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Static Cyclic Fatigue Resistance of Three Different Thermally Treated Nickel-Titanium Rotary Files: In-vitro Comparative Study

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Aim: compare cyclic fatigue resistance, length of the separated fragment and time to file fracture between Race Evo, TruNatomy and ProTaper Next files.
Materials and Methods: 75 new NiTi rotary files of ProTaper Next (PTN), TruNatomy (TN) and RaCe EVO (RE) were divided into 3 equal groups (n=25). Tested files were subjected to static cyclic fatigue protocol by rotating the file in 45o curved simulated canal in stainless steel block with 5 mm radius until the file separated. Time to file fracture and length of separated instrument was recorded while the number of cycles to fracture (NCF) were calculated. Data was statistically analyzed using one way ANOVA test.
Results: NCF in RE group was significantly higher than that obtained from TN and PTN, while PTN was lowest significantly. RE group recorded the least time to fracture between the tested groups with no significant difference between TN and PTN groups. PTN recorded significantly longer separated fragments than the other two tested groups.
Conclusion: Within the limits of the current investigation, RE files demonstrated the highest cyclic fatigue resistance in comparison to TN and PTN NiTi files regarding a static cyclic fatigue testing protocol. However, the RE files also fractured in a shorter duration than the other two systems.

Keywords: cyclic fatigue resistance, Trunatomy, Race EVO, bending test

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Introduction

Substitution of stainless-steel alloy with NiTi alloy for manufacturing of files needed mechanical root canal preparation had marked impact on quality of endodontic treatment and resulted in a reduction in treatment-related issues.[1] Nevertheless, while mechanically preparing root canals, endodontic NiTi rotary files still pose the risk of fracture within the canals. The main problem related to separated instrument is that it would reduce access to root canal areas, which in turn reduces the success rate of endodontic therapy. [2]

NiTi rotary files can fracture due to either cyclic or torsional failures. Cyclic fatigue is widely regarded as the prime reason of breakage in curved root canal systems. [3] It is caused by the repetitive cycles of tension and compression stresses experienced in the curved part of root canal. Hence, these instruments are constantly having their mechanical and metallurgical qualities improved to booster their resistance to cyclic fatigue, specifically, file production procedures and file design. [4]

M-wire alloy had been developed with special manufacturing technique with thermal processing of conventional NiTi alloy to improve the instrument's ability to withstand repeated fatigue and increase its flexibility. [5] ProTaper Next (Dentsply Sirona, Ballaigues, Switzerland) is an M-Wire rotary file system that features an off-centered rectangular cross-section alloy which developed with special heat treatment to improve the instrument's ability to withstand repeated fatigue and increase its flexibility. [5] TruNatomy is a file system (Dentsply Sirona, Ballaigues, Switzerland) that is made of a heat-treated, annealed nickel-titanium alloy that is designed for continuous rotational movement. It features a parallelogram-shaped, off-centered cross-section with a variable regressive taper, reaching a maximum diameter of 0.8 mm at the coronal end. These files undergo various heat treatment processes, which the manufacturer claims that it enhances their flexibility and resistance to cyclic fatigue. [6] Recently, the RaCe Evo file system was introduced, which is produced from a thermally processed nickel-titanium alloy and reported enhanced file flexibility and greater resistance toward cyclic fatigue and fracture. [7] The file features an electropolished surface with a triangular cross-section and alternating cutting edges. As formerly mentioned, utilizing different methods for alloy heat treatment would enhance its metallurgical properties. Nevertheless, rotary files would behave differently according to the manufacturing method and its design features. Therefore, the aim of this study was to compare the durability against cycle fatigue, duration until breakage, and length of the detached fragment of RaCe EVO (RE), TruNatomy (TN), and ProTaper next (PTN) NiTi rotary files.

Materials and Methods

Ethical approval of present study was obtained from Research Ethics committee at Faculty of Oral and Dental Medicine at Delta University, Egypt (DU:0240821042).

