Original Article

Influence of different cross-section on cyclic fatigue resistance of two nickel–titanium rotary instruments with same heat treatment: An *in vitro* study

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Abstract

Introduction: The aim of this study was to investigate the role of the cross-sectional design surface in improving the cyclic fatigue resistance by comparing two nickel–titanium (NiTi) rotary instruments with the same heat-treatment and grinding procedure.

Materials and Methods: A total of 40 new NiTi instruments (20 S-One 25.06 taper and 20 AF Blue S4 25.06 taper) were tested in the present study. Both instruments were rotated at 300 rpm and with a torque setting of 2 Ncm) using an endodontic motor in the same artificial canal (90° angle of curvature and 3 mm radius). A Student's *t*-test was performed to determinate the differences in terms of time to fracture (TtF) and the length of the fractured portion between the two different instruments. Significance was set at $P < 0.05$.

Results: The differences in terms of TtF for cyclic fatigue resistance between the two files were statistically significant ($P < 0.05$). In terms of fractured length, not statistically significant differences were found ($P > 0.05$). Scanning electron microscopy images showed patterns of cyclic fatigue striations.

Conclusion: The results of this study confirm and enhance the role of cross-section in increasing the cyclic fatigue resistance of NiTi rotary instruments.

Keywords: Cross-section, cyclic fatigue, endodontics, heat treatment, nickel–titanium rotary instruments

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INTRODUCTION

The introduction of nickel–titanium (NiTi) rotary instruments in endodontics brought significant improvement in root canal treatment. Thanks to this alloy, excellent results in terms of shaping and cleaning of root canals were reached.[1] Despite the superior qualities of the NiTi alloy compared to the traditional stainless steel instruments, the risk of unexpected fracture could still occur. Several factors could affect the unexpected file breakage, among those, the most remarkable are flexural and torsional stresses.[2] During instrumentation, the torsional fracture could occur when the tip or a part of the file binds inside the canal while the remaining part still rotates, overloading the torsional resistance of the instrument.[3,4] On the other hand, repetitive compression and tension that the files endure could cause cyclic

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fatigue failures.[5] Intracanal cyclic failure is an unexpected complication that is clinically predictable, but it is not possible to know when it will happen exactly. Cyclic fatigue stresses result in the formation of microcracks on the file's surface, usually beginning with minimal defects on the instrument outer part.[6,7] The fatigue separation is particularly insidious and can occur without any warnings. Geometrical discontinuities, porosities, inclusions, and overheating that occurred during manufacturing could lead to fatigue failure.[8]

Moreover, many published studies demonstrate the presence of hidden curvature inside the root canal anatomy; this kind of curvature enhances the bending stresses in NiTi rotary files.[9]

One of the most used ways to evaluate the resistance to flexural stresses is to study the *in vitro* cyclic fatigue lifespan.[10] The *in vitro* flexural resistance, as shown in many studies, is affected by many factors, such as speed, motion, alloy, mass/cross-section, tip diameter and taper dimension, surface quality treatment, and canal features such as radius of curvature.[11-14] Furthermore, the grinding procedure could influence the lifespan of the rotary files, but this parameter is often difficult to evaluate.[15]

The S-One (Fanta Dental CO., Ltd., Shanghai, China) is a heat-treated instrument recently introduced on the marketplace. This file is thought to be used in a single file system technique and in continuous rotation.[16] The instrument presents an S-Shaped cross-section with two cutting blades along the cutting surface. The tip diameter is 25, and the taper 6% along with the whole instrument.

The AF Blue S4 (Fanta Dental CO., Ltd., Shanghai, China) is a 4-file system. The file taken into consideration in this study is the 25.06. It presents a convex triangular cross-section along with the instrument with three cutting blades. AF-R wire is the proprietary heat treatment used for both files. According to the manufacturer's studies, it should improve file flexibility, elastic behavior, and ultimately provide better shaping abilities. However, there are no published studies that demonstrate the manufacturer's claims.[17]

To date in the present literature, there are no studies that compare the resistance of S-One and AF Blue S4 instruments to cyclic fatigue in a stainless steel artificial canal.

The aim of the present study was to evaluate the role of the cross-sectional design of the instrument regarding the cyclic fatigue resistance.

MATERIALS AND METHODS

A total of 40 new NiTi instruments 25 mm in length were tested in this study and divided into two groups: 20 S-One, tip size 25 and constant 0.06 taper in Group A and 20 AF Blue S4 tip size 25 and constant taper 0.06 in Group B.

