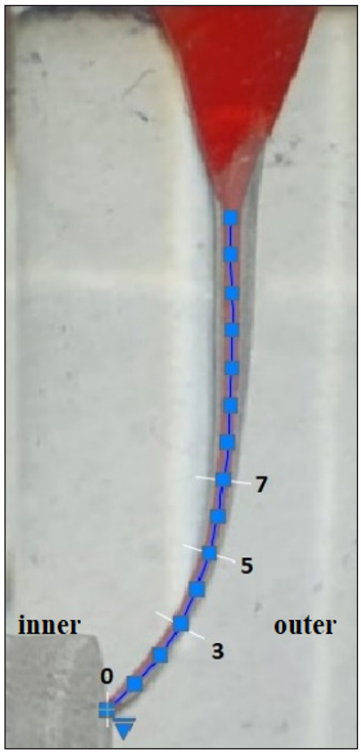

Figure 3. Identifying measurement points in the superimposed image

Statistical Analysis of Deformation

The relationship between categorical variables according to groups was examined using Fisher's exact test. Cochran's Q test was used to compare the deformation states within each file. Kappa tests were used to investigate the agreement between observers. Analysis results were presented as frequencies (Tables 1, 2, and 3). The significance level was taken as $p<0.05$.

Statistical Analysis of Transportation

The mean, standard deviation (SD), median, minimum (min), and maximum (max) values were calculated for the two file systems (Table 4). Conformity to normal distribution was evaluated using the Shapiro–Wilk test. Data were analyzed by one-way ANOVA, independent samples T, Kruskal–Wallis H, and Mann–Whitney U tests using SPSS 21.0 Software (IBM Corp, Armonk, NY, USA). The alpha-type error was set at 0.05.

Table 1. Comparison of tip deformation as a result of use within and between files

	Before usage	First usage	Second usage
TRN	0^{b}/10	0^{b}/10	5^{a}/10
MIS	0/10	0/10	2/10

Cohran's Q, Fisher's Exact test, a, b: The same letter indicates no difference between uses for each file.

Table 2. Comparison of cutting edge deformation as a result of use within and between files

	Before usage	First usage	Second usage
TRN	0/10	0/10	1/10
MIS	0/10	1/10	3/10

Cohran's Q, Fisher's Exact test

Table 3. Comparison of surface deformation as a result of use within and between files

	Before usage	First usage	Second usage
TRN	0/10	0/10	1/10
MIS	0^{a}/10	1^{ab}/10	5^{b}/10

Cohran's Q, Fisher's Exact test, a, b: The same letter indicates no difference between uses for each file.

RESULTS

Deformation

An excellent level of agreement between observers was obtained in all deformation assessments ($p<0.05$).

Tip deformation

In the TRN file, tip deformation increased significantly after the second use ($p<0.05$), and no difference was observed for the MIS file between the first and second uses ($p>0.05$) (Table 1).

Cutting-edge deformation

The file systems did not show a significant difference in cutting-edge deformation relative to each other and according to the number of uses ($p>0.05$) (Table 2).

Surface deformation

While the surface deformation of the MIS file increased significantly compared to before use ($p<0.05$), there was no significant difference in the TRN file ($p>0.05$) (Table 3).

Table 4. Evaluation of the transportation created by the files according to the number of uses and the level

Level (mm)	Transportation (mm)			
	Usage 1		Usage 2	
	Mean±SD	Median (Min-Max)	Mean±SD	Median (Min-Max)
MIS				
3	0.049±0.036	0.042 (0.014-0.139)^{xy}	0.160±0.284	0.029 (0.017-0.703)
5	0.024±0.015	0.025 (0.006-0.055)^{x}	0.111±0.251	0.031 (0.011-0.823)
7	0.101±0.053	0.121 (0.010-0.171)^{y}	0.102±0.053	0.105 (0.018-0.201)
TRN				
3	0.027±0.012^{a}	0.028 (0.002-0.049)	0.027±0.02^{a}	0.021 (0.001-0.066)
5	0.013±0.010^{b}	0.010 (0.001-0.032)	0.026±0.02^{a}	0.020 (0.003-0.069)
7	0.101±0.048^{c}	0.109 (0.033-0.162)	0.096±0.036^{b}	0.105 (0.044-0.154)

One way ANOVA, Independent Samples T, Kruskal Wallis H and Mann Whitney U test, a,b; x,y: Expresses differences within the same column.

Transportation

There was no difference in transportation values between the MIS and TRN file systems at any level (p>0.05). The file systems did not show a significant difference in the amount of transportation between the first and second use (p>0.05). For the MIS file, there was significantly more transportation at 7 mm than at the 5 mm level (p<0.05). For the TRN file, there was more transportation at 7 mm than at 3 and 5 mm levels (p<0.05).