The sample size for the present study was determined using G*Power 3.1.9.7 software (Heinrich-Heine-Universität, Düsseldorf, Germany), taking into account an alpha error probability of 0.05, a power of 0.8, and an effect size of 0.5. the present investigation included 75 NiTi rotary files with near tip diameter of #25 and length 25 mm that equally divided into three groups (n=25) according to the type of the rotary file. The groups consisted of RE files (4% taper), TN prime file (4%), and PTN X2 file (6%). All files were inspected at high level of magnification using a dental operating microscope (Zumax OMS2380, Zumax medical ltd, Suzhou, China), and Any files found to be defective were substituted with new ones.

Cyclic fatigue test was performed using static artificial canal following ISO 3630-1 standard. Artificial canal was fabricated using a die-sinking electrical-discharge machining process (D-7135 LCD, Ningbo Bohong Machinery Manufacture Development Co., Zhejiang, China) in a hard stainless-steel block mounted on stainless steel base plate. The canal has curvature angle of 45^{o} of with 5 mm radius. Artificial canal had 14 mm total length with 1.2 mm maximum canal width at the simulated canal orifice and the center of curvature approximately 5 mm from canal tip. Depth of artificial canal was machined by incrementing the maximum diameter of the instrument by 0.2 mm to enable free instrument rotation within the canal. A transparent glass cover was positioned over a designated cut-out chamber to collect the file segment located at the top of the canal apex, allowing for visualization of the revolving instruments in the canal and preventing them from slipping out of the chamber.

Each file was mounted to a torque-controlled electric motor (FKG Rooter S, FKG Dentaire, La Chaux-de-Fonds, Switzerland) with a contra angled head (16:1 reduction speed) and positioned within the canal to the desired length using a custom-made jig connected to the base device which could be adjusted in vertical and horizontal planes to allow for three-dimensional reproducible positioning. file rotation was set and continued under constant rotating speed and torque according to the manufacturer's instructions (800 rpm/1.5 Ncm for RE, 500 rpm/1.5 Ncm for TN, and 350 rpm/2 Ncm for PTN) until the file fractured. Glycerin was used to reduce the friction of instruments with stainless steel walls. for each instrument, the time to fracture of each instrument was recorded and the number of cycles to fracture (NCF) was calculated by multiplying the time recorded in seconds by the recommended motor speed divided on 60. Apical instrument fragments were then collected, and length measured with a digital caliper.

Statistical analysis was conducted using SPSS Statistics for Windows software (SPSS v20, IBM Corp, NY, USA). Normality tests, including the Shapiro-Wilk and Kolmogorov-Smirnov tests, revealed that the data followed a normal distribution. Accordingly, the mean and standard deviation of the NCF and instrument length were calculated for each group and compared at 0.05 level of significance using ANOVA and Tukey's multiple comparison postHOC tests.

Results

Data regarding NCF, time to fracture and separated fragment length is detailed in table 1 and presented in figure 1. In summary, RE demonstrated the highest value regarding NCF with shortest duration regarding time to fracture significantly than PTN and TN files. There was no significant difference between PTN and TN files regarding time to fracture, however TN files were more resistant toward cyclic fatigue significantly. There was significant difference regarding separated fragment length between the three tested groups.

Table 1: Mean values and standard deviation of the number of cycles to fracture (NCF), time to fracture (TTF) (in seconds) and fragment length (FL) (in mm) after testing with static cyclic fatigue protocol

	NCF			TTF			FL		
PTN	915.4	±	177.2^{c}	156.9	±	30.4^{a}	4.3	±	0.07^{a}
TN	1281.5	±	251.3^{b}	153.8	±	30.2^{a}	5.2	±	0.10^{c}
RE	1720.7	±	357.9^{a}	129.1	±	26.8^{c}	4.9	±	0.14^{b}
P-value	0.000			0.002			0.000		

Values with different lower-case superscript at the same column are statistically significant different at p-value <0.05.

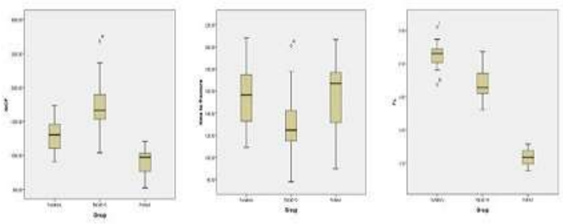

Figure 1: Box Plot analysis of the static cyclic fatigue resistance of TN, RE and TN files showing comparison regarding NCF (a), TTF (b) and FL (c).

