Original Article

Analysis of cyclic fatigue resistance of different endodontic nickel–titanium rotary instruments: An *in vitro* study

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Abstract

Aims: The aim of this *in vitro* study was to compare the cyclic fatigue resistance of three different endodontic nickel–titanium rotary instruments using a dynamic testing device.

Materials and Methods: Ten files each of ProTaper Gold (PG), Hyflex Electro-discharge Machining (HEDM), and TruNatomy (TN) were tested in a custom-fabricated dynamic cyclic fatigue testing device at 60° curvature having a radius of curvature of 5 mm. The number of cycles to the fracture (NCF) of each instrument was calculated and three continuous groups were compared by the Kruskal–Wallis test and Dunn *post hoc* test was used for pairwise comparison.

Results: Cyclic fatigue resistance of HEDM was the highest, followed by TN. PG had the lowest among the three.

Conclusion: Within the limitations of the present *in vitro* results, it can be concluded that HEDM files appeared to be suitable for shaping complex canals with the greater number of cycles before it fractures.

Keywords: Cyclic fatigue; Hyflex Electro-Discharge Machining; NiTi; rotary files; TruNatomy

INTRODUCTION

With the development of nickel–titanium alloys by Buehler and Wang, it has paved the way toward its usage in dentistry.[1] Since its introduction in endodontics by Walia *et al*., these NiTi rotary instruments have undergone numerous changes in their form, shape, and physical properties over the course of three decades.[2] These improvements have been made to more efficiently and simply assist in the cleaning and shaping procedure.[3]

The separation of NiTi files occurs due to cyclic or flexural fatigue and torsional fatigue. Cyclic fatigue emerges when a metal undergoes a series of alternating tension and compression cycles, resulting in structural deterioration and eventual fracturing.[4] Detecting flexural failure is difficult since it presents with no signs of deformation.[5] In addition, the chance of separation increases with increase in the canal curvature.[6]

ProTaper Gold instrument (PG; Dentsply, Tulsa Dental Specialties, Tulsa, OK, USA) has a convex triangular cross-section and progressive taper similar to ProTaper Universal (Dentsply Maillefer, Ballaigues, Switzerland). Its 2-stage specific transformation and high austenitic fusion temperature (55°C) renders it soft and ductile.[7,8] The Hyflex Electro-Discharge Machining (HEDM) (Coltene/Whaledent, Altstätten, Switzerland) has a quadratic cross-section at the tip, trapezoidal at the middle third, and triangular at the top. It is manufactured using "Electrical Discharge Machining," which hardens the surface and

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provides the controlled memory effect similar to Hyflex CM.[9] TruNatomy instruments (TN) (Dentsply Sirona) are off-centered parallelogram cross-section manufactured using a special NiTi heat-treated wire that supposed to enhance the flexibility of the instrument. The slim NiTi wire design is 0.8 mm instead of up to 1.2 mm of the most other variable tapered instruments.[10,11]

These new metallurgical and manufacturing advances have been claiming to have brought a lot of progress in improving cyclic fatigue resistance. However, these claims of the manufacturers of these NiTi files have not been adequately tested by independent research using a novel custom-made dynamic cyclic fatigue testing device. Therefore, the purpose of this study was to evaluate *in vitro* the cyclic fatigue of ProTaper Gold, HEDM, and TN NiTi files using a dynamic model. The null hypothesis is that there is no difference in the cyclic fatigue resistance of the above-mentioned files.

MATERIALS AND METHODS

This study was approved by the AMC Institutional Ethics Committee (AMC/IRB/ENDO/PG52/21).

Grouping

- Group 1: ProTaper Gold Rotary files (PG; Dentsply, Tulsa Dental Specialties, Tulsa, OK, USA)
- Group 2: HEDM Rotary files (Coltène Whaledent, Switzerland)
- Group 3: TN Rotary files (TN; Dentsply Sirona, Maillefer, Ballaigues, Switzerland).

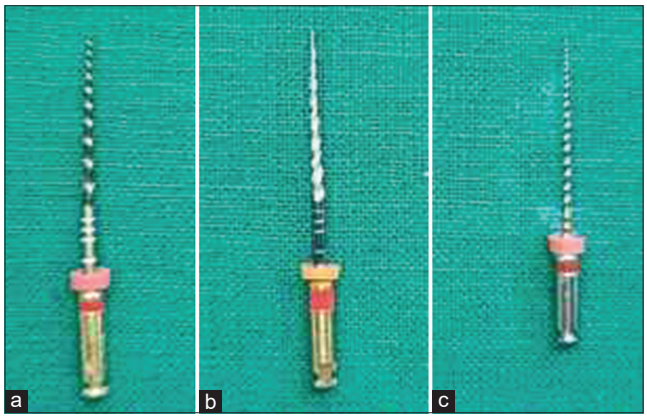

Figure 1: NiTi rotary files (a) Group 1-ProTaper Gold-PTG, (b) Group 2-Hyflex electro-discharge machining and (c) Group 3-TruNatomy