DISCUSSION

Thanks to NiTi file technology, which continues to improve and progress from past to present, manufacturers aim to increase the fracture resistance and clinical performance of root canal instruments. Current NiTi files with increased flexibility and cyclic fatigue resistance compared to traditional ones make root canal preparation even easier.[19,20] With this technology (i.e., m-wire, blue-wire, gold-wire, t-wire, cm-wire, r-phase), clinicians use the files more than once because they find them more reliable against fracture and also to reduce the cost of treatment. However, it has been shown that cutting efficiency and flexibility decrease due to repeated use and sterilization cycles.[21] All these changes may cause an increase in the amount of transportation in the root canals.[22]

The fact that the TRN file system creates less transportation in the canal compared to many other files shows that this file system is suitable for use within the framework of MIE principles.[23,24] There is no study in the literature that measures the amount of transportation caused by this file when used multiple times. In addition, very few studies compare the TRN file with other files with similar tip diameters and tapers.[25]

In this study, the transportation that occurs at three levels in acrylic simulated canals as a result of the repeated usage and sterilization of two different minimally invasive file systems (TRN and MIS) was investigated in two dimensions. In addition, the deformation of the files as a result of use was evaluated by using SEM. According to the results of this study, the files did not show a significant difference in transportation between first and second use, within themselves and relative to each other. Therefore, the first H0 hypothesis was accepted.

In a study comparing the shaping ability of TRN (26.04), OneCurve (25.06), and Jizai (25.04) file systems, the Jizai file, which has the same tip diameter and taper with the MIS file we used in our study was not different from TRN in terms of transportation.[25] Kumar et al.[26] showed that TRN (26.04), Protaper Gold (25.08), and HyFlex EDM (25.08) files cause similar apical transportation in extracted teeth. In other words, although the apical diameter of the TRN file is larger than that of these files, there was no significant difference between them. The MIS Finisher (25.04) file we used in our study showed similar results to those for TRN regarding apical transportation, although it has a smaller apical diameter. The manufacturer states that TRN files' design and heat treatment give them more flexibility when shaping of root canal walls, resulting in efficient shaping.[14] Our result supports the manufacturer's claim.

It has been shown that multiple use of conventional NiTi files increases transportation in the apical region of resin canals.[3] On the other hand, increasing the use of another conventional NiTi file did not make a significant difference in transportation in resin blocks.[18] According to the results of our study, the first and second uses do not create a significant difference in the amount of transportation at the three levels in either file system. However, when both previous literature and our study are included, the microhardness and degree of curvature of the resin blocks, the number of uses, and the variety of files used may have affected all these results.

Transportation greater than 0.30 mm can have an adverse effect on apical sealing after obturations.[27] In our study, no transportation exceeding 0.16 mm was observed in either group at any level. This may be due to the flexibility of the TRN and MIS files and their smaller taper than most root canal files.

When the files were compared after the first and second use, there was no significant difference in deformation. In contrast, files from both systems showed increased deformation according to the number of uses. While tip deformation in the TRN file increased after the second use compared to the first, damage to the MIS file after the second use was insignificant compared to the first use. Therefore, the second H0 hypothesis was partially rejected. According to the manufacturers' information, MIS and TRN have a non-cutting tip design.[13,14] The apical 3 mm part of the MIS file is square, and the coronal part has a rectangular cross-section design.[13] The difference in cross-sectional design between the two file systems may have affected the rate of tip deformation.

When examined in terms of the cutting edge, there is no significant difference between the two file systems in terms of either the number of uses or the level of cross-section. The fact that there is no difference between the systems in terms of transportation confirms that the cutting efficiency of these files does not change with increasing use. In terms of surface deformation, while the MIS file was significantly deformed, the amount of deformation was insignificant in the TRN file. This may be due to TRN's NiTi alloy and off-centered parallelogram cross-section design. Clinically, the larger taper of a file causes more contact with the dentin surface and this

might increase the risk of the deformation and fracture of the file.[28,29] The TRN file has a variable regressive taper, while the MIS file has a constant taper. In this case, the surface deformation of the MIS file may have increased since it has more contact with the resin block.

Studies have been conducted examining the shaping ability, cutting efficacy, or deformation of files from 1 use to 10 uses.[4,21,30,31] In this study, we used the files twice and included them in the sterilization cycle twice. In addition to studies showing that sterilization causes file deformation and fatigue,[32] some studies claim the opposite.[33] In our study, we evaluated the deformation of the files after the shaping and sterilization process. Therefore, the effect of sterilization alone on surface deformation could not be tested. We repeated the same sterilization procedure after two uses to provide standardization. Uslu et al.[34] showed that exposure to 5.25% sodium hypochlorite (NaOCl) solution for 5 minutes and 17% EDTA for 10 minutes affects the surface roughness of the file. In our study, distilled water was used to irrigate acrylic blocks. Thus, NaOCl and EDTA's effect on the files' possible deformation was eliminated.