All instruments were used in continuous motion with 300 rpm and 2 Ncm torque value with the same endodontic motor (Eighteeth, Shanghai, China). All the instruments had been previously inspected for manufacturer defects or any visible signs of deformations using a stereomicroscope at ×20 magnification. As a result, none of them were discarded. To perform the tests, a customized self-assembled cyclic fatigue testing device already adopted in previously published studies[18,19] was used. The device consists of a main platform to which is connected to an electric handpiece and a stainless-steel block containing the artificial canals [Figure 1]. The electric handpiece, mounted on a mobile device, allowed a precise and reproducible placement of each instrument inside the stainless steel canal and permitted each instrument to reach the same depth (18 mm). The stainless steel artificial root canal used in this study present a 90° angle of curvature and 3 mm radius of curvature. The whole procedure has been performed by the same operator, to keep as low as possible the variability during the testing procedure. Time to fracture for each (TtF) instrument was recorded. The time was stopped as soon as the fracture was visible and registered with a 1/100 s chronometer. Fragment length (FL) was also collected and measured using a digital caliper. The data were collected, and mean and standard deviation (SD) were calculated. Differences among groups were statistically evaluated with Student's t-test, and the significance level was set at $P < 0.05$. Data were statistically analyzed using the

Figure 1: Device used with the instrument engaged in the artificial, stainless steel canal

SPSS 17.0 software (SPSS Incorporated, Chicago, IL, USA). After the test, the fragment of used instrument underwent to scanning electron microscope (SEM) (Hitachi, Tokyo, Japan) analysis to investigate the fracture pattern.

RESULTS

As illustrated in Table 1, TtF for each instrument was recorded, and statistical analysis found significant differences between the two groups ($P < 0.05$). Mean values for TtF for Group A were 29.54 s (SD ± 4.73), and Group B instruments were 10.67 s (SD ± 2.51). The Group A (S-One) showed higher TtF than the Group B (AF Blue), and statistical analysis found significant differences between the two instruments ($P < 0.05$). Mean values for FL showed no significant differences ($P > 0.05$) between the two instruments.

Fractographic analysis of the fractured surfaces performed at the SEM showed patterns of cyclic fatigue striations, confirming that the fracture occurred due to repeated flexural stresses [Figures 2 and 3].

DISCUSSION

The present *in vitro* study compares cyclic fatigue resistance among the selected Ni-Ti rotary files. In literature, there are no studies comparing the fatigue lifespan of these two files. S-One 25.06 exhibited higher cyclic fatigue resistance compared to S4 25.06 ($P < 0.05$). The results in terms of fragment's length demonstrated no differences in the insertion of the instruments inside the stainless steel canal and no differences in the portion of the instrument subjected to the stresses.

Table 1: Time to fracture and fragment length analysis

	Mean±SD	
	TtF (s)	FL (mm)
S-One	29.54±4.73	3.15±0.74
AF Blue S4	10.67±2.51	3.25±0.75

SD: Standard deviation, FL: Fragment length, TtF: Time to fracture

Several variables, such as instrument taper, size, cross-sectional design, and manufacturing techniques, could influence the clinical performance of the endodontic files as well as their resistance to cyclic fatigue lifespan.[20-22]

The two Ni-Ti rotary files have the same tip #25 and constant 0.06 taper. The same dimension parameters such as tip and taper allow the comparison of the performance of the two files. To avoid the influence of the motion on cyclic fatigue resistance, each of the tested instruments was rotated in continuous motion at the same speed 300 rpm, and the torque value has been set at 2 Ncm.

According to previous studies, fatigue resistance can be influenced by the alloy and the manufacturing process of the instruments.[22,23] To avoid influence due to metallurgical behavior, both instruments taken into account in this study are made with the same grinding process and have the same heat-treated alloy, the AF-R Wire. According to the manufacturer's claims,[17] this proprietary thermal treatment could improve the cyclic fatigue lifespan, but no published studies have already demonstrated it.

