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Mechanical Properties of Anatomic Finishing Files: XP-Endo Finisher and XP-Clean

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The aim of the present study was to evaluate the cyclic fatigue of two anatomic finishing files: XP-Endo Finisher and XP-Clean. Roughness pattern and the micro-hardness of the files were also assessed. Instruments were subjected to cyclic fatigue resistance measuring the time to fracture in an artificial stainless-steel canal with a 60° angle and a 5-mm radius of curvature. The fracture surface of all fragments was examined with a scanning electron microscope. The roughness of the working parts was quantified by using a profilometer and the micro-hardness test was carried out using a Vickers hardness tester. Results were statistically analyzed using a student´s t-test at a significance level of P < 0.05. Weibull analysis was also performed. XP-Endo Finisher presented significantly longer cyclic fatigue life than XP-Clean instruments (P<0.05). XP-Endo Finisher was able to withstand 1000% more cycles to fracture when compared to XP-Clean instruments. SEM visual inspection of the fracture surfaces revealed fractographic characteristics of ductile fracture in all tested instruments; wide-ranging forms of dimples were identified and no plastic deformation in the helical shaft of the fractured instruments was observed. When mean life was compared XP-Endo Finisher lasted longer than XP-Clean with a probability of 99.9%. XP-Endo Finisher instruments also exhibited significantly lower roughness than XP-Clean instruments (P<0.05). No differences in the micro-hardness was observed between the files (P>0.05). It can be concluded that XP-Endo Finisher instruments showed improved performance when compared with XP-Clean instruments, demonstrating higher cyclic fatigue resistance and lower roughness.

Key Words: cyclic fatigue, XP-Endo Finisher, XP-Clean

Introduction

The advances in techniques and instruments for root canal preparation over the past decades led a more predictable, safer and faster endodontic treatment (1, 2). However, irrespective of the instrumentation techniques, instruments, and irrigants, a thorough cleaning and shaping of the root canals in its totality have not been achieved, especially in teeth with curved canals or complex anatomies (3-5). Recent studies have shown that 30%-50% of the canal wall surface area may remain untouched after instrumentation and covered with biofilms that have the potential to put the treatment outcome at risk (4-6).

To overcome these problems, new instruments and strategies have been proposed to obtain a more thorough cleaning and disinfection. A new concept of anatomic finishing file, the XP-endo Finisher (FKG Dentaire, La Chaux-de-Fonds, Switzerland) was introduced to be used after any root canal instrumentation, as a final step to improve root canal cleaning while conserving dentin. It consists in a small core size (tip size 25 and nontapered) rotary NiTi instrument made of a proprietary alloy (MaxWire; Martensite-Austenite Electropolish Flex, FKG Dentaire). Because of this new alloy, the file changes its shape according to the temperature. In room temperature, in its martensitic phase (M-phase), the file stands straight. However, when submitted to body temperatures, it changes to its austenitic phase (A-phase) assuming a spoon shape of 1.5 mm depth in the final 10 mm of its length. According to the manufacturer, when the instrument is placed inside the canal in the rotation mode, the A-phase shape allows the files to access and clean areas that other instruments might not have reached, without damaging dentin or altering the original canal shape (7). Previous studies demonstrated that this new instrument effectively removed accumulated hard tissue debris, smear layer and calcium hydroxide paste from the root canal system (8-10). In addition, XP-Endo Finisher showed encouraging results regarding its disinfection effectiveness (5,11).

XP-Clean (MK Life, Porto Alegre, Brazil) is another finishing file, recently launched in the market. According to the manufacturer, this instrument can be used after the chemo-mechanical preparation (CMP), such as XP-Endo Finisher, and it has 2 mechanisms of action: (1) By the agitation of the irrigating solution, increasing its cleaning power and (2) by mechanical contact on the inner walls of the canal, removing debris and microorganisms, touching root canal walls that were not touched during CMP.

