ORIGINAL RESEARCH

Comparison of Cyclic Fatigue Resistance of Novel TruNatomy Files with Conventional Endodontic Files: An *In Vitro* SEM Study

Bharath Naga Reddy[1], Sabari Murugesan[2], Syed Nahid Basheer[3], Rajeswary Kumar[4], Vinoth Kumar[5], Saravanan Selvaraj[6]

Abstract

Aim and objective: To compare and analyze the cyclic fatigue resistance of novel TruNatomy files against the conventionally used rotary files and reciprocating files in a simulated canal system with curvatures in the middle, apical portions root, and S-shaped canal employing scanning electron microscopy.

Materials and methods: Endodontic files tested in the study include ProTaper, HyFlex EDM, Reciproc blue, and TruNatomy files operated in a simulated root canal system. A total of 96 files were employed in this study. They were categorized into four groups. Group 1 employed 24 TruNatomy files, group 2 employed 24 ProTaper gold files, group 3 employed 24 HyFlex EDM files, and group 4 employed 24 Reciproc blue files. All the groups employed eight files each under three subgroups namely A, B, and C representing middle, apical, and double curvatures, respectively.

Artificial grooves were incorporated in the stainless steel blocks having three different curvatures. All the file systems were operated with a torque-controlled electric motor. The files were engaged in the artificial canal until the occurrence of fracture. The time required for the fracture was noted. Length of fractured tip was measured using the digital Vernier caliper. The number of cycles of failure (NCF) was calculated. The fractured parts were subjected to scanning electron microscope to analyze the mode of fracture.

Results: TruNatomy files had the highest mean NCF values of 588.01 in middle curvature, 1,321 in apical curvature, and 642.5 in S-shaped curvature HyFlex EDM and Reciproc blue file system exhibited comparable cyclic fatigue resistance among them. ProTaper gold file system exhibited least mean NCF values of 158.13 in the middle, 196.5 in the apical curvature, and 116.88 in the S-shaped canal system. Middle portion fractured first than the apical curvature. The mean length of fractured segments was found to be insignificant among the experimental study groups tested.

Conclusion: All the file systems employed in the study had good cyclic fatigue resistance while TruNatomy files had the highest cyclic fatigue resistance while HyFlex EDM and Reciproc blue had comparable fatigue resistance. ProTaper gold file system had the least fatigue resistance at different radius of curvature in the simulated canal system in the apical and middle portions and S-shaped root canal.

Clinical significance: The selection of file systems in cleaning and shaping protocols is an enigma to the endodontics. This *in vitro* study explored the selection protocols for the execution of root canal preparation. Heat treatment of nickel–titanium (NiTi) endodontic files had improved the cyclic fatigue résistance significantly enhancing the clinical life of file systems.

Keywords: Canal curvature, Cyclic fatigue, Dynamic, Heat treatment, HyFlex EDM, ProTaper gold, Reciproc blue, TruNatomy.

The Journal of Contemporary Dental Practice (2021): 10.5005/jp-journals-10024-3177

Introduction

The objective of root canal procedures includes elimination of bacterial biofilm species. The incorporation of Schinders principles had positive impact on outcome of cleaning and shaping. The practice of microendodontic access preparation relies on minimal invasive concepts that aid in preservation of pericervical dentin. The nickel–titanium (NiTi) rotary file system aids in the preservation of original canal anatomy and curvature with less iatrogenic errors.[1]

Kaval et al. reported that incidence of file separation was predominantly related to the cyclic fatigue in the range of 65–70% and a lesser extent by the torsional fatigue in the range of 25–30%.[2]

The risk of instrument separation during the clinical use had been found to be inseparable. The key parameters in the successful usage of NiTi rotary file system include understanding the armamentarium and canal complexities during the shaping and cleaning protocols.[3]

The paramount increase in the incidence of the files separation during the clinical use had been an enigma to the endodontist. Judgment of canal curvatures in three-dimensional aspects

[1,5]Department of Conservative Dentistry and Endodontics, Adhiparasakthi Dental College and Hospital, Melmaruvathur, Tamil Nadu, India

[2]Department of Restorative Dental Sciences, College of Dentistry, Jazan University, Jazan, Saudi Arabia

[3]Department of Restorative Dental Sciences, Jazan, Saudi Arabia

[4]Department of Public Health Dentistry, Adhiparasakthi Dental College and Hospital, Melmaruvathur, Tamil Nadu, India

[6]Department of Conservative Dentistry and Endodontics, Madha Dental College and Hospital, Chennai, Tamil Nadu, India

Corresponding Author: Bharath Naga Reddy, Department of Conservative Dentistry and Endodontics, Adhiparasakthi Dental College and Hospital, Melmaruvathur, Tamil Nadu, India, Phone: +91 9444792260, e-mail: drbharathendo999@gmail.com

How to cite this article: Reddy BN, Murugesan S, Basheer SN, *et al.* Comparison of Cyclic Fatigue Resistance of Novel TruNatomy Files with Conventional Endodontic Files: An *In Vitro* SEM Study. J Contemp Dent Pract 2021;22(11):1243–1249.