In literature, there are several studies evaluating the relation between cross-section and cyclic fatigue resistance, but none of them could exclude the influence of other confounding factors in cyclic fatigue lifespan, such as grinding machine and manufacturing process. These factors are eliminated in these factors because the two studied files are realized

Figure 2: Scanning electron microscope analysis × 250 magnification SE + B. C + B. T of S One

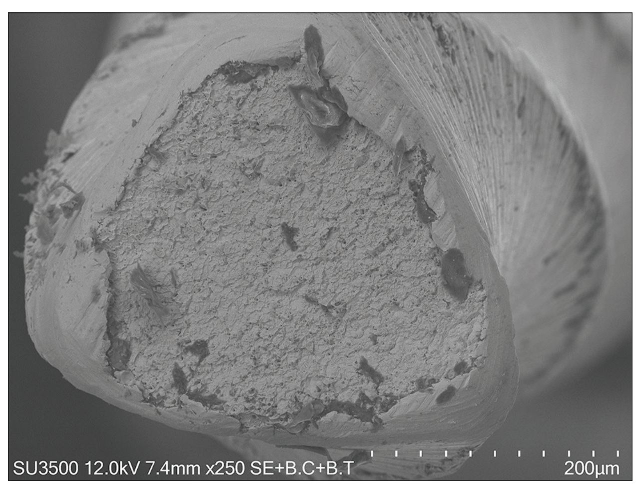

Figure 3: Scanning electron microscope analysis × 250 magnification SE + B. C + B. T of AF Blue S4

by the same manufacturer with the same grinding machine and the same procedure.[24,25]

Differently from previous studies that have been focused on cyclic resistance parameters such as manufacturers and metallurgical features, heat treatments and different motion techniques were eliminated in this study, allowing a more precise evaluation of the influence of the cross-sectional design.

The mean value for the FL is 3, 20 mm for both instruments tested (no significant difference found). The stainless steel artificial canal presents a 90° curvature at 3 mm from the apex. Therefore, 3 mm correspond to the point of maximum stress of the instruments. At this point, the cross-section is the only parameter that could influence the fatigue resistance between the S-One and AF Blue S4. Thus, an explanation of the longer lifespan of S-One could be related to the different cross-sections of the two instruments. The S-One has an S-shaped cross-section while the AF Blue S4 has a convex triangular cross-section. Previous studies have already demonstrated that an instrument rotating freely inside a canal can enhance its cyclic fatigue lifespan, for this reason, the canal dimension should be tight to the instrument tip and taper.[26] Using the same canal, the S-shaped cross-sectional design could be also advantageous in reducing torsional stresses because of the less surface in contact with the canal walls.[27,28] Moreover, the S-Shaped cross-sectional design presents less blade engagement compared to the convex triangular cross-section, and it could influence the instrument cyclic fatigue resistance.[29]

Recent studies indicated that the amount of metal mass could affect the fatigue resistance of rotary instruments. In the past 13 years, it has been investigated the influence of metal mass in the flexural resistance, and previous studies already demonstrated that the S-Shaped cross-section design presents lower mass percentage than a conventional triangular convex section.[30,31] Thus, the S-Shaped cross-section of the 25.06 S-One instrument must be considered as one of the most relevant characteristics as well as the metal mass in the influence of flexural resistance.[32]

Both instruments were analyzed using SEM and showed similar fracture patterns. The fractured surfaces were inspected to assess their topographic features and to confirm that the files fractured because of cyclic fatigue that is characterized by the presence of typical fatigue striations [Figures 4 and 5]. Similar findings were reported by Gambarini *et al*.[33]

S-One 25.06 and AF Blue S4 25.06 showed statistically significant differences in cyclic fatigue test. Since motion and the heat treatment were the same, differences could be related to the different cross-sectional design and the mass present along the instrument. However, further studies are needed to better evaluate the role of the different cross-sectional design and metal mass in improving instruments fatigue resistance to fracture.

CONCLUSION

The results of this study confirm and enhance the role of cross-section in increasing the cyclic fatigue resistance of NiTi rotary instruments.

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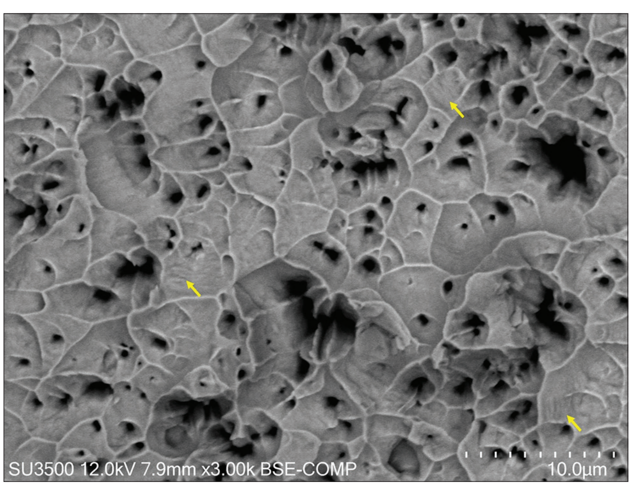