Discussion

Thermo-mechanical processing is commonly employed to enhance the microstructure and phase transformation characteristics of nickel-titanium instruments, thereby improving their performance in root canal mechanical preparation, including increased resistance to cyclic fatigue. [8] Thus, the present study focused on comparing the cyclic fatigue resistance between three different thermally treated NiTi alloy rotary systems. Based on current data, significant differences between the tested groups regarding all testing criteria were noted, thus, null hypothesis has been rejected.

Present study utilized a static cyclic fatigue testing protocol, subjecting the instruments to a steel canal with a 45° angle and 5-mm radius of curvature, as described in prior research. [9–11] In the static test model, the concentrated alternating stresses in a single area of the instrument at the center of the curve can induce changes in the alloy's micro-structure. [12] In contrast, the dynamic test model permits the instrument to glide vertically across the curve, thus reducing stress and increasing the likelihood of fatigue life extension. [13] In this case, we used the static model to control for operator-dependent and subjective factors such axial motion and speed, even though the dynamic model better represents real-world root canal preparation.[14,15]

The RE files have been introduced by the manufacturer as an improved generation of the RaCe files, featuring similar design characteristics. To the best of our knowledge, there is limited published data comparing the cyclic fatigue resistance of RE files with other rotary files, making it challenging to justify and draw comparisons. Existing research have demonstrated the enhanced cyclic fatigue resistance of RE instruments compared to the predecessor RaCe files made from pseudo-elastic nickel-titanium alloy [7,16], as well as other heat-treated file systems. [17] The present study revealed that RE has superior resistance to cyclic fatigue compared to TN and PTN files. One explanation of the improved fatigue resistance may be attributed to the heat treatment utilized in the manufacturing process, which alters the metallurgical properties of the alloy. Even though all the tested files are heat-treated, the differences in the thermal treatment of the NiTi alloy in each system may have influenced the results. The manufacturer claimed that the applied heat treatment to the alloy triggers a phase transition (between martensite and austenite) just below body temperature (between 32°and 35°C). Previous studies [18,19] have shown that heat-treating NiTi alloy results in maintaining file alloy in the martensitic phase at body temperature, which subsequently increases its resistance to cyclic fatigue. Another explanation for the improved cyclic fatigue resistance of the RE files is their cross-sectional design. The importance of a reduced core area of the files has been thoroughly investigated in previous studies [20,21], which have indicated that this design feature enhances the fatigue resistance of the instruments. In recent research by Pedulla et al [22], authors explained that instruments with triangular cross sections would be more resistant toward cyclic fatigue in comparison with rectangular or parallelogram cross sections in static cyclic fatigue test. Moreover, The RE has a centered triangular cross-section, in contrast to the off-centered parallelogram cross-section of the TN and PTN files. Research by Galal and Hamdy [23] has shown that minimizing stress accumulation during the bending of rotary files in curved root canals can be achieved by using rotary NiTi instruments with a centered cross-section, rather than an eccentric cross-section as the centered design improves the flexibility of the rotary NiTi instruments during bending.

The present study also revealed a significant resistance of TN files compared to PTN files. this could be explained because of both design features and metallurgical properties of files. [6] according to the manufacturer, both TN and PTN share an off-centered cross-section with a parallelogram-shaped and rectangular cross-section, respectively. however, TN file has less tapering in comparison with PTN which would have larger core diameter, the reduced core diameter related to TN may has increased flexibility resulting in less stress on the file during bending or rotation. in contrast, the increased core diameter mass of PTN could result in greater stress accumulation in the file during bending in curved canals, leading to lower cyclic fatigue resistance. [22] present results come in agreement with former research. [6,24]