In spite of the promising results presented by anatomic finishing files, little is known about the mechanical properties of these instruments. Therefore, the aim of the present study was to compare the cyclic fatigue resistance of XP-Endo Finisher and XP-Clean. In addition, the roughness pattern and the micro-hardness of the files were assessed. The null hypotheses tested were as follows that:

There are no differences in the cyclic fatigue fracture resistance between the instruments; There are no differences in the roughness pattern of the instruments; There are no differences in the micro-hardness between the instruments;

Material and Methods

Cyclic Fatigue Test

The cyclic fatigue test was performed using a custom-made device that allowed a reproducible simulation of an instrument confined in a curved canal, similar to that previously described (12). It consists of an artificial canal with an 60-degree angle of curvature and 5 mm radius of curvature, with a size 30 tip and a 0.08 taper. The center of the curvature was 5 mm from the tip of the instrument, and the curved segment of the canal was 5 mm in length. The artificial canal was open in its upper part and covered with tempered glass to prevent the instruments from slipping out. Before testing, each instrument was examined for defects and deformities using an operating microscope (Zeiss Opmi; Carl Zeiss, Jena, Germany) at 24X magnification.

Ten XP-Endo Finisher and ten XP-Clean instruments were activated with a 6:1 reduction handpiece (Sirona Dental Systems GmbH, Bensheim, Germany) powered by a torque-controlled motor (Silver Reciproc; VDW, Munich, Germany), according to the manufacturer´s recommendations (800 rpm and 1 Ncm^{-1} torque). The electric handpiece was mounted on a device to allow for precise and reproducible placement of each file inside the simulated canal.

All instruments were driven following the manufacturer's instructions until fracture occurred. The instruments rotated freely within the simulated canal, which was filled with warmed distilled water (37°C). All procedures were performed at 37°C inside a cabinet. The time was recorded and the experiment stopped as soon as a fracture was detected visually and/or audibly. To avoid human error, video recording was performed simultaneously, with the recordings then observed to crosscheck the time of file fracture. The number of cycles to failure (NCF) was calculated by multiplying the rotational speed by the time (in s) until fracture occurred.

Scanning electron microscopy (SEM) (JSM 5800; JEOL, Tokyo, Japan) was used to analyze the surface finish, helical shaft, tips and fracture surfaces of the instruments in order to observe defects originating from the manufacturing process, the occurrence of plastic deformation in the helical shaft and the fracture mode, respectively. Different magnifications were used to evaluate the surface fracture (×1000) and surface finish (×1200) characteristics.

Surface Finishing

The roughness (*Ra*) of the working parts of ten XP-Endo Finisher and ten XP-Clean instruments was quantified using a New View 7100 Profilometer (Zygo Co, Middlefield, CT, USA), an interferometric non-contact 3-dimensional surface measurement system. The profiler provides ultra-precise 3-dimensional analyses of complex surfaces and rapidly measures heights from 0.1 nm to 1.0 mm with a vertical resolution as low as 0.1 nm.

The equipment allows the measurement of the roughness of the files, even on surfaces that are not flat, as in the deeper zone of the instruments helical shaft. A 0.2 mm circular shaped mask was set for this region to define a standard area to measure the Ra roughness. This parameter considers the roughness of an area that needed to be well defined. The 0.1 mm area was adjusted because it was the highest allowed by these instruments with small diameters. A larger area was considered for greater representativeness of the sample.

Roughness was quantified at the tip, middle and D16 parts of the instruments; 3 measurements were performed per third in randomly selected areas. The average roughness (*Ra*) for each group of instrument was then established as the mean of the 9 measurements.

