Original Article

Cyclic Fatigue Resistance of WaveOne Gold, Protaper Next and 2Shape Nickel Titanium Rotary Instruments Using a Reliable Method for Measuring Temperature

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ABSTRACT

Objective: The purpose of this study was to evaluate the cyclic fatigue resistances of the WaveOne Gold (WOG), ProTaper Next (PTN), 2Shape (TS) instruments. **Materials and Methods:** Totally 45 new WOG (25/.07), PTN (25/.06), TS (25/.06) files were tested inside the artificial canal of a custom-made stainless steel block with an inner diameter of 1.5 mm, a 60° angle, and a 5-mm radius of curvature. A 16-mm-long file segment (from the tip) was introduced and was immersed in 37°C water. The number of cycles to fracture (NCF), time to failure (TTF), fractured fragment length (FL) was recorded and the fractured surface was examined using microscope. **Results:** WOG > PTN > TS according to TTF results ($P = 0.00$). PTN > TS according to NCF results ($P = 0.00$). The FL values showed no significant difference ($P = 0.335$). **Conclusions:** Reciprocating motion can be used more safely than continuous rotation due to the higher cyclic fatigue resistance.

Keywords: *2shape, cyclic fatigue resistance, nickel-titanium rotary instruments, WaveOne Gold. Protaper Next*

Introduction

The mechanical behavior of endodontic instruments is very important for safe root canal shaping. Nickel--titanium (NiTi) rotary instruments are frequently used in endodontic practice because of their advantages in curved canals, including flexibility, increased cutting efficiency,[1] and especially, superelasticity.[2] In spite of these important advantages, unexpected instrument separation can occur within the root canal during the shaping procedure.

The fracture modes of rotary NiTi files can be classified into two types: flexural cyclic fatigue and torsional failure.[3] Torsional failure arises when part of the instrument binds to the dentin while the shank is rotating.[4] Cyclic fatigue occurs when the tip or some part of the file binds in the root canal, and cycles of tension/compression are repeatedly generated at the point of maximum flexure until a fracture occurs.[5,6] A cyclic fatigue fracture is a clinically undesirable condition because of the sudden and unannounced occurrences.

In this context, improved methods for resistance to cyclic fatigue fracture have been proposed for endodontic instruments, including modifying the chemical composition of the NiTi alloy, changing the manufacturing process, and new cross-sectional designs, thermomechanical processes, and kinematics.[5,7-9] In addition, reciprocating motion has been suggested to enhance the fracture resistance of endodontic instruments during instrumentation.[10] It has been claimed that reciprocating motion works continuously under the elastic limit of the instruments, consequently prolonging the cyclic fatigue life when compared with their use in conventional rotary motion.[11-13]

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Recently, a reciprocating single-file system, the WaveOne Gold (WOG; Dentsply Maillefer, Ballaigues, Switzerland) has been launched. The WOG combines the original WaveOne reciprocating instrument technique and the metallurgical advancements of a gold thermal treatment, which gives the file a characteristic golden appearance. It has an off-centered parallelogram-shaped cross-section that differs from the triangular shape of its predecessor, and it has been reported that the gold heat treatment is applied to improve the cyclic fatigue resistance of the file.[14] It has been verified in previous studies that the WOG showed better cyclic fatigue resistance than the other reciprocating or conventional motion rotary systems.[15-19]

The ProTaper Next (PTN; Dentsply Maillefer, Ballaigues, Switzerland) is another NiTi file system. The PTN instruments have variable tapers and an off-centered rectangular cross-sectional design that is offset from the center point. The rotation of the off-centered cross-section generates an enlarged space for debris hauling, as suggested by the manufacturer. The M-Wire alloy used for this instrument improves the file flexibility, while retaining the cutting efficiency and it also provides greater resistance to cyclic fatigue, which is the leading cause of file separation.[4,20]