Figure 4: Scanning electron microscope magnification (×3000) showing fatigue stripes (yellow arrows) on the fractured surface of the S-One endodontic instrument

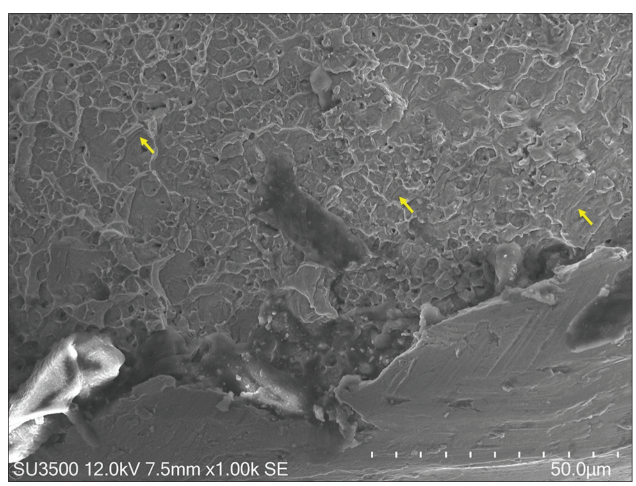

Figure 5: Scanning electron microscope magnification (×1.000) showing fatigue stripes (Yellow arrows) on the fractured surface of the AF-Blue endodontic instrument

