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Original Article

Effect of Two Different Temperatures on Resistance to Cyclic Fatigue of Hyflex EDM TruNatomy and ProTaper Next Files: An *In Vitro* Study

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Abstract

Introduction: One of the important aspects in success of endodontic treatment is root canal instrumentation. Nickel-titanium rotary instruments drastically improved the root canal preparation technique. However, the major disadvantage of these instruments is their unexpected fracture. Intracanal temperature plays an important role in the cyclic fatigue resistance. This study was conducted to compare the effect of two different temperatures on resistance to cyclic fatigue of HyFlex EDM, TruNatomy, and ProTaper Next files.

Methods: A total of 30 endobloc and 30 continuous rotary files from each system (n = 10) (GROUP 1: HyFlex EDM, GROUP 2: TruNatomy, GROUP 3: ProTaper Next) were used for the study. Samples were further divided into two subgroups (n = 5) and tested at room temperature and at stimulated intracanal temperature (45–50°C). A digital thermometer was used to measure the temperature of the water. The number of cycles to fracture was calculated. Length of fractured segments was measured using a digital caliper. The fractured files were examined under a scanning electron microscope to determine morphological characteristics. Data were analyzed using I Kruskal–Wallis test, *post hoc* Mann–Whitney test, and Wilcoxon sign test.

Results: At both temperatures, HyFlex EDM files showed the highest number of cycles to fracture compared with ProTaper Next and TruNatomy files (P < 0.05). There was no significant difference in fractured segment length at intracanal stimulated temperature whereas TruNatomy showed higher fracture segment length at room temperature.

Conclusion: Within the limitations of this *in vitro* study, it can be concluded that HyFlex EDM showed the highest cyclic fatigue resistance both in the room and stimulated intracanal temperature compared to TruNatomy and ProTaper Next. There was increase length of fracture segment of TruNatomy at room temperature. Scanning electron microscope analysis showed the presence of morphological changes in the fractured files.

Key words: Cyclic fatigue, HyFlex EDM, ProTaper Next, Temperature, TruNatomy

INTRODUCTION

The primary goals of root canal instrumentation are to provide a biologic environment for healing and to develop a canal shape to receive three-dimensional obturation. Recently, rotary instrumentation has gained considerable popularity and may be used in conjunction with hand instruments.[1]

Nickel-titanium (NiTi) alloys have become the most popular shape memory (SM) alloys due to their unique ability to recover their original shape after undergoing large deformations (up to 8%) through heating, known as SM effect or through the removal of the load known as superelastic (SE) effect.[2]

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Rotary instrument separation caused by cyclic fatigue has remained a primary concern in the practice of endodontics, especially for root canals with severe curvatures. Hence, the rotary instruments are subjected to various thermomechanical processing or new manufacturing technologies to overcome iatrogenic mishaps. Recently, a new NiTi wire (termed M-Wire) has been developed through a proprietary thermomechanical processing procedure and showed significantly improved cyclic fatigue resistance on endodontic rotary instrument products.[1,2]

It has been described that two main events lead to instrument fracture are cyclic fatigue and torsional loading. In certain instrument designs, torsional loading results in unwinding. Although these two conditions may be simulated separately *in vitro,* it is difficult to evaluate under different clinical scenarios because the morphological structure and stress acting on the file may not be able to stimulate practically. Clinically, both events occur simultaneously. Therefore, it is appealing to consider both strict conditions as well as simulated clinical use in benchtop conditions when assessing the physical properties of novel root canal instruments.[2]

To date, many of the studies examining the cyclic fatigue failures of files have been carried out at room temperature. There is very limited literature regarding the cyclic fatigue resistance of files in intracanal temperature. Hence, the purpose of the study is to compare and evaluate the effect of two different temperatures on resistance to cyclic fatigue of nickel-titanium files.

MATERIALS AND METHODS

A total of 30 endobloc and ten rotary files from each group (HyFlex EDM, TruNatomy, ProTaper Next) were used for the study. Then, samples were divided into three groups:

- GROUP 1: Hyflex EDM (Coltene)
- GROUP 2: TruNatomy (Dentsply)
- GROUP 3: PTN (Dentsply)

Then, the electric handpiece (Endomotor, J MORITA) was used to allow for precise and reproducible placement of each file inside the canal. All the files were operated with a torque-controlled electric motor and were used according to the manufacturer's recommendation in terms of speed and torque. With the following procedure, all the samples are divided into two subgroups:

a. A total of five samples from each group and five files from each group were tested at room temperature and with normal-temperature intracanal irrigants (sodium hypochlorite and normal saline) within the artificial canal
b. A total of five samples from each group and five files from each group were tested in simulated temperature. The artificial canal was open to water (i.e., submerged