Source of support: Nil

Conflict of interest: None

ensures the endodontic success. The shaping procedures rely on understanding the factors such as file kinematics, geometry, design, taper, tip diameter, and heat treatment employed by the manufacturer. The cyclic fatigue behavior might be improved by novel concepts in design of file systems.[4]

Cyclic fatigue occurs due to the repeated stress and strain induced by the clinician during the shaping procedures. It can be related to number of canals used, curvature, and clinical complexity. Design of file with less central core diameter and metal mass reduces the chance of file separation. Incorporation of variable taper design enhances flexibility and bending properties.[5]

The reciprocating motion has been explored in the previous studies to assess the impact of cyclic fatigue resistance of endodontic files. It has clockwise and anti-clockwise motions, which induce lesser stresses in the root canal system. Reciproc blue file system had been included as a study group in this study.[6]

Thermal heat treatment had been found to improve flexural characteristics due to change in crystalline phases from austenite to martensitic at the intracanal temperature.[7]

Reciproc blue files were designed as a single instrument. Requires only one instrument for canal preparation. The unique feature of this file includes that no manual glide path is required and the shape obtained by the file enables effective cleaning and shaping protocols with less induction of cyclic fatigue. It is available in three different sizes and has an S-shaped transverse cross-section with two cutting edges. Induction of stresses during the clinical use causes crystalline changes, which retains more martensite phase due to the heat treatment.[8]

ProTaper gold files were introduced as a modified version of conventional ProTaper files. It is available as shaping and finishing files: Sx, S1, S2, F1, F2, and F3. The tapers vary across the file from apical to coronal sections. F2 file has 8% taper at apical 3 mm which progressively decreases till D 16.[9]

HyFlex EDM files were introduced as an improvised version of HyFlex CM files. It was manufactured employing controlled memory technology. It has three different horizontal cross-sections at various levels: triangular at apical-third, quadratic in the coronal half, and trapezoidal in the middle-third. It is available as single file system with 5% taper and 0.10 tip.[10]

TruNatomy files have been introduced to improve the cyclic fatigue resistance. It is available in various sizes ranging from small, medium, and prime. It is available as a variable taper geometry with off-centered parallelogram cross-section design. The heat treatment improves the elasticity and flexibility due to metallurgical phase conversion from austenite tomaretensite.[11]

It had been evidenced in the literature that cleaning and shaping procedures in double-curved S-shaped files system tend to fail in the apical curvature initially followed by the coronal curvature; thus all the shortcomings related to the assessment process of cyclic resistance behavior were included as a parameter in this *in vitro* study.[12]

The present study has taken into consideration the analysis of impact of three types of canal curvatures and two different types of heat treatment behavior namely blue Gold technology employing different two different motion kinematics namely rotary and reciprocation.

Scanning electron microscopy images were recorded before and after the experimental protocols to compare and contrast the characteristics of the file system with respect to the cyclic fatigue behavior.

Materials and Methods

The standard guideline for the assessment of cyclic fatigue resistance was given by Haikel et al.[13] Artificial grooves were depicted in stainless steel plate resembling the root canals measuring 2 mm in width, 20 mm in length, and 2.5 mm in depth with U-shaped cross-section, and 316 L standard stainless steel blocks were subjected to computer-aided milling followed by hardening procedures employing chrome finish.

Experimental Grouping

A total of 96 files were employed in this study. They were categorized into four groups. Group 1 employed 24 TruNatomy files, group 2 employed 24 ProTaper gold files, group 3 employed 24 HyFlex EDM files, and group 4 employed 24 Reciproc blue files. All the groups employed eight files each under three subgroups namely A, B, and C representing middle, apical, and double curvatures, respectively.

Three types of canal morphology were included as key inclusion criteria with the following specifications.

Subgroup A had a straight cervical segment measuring 5.29 mm with the arc length of 9.42 mm and a curvature of radius 6 mm, and the arc location was depicted in the middle portion of the canal.