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Mehlawat R, Kapoor R, Gandhi K, Kumar D, Malhotra R, Ahuja S, *et al.* Comparative evaluation of instrumentation timing and cleaning efficacy in extracted primary molars using manual and NiTi rotary technique – *In vitro* study. J Oral Biol Craniofac Res 2019;9:151-5.
2. Pedullà E, Lo Savio F, La Rosa GRM, Miccoli G, Bruno E, Rapisarda S, *et al.* Cyclic fatigue resistance, torsional resistance, and metallurgical characteristics of M3 rotary and M3 pro gold NiTi files. Restor Dent Endod 2018;43:e25.
3. Gambarini G, Seracchiani M, Piasecki L, Valenti Obino F, Galli M, Di Nardo D, *et al.* Measurement of torque generated during intracanal instrumentation *in vivo*. Int Endod J 2019;52:737-45.
4. Tokita D, Ebihara A, Nishijo M, Miyara K, Okiji T. Dynamic torque and vertical force analysis during nickel-titanium rotary root canal preparation with different modes of reciprocal rotation. J Endod 2017;43:1706-10.
5. 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;41:913-5.
6. 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;35:112-8.
7. Yılmaz A, Gökyay SS, Dağlaroğlu R, Küçükay IK. Evaluation of deformation and fracture rates for nickel-titanium rotary instruments according to the frequency of clinical use. Eur Oral Res 2018;52:89-93.
8. Rodrigues RC, Lopes HP, Elias CN, Amaral G, Vieira VT, De Martin AS. Influence of different manufacturing methods on the cyclic fatigue of rotary nickel-titanium endodontic instruments. J Endod 2011;37:1553-7.
9. Valenti-Obino F, Di Nardo D, Quero L, Miccoli G, Gambarini G, Testarelli L, *et al.* Symmetry of root and root canal morphology of mandibular incisors: A cone-beam computed tomography study *in vivo*. J Clin Exp Dent 2019;11:e527-33.
10. Bukhari KA, Almalki MA, Daghestani MH, Bogari DF, Aljifan MK, Alharbu YM *et al.* Cyclic fatigue comparison of different manufactured endodontic files. Saudi Endod J 2019;9:186-91.
11. Gambarini G, Miccoli G, Seracchiani M, Morese A, Piasecki L, Gaimari G, *et al.* Fatigue resistance of new and used nickel-titanium rotary instruments: A Comparative study. Clin Ter 2018;169:e96-101.
12. Kırıcı DÖ, Karataş E, Uygun AD, Doğanay Yıldız E, Çolak KM, Arslan H. Comparison of the cyclic fatigue resistance of proGlider, pathGlider and one G path-finding instruments. J Dent Res Dent Clin Dent Prospects 2019;13:57-60.
13. Miccoli G, Gaimari G, Seracchiani M, Morese A, Khrenova T, Di Nardo D. *In vitro* resistance to fracture of two nickel-titanium rotary instruments made with different thermal treatments. Ann Stomatol (Roma) 2017;8:53-8.
14. Ozyurek T, Uslu G, Yılmaz K. Influence of different movement kinematics on cyclic fatigue resistance of nickel-titanium instruments designed for retreatment. Saudi Endod J 2017;7:151-5.
15. Pedullà E, Plotino G, Grande NM, Pappalardo A, Rapisarda E. Cyclic fatigue resistance of four nickel-titanium rotary instruments: A comparative study. Ann Stomatol (Roma) 2012;3:59-63.
16. Dagna A. Nickel-titanium single-file system in endodontics. J Contemp Dent Pract 2015;16:834-9.
17. Fanta Dental Society, Internal Studies. Available from: https://www.fantausa.com/copy-of-resources. [Last accessed on 2019 Oct 11].
18. Gambarini G, Gergi R, Naaman A, Osta N, Al Sudani D. Cyclic fatigue analysis of twisted file rotary NiTi instruments used in reciprocating motion. Int Endod J 2012;45:802-6.
19. Gambarini G, Tucci E, Bedini R, Pecci R, Galli M, Milana V, *et al.* The effect of brushing motion on the cyclic fatigue of rotary nickel titanium instruments. Ann 1st Super Sanita 2010;46:400-4.
20. Ounsi HF, Nassif W, Grandini S, Salameh Z, Neelakantan P, Anil S. Evolution of nickel-titanium alloys in endodontics. J Contemp Dent Pract 2017;18:1090-6.
21. Grande NM, Plotino G, Silla E, Pedullà E, DeDeus G, Gambarini G, *et al.* Environmental temperature drastically affects flexural fatigue resistance of nickel-titanium rotary files. J Endod 2017;43:1157-60.
22. Pedullà E, Lo Savio F, La Rosa GRM, Miccoli G, Bruno E, Rapisarda S, *et al.* Cyclic fatigue resistance, torsional resistance, and metallurgical characteristics of M3 rotary and M3 pro gold NiTi files. Restor Dent Endod 2018;43:e25.
23. Chi CW, Lai EH, Liu CY, Lin CP, Shin CS. Influence of heat treatment on cyclic fatigue and cutting efficiency of proTaper universal F2 instruments. J Dent Sci 2017;12:21-6.
24. Di Nardo D, Galli M, Morese A, Seracchiani M, Ferri V, Miccoli G, *et al.* A comparative study of mechanical resistance of two reciprocating files. J Clin Exp Dent 2019;11:e231-5.
25. Gambarini G, Grande NM, Plotino G, Somma F, Garala M, De Luca M, *et al.* Fatigue resistance of engine-driven rotary nickel-titanium instruments produced by new manufacturing methods. J Endod 2008;34:1003-5.
26. Inan U, Aydin C. Comparison of cyclic fatigue resistance of three different rotary nickel-titanium instruments designed for retreatment. J Endod 2012;38:108-11.
27. Schäfer E, Tepel J. Relationship between design features of endodontic instruments and their properties. Part 3. Resistance to bending and fracture. J Endod 2001;27:299-303.
28. Versluis A, Kim HC, Lee W, Kim BM, Lee CJ. Flexural stiffness and stresses in nickel-titanium rotary files for various pitch and cross-sectional geometries. J Endod 2012;38:1399-403.
29. Ha JH, Cheung GS, Versluis A, Lee CJ, Kwak SW, Kim HC. 'Screw-in' tendency of rotary nickel-titanium files due to design geometry. Int Endod J 2015;48:666-72.
30. Grande NM, Plotino G, Pecci R, Bedini R, Malagnino VA, Somma F. Cyclic fatigue resistance and three-dimensional analysis of instruments from two nickel-titanium rotary systems. Int Endod J 2006;39:755-63.
31. Pedullà E, Plotino G, Scibilia M, Grande NM, De Santis D, Pardo A, *et al.* Cyclic fatigue comparison among endodontic instruments with similar cross section and different surface coating. Minerva Stomatol 2019;68:67-73.
32. Plotino G, Grande NM, Testarelli L, Gambarini G, Castagnola R, Rossetti A, *et al.* Cyclic fatigue of reciproc and reciproc blue nickel-titanium reciprocating files at different environmental temperatures. J Endod 2018;44:1549-52.
33. Gambarini G, Miccoli G, Seracchiani M, Khrenova T, Donfrancesco O, D'Angelo M, *et al.* Role of the flat-designed surface in improving the cyclic fatigue resistance of endodontic NiTi rotary instruments. Materials (Basel) 2019;12. pii: E2523.