Figure 1: Stimulated canal temperature to test for CFR

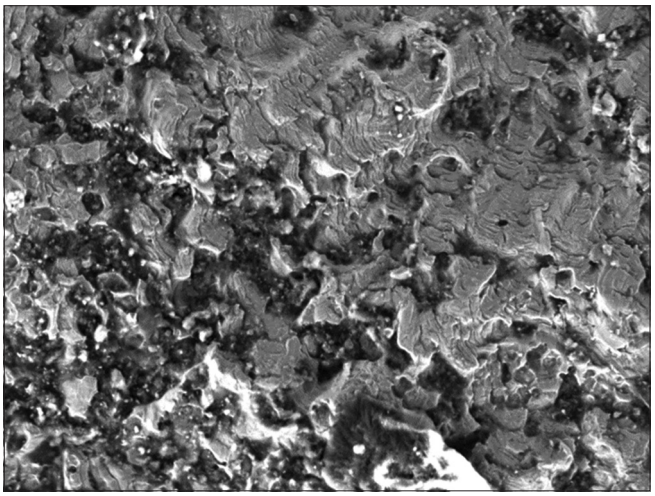


Figure 2: SEM images of ProTaper Next

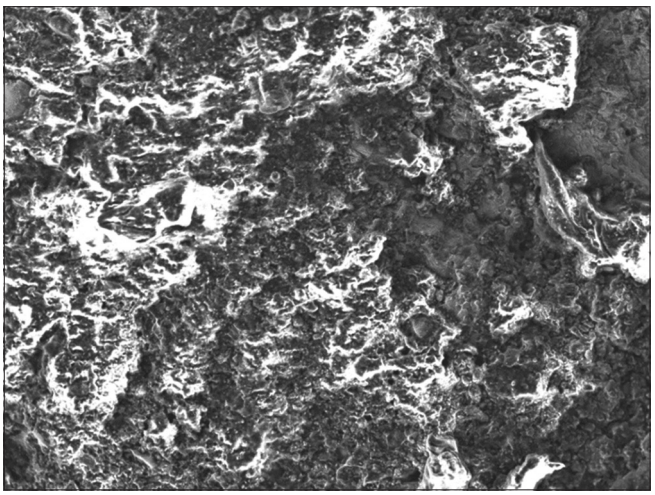


Figure 3: SEM images of TruNatomy

in a water bath Figure 1) allowing the file to be exposed to the experimental temperature of the water in the water bath with stimulated temperature intracanal irrigants (sodium hypochlorite and saline).

A digital thermometer was used to measure the temperature of the water. All the procedure was timed and the clock was stopped as soon as the fracture will be visually detected. The number of cycles to fracture for each instrument was calculated by multiplying the number of rotations per the effective seconds of continuous rotation require to fracture. Fractured pieces were measured for length using a digital caliper.

The fractured files were examined to determine morphological characteristics using a scanning electron microscope. The collected data were analyzed using the Statistical Package for the Social Sciences version 20 (IBM SPASS statistics [IBM Corp. Armonk, NY, USA released 2011]). Inferential statistics such as the Kruskal–Wallis test were applied to compare the temperature difference among the groups with *post hoc* Mann–Whitney for pairwise comparison. Wilcoxon sign test was applied to compare the temperature difference within the group.

RESULTS

Among group comparison between body temperature and intracanal stimulated temperature, it was observed that:

At both, body temperature and intracanal stimulated temperature GROUP 1(HEDM) has got more CFR than GROUP 2 (TN) and GROUP 3(PTN)

- At room temperature, fracture fragment length was more for GROUP 2 (TN) compared to that of GROUP 1 (HEDM) and GROUP 3(PTN)
- At stimulated intracanal temperature, there was no significant difference in the length of the fractured fragment
- SEM analysis showed morphological changes in fractured segments of all groups
- The HEDM group showed the highest CFR in both room and stimulated intracanal temperature.