Subgroup B had a straight cervical segment measuring 10.58 mm with an arc length of 9.52 mm and a curvature radius of 6 mm, and the arc was located in the apical portion of the canal.

Subgroup C had S-shaped canal morphology with a coronal curve of 50° and a radius of 5 mm and was located 8 mm from the tip of the instrument. The second was an apical curve with a 70° angle of curvature a radius of 2 mm and a center of 2 mm from the tip.

All the file systems were rotated and reciprocated in simulated canal with different curvatures as per the recommendations given by the manufacturer and were represented in Figure 1.

All of the instruments were operated with a torque-controlled electric motor with intermittent usage of lubricant to reduce the friction and prevent the overheating of files tested. The experimental protocol was carried out in a dynamic operatory setup and was represented in Figure 2.

The experiments were carried out by a single operator to avoid the bias related to file selection and execution of the shaping protocols. The files were engaged in the artificial canal until the occurrence of fracture.

Fig. 1: It denotes the stainless steel jig to assess the cyclic behavior of three different canal curvatures

The time required for the fracture was noted with digital clock; this procedure was followed by measurement of the length of fractured tip employing a digital Vernier caliper.

The numbers of cycles to failure (NCFs) were calculated with the following formula:

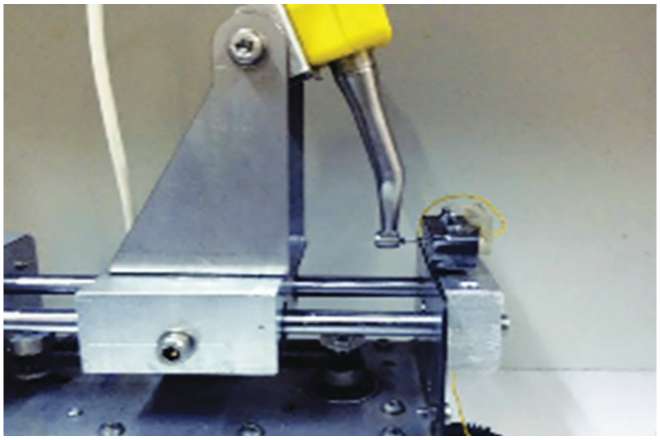


Fig. 2: It denotes the dynamic cyclic fatigue resistance testing apparatus

Number of cycles of failure was equal to the revolutions per minute multiplied by time to fracture (seconds) divided by 60.

The lengths of the fractured parts were measured using a digital caliper. The fractured segments were examined under a scanning electron microscope (JSM-7001F; JEOL, Tokyo, Japan) in order to assess the fracture characteristics of cyclic fatigue.

Statistical Analysis

Shapiro–Wilkinson test was conducted to assess normal distribution with a p value >0.05, which was considered as normal distribution.

For normally distributed quantitative parameters, the mean values were compared between study groups using the analysis of variance (ANOVA) (>2 groups). A p value <0.05 was considered statistically significant.

Results

The mean and standard deviations of the lengths of fractured segments among the file systems tested are shown in Table 1. The mean and standard deviations of the NCF values of fractured segments among the file systems tested were shown in Tables 2 to 4.

Table 1: Comparison of mean fragment length across the middle curvature of the root canal system

File system	*Mean fragment length in middle curvature*	*Mean fragment length in apical curvature*	*Mean fragment length in middle curvature*
Reciproc blue	6.688 ± 0.53	3.563 ± 0.417	7.750 ± 0.4629
ProTaper gold	6.963 ± 0.50	4.750 ± 0.463	9.188 ± 0.5303
TruNatomy file	5.875 ± 0.52	4.950 ± 0.463	8.313 ± 0.3720
HyFlex EDM	6.571 ± 0.80	5.150 ± 0.597	8.500 ± 0.6547

Table 2: Comparison of mean NCF values across the middle curvature of the root canal system

File system	*NCF (middle) Mean ± SD*	*Mean difference*	*95% CI*		*p value*
			Lower	*Upper*	
TruNatomy	588.01 ± 165.02	296.80	223.02	370.58	<0.001
Reciproc blue	539.44 ± 12.83	51.78	–22.00	125.56	0.164
ProTaper gold	158.13 ± 13.35	133.09	59.30	206.87	0.001
HyFlex EDM	533.88 ± 62.81	242.66	168.88	316.44	<0.001

Table 3: Comparison of mean NCF values across the apical curvature of the root canal system

