Influence of Temperature on Cyclic Fatigue Resistance of ProTaper Gold and ProTaper Universal Rotary Files

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Abstract

Introduction: The aim of this study was to evaluate the cyclic fatigue resistance of ProTaper Universal (PTU; Dentsply Maillefer, Baillagues, Switzerland) and ProTaper Gold (PTG, Dentsply Maillefer) nickel-titanium rotary files at room and intracanal temperatures. **Methods:** A total of 120 files were used to test the cyclic fatigue resistance of PTU (S1 and F2) and PTG (S1 and F2) in an artificial canal at room temperature (20°C) and at intracanal temperature (35°C). The number of cycles to failure and the fracture length of the fragment were recorded, and data were subjected to statistical analysis. **Results:** PTG registered no differences in fatigue life between the 2 temperatures tested ($P > .05$), whereas PTU showed a statistically significant reduction in fatigue life at intracanal temperature compared with room temperature ($P < .05$). PTG instruments exhibited a statistically higher resistance to cyclic fatigue than PTU instruments both at room and intracanal temperatures ($P < .05$). There were no statistically significant differences among the fracture length of separated instruments ($P > .05$). **Conclusions:** Intracanal temperature influenced the cyclic fatigue resistance of instruments produced with traditional nickel-titanium, whereas it did not influence the fatigue life of instruments produced with gold heat treatment. Gold heating treatment enhances the resistance to cyclic fatigue of ProTaper instruments. *(J Endod 2017;43:200–202)*

Key Words

Heat treatment, nickel-titanium alloys, ProTaper Gold, ProTaper Universal

Significance

This study aims to evaluate the cyclic fatigue resistance of Protaper Universal and Protaper Gold rotary files at room and intracanal temperatures. Results indicate that intracanal temperature influenced the cyclic fatigue resistance of instruments produced with traditional nickel-titanium, whereas it did not influence the fatigue life of instruments produced with gold heat treatment.

Nowadays, nickel-titanium (NiTi) instruments are an important part of the root canal instrumentarium. Recently, a number of different thermomechanical treatments of NiTi have been developed to overcome some of the drawbacks of the traditional NiTi alloy, namely, separation and distortion of instruments (1, 2). The manufacturers claim that these new thermal treatments yield greater resistance to cyclic fatigue when compared with conventional superelastic NiTi instruments (3, 4). The NiTi alloy exists in 2 different crystal phases (martensite and austenite), which are temperature dependent (5). The properties of these 2 phases are notably different. When martensitic NiTi is heated, it begins to change to austenite, and once converted to austenite, the alloy will have completed its shape memory transformation and will display its superelastic characteristics (6). The temperature at which this phenomenon is complete is called the austenite finish temperature (A_f) (6).

ProTaper Gold (PTG; Dentsply Maillefer, Baillagues, Switzerland) instruments feature identical geometry as ProTaper Universal (PTU, Dentsply Maillefer) files and have been recently developed with proprietary advanced metallurgy through heat treatment technology. PTG files have a 2-stage specific transformation behavior and high A_f temperatures, whereas PTU instruments have 1-stage transformation (3, 7).

The A_f temperature for PTU files is below body temperature (between 16°C and 31°C) (8–10), whereas the A_f temperature for the new PTG files is clearly above body temperature, being similar to controlled memory wire and thus around 55°C (1, 7). As a result, the PTU files are in the austenite phase during clinical use (the material is quite hard and strong), whereas the PTG files are in the martensite phase (the material is soft, ductile, and can easily be precurved).