The 2Shape (TS; MicroMega, Besançon, France) is a new generation NiTi file system that works with continuous rotary motion.[21] The TS has a triple-helix cross-section, and according to the manufacturer, the T-Wire technology demonstrated up to 40% more resistance to cyclic fatigue.[21]

The NiTi alloys are present in two different phases, martensite and austenite, which are influenced by temperature.[22] It has been reported that to better simulate clinical conditions, body temperature should be added to fatigue study methods as a parameter that affects the cyclic fatigue resistance of NiTi files.[23] However, in many previous studies, the water temperature was measured using an infrared thermometer, which is not suitable for this purpose.

Based on these observations, the present investigation aimed to evaluate the cyclic fatigue resistances of the WOG, PTN, and TS NiTi instruments at body temperature. These were tested in a custom-made stainless steel metal block submerged in a water bath using an immersed transducer temperature sensor. The null hypothesis was that there would be no differences in the cyclic fatigue performances of the NiTi rotary instruments tested.

Materials and Methods

Sample size

The sample size was calculated as a minimum of 15 for each group, a type I error of 0.05, and a statistical power of 85% using the Minitab 18 Statistical Software (Minitab, Inc., State College, PA, USA). Based on the post-hoc power analysis performed at the end of the research, this study was found to be reliable, with over 99% power and a high size effect.

Cyclic fatigue test

The following NiTi rotary instruments were used in this experiment: 15 TS (25/.06), 15 WOG (25/.07), and 15 PTN (25/.06). In total, 45 NiTi instruments were inspected under a stereomicroscope (Axio Zoom.V16; Carl Zeiss, Jena, Germany) for defects or deformities, and none were discarded. All the instruments were 25 mm long. The entire working length of each file was placed into an artificial canal in a metal block, which was submerged in a water bath. The artificial canal was open to the water, allowing the file to be exposed to the experimental temperature of the water in the water bath. The metal block was made of stainless steel with a milled canal that simulated a 60° canal curvature and a 5-mm radius of curvature, with a width of 1.5 mm [Figure 1]. The working length was fixed at 16 mm for each instrument tested. The TS (lot number 110617), WOG (lot number 1430282), and PTN (lot number 1419827) instruments were rotated at the manufacturers' recommended speeds and torques for each system (300 rpm for the TS, 350 rpm for the WOG, and 300 rpm for the PTN) using a torque-controlled motor (X-Smart Plus; Dentsply Maillefer, Ballaigues, Switzerland). Fifteen instruments from each group were tested at a controlled temperature of (37 ± 0.5°C), simulating the body temperature using an immersed digital temperature meter (Testo 922; Testo AG, Lenzkirch, Germany, serial number 33622158/206).

In order to define the temperature, a glass container was filled with distilled water at 37°C. The level of the distilled water was set so that the working part of the NiTi file could be submersed in the water. To reach the desired temperature, hot water was added until the water temperature was stabilized at 37°C. During the test procedure, to keep the temperature at 37°C after every file, some of the water was removed from the glass container and some hot water was added. Extreme care was taken to keep the water at the same level for each file. During all the tests, the temperature was measured by using an immersed digital temperature meter 12, Testo AG), and the water temperature was allowed to equilibrate for a few minutes before initiating the testing of each file. To reduce the friction between the instrument and the metal canal walls, the artificial canal wall was flooded with synthetic oil (WD-40 Company, Milton Keynes, UK) prior to use.

All the instruments were rotated until a fracture occurred. The time to fracture (TTF) was recorded (in seconds) for each file with the aid of a 1/100th of a second chronometer, and the timing was stopped as soon as a fracture was detected either visually and/or audibly. The TTF was converted to the number of cycles to fracture (NCF) by using the following formula: TTF (in seconds) × rotational speed (rpm)/60. The length of the fractured fragment was measured using digital calipers (Model CD-6" BS 500-136; Mitutoyo, Tokyo, Japan) to evaluate the correct positioning of the instrument tested. The fractured instruments were further cleaned in an ultrasonic bath with absolute alcohol (ethanol) for 3 min. The broken instruments were evaluated with a scanning electron microscope (SEM) (EVO HD 15; Zeiss, Jena, Germany) under different magnifications (300× to 3000×) to assess the topographic features of the fractured surfaces.