File system	*NCF (apical) Mean ± SD*	*Mean difference*	*95% CI*		*p value*
			Lower	*Upper*	
HyFlex EDM	1251.25 ± 175.88	42.50	–71.597	156.597	0.456
Reciproc blue	1094.13 ± 87.20	799.63	685.53	913.72	<0.001
ProTaper gold	815.63 ± 71.49	978.13	864.03	1092.22	<0.001
TruNatomy	1321.45 ± 129.49	27.70	–86.397	141.797	0.627

Table 4: Comparison of mean NCF values across the S-shaped curvature of the root canal system

File system	*NCF (S-shaped) Mean ± SD*	*Mean difference*	*95% CI*		*p value*
			Lower	*Upper*	
TruNatomy	642.50 ± 157.43	457.34	388.20	526.47	<0.001
Reciproc blue	279.76 ± 35.94	55.40	–13.74	124.54	0.113
ProTaper gold	116.88 ± 15.10	68.29	–0.85	137.42	0.053
HyFlex EDM	300.50 ± 32.52	115.34	46.20	184.47	0.002

TruNatomy files had highest cyclic fatigue resistance in the apical curvature among the files tested with mean NCF value of 1321.45 ± 129.49 while ProTaper gold had the least cyclic fatigue resistance with mean NCF value of 196.50 ± 32.87 with *p* value <0.05.

The TruNatomy files had the highest mean NCF values of 588.01 ± 165.02 among the files tested in the middle curvature while ProTaper gold file had the least mean NCF values of 158.13 ± 13.35 (*p* <0.05) in the canal with middle curvature.

In the S-shaped canals, the mean values of TruNatomy file system 642.50 ± 157.43 were found to be statistically higher while ProTaper gold file 116.88 ± 15.10 had the least mean NCF values with *p* value less than 0.05.

The mean lengths of the fractured segments were recorded in order to evaluate the correct positioning of the tested files inside the canal curvature and were found to be insignificant with maximum mean length of 9.1 mm and minimum mean length of 4.7 mm.

The scanning electron microscopic images of the fracture surface revealed the nature of the mechanical characteristic of the cyclic fatigue failure for TruNatomy and ProTaper file groups, which were represented in Figures 3 and 4.

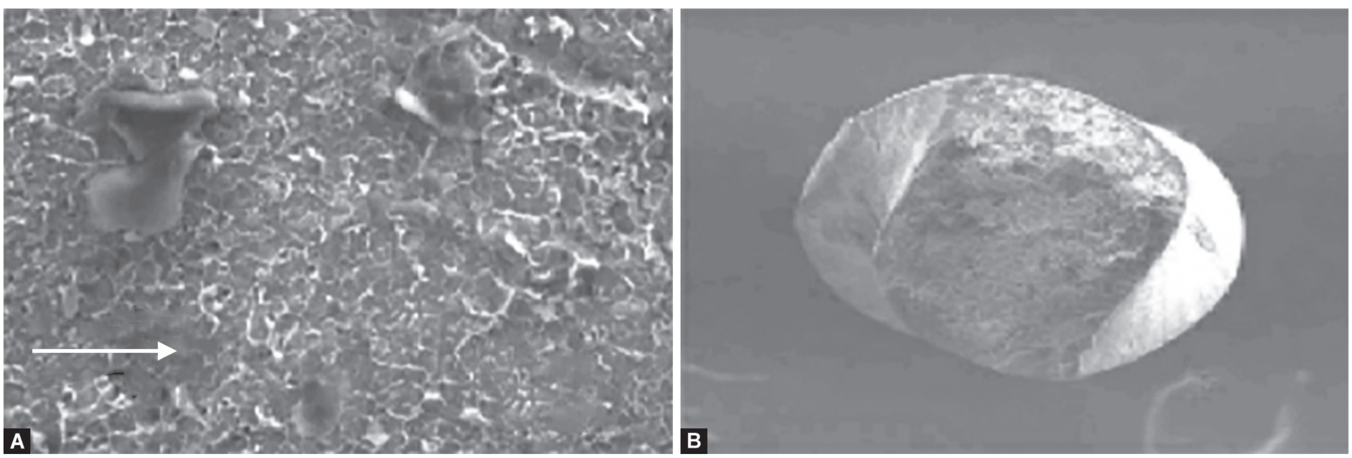
The crack propagation traces were evidenced more in the ProTaper gold file system after subjection to cyclic resistance challenge on surface view. Additionally, microbubbles were also evidenced more in the ProTaper gold group in comparison to the other groups tested. The presence of microbubbles indicates a ductile mode of fracture as a predominant mode of fracture.