While human teeth with various anatomical variations can be used to examine the shaping ability of files, it is possible to perform this examination in standardized resin blocks. Although 3D evaluation cannot be done using this method, examining shaping ability in resin blocks has been widely accepted in the endodontic literature.[3,16,18,23] Although we preferred resin blocks to provide standardization and strengthen the methodology in our study, the fact that the hardness of these blocks is different to that of human teeth[35] is one of the limitations of our study. Another limitation of this methodology is that the deformation of the files was evaluated for two cycles of use and sterilization. Increasing the number of uses may affect the amount of transportation and deformation.

CONCLUSION

Within the limits of our study, when TRN (26.04) and MIS (25.04) NiTi rotary files were used twice on J-shaped resin blocks, the deformation they showed against physical stress and sterilization processes was not different from each other. In addition, neither has an advantage regarding transportation. Both file systems can be alternatives for minimally invasive shaping.

ETHICAL DECLARATIONS

Ethics Committee Approval: The authors declare that no experiments were performed on humans or animals for this study. Therefore, it does not require an ethical committee decision.

Informed Consent: The authors declare that no experiments were performed on humans for this study. Therefore, it does not require an informed consent.

Referee Evaluation Process: Externally peer reviewed.

Conflict of Interest Statement: The authors have no conflicts of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

Author Contributions: All the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

REFERENCES

1. Haikel Y, Serfaty R, Bateman G, Senger B, Allemann C. Dynamic and cyclic fatigue of engine-driven rotary nickel-titanium endodontic instruments. *J Endod.* 1999;25:434-440.
2. Yang Y, Hou B, Hou X. Effect of autoclave on surface microstructure and cyclic fatigue resistance of R-phase rotary instruments. *J Peking Univ Health Sci.* 2018;50:882-886.
3. Ounsi HF, Franciosi G, Paragliola R, Goracci C, Grandini S. Effect of repeated use on the shaping ability of Protaper Universal rotary files. *Int Dent SA.* 2010;12:30-35.
4. Armagan S, Haznedaroglu F. Scanning electron microscopy analysis of conventional and controlled-memory nickel titanium files before and after multi-uses in root canals. *Micros Res Tech.* 2021;84:1321-1327.
5. Valois CR, Silva LP, Azevedo RB. Multiple autoclave cycles affect the surface of rotary nickel-titanium files: an atomic force microscopy study. *J Endod.* 2008;34:859-862.
6. Paqué F, Ganahl D, Peters OA. Effects of root canal preparation on apical geometry assessed by micro–computed tomography. *J Endod.* 2009;35:1056-1059.
7. Maske A, Weschenfelder VM, Soares Grecca Vilella F, Burnett Junior LH, de Melo TAF. Influence of access cavity design on fracture strength of endodontically treated lower molars. *Aust Endod J.* 2021;47:5-10.
8. Mendes E, Soares A, Martins J, Silva E, Frozoni M. Influence of access cavity design and use of operating microscope and ultrasonic troughing to detect middle mesial canals in extracted mandibular first molars. *Int Endod J.* 2020;53:1430-1437.
9. Morales MdlNP, Sánchez JAG, Olivieri JG, et al. Micro–computed tomographic assessment and comparative study of the shaping ability of 6 nickel-titanium files: an in vitro study. *J Endod.* 2021;47:812-819.
10. de Oliveira DJF, Leoni GB, da Silva Goulart R, de Sousa-Neto MD, Sousa YTCS, Silva RG. Changes in geometry and transportation of root canals with severe curvature prepared by different heat-treated nickel-titanium instruments: a micro–computed tomographic study. *J Endod.* 2019;45:768-773.
11. Usta SN, Solana C, Ruiz-Linares M, et al. Effectiveness of conservative instrumentation in root canal disinfection. *Clin Oral Invest.* 2023;27:3181-3188.
12. Silva EJ, de Lima CO, Barbosa AFA, Lopes RT, Sassone LM, Versiani MA. The impact of TruNatomy and ProTaper Gold instruments on the preservation of the periradicular dentin and on the enlargement of the apical canal of mandibular molars. *J Endod.* 2022;48:650-658.
13. T-endo MIS catalogue. Accessed on: June 1, 2023. Avaible at: https://oncudental.com/ Urunler/Endodonti/T-Endo-Mis.aspx.

