A comparative evaluation of cyclic fatigue resistance of different endodontic Nickel-Titanium rotary files in a curved canal: an in-vitro study

By Bakr Al-Obaidi

WORD COUNT	3425	TIME SUBMITTED	03-JUL-2024 01:12PM
		PAPER ID	110020326

A comparative evaluation of cyclic fatigue resistance of different endodontic Nickel-Titanium rotary files in a curved canal: an *in-vitro* study

Bakr Al-Obaidi

Department of Conservative Dentistry, Dental Teaching Hospital, College of Dentistry, Mustansiriyah University, Baghdad, Iraq

ORCID ID: 0009-0004-0544-3131
E.mail: bakr.ryadh@yahoo.com

ABSTRACT

Background. The objective of this study was to analyze the resistance ability to cyclic fatigue failure of ProTaper Universal files (PTU; size 25, 0.08 taper), ProTaper Gold files (PTG; size 25, 0.08 taper), and Hyflex CM files (HCM; size 25, 0.06 taper).

Materials and Methods. An overall number of 120 new instruments of PTU, PTG, and HCM were tested in a stainless steel block that replicated artificial root canal morphology with an angle of curving point (45°) and the radius of curvature (5mm). Forty files from each group were employed inside the canal until fracture. The timing of the instruments fracture was recorded by a digital stopwatch. The time to separation was analyzed and the figure of cycles to failure (NCF) of the rotary files was measured and registered. The obtained data was statistically analyzed.

Results. All files suffered a fracture at a precise number of cycles. The highest resistance to breakage of the rotating files demonstrated a superior number of cycles to fatigue separation. The HCM and PTG files showed greater grades of NCF than PTU files with significant differences ($P < .05$). The HCM and PTG groups recorded comparable standards of resistance to repeated fatigue inside the

canal (P > .05). On the contrary, PTU exhibited the smallest competence to fracture resistance among the other tested files.
Conclusions. The present findings showed that the HCM files appeared to be proper for shaping complicated root canal system as HCM files illustrated a remarkable performance in fatigue resistance followed by PTG and PTU, respectively.

Key Words: Cyclic Fatigue, Curved Canal, NiTi Files, Flexibility, Fracture

INTRODUCTION

The nickel-titanium (NiTi) endodontic instruments have more flexible capability and elasticity than stainless steel that minimizes the restoring forces and improves the canal preparation [1,2].The central concern when operating NiTi rotary instrument is files fracture. In view of that, study showed that the cyclical fatigue is presumably to take place inside a root canal with small radius of curvature especially with morphology of an acute curve [3,4].

The thickness of the instrument and the curvature radius of the root canal system can both influence on the degree of the compression and tensile forces that subjected on the flexed zone of the instrument [5].

According to the study by Haïkel Y. and al., it was reported that the generated forces upon the instrument have a potential to increase with a less significant radius of the canal twist and larger instrument's diameter. Accordingly, the fracture resistance potential of the instrument is reduced [6].

The NiTi root canal instruments tend to fracture as an end result bending fatigue [7]. A mechanical load occurs as a result of endodontic instrument's rotation inside a curved canal which can be shown by changing compression and tensile stresses.

The recurrence of these loads causes fracture to the endodontic instruments [8]. Mechanical test of rotating-torsional fatigue is implemented in order to calculate the resistance to crack of the endodontic preparation instruments. Therefore, many studies reported that both cyclic and torsional weakness are the major causes of the NiTi endodontic files fracture inside the canals during the clinical use [9].

Recently, manufacturers have developed the designs and metallurgy of the NiTi files and added elite technology with the purpose of optimizing the fracture resistance and functionality [10]. The advanced thermo-mechanical treatment for NiTi files were emerged to upgrade the clinical performance and to degrade the issues that associated with the conventional NiTi alloy, such as file distortion and fracture [11].

The ProTaper Universal (PTU; Dentsply Maillefer, Ballaigues, Switzerland) files were generated in the canal instrumentation with a conventional NiTi materials, their design is aimed to decrease the breakage, torsional stress, and prospective separation [12]. The ProTaper Gold (PTG; Dentsply Maillefer, Ballaigues, Switzerland) rotary files have lately developed, although their design is geometrically identical with PTU files, with a Gold-Wire alloy and were processed with a heat treatment technology that shows signs of a considerable flexibility [13].