Vickers Microhardness Test

The microhardness test was carried out using a Vickers microhardness tester (Shimadzu HMV-G, Shimadzu; Kyoto, Japan). Ten XP-Endo Finisher and ten XP-Clean instruments were embedded in resin to expose the core using sandpaper sequence (Norton sandpapers, São Paulo, Brazil). The sandpaper granulations used in metallographic preparation were 600, 800 and 1200. The flat surface obtained was polished with a suspension of 1 µm and 0.5 µm alumina using a felt disc in a politrix (Fortel PLF DV, Fortel, São Paulo, Brazil). After this, the diamond penetrator was used at 100 g for 15 s, with evaluations carried out at 20 times increments for ten indentations on each instrument. Indentations were created at the core of each examined instrument and the distance between the indentations was 2.5 times the diagonal of the previous stamp.

Statistical Analysis

Because preliminary analysis of the raw pooled and isolated data revealed a normal distribution (D'Agostino and Person omnibus normality test), statistical analysis was performed using a student´s t-test, with the alpha-type error set at 0.05. SPSS 11.0 (SPSS Inc., Chicago, IL, USA) and Origin 6.0 (Microcal Software, Inc., Northampton, MA, USA) were used as analytical tools.

Weibull analysis (MINITAB® Student Version, Release 14.11.1, State College, Pensilvania, USA) was used to calculate the following parameters:

1. Mean life (s): the expected or average time to failure

2. Beta: the slope or shape parameter (dimensionless), the values of which are equal to the slopes of the regressed lines in the Weibull probability plot and are particularly significant because they provide a clue to the physics of the failure

3. Eta (s): characteristic life or scale parameter. Eta is the typical time to failure in Weibull analysis related to the mean time to failure. It is defined as the expected time that 63.2% of the files will attain without breakage (ie, the probability of failure being 0.63 at this time point).

Comparison between the groups allowed for the determination of whether items from one set would outlast those of the others.

Results

XP-Endo Finisher presented significantly longer cyclic fatigue life than XP-Clean instruments (p<0.05) (Table 1). SEM visual inspection of the fracture surfaces revealed fractographic characteristics of ductile fracture in all tested instruments, presenting rough apearence with microvoids that nucleates during the fatigue test. This aspect are typical in ductile materials that suffers catastrophic fatigue failure. Wide-ranging forms of dimples were identified and no plastic deformation in the helical shaft of the fractured instruments was observed (Fig. 1). The distribution of reliability versus time by group is shown in Figure 2. Table 1 presents the results for beta, eta, and mean life parameters. When mean life was compared among the brands, XP-Endo Finisher lasted longer than XP-Clean with a probability of 99.9% (statistically significant).

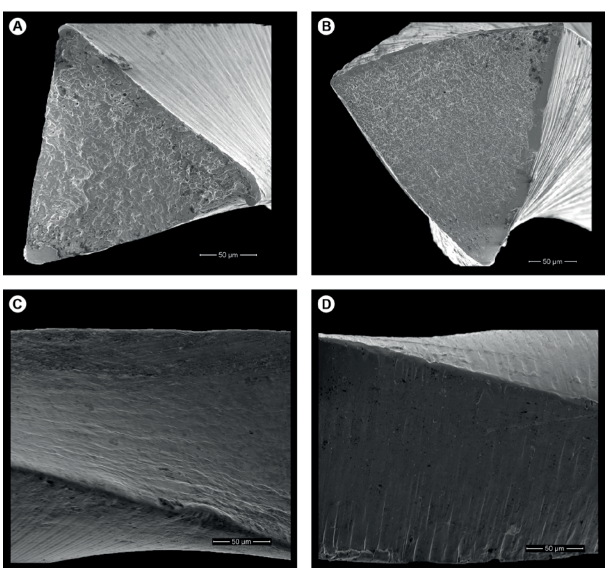

Figure 1. SEM analysis of the fractured surfaces of the tested instruments after cyclic fatigue test. (A) XP-Endo Finisher and (B) XP-Clean (original magnifications 1000×). Both instruments presented dimples, characteristic of ductile fracture. The lateral views of XP-Endo Finisher (C) and XP-Clean (D) showing the surface finish (original magnification 1200×).