Discussion

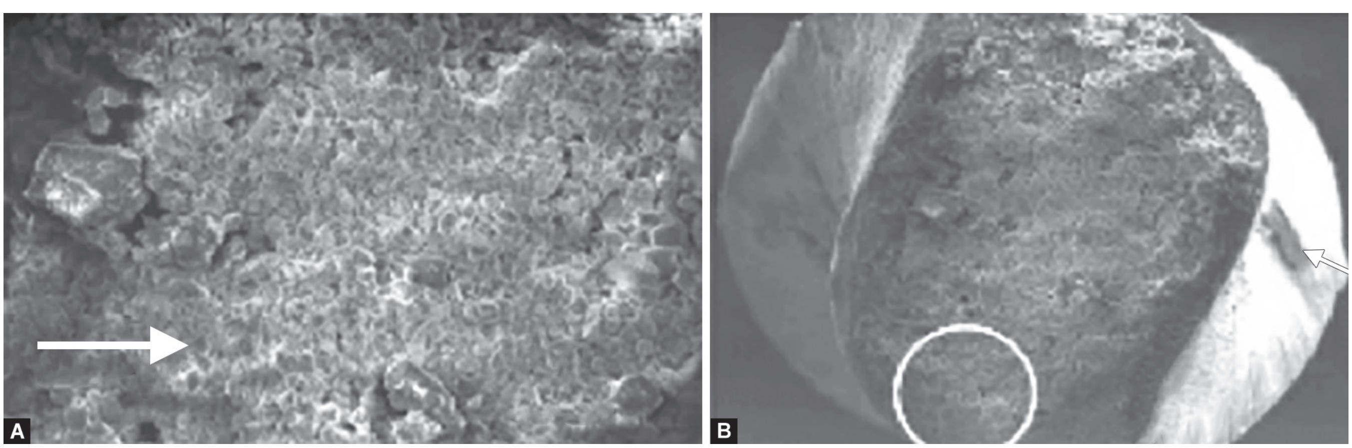
File separation occurs due to the progression of microcracks from the irregularities due to the induction of cyclic fatigue. It depends upon the composition of alloy, manufacturing process, cross-section geometry, flute design, tip size, and instrument taper. Innovation in file geometry, kinematics, and surface characteristics tends to improve the performance and life of endodontic files system.

There was no literature evidence for comparison of cyclic fatigue resistance of TruNatomy files in a dynamic testing protocol in a double-curved root canal system.

The cyclic resistance behavior in our study was found to be highest in the apical curvature followed by middle and double curvature. TruNatomy file system had highest cyclic fatigue resistance in the apical curvature among the files tested with mean



Figs 3A and B: (A) Scanning electron microscopic image of TruNatomy files at 500× magnification; the arrow mark reveals the presence of minimal voids; (B) Fracture surface view of TruNatomy file which reveals the presence of negligible microcrack over the surface



Figs 4A and B: (A) Scanning electron microscopic image of ProTaper gold at 500× magnification; the arrow mark reveals the presence of bubbles and denotes the ductile mode of fracture; (B) Fracture surface view of ProTaper gold file. Encircled portion reveals the presence of minor crack radiating toward the surface leading to brittle fracture

NCF value of 1321.45 ± 129.49 while ProTaper gold had the least cyclic fatigue resistance 196.50 ± 32.87.

In our study, middle curvature ranked between the apical and middle curvatures with following mean values. TruNatomy files had the highest mean NCF values of 588.01 ± 165.02 among the files tested in the middle curvature while ProTaper gold file had the least mean NCF values of 158.13 ± 13.35.

Our study revealed that in S-shaped double curvature canals, the cyclic fatigue behavior stands compromised and is lower than the apical and middle curvatures. The mean values of TruNatomy file system 542.50 ± 157.43 were found to be statistically higher while ProTaper gold file 116.88 ± 15.10 had the least mean NCF values.

TruNatomy file system has good survival rate than the Reciproc blue files and HyFlex EDM files, and the ProTaper gold file system had least survival rate.

The controlled memory heat treatment of TruNatomy files helped in the maintenance of canal curvatures better than the conventional NiTi alloys. Thermal heat treatment of the NiTi alloys improved the flexibility and fatigue resistance by changing the arrangement of crystal lattice and additionally modifies the transition temperature and microstructure of alloys. In the martensitic phase, the file tends to be soft and ductile. It increases the fracture resistance.

ProTaper gold file system exhibited least cyclic fatigue resistance among the experimental files tested in all the three different curvatures.

The least cyclic fatigue resistance of the ProTaper gold might be attributed to the convex triangular design that provides the bulk metal mass in the central core area and might be due to the increases in transition temperature.