Statistical analysis

The study findings were recorded in a Microsoft Excel (2010) spreadsheet (Microsoft Office, Redmond, CA, USA), and the statistical evaluation was performed using the Statistical Package for the Social Sciences (SPSS) version 15.0 (SPSS Inc., Chicago, IL, USA). The Shapiro-Wilk's test was used to confirm the assumption of the normality of the data. The variables with normal distributions were expressed as the mean and standard error (mean ± SE), and those without normal distributions were expressed as the median. The TTF data were analyzed statistically using the one-way analysis of variance (ANOVA) because the data showed a normal distribution. The homogeneity of the variances was determined using the Levene's test. Those variables found to be significant in the ANOVA test were compared using the Tamhane's T2 post-hoc test to determine the significant differences between the groups. The Student's t-test was used to detect the statistical significance between the NCF values obtained for two rotary files, except the WOG instruments. For the statistical analysis of the fractured fragment length (FL) values, the Kruskal--Wallis test was used because the data were not normally distributed. The significance was set at the 95% confidence level.

Results

Table 1 presents the means and SEs of the NCF, TTF, and median FL values for each test group. There was a statistically significant difference between the groups in terms of the cyclic fatigue resistance (P = 0.00). The ranking in the fatigue resistance test was highest in WOG group (239.60 ± 12.84) (P = 0.00), following PTN group (161.40 ± 6.68) (P = 0.00) and TS group (77.73 ± 2.61) (P = 0.00), respectively [Table 1]. The mean NCF of the PTN files (807.0 ± 33.43) was statistically higher than the TS file (388.6 ± 13.08) (P = 0.00). Furthermore, the FLs were not significantly different in any of the instruments tested (P = 0.335), and they ranged from 4.26 to 6.70 mm (mean = 5.83 mm). The SEM images of the fracture surfaces of all the tested instruments exhibited similar and typical features of cyclic fatigue failure, including crack origins, fatigue zones, dimples, cones, and smoothed borders [Figure 2].

Figure 1: Photograph of the artificial canal used during the test

Table 1: Comparison of the mean±standard error of the number of cycles (NCF), time to fracture (TTF) values (in seconds) and the median of the fragment length (FL) values (in mm) for each study group

Study Groups	NCF*	TTF*	FL#
WaveOne Gold	-	239.60±12.84[a]	6.14[a]
Protaper Next	807.00±33.43[a]	161.40±6.68[b]	6.06[a]
2Shape	388.66±13.08[b]	77.73±2.61[c]	5.65[a]
P value	<.05	<.05	>.05

*Mean values±Std. Error (SE) values are presented. #Median was presented since the data were not normally distributed. Different superscript lowercase letters in the same column indicate a significant difference between groups (P<0.05)