Despite the results revealed that the RE files exhibited the greatest resistance to cyclic fatigue, it also indicated that they failed significantly faster than the PTN and TN files. This could be explained by the fact that the RE files were rotated at a higher speed compared to the other tested instruments according to the manufacturer's instruction. Prior research[14] has shown that higher rotational speeds can diminish the cyclic fatigue resistance of rotary nickel-titanium instruments. This is because increased rotational speed leads to a greater number of cycles per unit of time, resulting in earlier instrument fracture. on contrary, Pedulla et al [25] reported that rotational speed did not affect the fatigue resistance but decrease the preparation time needed. The contradictory findings regarding the effect of rotational speed on cyclic fatigue resistance may be related to the lack of a standardized protocol for comparing the cyclic fatigue of different file systems under the same speed and torque settings. It is noteworthy that the time to instrument separation has important clinical implications, as the operator must be aware that files rotated at higher speeds may separate in a shorter time, even if they have high cyclic fatigue resistance.

Results of the present study indicated significant difference between the length of the separated fragment as PTN represented the shortest separated fragment. Furthermore, Existing data also indicate that the fracture of instruments occurred near the point of maximum curvature of the canal which was 5 mm, which come in ordinance with Stošić et al. [11] and Aksoy et al. [26] An explanation for that might be attributed to reduced flexibility when compared to the tested files because of increased taper and core area at the point of fracture which agree with previous research.[12]

Conclusion

Within the limits of the current investigation, RE files demonstrated the highest cyclic fatigue resistance compared to the TN and PTN NiTi rotary file systems regarding a static cyclic fatigue testing protocol. However, the RE files also fractured in a shorter duration than the other two systems.

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Data availability

Data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethical approval:

Ethical approval of present study was obtained from Research Ethics committee at Faculty of Oral and Dental Medicine at Delta University, Egypt (DU:0240821042).

Conflicts of Interest

Authors declare that they have no conflicts of interest.