The mid canal curvatures are relatively difficult to manage reported to end up with iatrogenic errors like ledge formation and perforations.

The mean lengths of the fractured segments in all the groups did not show any significant difference. This observation revealed that the tested instruments were correctly positioned in the canal curvature and also demonstrated that similar stresses were induced.

The cyclic fatigue occurs due to subjection of repeated cycles of compression and tension in root dentin and necessitates the technical modifications by the clinician during the canal preparation. This can be reduced by establishment of glide path and judgment of canal curvature in three-dimensional aspects during the clinical use.[14]

Pedulla et al. reported that the cyclic fatigue resistance of HyFlex EDM files was higher than that of Reciproc blue files performing reciprocal motion. The results of the present study were in agreement with the abovementioned statement.[15]

Parashos et al. reviewed the incidence and causes of fracture of NiTi instruments and reported that predominant mode of fracture occurs due to flexural stresses inducted by the cyclic fatigue resistance in the range of 70% while 30% incidence was due to torsion fatigue.[16]

Pirani et al. reported that the cyclic fatigue resistance of HyFlex EDM files was higher than the HyFlex CM files, ProTaper Universal, and ProTaper gold. These findings were partially similar to the findings of our study.

The reason might be related to the electro-discharge machining procedure performed during the manufacturing process. It might also be attributed to their transformation temperature that was higher than the other files tested.[17]

Zupanc et al. reviewed the efficacy of novel thermomechanically treated files and concluded that heat-treated files exhibit superior fatigue resistance than the austenite and M wire-based alloys.[18]

In a recent study by Piț et al., cyclic fatigue resistance of novel TruNatomy file system was compared against the R-Pilot, HyFlex EDM, and VDW rotate files. It was concluded that R-Pilot files had the maximum CFR followed by HyFlex EDM files, VDW rotate files, and TruNatomy files.[19]

HyFlex EDM files were introduced as a controlled memory file. It has different cross-section at various levels: triangular at shaft, quadratic at tip, and trapezoidal in the middle. It is available as a single file system with 5% taper and 0.10 tip diameter.[20]

Reciproc blue files were introduced as an improvised version of Reciproc files and have a S-shaped transverse cross-section with two cutting edges. In narrow canals, 0.25 mm tip diameter files with a taper of 8% were indicated while in medium to large canals 0.40 to 0.50 mm tip diameter and 6 to 5% taper files were employed. The blue surface oxide layer modifies the characteristics of the file and retains the martensitic phase in due course improves the file longevity.[21]

TruNatomy file systems were introduced with special design features and geometry. The reduced taper aids in maximum preservation of pericervical dentin. File geometry includes variable taper, off-center design with square cross-section. Heat treatment increases the elasticity and flexibility due to metallurgical phase changes from austenite to martensite.[22]

Gündoğar et al. reported that the kinematics of the endodontic files acts as a key factor in the induction of cyclic fatigue resistance. The clockwise and anti-clockwise movements of reciprocation files create less stresses in the root dentin and improve the longevity due to the presence of high martensite content and a smaller number of uses.

Larsen et al. had evaluated the importance of dynamic testing protocols employed in the clinical environment for assessment of cyclic fatigue resistance of new generation NiTi alloys.[23]

Pruett et al. have given the recommendations for cyclic fatigue testing of NiTi endodontic instruments. The standardization of the root canal curvature was based on their recommendations with 60° angle and 5 mm radius of curvature.[24]

Elnaghy et al. revealed that the presence of double curvature amplifies the stresses generated on the files, influences the cyclic resistance, and poses a challenge to the clinician in debridement of the canal. The instrument separation occurs first in the apical curvature than the coronal curvature. The abovementioned findings were not agreed in this study.[25]

In this study, a custom-made stainless steel Jig incorporated with various canal curvatures was used to assess the cyclic fatigue test. In previous studies, stainless steel artificial canals were used to compare the cyclic fatigue resistance of various NiTi instruments as they eliminate the influence of other confounding factors for separation of files other than cyclic fatigue.[26]

It has been accepted that SEM studies seem to be the most adequate method for accurate evaluation of fractured sites. Examination of fracture surface through SEM images may help in understanding the fatigue behavior of the NiTi alloys. It is essential to analyze and study the distinctive features to identify the pattern and type of fracture. Brittle type of fracture occurred in the ProTaper gold files where the crack front radiates away from the point of initiation, and this type of pattern was revealed as less in our study.

The fractured files were examined under a scanning electron microscope in order to assess the cyclic fatigue behavior.