The sample size formula was:

$$n = 2 \text{ sigma } (Z_{1-2} + Z_{ip})/(m_1 - m_2)^2$$

If power of the test was 80%, level of significance was 5%, to detect mean differences of 5 unit between groups with pooled sigma – 6.5 was considered. The required sample size per group was 10. The total number of groups was 3. A total of 6 pairwise comparisons were possible.

These files had a taper similar or close to 25/0.04 and 25 mm of length [Figure 1]. Separated files can be seen in the Figure 2.

These instruments were tested in a custom made cyclic fatigue testing device [Figure 3].

Cyclic fatigue testing

The test apparatus here was used to simulate the movements during the endodontic root canal procedure. The artificial canal was created onto a stainless-steel cylinder with an angulation of 60° having a radius of curvature of 5 mm and diameter of canal of 2 mm. The whole assembly was mounted on an iron base supported on four rubber feet to prevent displacement due to vibration. Tripod was set onto the assembly for stable and constant video recording. The NiTi instruments were inserted up to 20 mm. Glycerin (Bharat Pharmaceuticals, Chennai, India) was used to reduce the friction of the file.

The instruments were rotated at the manufacturer's recommended speed and torque. This was done by using a 16:1 reduction handpiece powered by a torque-controlled Endomotor (E-Connect Pro, Changzhou Eighteeth Medical Technology Co., Ltd.) which had a speed range of 120–1000 rpm and torque 0.5–4.0 Ncm.

Simultaneously, cyclic fatigue device and the endomotor were switched on by two different persons which resulted

Figure 2: Separated NiTi rotary files (a) PTG, (b) Hyflex electro-discharge machining and (c) TruNatomy

Figure 3: Setup of custom fabricated cyclic fatigue device

in rotation of the files and back-and-forth pecking motion at the same time. This was considered the beginning of the time to fracture. Instruments were rotated until fracture and the time of fracture (T) was recorded with a 1/100 s digital stop watch. A constant video recording was performed in real time [Figure 4]. Furthermore, as there were two hands at work, observer and experimental bias were avoided.

The time to fracture (*T*) was noted for each file. This was multiplied by the number of rotations per minute (rpm) (*N*) to obtain the number of cycles to fracture (NCF) for each instrument. The formula used was NCF = T × *N*. Separated files can be seen in the Figure 2.

Three continuous groups were compared by Kruskal–Wallis test and Dunn *post hoc* test was used for pairwise comparison. The entire data were statistically analyzed using the Statistical Package for the Social Sciences (SPSS Software IBM Corp. Released 2011. IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.). $P < 0.05$ and 0.01 were accepted as statistically significant and highly significant, respectively.

RESULTS

The mean NCF of PG was 523.298, HEDM was 5649.424, and TN was 2204.482. *P* value of all the groups was 0.000 which means that the results were statistically significant. The mean rank of HEDM was 25.50. While the mean rank of PG and TN was 5.50 and 15.50, respectively [Table 1]. Pairwise comparison for each file using the Dunn *post hoc* test was conducted. *P* value for PG-HEDM was 0.000. *P* value for PG-TN was 0.015. *P* value for HEDM-TN was 0.008. $P < 0.05$ denotes that the pairwise comparison was statistically significant [Table 2].

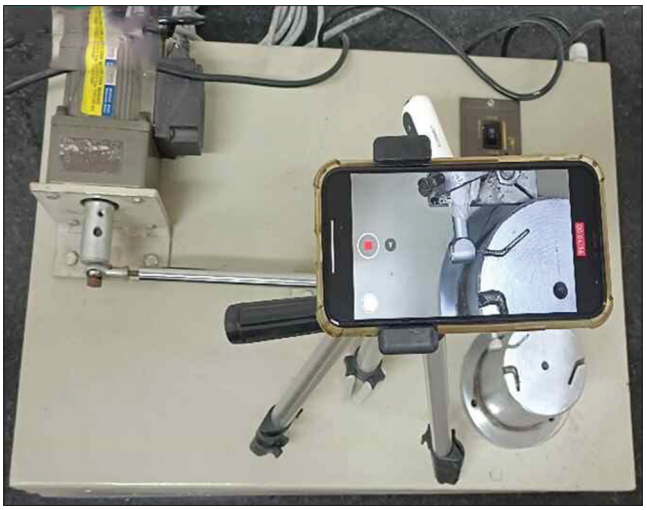

Figure 4: Video recorder for calculation of the time to fracture (*T*)

This denoted that the mean NCF of HEDM was the highest among the three. Hence, HEDM had a greater cyclic fatigue resistance, followed by TN and PG.