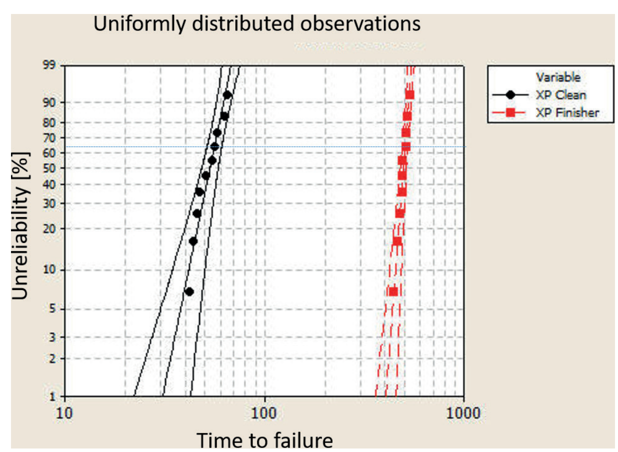

Figure 2. Weibull probability distribution per groups. The vertical scale in ordinates is unreliability (ie, the probability of failure). Time (s) is represented in the abscissa. The horizontal blue dashed line on the plot represents eta (ie, the time [s] at which 63.2% of the files will have failed).

Table 1. Mean and standard deviation of time to failure, roughness and microhardness for XP-Endo Finisher and XP-Clean instruments (n = 10 per Instrument and per Test). Weibull Parameters Eta and Beta

Instruments	Time to failure (s)	Number of cycles	Roughness (*Ra*)	Microhardness (HV)	Eta	Beta
XP-Endo Finisher	493 ± 28^{A}	6582 ± 376^{A}	0.70 ± 0.06^{A}	318 ± 21^{A}	506.2^{A}	21.0^{A}
XP-Clean	52 ± 8^{B}	702 ± 106^{B}	1.02 ± 0.18^{B}	304 ± 17^{A}	56.0^{B}	7.7^{B}

Different superscript letters represent statistically significant differences (p<0.05).

XP-Endo Finisher instruments also exhibited significantly lower roughness than XP-Clean instruments (p<0.05) (Fig. 3 and Table 1). No differences in the instruments micro-hardness were observed (p>0.05) (Table 1).

Discussion

The fracture of rotary files has been attributed to torsional failure and cyclic fatigue (13,14). Cyclic fatigue occurs as a result of the alternating tension-compression cycles to which the NiTi files are subjected when flexed in the region of maximum curvature of the canal (14). Different methods have been used to evaluate the cyclic fatigue resistance of NiTi files. In the present study, cyclic fatigue resistance tests were performed using a commonly applied and validated methodology (12,13,15,16), consisting in rotating NiTi file until fracture in a simulated canal machined in a steel block. The use of standardized artificial canals minimizes the other variables present in cyclic fatigue tests. However, it has been stated that using this model the instruments may fit loosely in the canal creating an artificial environment allowing for extreme flexibility apically at the point of curvature (17). This might not be a problem for the present study, as both tested files are claimed to be anatomic finishing file; therefore, both are used after root canal preparation, in a situation close to that present in the artificial canal.

Previous studies suggested a dynamic cyclic fatigue model to evaluate cyclic fatigue resistance of NiTi files (18,19). In fact, dynamic models approximate a clinical brushing or pecking motion; however, the dynamic method design have some limitations. First, the instruments being tested are not clinically constrained in a precise trajectory. In addition, the speed and amplitude of the axial movements could be standardized in a dynamic model, but these variables are completely subjective and it is doubtful that they are constant and reproducible in a clinical situation because this up-and-down motion is manually controlled. Therefore, static model was selected in order to minimize confounding causes by other mechanisms of instrument separation apart from cyclic fatigue.