The presence of numerous microbubbles on the fractured surface indicates the ductile mode of fracture; this type of behavior was revealed in ProTaper gold file system.

Oxides particles serve as nucleating sites for formation of microvoids in Reciproc blue file system. The predominant mode of fracture in our study was due to ductile mode of fracture, which occurs due to the fusion of microvoids formed in the metal mass.

The surface characteristics give us clues on the type of load induced as well as the origin of the fracture. In this study, the dull round dimpled surface characteristic was revealed for ProTaper gold file and is an indicator of its poor cyclic behavior. Presence of ovoid dimples indicates the induction of tensile and shearing forces induced over the file system.

The unique features of this study include the following: (1) Assessment of cyclic fatigue resistance in three different types of curvature. (2) Comparative assessment of implications of cyclic fatigue behavior in two types of motion kinematics. (3) Comparative files with different instrument geometry such as cross-section, taper, and tip diameter commonly by clinicians. (4) Three types of heat treatment namely blue heat treatment, Gold heat treatment and Controlled Memory alloys were assessed for the cyclic fatigue behavior. (5) Elaboration of SEM analysis of cyclic behavior before and after subjection to cyclic resistance as a criterion for assessment of outcome. (6) Employment of dynamic cyclic fatigue testing protocols over the static assessment method.

Limitations of the Study

Although the stainless steel artificial canal system was milled to replicate, the various canal curvatures based on standard guidelines recommended for an *in vitro* study do not depict the real clinical scenario. In clinical practice, the axial movement of the handpiece was controlled manually and these variables were difficult to replicate in this *in vitro* study and hence further *in vivo* investigations are required to confirm the results of the present study.

Conclusion

With the limitations of this *in vitro* study, it can be concluded that all file systems had good cyclic fatigue resistance. TruNatomy files had the highest cyclic fatigue resistance. HyFlex EDM and Reciproc blue had comparable fatigue resistance. ProTaper gold file system had the least fatigue resistance at different radius of curvature in the simulated canal system in the apical and middle portions and S-shaped root canal. The length of the fractured segments does not vary among the files tested in the experimental study.