DISCUSSION

The aim of this study was to assess the cyclic fatigue resistance of three different endodontic NiTi rotary instruments – ProTaper Gold, HEDM, and TN – using a custom-made dynamic cyclic fatigue testing device.

In the past, both static and dynamic tests have been used to measure cyclic fatigue resistance.[12,13] Various static cyclic fatigue devices have been developed based on ADA specification no. 28 since 1976.[14] These devices evaluate resistance to cyclic fatigue without linear motion. Conversely, dynamic test devices replicate the back-and-forth pecking motion observed during endodontic canal preparation. Dederich and Zakariasen were among the pioneers of dynamic testing devices with pecking file movement.[15]

In this study, dynamic elements were incorporated using a motor and linkages to translate rotary motion into pecking motion. A 3-mm back-and-forth motion was used, following the model established by Yao *et al*.,[16] although distances such as 2 and 8 mm have also been employed.[17]

Schneider's work on measuring canal angulation has aided in assessing complexity and favorable outcomes.[18] The present study used a 60° angulation to replicate a challenging canal, as curvature beyond 30° is considered highly difficult by the AAE standards.

The study simulated the canal on a stainless steel cylinder. Although extracted teeth models resemble clinical situations, they are not ideal for purely assessing NiTi file properties

Table 1: Kruskal–Wallis test for files

Files	Mean NCF	SD	Mean rank	χ^2	*P*
ProTaper gold files	523.298	46.578	5.50	25.806	0.000*
HEDM	5649.424	145.766	25.50		0.000*
TruNatomy	2204.482	179.081	15.50		0.000*

SD: Standard deviation, NCF: Number of cycles to fracture, HEDM: Hyflex electro-discharge machining

Table 2: Dunn *post hoc* test for pairwise comparison

Pair	*P*
ProTaper gold files-HEDM	0.000*
ProTaper gold files - TruNatomy	0.015*
HEDM - TruNatomy	0.008*

HEDM: Hyflex electro-discharge machining

due to variations in root canals. A nontooth model was chosen to standardize the conditions and minimize other failure mechanisms aside from cyclic fatigue.

Three file systems, ProTaper Gold (PTG), HEDM, and TN, were analyzed for cyclic fatigue resistance. All had a 25/04 or similar taper, commonly used in endodontic treatment.[19] These systems differed in cross-section and machining procedures, influencing their fatigue behavior.

HEDM displayed the highest mean NCF (5649.424 ± 145.766) due to its EDM procedure, causing multiple crack sites that enhance fatigue life.[20] PG exhibited the least cyclic fatigue resistance (523.298 ± 46.578), attributed to its convex triangular design and increased transition temperature.[21] TN fell between HEDM and PTG (2204.482 ± 179.081), offering unique geometry, reduced taper, and enhanced flexibility due to heat treatment.[22] As the study showed difference in the mean NCF of the files, consequently, in the cyclic fatigue resistance, the null hypothesis is rejected.

The standard deviation for PG, HEDM, and TN was 46.578, 145.766, and 179.081, respectively. In the study by Uygun *et al*., the standard deviation for PG and HEDM was 66.49 and 114.89, respectively. Another study by Reddy *et al*. had standard deviation of 13.35, 62.81, and 165.02 for PG, HEDM, and TN.[23,24] This variance highlights the lack of standardization in cyclic fatigue tests, possibly due to fabrication quality variation of NiTi instruments and testing methodology discrepancies.

One limitation of the study was the taper of the file could not be standardized since the files had variable taper. However, since our primary objective was to assess the cyclic fatigue resistance of files with diverse manufacturing methodologies and cross-sections, these specific files were chosen for the investigation.

CONCLUSION

To conclude, the study utilized a custom dynamic cyclic fatigue testing device to evaluate the cyclic fatigue resistance of three NiTi rotary instruments. Results indicated superior performance by HEDM, followed by TN and PTG. It can be concluded that cross-section and machining process for manufacturing these rotary instruments plays a vital role in determining its mechanical properties, one such being cyclic fatigue resistance. Within the limitations of the present *in vitro* results, it can be concluded that EDM files appeared to be suitable for shaping complex canals with greater number of cycles before it fractures.

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Conflicts of interest
There are no conflicts of interest.

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