14. Dentsply Sirona TruNatomy Brochure. Accessed on June 1, 2023. Avaible at: https://www. dentsplysirona.com/en/explore/endodontics/trunatomy.html.
15. Weine FS, Kelly RF, Lio PJ. The effect of preparation procedures on original canal shape and on apical foramen shape. *J Endod.* 1975;1:255-262.
16. Merrett SJ, Bryant ST, Dummer PM. Comparison of the shaping ability of RaCe and FlexMaster rotary nickel-titanium systems in simulated canals. *J Endod.* 2006;32:960-962.
17. Berutti E, Paolino DS, Chiandussi G, et al. Root canal anatomy preservation of WaveOne reciprocating files with or without glide path. *J Endod.* 2012;38:101-104.
18. Elemam RF, Capelas JA, Vaz M, Viriato N, Pereira MdLFL, Azevedo Á. In vitro evaluation of root canal transportation after use of BT-Race files. *Rev Port Estomatol Med Dent Cir Maxilofac.* 2016;57:87-93.
19. Ha J-H, Kim SK, Cohenca N, Kim H-C. Effect of R-phase heat treatment on torsional resistance and cyclic fatigue fracture. *J Endod.* 2013;39(3):389-393.
20. Keskin C, Sivas Yilmaz Ö, Keleş A, Inan U. Comparison of cyclic fatigue resistance of Rotate instrument with reciprocating and continuous rotary nickel–titanium instruments at body temperature in relation to their transformation temperatures. *Clin Oral Invest.* 2021;25:151-157.
21. Seago ST, Bergeron BE, Kirkpatrick TC, et al. Effect of repeated simulated clinical use and sterilization on the cutting efficiency and flexibility of Hyflex CM nickel-titanium rotary files. *J Endod.* 2015;41:725-728.
22. Kamali S, Turkaydin D. Cyclic fatigue resistance and shaping ability of heat-treated nickel-titanium instruments after repeated use. *Niger J Clin Pract.* 2021;24:247-253.
23. Kim H, Jeon S-J, Seo M-S. Comparison of the canal transportation of ProTaper Gold, WaveOne Gold, and TruNatomy in simulated double-curved canals. *BMC Oral Health.* 2021;21:1-7.
24. Alarfaj B, Elsewify T, El-Sayed W, Eid B. Canal transportation and centering ability of thermally-treated niti files. *J Int Dent Med Res.* 2022;15:556-560.
25. Manocha S, Saha S, Agarwal R, Vijaywargiya N, Saha M, Surana A. Comparative evaluation of canal transportation and canal centering ability in oval canals with newer nickel-titanium rotary single file systems-A cone-beam computed tomography study. *J Conserv Dent.* 2023;26:326-333.
26. Kumar M, Paliwal A, Manish K, Ganapathy SK, Kumari N, Singh AR. Comparison of canal transportation in TruNatomy, ProTaper Gold, and Hyflex electric discharge machining file using cone-beam computed tomography. *J Contemp Dent Pract.* 2021;22:117-121.
27. Wu M-K, Fan B, Wesselink PR. Leakage along apical root fillings in curved root canals. Part I: effects of apical transportation on seal of root fillings. *J Endod.* 2000;26:210-216.
28. Gambarini G. Cyclic fatigue of nickel-titanium rotary instruments after clinical use with low-and high-torque endodontic motors. *J Endod.* 2001;27:772-4.
29. Haikel Y, Serfaty R, Bateman G, Senger B, Allemann C. Dynamic and cyclic fatigue of engine-driven rotary nickel-titanium endodontic instruments. *J Endod.* 1999;25:434-440.
30. Arantes WB, da Silva CM, Lage-Marques JL, Habitante S, da Rosa LCL, de Medeiros JMF. SEM analysis of defects and wear on Ni–Ti rotary instruments. *Scanning.* 2014;36:411-418.
31. Subha N, Sikri VK. Comparative evaluation of surface changes in four Ni-Ti instruments with successive uses-An SEM study. *J Conserv Dent.* 2011;14:282-286.
32. Kim W, Oh S, Ryu G-J, et al. Effect of autoclave sterilization on cyclic fatigue and torsional fracture resistance of NiTi rotary instruments. *Odontology.* 2020;108:194-201.
33. Casper RB, Roberts HW, Roberts MD, Himel VT, Bergeron BE. Comparison of autoclaving effects on torsional deformation and fracture resistance of three innovative endodontic file systems. *J Endod.* 2011;37:1572-1575.
34. Uslu G, Özyürek T, Yılmaz K. Effect of sodium hypochlorite and EDTA on surface roughness of HyFlex CM and HyFlex EDM files. *Micros Res Tech.* 2018;81:1406-1411.
35. Schäfer E, Diez C, Hoppe W, Tepel J. Roentgenographic investigation of frequency and degree of canal curvatures in human permanent teeth. *J Endod.* 2002;28:211-216.