References

1. Uygun AD, Unal M, Falakaloglu S, et al. Comparison of the cyclic fatigue resistance of hyflex EDM, vortex blue, protaper gold, and onecurve nickel–titanium instruments. Niger J Clin Pract 2020;23(1):41. DOI: 10.4103/njcp.njcp_343_19.
2. Kaval ME, Capar ID, Ertas H. Evaluation of the cyclic fatigue and torsional resistance of novel nickel-titanium rotary files with various alloy properties. J Endod 2016;42(12):1840–1843. DOI: 10.1016/j.joen.2016.07.015.
3. Gambarini G, Grande NM, Plotino G, et al. Fatigue resistance of engine-driven rotary nickel-titanium instruments produced by new manufacturing methods. J Endod 2008;34(8):1003–1005. DOI: 10.1016/j.joen.2008.05.007.
4. Tewari RK, Kapoor B, Kumar A, et al. Fracture of rotary nickel titanium instruments. J Oral Res Rev 2017;9(1):37. DOI: -10.4103/jorr.jorr_40_16.
5. Rubini AG, Sannino G, Pongione G, et al. Influence of file motion on cyclic fatigue of new nickel titanium instruments. Ann Stomatol 2013;4(1):149. DOI: 10.11138/ads.0149
6. Pedullà E, Grande NM, Plotino G, et al. Influence of continuous or reciprocating motion on cyclic fatigue resistance of 4 different nickel-titanium rotary instruments. J Endod 2013;39(2):258–261. DOI: 10.1016/j.joen.2012.10.025.
7. Elsewify TM, Saber SM, Plotino G. Cyclic fatigue resistance of three heat-treated nickel-titanium instruments at simulated body temperature. Saudi Endod J 2020;10(2):131. DOI: 10.4103/sej.sej_122_19
8. Plotino G, Grande NM, Testarelli L, et al. Cyclic fatigue of Reciproc and Reciproc Blue nickel-titanium reciprocating files at different environmental temperatures. J Endod 2018;44(10):1549–1552. DOI: 10.1016/j.joen.2018.06.006.
9. Khandagale PD, Shetty PP, Makandar SD, et al. Evaluation of cyclic fatigue of hyflex EDM, twisted files, and protaper gold manufactured with different processes: an in vitro study. Int J Dent 2021;2021:7402658. DOI: 10.1155/2021/7402658.
10. Al-Obaida MI, Merdad K, Alanazi MS, et al. Comparison of cyclic fatigue resistance of 5 heat-treated nickel-titanium reciprocating systems in canals with single and double curvatures. J Endod 2019;45(10):1237–1241. DOI: 10.1016/j.joen.2019.06.011.
11. Gündoğar M, Uslu G, Özyürek T, et al. Comparison of the cyclic fatigue resistance of VDW. Rotate, TruNatomy, 2Shape, and HyFlex CM nickel-titanium rotary files at body temperature. Restor Dent Endod 2020;45(3). DOI: 10.5395/rde.2020.45.e37.
12. La Rosa GR, Shumakova V, Isola G, et al. Evaluation of the cyclic fatigue of two single files at body and room temperature with different radii of curvature. Materials 2021;14(9):2256. DOI: 10.3390/ma14092256.
13. Haikel Y, Serfaty R, Bateman G, et al. Dynamic and cyclic fatigue of engine-driven rotary nickel-titanium endodontic instruments. J Endod 1999;25(6):434–440. DOI: 10.1016/S0099-2399(99)80274-X.
14. Grande NM, Plotino G, Pecci R, et al. Cyclic fatigue resistance and three-dimensional analysis of instruments from two nickel–titanium rotary systems. Int Endod J 2006;39(10):755–763. DOI: 10.1111/j.1365-2591.2006.01143.x.
15. Pedullà E, Savio FL, Boninelli S, et al. Torsional and cyclic fatigue resistance of a new nickel-titanium instrument manufactured by electrical discharge machining. J Endod 2016;42(1):156–159. DOI: 10.1016/j.joen.2015.10.004.
16. Parashos P, Messer HH. Rotary NiTi instrument fracture and its consequences. J Endod 2006;32(11):1031–1043. DOI: 10.1016/j.joen.2006.06.008.
17. Pirani C, Cirulli PP, Chersoni S, et al. Cyclic fatigue testing and metallographic analysis of nickel-titanium rotary instruments. J Endod 2011;37(7):1013–1016. DOI: 10.1016/j.joen.2011.04.009.
18. Zupanc J, Vahdat-Pajouh N, Schäfer E. New thermomechanically treated NiTi alloys – a review. Int Endod J 2018;51(10):1088–1103. DOI: 10.1111/iej.12924.
19. Piț AB, Borcean IA, Vărgatu IA, et al. Evaluation of the time and efficiency of trunatomy, VDW. Rotate, protaper gold and reciproc blue in shaping root canals – an in vitro study. Roman J Oral Rehabil 2020;12(3):250. DOI: 12.1011/rjor.2020.043.
20. Oh S, Kum KY, Kim HJ, et al. Bending resistance and cyclic fatigue resistance of WaveOne Gold, Reciproc Blue, and HyFlex EDM instruments. J Dent Sci 2020;15(4):472–478. DOI: 10.1016/j.jds.2019.10.003.
21. Özyürek T, Gündoğar M, Yılmaz K, et al. Bending resistance and cyclic fatigue life of Reciproc Blue, WaveOne Gold, and Genius files in a double (S-shaped) curved canal. J Dent Res Dent Clin Dent Prospects 2017;11(4):241. DOI: 10.15171/joddd.2017.042.
22. Uslu G, Gundogar M, Özyurek T, et al. Cyclic fatigue resistance of reduced-taper nickel-titanium (NiTi) instruments in doubled-curved (S-shaped) canals at body temperature. J Dent Res Dent Clin Dent Prospects 2020;14(2):111. DOI: 10.34172/joddd.2020.024.

23. Larsen CM, Watanabe I, Glickman GN, et al. Cyclic fatigue analysis of a new generation of nickel titanium rotary instruments. J Endod 2009;35(3):401–403. DOI: 10.1016/j.joen.2008.12.010.
24. Pruett JP, Clement DJ, Carnes Jr DL. Cyclic fatigue testing of nickel-titanium endodontic instruments. J Endod 1997;23(2):77–85. DOI: 10.1016/S0099-2399(97)80250-6.
25. Elnaghy AM, Elsaka SE, Mandorah AO. In vitro comparison of cyclic fatigue resistance of TruNatomy in single and double curvature canals compared with different nickel-titanium rotary instruments. BMC Oral Health 2020;20(1):1–8. DOI: 10.1186/s12903-020-1027-7.
26. Shen Y, Zhou HM, Zheng YF, et al. Current challenges and concepts of the thermomechanical treatment of nickel-titanium instruments. J Endod 2013;39(2):163–172. DOI: 10.1016/j.joen.2012.11.005.