The present results demonstrated that XP-Endo Finisher presented significantly longer cyclic fatigue life than XP-Clean instruments (p<0.05); therefore, the first null hypothesis was rejected. Many factors, such as the type

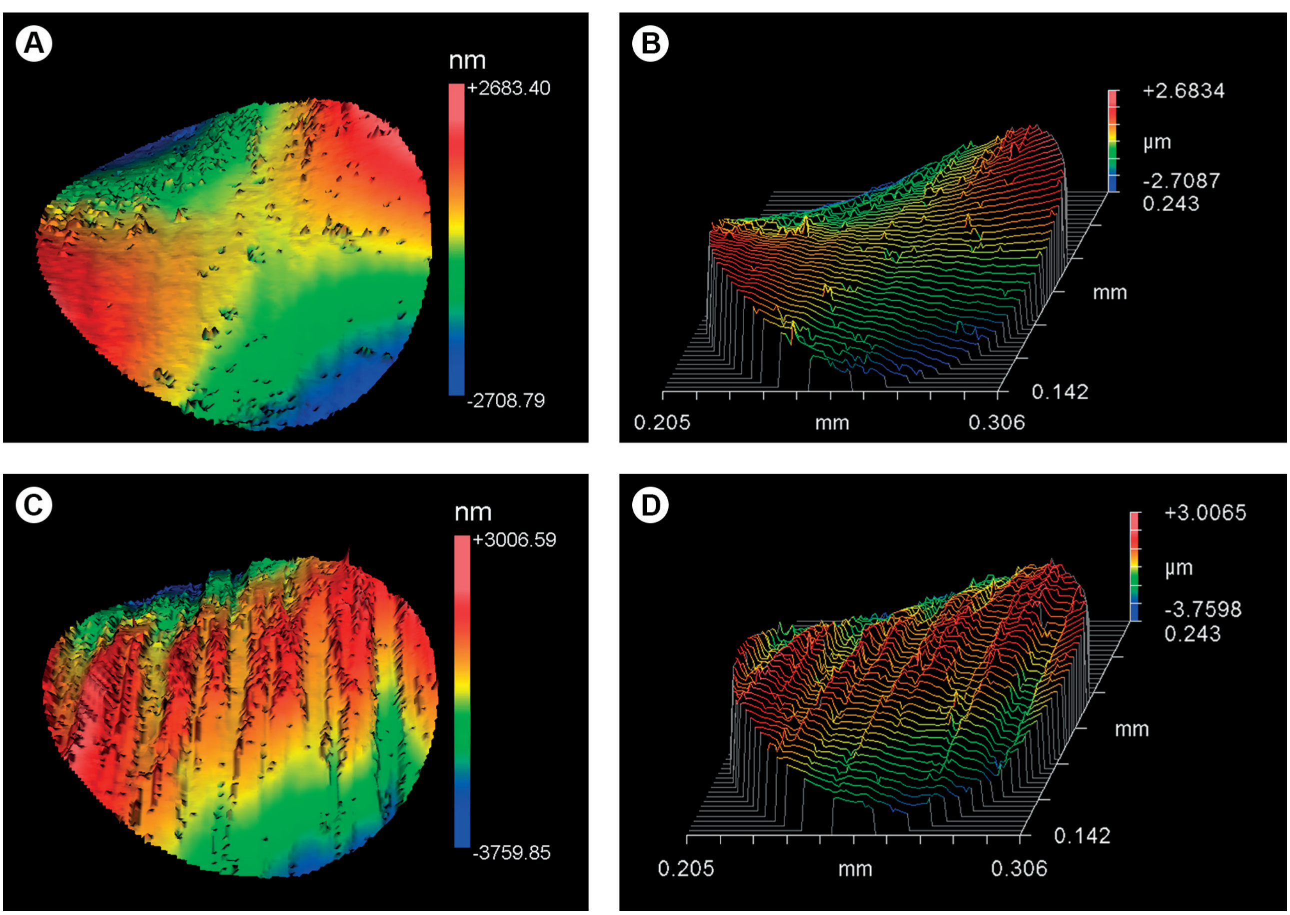

Figure 3. Instrument surface finish obtained by interferometry. (A and B) XP-Endo Finisher (C and D) XP-Clean.