Lately, the newer generation of NiTi system is Hyflex CM files (HCM; Coltene-Whaledent, Allstetten, Switzerland) are manufactured with a contemporary NiTi technology that uses the controlled recall memory (CM) wire, which have been treated with thermo-mechanical procedures making the files exceptionally flexible [14]. The goal of this *in-vitro* research was to assess the comparison of the resistance potentials to the repeated fatigue failure of various rotary endodontic files: PTU, PTG, and HCM. The null hypothesis was that there is no distinction in the resistance capability to recurring fatigue fracture among the tested rotary systems.

MATERIALS AND METHODS

Cyclical fatigue testing

The tested endodontic instruments were applied in this study were ProTaper Universal (PTU) (Dentsply Maillefer, Ballaigues, Switzerland) with file size 25, 0.08 taper, ProTaper Gold (PTG) (Dentsply Maillefer, Ballaigues, Switzerland) with file size 25, 0.08 taper, and Hyflex CM files (HCM) (Coltene-Whaledent, Allstetten, Switzerland) with file size 25, 0.06 taper as displayed in Table 1. Each single instrument was carefully checked for any visible structural micro-defects under magnifying images (OPMI pico, Zeiss, Oberkochen, Germany), and none was rejected.

The fabrication process of the artificial root canals was done by the simulation of the canals into a stainless steel block.

The measurements were as follows: - Angle of the curving point (45°) - Radius of the bending (5mm) - Distance from files tip to the center of curvature (5mm).

Table 1. The Tested Rotary Endodontic Files, Sizes, and Tapering Degree

Rotary Files	Manufacturer	Files Size	Files Taper
• Pro Taper Universal Files (PTU)	Dentsply Maillefer, Ballaigues, Switzerland	25 mm	0.08 %
• Pro Taper Gold Files (PTG)	Dentsply Maillefer, Ballaigues, Switzerland	25 mm	0.08 %
• Hyflex CM Files (HCM)	Coltene-Whaledent, Allstetten, Switzerland	25 mm	0.06 %

The instruments were classified into three groups, 40 samples for each group (120 samples in total) and were exposed to repeated fatigue testing procedure. A stainless steel block was distinctively made in order to simulate the artificial canal

morphology and to achieve a close contact between the tested rotary instruments and the canal walls [15].

Cyclic fatigue testing was specifically conducted by using a rotary handpiece (X-Smart Plus, Dentsply Maillefer, Baillagues, Switzerland). The handpiece was fixed and adjusted to the speed and torque with a constant and controlled pressure with no sliding as instructed by the producer [16]. Subsequently, the tested rotary files were worked in a continuous clockwise rotation.

The PTU files performed at 300 rounds per minute (rpm) and 3 N/cm torque, PTG worked at 300 rpm and 2.5 N/cm torque, and HCM files at 500 rpm and 2.5 N/cm torque. The working length of the canal was allocated to be 19 mm for the all tested rotary files.

In relation to the study by Zubizarreta A. and al., the synthetic oil was applied knowingly as a lubricant in order to lessen the friction effect that generates between the rotating files and the walls (Singer All-Purpose Oil; Singer Corp., Barcelona, Spain) [17].

In accordance with the research by De Almeida F. and al., stated that the NiTi files were used inside the canal until breakage happened and the timing of the instruments separation was reported by a digital stopwatch (HS-80TW, Casio Computer Co., Inc., Tokyo, Japan) [18]. The time to breakage failure was analyzed and the number of cycles to failure (NCF) of the rotary files was measured and registered.

The data of both rotary file systems was obtained through applying the following formula: the figure of cycles to fatigue fracture (NCF) = rotational speed of files X time to failure in seconds and dividing the results by 60 [19].

$$NCF = \frac{time\ (sec) \times speed}{60}$$

Statistical Analysis

The mean and standard deviations values of NCF were analyzed and measured for each tested instrument. All collected data were subsequently investigated and submitted to statistical assessment using one-way analysis of variance and Tukey post hoc tests. The significance level was established at $P < 0.05$. All statistical investigations were executed by applying SPSS software (SPSS Inc, Chicago, IL).

RESULTS

Resistance to fatigue failure

The NCF was statistically analyzed for PTU, PTG, and HCM instruments. All files demonstrated a separation at a certain number of cycles at the apical one/ third of the canal at angle of curvature 45°. The greater resistance to fatigue fracture of the testing rotary files showed a superior digit of cycles to fracture as presented in Table 2.

Table 2. Mean Values of Cycles to Fatigue Fracture and Standard Deviation of the Instruments

Instruments Groups	NCF	
	Mean	SD
• ProTaper Universal Files	513.94[a]	121.28
• ProTaper Gold Files	752.61[b]	168.57
• Hyflex CM Files	791.56[b]	202.74

Different superscript letters indicate a significant difference at ($P < 0.05$). Abbreviations: SD= Standard deviations. NCF= Number of cycles to failure.