References

1. Baumann MA. Nickel–titanium: options and challenges. Dent Clin North Am. 2004 Jan 1;48(1):55–67.
2. McGuigan MB, Louca C, Duncan HF. The impact of fractured endodontic instruments on treatment outcome. Br Dent J. 2013 Mar;214(6):285-9.
3. Pedullà E, Canova FS, La Rosa GRM, Naaman A, Diemer F, Generali L, Nehme W. Influence of NiTi Wire Diameter on Cyclic and Torsional Fatigue Resistance of Different Heat-Treated Endodontic Instruments. Materials (Basel). 2022 Sep 22;15(19):6568.
4. Srivastava S, Alghadouni MA, Alotheem HS. Current strategies in metallurgical advances of rotary NiTi instruments: A review. J Dent Health Oral Disord Ther. 2018 Feb;9(1):72.
5. Ye J, Gao Y. Metallurgical characterization of M-Wire nickel-titanium shape memory alloy used for endodontic rotary instruments during low-cycle fatigue. J Endod. 2012 Jan;38(1):105-7.
6. Peters OA, Arias A, Choi A. Mechanical Properties of a Novel Nickel-titanium Root Canal Instrument: Stationary and Dynamic Tests. J Endod. 2020 Jul;46(7):994-1001.
7. Basturk FB, Özyürek T, Uslu G, Gündoğar M. Mechanical Properties of the New Generation RACE EVO and R-Motion Nickel-Titanium Instruments. Materials (Basel). 2022 May 6;15(9):3330.
8. Hieawy A, Haapasalo M, Zhou H, Wang ZJ, Shen Y. Phase Transformation Behavior and Resistance to Bending and Cyclic Fatigue of ProTaper Gold and ProTaper Universal Instruments. J Endod. 2015 Jul;41(7):1134-8.
9. Plotino G, Grande NM, Cordaro M, Testarelli L, Gambarini G. A review of cyclic fatigue testing of nickel-titanium rotary instruments. J Endod. 2009 Nov;35(11):1469-76.
10. Abd allah D, Nagy M, Yehia T. Comparison of Cyclic Fatigue Resistance of Two Different Rotary NiTi Instruments (An In-Vitro Study). Ain Shams Dental Journal. 2024 Mar 1;33(1):121-6.
11. Stošić N, Popović J, Anđelković Apostolović M, Mitić A, Nikolić M, Barac R, Kostić M. Effects of Autoclave Sterilization on Cyclic Fatigue Resistance in 5 Types of Rotary Endodontic Instruments: An In Vitro Study. Med Sci Monit. 2023 Mar 27;29:e939694.
12. Allahem Z, Bendahmash M, Almeaither R, Alfawaz H, Alqedairi A. Evaluation of cyclic fatigue behavior of RACE EVO rotary Files: In-vitro comparative study. Saudi Dent J. 2024 Apr;36(4):656-660.
13. Arias A, Hejlawy S, Murphy S, de la Macorra JC, Govindjee S, Peters OA. Variable impact by ambient temperature on fatigue resistance of heat-treated nickel titanium instruments. Clin Oral Investig. 2019 Mar;23(3):1101-1108
14. Li UM, Lee BS, Shih CT, Lan WH, Lin CP. Cyclic fatigue of endodontic nickel titanium rotary instruments: static and dynamic tests. J Endod. 2002 Jun;28(6):448-51.
15. Alcalde MP, Duarte MAH, Bramante CM, de Vasconselos BC, Tanomaru-Filho M, Guerreiro-Tanomaru JM, Pinto JC, Só MVR, Vivan RR. Cyclic fatigue and torsional strength of three different thermally treated reciprocating nickel-titanium instruments. Clin Oral Investig. 2018 May;22(4):1865-1871.
16. AbuMostafa A, Alfadaghem M. Influence of short-term cooling on the performance of superelastic and thermally-treated rotary NiTi files tested in dynamic cyclic fatigue model. Front Biosci (Landmark Ed). 2021 Dec 30;26(12):1464-1469.
17. Ramadan F, AbuMostafa A, Alharith D. Evaluation of cyclic fatigue and bending test for different Nickle-Titanium files. PLoS One. 2023 Aug 25;18(8):e0290744.
18. Yahata Y, Yoneyama T, Hayashi Y, Ebihara A, Doi H, Hanawa T, Suda H. Effect of heat treatment on transformation temperatures and bending properties of nickel-titanium endodontic instruments. Int Endod J. 2009 Jul;42(7):621-6.
19. Fouad HK, Hashem AA, Abdel Aziz TM. Evaluation of cyclic fatigue of three different Rotary Nickel Titanium Systems. Ain Shams Dental Journal. 2021 Jun 1;22(2):39-50.
20. Kurt SM, Kaval ME, Serefoglu B, Kandemir Demirci G, Çalışkan MK. Cyclic fatigue resistance and energy dispersive X-ray spectroscopy analysis of novel heat-treated nickel-titanium instruments at body temperature. Microsc Res Tech. 2020 Jul;83(7):790-794.
21. Gambarini G, Grande NM, Plotino G, Somma F, Garala M, De Luca M, Testarelli L. Fatigue resistance of engine-driven rotary nickel-titanium instruments

produced by new manufacturing methods. J Endod. 2008 Aug;34(8):1003-5.

22. Pedullà E, Kharouf N, Caruso S, La Rosa GRM, Jmal H, Haikel Y, Mancino D. Torsional, Static, and Dynamic Cyclic Fatigue Resistance of Reciprocating and Continuous Rotating Nickel-Titanium Instruments. J Endod. 2022 Nov;48(11):1421-1427.

23. Galal M, Hamdy TM. Evaluation of stress distribution in nickel-titanium rotary instruments with different geometrical designs subjected to bending and torsional load: a finite element study. Bulletin of the National Research Centre. 2020 Dec;44:1-1.

24. Riyahi AM, Bashiri A, Alshahrani K, Alshahrani S, Alamri HM, Al-Sudani D. Cyclic Fatigue Comparison of TruNatomy, Twisted File, and ProTaper Next Rotary Systems. Int J Dent. 2020 Feb 26;2020:3190938.

25. Pedullà E, Plotino G, Grande NM, Scibilia M, Pappalardo A, Malagnino VA, Rapisarda E. Influence of rotational speed on the cyclic fatigue of Mtwo instruments. Int Endod J. 2014 Jun;47(6):514-9.

26. Karataşlıoglu E, Aydın U, Yıldırım C. Cyclic Fatigue Resistance of Novel Rotary Files Manufactured from Different Thermal Treated Nickel-Titanium Wires in Artificial Canals. Niger J Clin Pract. 2