Most of the studies compared the cyclic fatigue of instruments at room temperature, but clinically the instruments are used inside the root canal, which, according to a recent article by De Hemptinne et al (11), presents a temperature around 35°C. To date, there are no articles comparing the cyclic fatigue between PTU and PTG at room and intracanal temperatures. The present investigation aims to determine if temperature has an influence on the cyclic fatigue resistance of heat-treated PTG instruments

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TABLE 1. Number of Cycles to Failure of the Instruments Tested (Mean ± Standard Deviation)

	Temperature	
Instrument	Room temperature (20°C)	Intracanal temperature (35°C)
S1	515 ± 90.35[a]	380 ± 39.43[d]
S1 Gold	674.17 ± 86.41[b]	629.17 ± 87.25[b]
F2	228.33 ± 52.45[c]	114.17 ± 47.14[e]
F2 Gold	504.17 ± 94.41[a]	457.5 ± 101.97[a]

Different superscript letters indicate statistically significant differences ($P < .05$).

compared with the traditional alloy of PTU. The null hypothesis tested was that no difference would be present between testing the instruments at room temperature (20°C) and intracanal temperature (35°C).

Material and Methods

Thirty PTU S1 and F2 and 30 PTG S1 and F2 rotatory endodontic instruments were purchased, and a total of 120 instruments were tested. Using a stereomicroscope (Leica M205 C; Leica Microsystems, Wetzlar, Germany), the instruments were inspected for defects or deformities and eventually discarded and replaced with a new one if defective. The instruments were subjected to a cyclic fatigue test using a static model for cyclic fatigue testing provided in previous studies (12, 13). The instrument was able to rotate freely inside a 60° angle and 5-mm radius of curvature artificial canal. The artificial canal was manufactured by reproducing the instrument's size and taper. Synthetic oil was used inside the root canal in order to reduce friction between the metallic instrument and the metallic walls of the root canal (13).

PTU and PTG instruments were activated by using a 6:1 reduction handpiece (Sirona Dental Systems GmbH, Bensheim, Germany) powered by a torque-controlled motor (Silver; VDW GmbH, Munich, Germany) at a speed of 300 RPM and following the manufacturer's instructions.

Fifteen instruments of each size (ie, S1 and F2) and each type (ie, PTU and PTG) were tested at a controlled room temperature (20°C) and a temperature of 35°C, simulating intracanal temperature, inside a temperature-controlled oven.

All instruments were activated until fracture occurred, and the time to fracture was recorded for each file by means of a 1/100-second chronometer. The number of cycles to failure for each instrument was calculated by multiplying the time (in seconds) to failure by the number of rotations or cycles per second. The length of the fractured tip was measured using a digital microcaliper (Mitutoyo Italiana srl, Lainate, Italy) at 50× under a stereomicroscope (SZR-10; Optika SRL, Ponteranica, Italy).

Means and standard deviations were calculated, and data were analyzed with 1-way analysis of variance and the Bonferroni test for multiple comparisons among groups. Significance was set at the 95% confidence level.

TABLE 2. Fracture Length (mm) of the Separated Instruments (Mean ± Standard Deviation)

	Temperature	
Instrument	Room temperature (20°C)	Intracanal temperature (35°C)
S1	5.25 ± 0.72	5.17 ± 0.25
S1 Gold	5.5 ± 0.30	5.17 ± 0.25
F2	6.08 ± 0.56	5.75 ± 0.66
F2 Gold	5.92 ± 0.36	5.83 ± 0.72

There were no statistical significant differences among the study groups ($P > .05$).

Results

The results of this study are reported in Table 1 and showed that both sizes of PTG files exhibited a statistically significant higher cyclic fatigue resistance when compared with the same size of PTU at both temperatures tested ($P < .05$). Temperature did not influence the cyclic fatigue resistance of PTG ($P > .05$), whereas the fatigue life of PTU was significantly reduced at intracanal temperature ($P < .05$). Regarding fracture length (Table 2), there was a statistical difference only between PTU size S1 and F2 ($P < .05$).