The file's groups of HCM and PTG illustrated higher scores of NCF than PTU group with significant differences ($P < 0.05$). The files groups of HCM and PTG reported comparable values of resistance to fatigue failure inside the canal ($P > 0.05$). Interestingly, file group HCM showed the greatest mean value of cycles to

fatigue fracture among the other tested groups. Conversely, the least capability to fracture resistance was observed in file group PTU and witnessed the poorer NCF.

DISCUSSION

The obtained results of this study rejected the null hypothesis which states that there is no diversity in the resistance ability to cyclic fatigue separation of the experimented NiTi endodontic rotary files.

The outcomes of the present work exhibited an agreement with the findings of the prior studies which state that the NiTi root canal rotary instruments suffered unexpected separation inside the canal regardless their superior flexibility [20]. The files separations were generated by the stress triggered by the recurring fatigue failure, torsional fatigue, or both of these combined factors [21].

Study described that the existence of history of a periapical lesion in conjunction with the breakage of the root canal file represents a decisive part that influences the success of the endodontic therapy. Moreover, the fragments of the separated files block the entrance to the root canal apex that compromises the healing of the periapical tissues and decreases the disinfection level of the root canal geometries [22].

The cyclic fatigue failure and torsional failure are the core reasons explaining the mechanism of the root canal files separation. Subsequently, the rotary file works in a curved canal with recurring compressive and tensile pressures that lead to cyclic fatigue and fracture, and when the file's tip is jammed inside the curved canal while the file's shank maintains rotating a torsional failure takes place [23,24].

The implementation of a simulated artificial canal specifically imperative when investigating the cyclic fatigue of the endodontic files inside the curved canal as the standardized artificial canal lessens the impact of other variables not related to the endodontic file itself. Therefore, it is virtually impracticable to select a sample of

human teeth with a standardized anatomy in order to mimic the curved canal with similar length, dimension, and geometries [25].

Studies recorded that the shaping endodontic rotary files with a symmetrical triangular cross-sectional pattern exhibit better confrontation to fatigue separation than those instruments with a square cross-sectional outline where the triangular design reduces the metal mass and the friction between the blades of the file and dentinal wall [26]. The HCM, PTG, and PTU files have symmetrical triangular, convex triangular, and triangular cross-sectional shapes, respectively.

The outcome of this study showed that HCM files (symmetrical triangular cross-sectional pattern) illustrated better resistance to fatigue failure and higher grade of NCF than PTG and PTU files. The heat-treated NiTi alloys are the essential elements that made HCM files which provide the files with remarkable flexibility and higher resistance to cyclical fatigue than the PTU instruments fabricated with a conventional NiTi alloy which are considered inferior in terms of bending capability [27].

In line with the study by Simpsy G. and al., emphasize that the HCM group demonstrated an exceptional fatigue resistance compared with the PTU group, and it was suggested for acutely curved root canals which concur with the findings of this present study [28].

The PTG group showed superior flexible properties that enabled it to grant a significant resistance against cyclic fatigue failure compared with PTU group [29]. The PTG files were developed with an innovative technology of heat treatment; as thus, it explains their enhanced clinical performance and behavior among PTU group [30].

This finding is in harmony with an earlier study results. The authors attributed the results to the diverse metallurgical and manufacturing advances of both PTG and PTU rotary files and that could essentially influence their fatigue resistance performance. Accordingly, thermally processed PTG files were correlated with significantly boosted flexibility than PTU files [31].

In fact, when comparing the resistance to cyclic fatigue between PTG and PTU files, PTG proved to be considerably more resistant to fatigue failure than PTU instruments. Although, the matching architecture of both PTG and PTU systems, dissimilarity of the manufacturing process among the two systems evidently influences their resistance behavior to cyclic fatigue [32].

Based on several studies and conclusions, indicated that multiple factors such as cross-sectional design, thermo-mechanical processing, and innovative technology could have a fundamental consequence on the microstructure of the NiTi alloys and consequently optimize the clinical performance and repeated fatigue resistance of the rotary files, and in addition to that, upgrade the flexibility of the instruments inside the curved canals [33].

CONCLUSIONS

Within the limitation of the findings of this *in-vitro* study, it can be summarized that HCM files seemed to be appropriate for preparing complicated root canal system with superior number of rotational cycles before they fracture. The Hyflex CM instruments showed the supreme presentation in terms of fatigue resistance, and the ranking of the other tested files in declining order of recurring fatigue resistance was as follows: ProTaper Gold and ProTaper Universal files.