DISCUSSION

Recently, canal instruments manufactured out of a nickel-titanium (NiTi) alloy have proven to be a valuable adjunct for root canal therapy. NiTi instruments are highly flexible and elastic and prevent iatrogenic mishaps.[3,4]

Ni-Ti is a biomedical alloy that can be processed to exhibit SM and SE properties that are mainly attributed to the stress and the temperature-induced austenitic to martensitic transformation.[5]

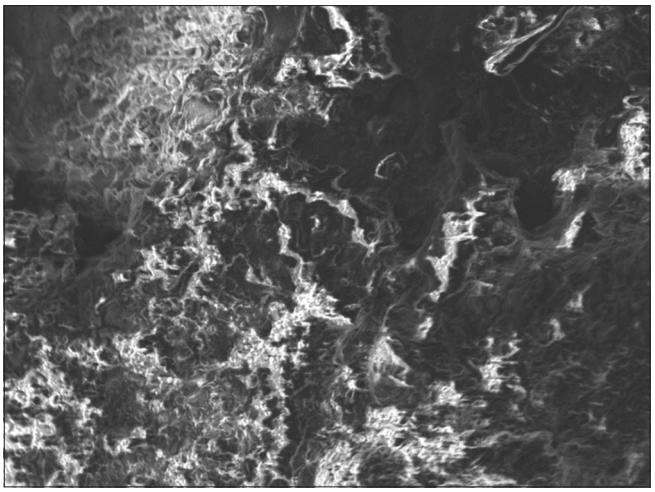


Figure 4: SEM images of Hyflex EDM

The previous studies have reported that dynamic motion tests are the most suitable with regard to testing the CFR of rotary NiTi files, as static tests are not able to reproduce the real conditions faced in clinical practice at different temperatures. In the present study, all NiTi files were tested for CFR on a dynamic test model to simulate clinical use. Furthermore, to eliminate the effect of movement type (i.e., rotation or reciprocating) of the files, only files that use continuous rotation movement were selected for CFR testing in the present study.[6]

In the present study, room temperature was at 37°C, and intra-canal temperature was maintained at 45–50°C to stimulate the clinical scenario. Proprietary heat treatments increase the so-called austenite start (As) and austenite finish (Af) temperatures, when the temperature is between As and Af, crystallographic rearrangements may occur when changing between room and body temperature. When the alloy cools down to a temperature close to As, the percentage of the martensitic phase could reach the maximum range possible for the alloy itself. A probable reason could be the interconversion of atoms causing the change in space lattice.[7-9]

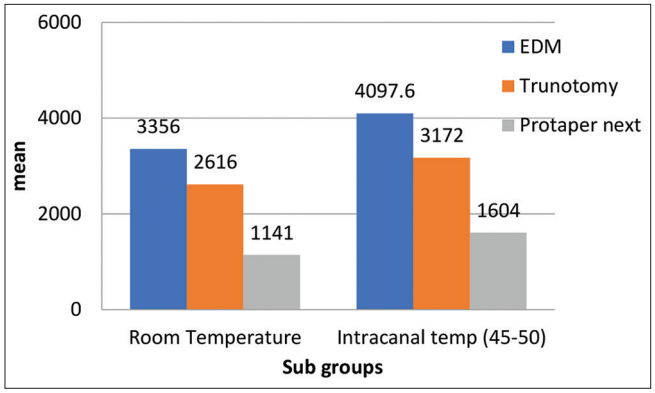
In the present study, the intracanal temperature was maintained with a warm water bath which influences the instrument's crystallographic rearrangement. The warm water bath may not universally represent what actually happens inside the root canal environment. Confounding variables might include the phase transformation temperature of each instrument, the extent of the instrument's surface exposed to the warmed environment, and the duration the instrument remains inside the canal.[9] Further studies have to be carried out to evaluate the CFR

of instruments at different temperatures which stimulate the intracanal environment.

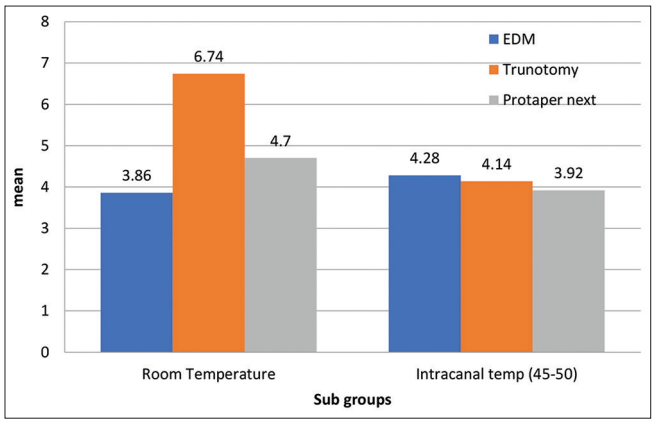
Phase transformation and crystallographic rearrangement may be the probable reason that HEDM has got higher NCF than TN and PTN in both room temperature and intracanal stimulated temperature [Graph 1]. It could be speculated that the cross-sectional area, metal mass, and core of the files tested may have an impact on these results because a higher number of molecules can switch from the austenite to the martensite phase in a low-temperature environment.