Discussion

Recently, different thermomechanical treatments have been used to improve the fatigue resistance and superelasticity of NiTi instruments (1). The superelastic property is the result of stress-induced martensite transformation, and it takes place in association with a reversible phase transformation between austenite and martensite; therefore, the transformation temperatures have a critical influence on the mechanical properties (1). Some authors have shown that austenitic instruments were more prone to fracture than martensitic ones (4, 14, 15). However, most of these tests have been performed at room temperature, and there is some evidence that an increase in temperature could affect the properties of NiTi alloys (16). When instruments are rotating inside the root canal, they are not working at room temperature but rather at intracanal temperature. There are only 2 *in vivo* studies that evaluated the temperature inside the root canal (11, 17), and it ranges from 31°C–35°C. Recently, 1 study reported that when Vortex Blue (Dentsply Maillefer, Ballaigues, Switzerland), TRUShape (Dentsply Tulsa Dental Specialties, Tulsa, OK), Hyflex (Coltene-Whaledent, Allstetten, Switzerland), and PTU instruments were tested at 37°C, there was a decrease in the fatigue life of all the instruments tested (16). The results of PTU were similar to those of our study. Regarding Vortex Blue and TRUShape, there was a huge decrease of fatigue resistance between 20°C and 37°C, showing that the temperature clearly affects the alloy. To explain this result, the transformation temperatures of these instruments must be considered. Vortex Blue and TRUShape have transformation temperatures between the austenitic and martensitic phases around body temperature (16); for this reason, they work better at room temperature.

In the present study, some of the drawbacks of cyclic fatigue laboratory testing have been controlled; specifically, the variables that may influence the fatigue behavior of different instruments, such as the design and dimensions, were eliminated by testing the same instruments (PTU and PTG). The only variables analyzed were the temperature of the test and the different thermomechanical processing of the instruments.

Despite the identical design and operation mode of the PTU and PTG instruments, the different manufacturing processes of the files noticeably affect their fatigue resistance performance, with PTG being statistically more resistant to cyclic fatigue for both sizes tested.

PTU files have a transformation temperature in between room and intracanal temperature; in fact, in the present study they performed statistically better at room temperature than at intracanal temperature. However, the gold metal processing of PTG instruments has a transformation temperature clearly above body temperature; consequently, they were not statistically affected by the increase of temperature during cyclic fatigue testing in the present study. Moreover, depending on the thermomechanical treatment, the martensitic transformation could occur either as a single-stage (austenite–martensite) or a 2-stage transformation (austenite–reverse phase–martensite). PTG exhibited a 2-stage transformation behavior; this could also explain the better results obtained because the reverse phase could be considered a potential martensitic phase (4, 7).

It is well-known that the radius of curvature and the size of the instrument influence the instrument's fatigue life (18, 19). Our results confirmed that the larger the diameter of the instrument, the lower the fatigue resistance (15, 20).

Regarding fragment fracture lengths, no statistically significant differences were found among the different instruments tested. One of the reasons for this finding could be the precision of the device used for the testing, confirming the results of previous studies (12, 21). The difference encountered only between PTU S1 and F2 may be related to the bigger cross-sectional area of ProTaper F2, which is more prone to fracture more coronally inside the curvature, and the higher rigidity of PTU compared with PTG.

Future studies may be designed to investigate the influence of different temperatures on the mechanical properties of the different instruments and the different metal treatments of the NiTi alloy, with the purpose of finding a clinical strategy that may improve the life span of endodontic instruments during clinical practice.

Within the limitations of this *in vitro* study, it can be concluded that

1. The temperature at which the instruments are tested may influence the results of cyclic fatigue resistance on NiTi files with a different behavior depending on the heat treatment of the alloy;
2. Cyclic fatigue resistance of instruments manufactured with the gold heat treatment is not influenced by room or intracanal temperature because the A_f temperature of these instruments is clearly above body temperature;
3. Cyclic fatigue resistance of the same ProTaper instruments manufactured with the traditional NiTi alloy is influenced by testing the file at intracanal temperature rather than room temperature, which is statistically reduced because the A_f temperature of these instruments is in between room and body temperature; and
4. The gold heat treatment of the NiTi alloy increases the resistance to cyclic fatigue compared with the traditional NiTi alloy of ProTaper files for both sizes tested (ie, S1 and F2).

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