REFERENCES

1. Peters, Ove A. Current challenges and concepts in the preparation of root canal systems: a review. *Journal of endodontics*, 2004, 30.8: 559-567.

2. Gergi, R., Abou Rjeily, J., Sader, J., & Naaman, A. Comparison of canal transportation and centering ability of twisted files, Pathfile-ProTaper system, and stainless steel hand K-files by using computed tomography. *Journal of endodontics*, 2010, 36.5: 904-907.

3. Pruett, John P.; Clement, David J.; Carnes Jr, David L. Cyclic fatigue testing of nickel-titanium endodontic instruments. *Journal of endodontics*, 1997, 23.2: 77-85.

4. Parashos, Peter; Gordon, Ian; Messer, Harold H. Factors influencing defects of rotary nickel-titanium endodontic instruments after clinical use. *Journal of endodontics*, 2004, 30.10: 722-725.

5. Moreira, E. J. L., Lopes, H. P., Elias, C. N., & Fidel, R. A. S. Fratura por flexäo em rotaçäo de instrumentos endodônticos de NiTi. *Rev. bras. odontol*, 2002, 412-414.

6. Haikel, Y., Serfaty, R., Bateman, G., Senger, B., & Allemann, C. Dynamic and cyclic fatigue of engine-driven rotary nickel-titanium endodontic instruments. *Journal of endodontics*, 1999, 25.6: 434-440.

7. Sattapan, B., Nervo, G. J., Palamara, J. E., & Messer, H. H. Defects in rotary nickel-titanium files after clinical use. *Journal of endodontics*, 2000, 26.3: 161-165.

8. Zelada, G., Varela, P., Martín, B., Bahíllo, J. G., Magán, F., & Ahn, S. The effect of rotational speed and the curvature of root canals on the breakage of rotary endodontic instruments. *Journal of endodontics*, 2002, 28.7: 540-542.

9. Lopes, H. P., Elias, C. N., Vedovello, G. A., Bueno, C. E., Mangelli, M., & Siqueira Jr, J. F. Torsional resistance of retreatment instruments. *Journal of endodontics*, 2011, 37.10: 1442-1445.

10 Shen, Y., Zhou, H. M., Zheng, Y. F., Peng, B., & Haapasalo, M. Current challenges and concepts of the thermomechanical treatment of nickel-titanium instruments. *Journal of endodontics*, 2013, 39.2: 163-172.

11. Uygun, A. D., Kol, E., Topcu, M. K. C., Seckin, F., Ersoy, I., & Tanriver, M. Variations in cyclic fatigue resistance among ProTaper Gold, ProTaper Next and ProTaper Universal instruments at different levels. *International endodontic journal*, 2016, 49.5: 494-499.
12. Bürklein, S., Hinschitza, K., Dammaschke, T., & Schäfer, E. Shaping ability and cleaning effectiveness of two single-file systems in severely curved root canals of extracted teeth: Reciproc and WaveOne versus Mtwo and ProTaper. *International endodontic journal*, 2012, 45.5: 449-461.

13. Zupanc, J.; Vahdat-Pajouh, N.; Schäfer, E. New thermomechanically treated NiTi alloys–a review. *International endodontic journal*, 2018, 51.10: 1088-1103.

14. Seago, S. T., Bergeron, B. E., Kirkpatrick, T. C., Roberts, M. D., Roberts, H. W., Himel, V. T., & Sabey, K. A. Effect of repeated simulated clinical use and sterilization on the cutting efficiency and flexibility of Hyflex CM nickel-titanium rotary files. *Journal of endodontics*, 2015, 41.5: 725-728.

15. Neelakantan, Prasanna; Reddy, Pallavi; Gutmann, James L. Cyclic fatigue of two different single files with varying kinematics in a simulated double-curved canal. *Journal of Investigative and Clinical Dentistry*, 2016, 7.3: 272-277.

16. Ruiz-Sánchez, C., Faus-Llácer, V., Faus-Matoses, I., Zubizarreta-Macho, Á., Sauro, S., & Faus-Matoses, V. The influence of NiTi alloy on the cyclic fatigue resistance of endodontic files. *Journal of Clinical Medicine*, 2020, 9.11: 3755.

17. Zubizarreta-Macho, Á., Alonso-Ezpeleta, Ó., Albaladejo Martínez, A., Faus Matoses, V., Caviedes Brucheli, J., Agustín-Panadero, R., ... & Vizmanos Martínez-Berganza, F. Novel electronic device to quantify the cyclic fatigue resistance of endodontic reciprocating files after using and sterilization. *Applied Sciences*, 2020, 10.14: 4962.