of metal alloy, cross-sectional shape and dimensions, may influence the flexibility and cyclic life span of NiTi instruments. XP-Endo Finisher are made with MaxWire alloy, a proprietary and innovative thermomechanical procedure (with which it is assumed that XP-Clean instruments are not made) that may provide greater flexibility and resistance when compared to other NiTi alloy. It is important to emphasize that instruments that contain the MaxWire (such as the XP-Endo Finisher) changes its shape according to the temperature. Therefore, when instruments is at room temperature (lower than 35°C) it has a straight shape. It is possible to observe that XP-Clean instrument, even at lower temperatures (such as 10°C cold water), do not assume a straight shape, confirming that is not made with the same innovative NiTi alloy of XP-Endo Finisher instruments. As the design and cross-section of both files are similar, the differences in the NiTi alloy could be one of the major responsible for the differences in the results.

Roughness analysis revealed significant differences between the two instruments, confirming the high manufacturing quality of XP-Endo Finisher when compared to XP-Clean instrument. Thus, the second null hypothesis was also rejected. Clinically, surface defects may act as stress concentration points, becoming spots that are highly vulnerable to the nucleation and propagation of cracks, whereas a smooth surface is less prone to fatigue-crack initiation (20); such features likely contributed to the lower cyclic fatigue life of the XP-Clean instruments.

The present experimental design has a noteworthy aspect that should be emphasized: artificial canal was filled with 37° C warmed water throughout the cyclic fatigue experiments. Experiments were also performed inside a cabinet with temperature kept at 37°C. This had to be done because XP-Endo Finisher instrument undergoes phase transformation at body temperature and to simulate the intracanal temperature during canal preparation. Previous studies using this testing design demonstrated a marked decrease in the fatigue life of different instruments when compared to tests performed at lower temperatures (21,22).

Despite the limitation of this in vitro study, it can be concluded that XP-Endo finisher instruments showed improved performance when compared with XP-Clean instruments, demonstrating almost 10 times more resistance to cyclic fatigue and lower roughness.

Resumo

O objetivo do presente estudo foi avaliar a fadiga cíclica de dois instrumentos finalizadores anatômicos: XP-Endo Finisher e XP-Clean. O padrão de rugosidade e a micro dureza dos instrumentos também foram avaliados. Os instrumentos foram submetidos à resistência à fadiga cíclica, medindo o tempo de fratura em um canal artificial de aço inoxidável com um ângulo de 60 ° e um raio de curvatura de 5 mm. A superfície de fratura de todos os fragmentos foi examinada com um microscópio eletrônico de varredura. A rugosidade dos instrumentos foi quantificada usando um perfilômetro e o teste de micro dureza foi realizado usando um testador de dureza Vickers. Os resultados foram analisados estatisticamente usando o teste t de student em um nível de significância de p<0,05. A análise Weibull também foi realizada. XP-Endo Finisher apresentou vida de fadiga cíclica significativamente mais longa do que os instrumentos XP-Clean (p<0,05). XP-Endo Finisher foi capaz de suportar 1000% mais ciclos para fratura quando comparado aos instrumentos XP-Clean. A inspeção visual em microscópio eletrônico de varredura das superfícies de fratura revelou características fractográficas da fratura dúctil em todos os instrumentos testados. Não foi observada deformação plástica no eixo helicoidal dos instrumentos fraturados. Quando o tempo para a fratura foi comparado entre os instrumentos, o XP-Endo Finisher durou mais do que o XP-Clean com uma probabilidade de 99,9%. Os instrumentos XP-Endo Finisher também exibiram uma rugosidade significativamente menor do que os instrumentos XP-Clean (p<0,05). Não foram observadas diferenças na micro dureza entre os arquivos (p>0,05). Pode-se concluir que os instrumentos XP-Endo Finisher apresentaram desempenho melhorado em comparação com os instrumentos XP-Clean, demonstrando maior resistência à fadiga cíclica e menor rugosidade.

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