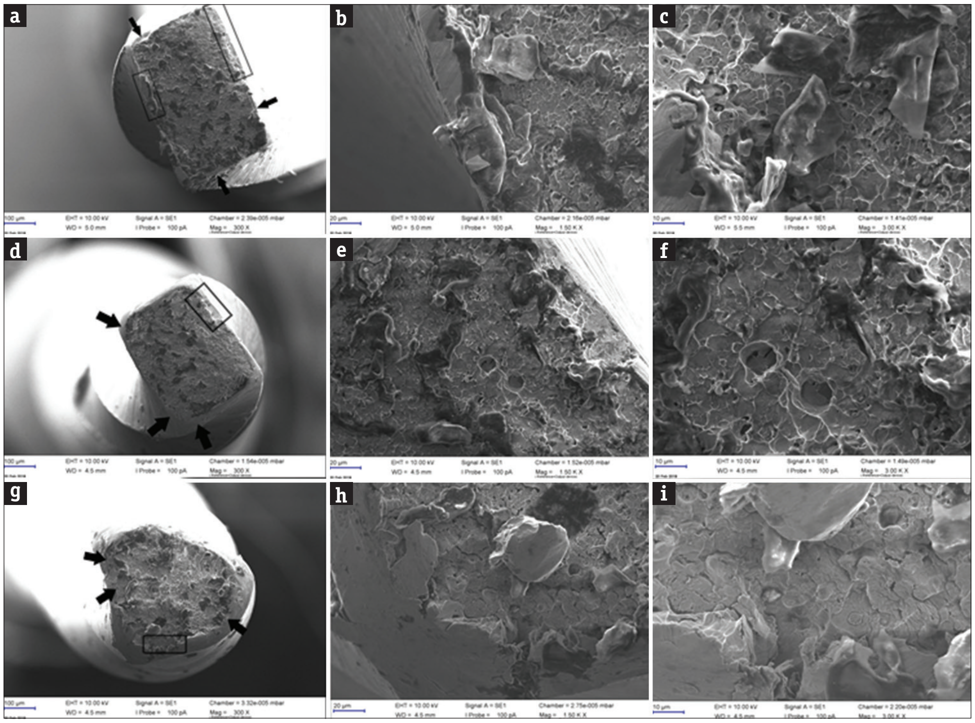

Figure 2: Scanning electron microscope images of the broken instruments after the cyclic fatigue test (a, b, c = WaveOne Gold, d, e, f = Protaper Next, and g, h, i = 2Shape). The typical cyclic fatigue (ductile) fracture surface pattern with dimples and cones, crack initiation origins, smoothed borders (black arrows), and final abrupt breakage (bounded area) was observed. b, c High magnification views of the fractured area enclosed by the rectangle in image a (1500 × and × 3000, respectively). e, f High magnification views of the fractured area enclosed by the rectangle in image d (1500 × and 3000×, respectively). h, i High magnification views of the fractured area enclosed by the rectangle in image g (1500 × and 3000×, respectively)

Discussion

The present study compared the cyclic fatigue resistances of the TS, WOG, and PTN NiTi rotary systems in an artificial canal with a 60° angle of curvature at body temperature. According to the findings of this study, the cyclic fatigue resistance of the WOG files was statistically higher than that of the other NiTi files tested. On the basis of the results, the null hypothesis (there will be no difference in the cyclic fatigue resistances between the TS, WOG, and PTN instruments when tested at body temperature) was rejected. The findings of this study correspond with these of previous studies reporting that the WOG files were significantly more resistant to cyclic fatigue than the other files tested.[15-19] However, none of the methods used in these studies were similar to the method used in the present work; thus, a direct comparison with the studies in the literature was not possible. One probable explanation of the outcome of this study could be due to the differences in the metallurgical characteristics, cross-sectional designs, and kinematic properties of the NiTi files between instruments tested. The TS files are made with a T-Wire alloy. The WOG files are more advanced versions of the WaveOne files, which have undergone a gold heat treatment, and the main structure of the WOG files consists of an M-Wire alloy. The PTN file also has the M-Wire structure, which may be why these two NiTi files showed better cyclic values than the TS file. In addition, the heat treatment in the WOG files could have improved the cyclic fatigue resistance of the instruments. The gold color of these files is caused by the heat treatment technology, in which the instrument is continually heated and slowly cooled after production. The manufacturer claims that this heating technique improves the flexibility and cyclic fatigue resistance of the file.[14] Moreover, the cross-sectional design also influences the cyclic fatigue resistance of the NiTi files. The WOG instruments have a parallelogram-shaped design with two cutting edges and an alternate one-point contact, whereas the TS instruments have a cross-sectional design with a triple helix, and the PTN instruments have an off-centered rectangular cross-sectional design. The design of the WOG files is likely associated with the increased cyclic fatigue resistance due to the reduced number of contact points between the file and the root canal wall.