18. De Almeida-Gomes, F., De Matos, H. R. M., Nunes, R. F. L. A., Arrais, A. M., Ferreira-Maniglia, C., De Morais Vitoriano, M., & Gurgel-Filho, E. D. Cyclic fatigue resistance of different continuous rotation and reciprocating endodontic systems. *Indian Journal of Dental Research*, 2016, 27.3: 278-282.

19. Khandagale, P. D., Shetty, P. P., Makandar, S. D., Bapna, P. A., Karobari, M. I., Marya, A., ... & Scardina, G. A. Evaluation of cyclic fatigue of Hyflex EDM, twisted files, and ProTaper gold manufactured with different processes: an in vitro study. *International Journal of Dentistry*, 2021, 2021: 1-6.

20. Bergmans, L., Van Cleynenbreugel, J., Wevers, M., & Lambrechts, P. Mechanical root canal preparation with NiTi rotary instruments: rationale, performance and safety. *Am J Dent*, 2001, 14.5: 324-3.

21. Wei, X., Ling, J., Jiang, J., Huang, X., & Liu, L. Modes of failure of ProTaper nickel–titanium rotary instruments after clinical use. *Journal of endodontics*, 2007, 33.3: 276-279.

22. Alapati, S. B., Brantley, W. A., Svec, T. A., Powers, J. M., Nusstein, J. M., & Daehn, G. S. SEM observations of nickel-titanium rotary endodontic instruments that fractured during clinical use. *Journal of endodontics*, 2005, 31.1: 40-43.

23. Cheung, Gary Sp. Instrument fracture: mechanisms, removal of fragments, and clinical outcomes. *Endodontic Topics*, 2007, 16.1: 1-26.

24. Cheung, Gary Sp; Shen, Ya; Darvell, Brian W. Effect of environment on low-cycle fatigue of a nickel–titanium instrument. *Journal of endodontics*, 2007, 33.12: 1433-1437.

25. Saleh, A. M., Gilani, P. V., Tavanafar, S., & Schäfer, E. Shaping ability of 4 different single-file systems in simulated S-shaped canals. *Journal of endodontics*, 2015, 41.4: 548-552.

26. Capar, I. D., Kaval, M. E., Ertas, H., & Sen, B. H. Comparison of the cyclic fatigue resistance of 5 different rotary pathfinding instruments made of conventional nickel-titanium wire, M-wire, and controlled memory wire. *Journal of endodontics*, 2015, 41.4: 535-538.

27. Peters, O. A., Gluskin, A. K., Weiss, R. A., & Han, J. T. An in vitro assessment of the physical properties of novel Hyflex nickel–titanium rotary instruments. *International endodontic journal*, 2012, 45.11: 1027-1034.

28. Simpsy, G. S., Sajjan, G. S., Mudunuri, P., Chittem, J., Prasanthi, N. N., & Balaga, P. Shaping ability of reciprocating motion of WaveOne and HyFlex in moderate to severe curved canals: A comparative study with cone beam computed tomography. *Journal of Conservative Dentistry*, 2016, 19.6: 578-582.

29. Elnaghy, A. M., & Elsaka, S. E. Mechanical properties of ProTaper Gold nickel-titanium rotary instruments. *International Endodontic Journal*, 2016, 49.11: 1073-1078.

30. Uygun, A. D., Kol, E., Topcu, M. K. C., Seckin, F., Ersoy, I., & Tanriver, M. Variations in cyclic fatigue resistance among ProTaper Gold, ProTaper Next and ProTaper Universal instruments at different levels. *International endodontic journal*, 2016, 49.5: 494-499.

31. Hieawy, A., Haapasalo, M., Zhou, H., Wang, Z. J., & Shen, Y. Phase transformation behavior and resistance to bending and cyclic fatigue of ProTaper Gold and ProTaper Universal instruments. *Journal of endodontics*, 2015, 41.7: 1134-1138.

32. Plotino, G., Testarelli, L., Al-Sudani, D., Pongione, G., Grande, N. M., & Gambarini, G. Fatigue resistance of rotary instruments manufactured using different nickel–titanium alloys: a comparative study. *Odontology*, 2014, 102: 31-35.
33. Al-Hadlaq, Solaiman M. Evaluation of cyclic flexural fatigue resistance of 25/0.04 and 25/0.06 twisted file rotary nickel-titanium endodontic instruments. *Australian Endodontic Journal*, 2013, 39.2: 62-65.