Patterson *et al.* reported Knoop hardness of dentin to range from 40 to 72.[9,10] To mimic the hardness of dentin, the present study utilized acrylic blocs with curved canals to test the CFR at different temperatures. Shen *et al.* reported that the performance and mechanical properties of NiTi instruments are influenced by factors such as cross-section, flute design, taper, raw material, and manufacturing processes.[11]

Manufacturing process: In the present study, GROUP-1 (HEDM) was made up of an electron discharge machining process, GROUP-2 (TN) and GROUP-3 (PTN) were made of M-wire technology.[12]



Graph 1: Mean distribution of cycles at both room and intracanal temperature



Graph 2: Mean distribution of fracture length at both room and intracanal temperature

Manufacturing processes with different technologies may be the probable reason that Group-1 (HEDM) has increased CFR compared to the other two groups. The improvement in CFR of HEDM can be attributed to the formation of a protective oxide layer during EDM, which resists the propagation of microcracks.

Cross-sectional area: In the present study, HEDM has a variable cross-section, TN has an off-centered parallelogram cross-section and PTN has a rectangular cross-section. The rectangular cross-section of PTN has shown a decrease in cyclic fatigue resistance at both in room and stimulated intracanal temperature. Probable reason for separation is due to the maximal adaptation of the instrument to the canal wall. Since variable taper comes in an alternate contact point with the radicular space, HEDM has shown better CFR than other groups.[13]

Taper, Pitch, Radial land, Helical angle, and Rake angle are the other governing factors for the high CFR rate of HEDM compared to TN and PTN for both room temperature and intracanal temperature. Further studies have to be carried out to evaluate the effect of these factors on CFR.

In the present study, saline and sodium hypochlorite were used as irrigating solutions. When NaOCl is used as an irrigant, it selectively removes nickel from the instrument surface and causes micropitting, negatively affecting the physical and mechanical properties of NiTi files.[14,15]

At room temperature, the fracture length of GROUP-2 (TN) file was higher than that of GROUP-1 (HEDM) file and GROUP-3 (PTN) file, this may be attributed to the manufacturing of TN that it is made up of a maximum fluted diameter of 0.8 mm instead of 1.2 mm but, at intracanal temperature, there was no significant difference in the fracture length [Graph 2].[2,16] Probable reason may be due to the maximum contact of the file in the canal and also the manufacturing process and constituent of the alloy.

After performing the cyclic fatigue test, fractured instruments of each system were selected and examined using a scanning electron microscope. The fractured surface and cross-section of each instrument were assessed to determine the morphological characteristics of each rotary file and to determine the propagation of microcrack in and around the margin of the file. All fractured files showed a change in the morphogenic characteristics [Figures 2-4].[17] Hence, before introducing the file into the canal, it should be properly examined under magnification for the presence of any deformities.

As a consequence, it can be concluded that controlled memory rotary files exhibited greater CFR than the file which is made of M-Wire NiTi alloy in a curved canal. All the above-mentioned variables such as temperature, canal curvature, taper, rotational speed, metallurgical properties, and cross-section of instruments are not individual factors but are confounding factors that play an important role in the CFR of particular instruments.

Difference in retrospective study conducted in different parts of the world on control conditions should exhibit reproducible internal and external validity. However, most of the studies usually lack external validity (i.e., the extent to which the results can be generalized to clinical situations). To test the CFR to date, there is no specification or international standard to evaluate the various parameters under controlled conditions. Further studies have to be carried out with innovative methodology to produce a relevant understanding of the instrument's performance on very specific conditions to overcome the present mechanical testing studies' drawbacks regarding inconsistency, lack of reproducibility, and low external validity.[9]

CONCLUSION

Within the limitations of this *in vitro* study, it was concluded that:

PTN (M-Wire file) exhibited the lowest CFR values compared with HEDM and TN files at both room and intracanal temperature. HEDM files have a significantly enhanced CFR compared with PTN and TN files. Due to an increased amount of the martensite phase, martensitic files (i.e., CM files) are more flexible with an enhanced CFR compared with austenitic files (i.e., M-Wire). At room temperature, fracture segment length was more for TN than HEDM and PTN. At intra-canal stimulated temperature, there was no difference in the length of the fractured segment.

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