The literature has suggested that reciprocating motion is significantly more effective than continuous rotation in increasing the cyclic fatigue resistance of the NiTi files.[11,13,24] The significant difference found when comparing the TTF values obtained in the current study could be explained by the fact that the WOG files were used with a reciprocating motion, while the TS and PTN files were used with a continuous rotation. There is only one study in the literature comparing the cyclic fatigue resistance of TS instruments.[25] In accordance with the results of the current study, those researchers found that the TS showed low cyclic fatigue resistance values. However further studies should be performed to determine whether or not the T-Wire alloy and/or tripe helix cross-sectional design affected these results.

The temperature increase in the NiTi files may have caused the material phase to change from martensite to austenite. The characteristics of the NiTi files at room temperature may change when working in the root canal, where the temperature is approximately 37°C. The NiTi files in the martensitic phase can be transformed to the austenitic phase in the root canal because the temperature exceeds the austenite starting point (A_s) value, which affects the martensitic properties of the file.[26] Therefore, the body temperature should be imitated when using *in vitro* setups of cyclic fatigue experiments, and the temperature should be kept constant over time to obtain more clinically relevant and reliable results. Most previous studies have been performed with cyclic fatigue testing at different temperatures. In some of these studies, the temperature measurement method was not defined, and others reported that an infrared thermometer was used to measure the temperature. However, the use of an infrared thermometer in such a setup is not suitable because this type of measurement device works on the radiation waves sourced from the surface of the object being measured.[27] Therefore, the temperature readings in previous studies are not actually at the desired temperature because the area of interest is below the water surface. In addition, one of the limitations of infrared thermometers is that the measured surface must be calibrated in the device, depending on the emissivity value.[28] The emissivity is the ratio of the electromagnetic flux emitted from a surface to the flux that would be emitted from an ideal blackbody at the same temperature, and it is generally wavelength dependent.[29] The emissivity value of water that is more than 0.1 mm thick is 0.96, which is higher than the emissivity value of a rock (0.88--0.95).[29] That is, when an infrared ray is sent to the surface of the water, it reflects the light from the surface in the same way as the rock. For this reason, there are doubts about the accuracy of the results of previous studies that have measured the water temperature with an infrared thermometer during cyclic fatigue experiments. Because the surface temperature of the water would be affected by the ambient temperature, it can be speculated that the internal temperature of the water in these studies was probably much higher than the target measured value. During cyclic fatigue experiments, the NiTi file is immersed in water, and the temperature of the water around the NiTi file is targeted to be measured homogeneously and held constant at a predetermined temperature level. In the current study, an immersed transducer temperature sensor (Testo 922) was used to measure the temperature. These sensors measure the liquid temperature in the vicinity of metal probe's surface; therefore, the measurements taken are the closest to the exact temperature of the water around NiTi instrument in the focus. As a result, immersed transducer temperature sensors must be used in order to obtain correct and reliable results when measuring the water temperature around a NiTi file in cyclic fatigue experiments.[30]

The present study showed that there was no significant difference between the NiTi files tested with regard to the FL. This demonstrates that the NiTi files were placed in the same position for each repetition of the experiment; therefore, they were separated from a center similar to the center of the curve, or just below this point.

Conclusions

Within the limitations of this *in vitro* study, it can be concluded that the reciprocal movement exhibited the best performance with regard to the cyclic fatigue resistance. In addition, the PTN instruments showed significantly longer NCF values than the TS instruments. Finally, reciprocating motion can be used more safely than continuous rotation in curved canals due to the higher cyclic fatigue resistance at body temperature.

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Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent

For this type of study, formal consent is not required.

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Conflicts of interest

There are no conflicts of interest.

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