Effects of Sodium Hypochlorite Concentration and Temperature on the Cyclic Fatigue Resistance of Heat-treated Nickel-titanium Rotary Instruments

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Abstract

Introduction: We tested the cyclic fatigue resistance of heat-treated instruments immersed in sodium hypochlorite solution under different concentrations and temperature conditions. **Methods:** Based on the irrigating solution's concentration and temperature, 135 ProTaper Gold (PTG; Dentsply Sirona, York, PA) F2 instruments were divided equally into 9 groups of 15. Cyclic fatigue testing was performed by using a block with artificial canals with a curvature angle of 60°, a curvature radius of 5 mm, and a curvature center 5 mm from the instrument tip. The block was fixed inside a water bath of distilled water, 2.5% sodium hypochlorite (NaOCl), or 5.25% NaOCl. The temperature was preset at 25°C, 37°C, or 60°C. The instrument was rotated at 300 rpm until fracturing occurred. The number of cycles to fracture was calculated, and the fragment length was measured. Fractured surfaces were examined via scanning electron microscopy. NCF data were analyzed statistically via Kruskal-Wallis and Mann-Whitney tests. All statistical analyses were performed using SPSS software Version 22 (IBM Corp, Armonk, NY) at a 5% significance level. **Results:** The number of cycles to fracture of the PTG F2 was highest in distilled water at 25°C and lowest in 5.25% NaOCl at 60°C. Changing the irrigating solution from distilled water to NaOCl and increasing the surrounding temperature reduced the fatigue resistance. **Conclusions:** NaOCl irrigating solution at different concentrations and temperatures influenced the cyclic fatigue resistance of PTG instruments. Future NiTi instrument failure studies should be conducted under simulated body temperature conditions in commonly used irrigating solutions. *(J Endod 2018;■:1–4)*

Key Words

Concentration, cyclic fatigue resistance, heat-treated file, ProTaper Gold, sodium hypochlorite, temperature

Significance

The irrigant temperature and concentration were shown to play a vital role in the cyclic fatigue resistance of endodontic instruments manufactured with heat-treated NiTi alloy.

Nickel-titanium (NiTi) alloy is used in endodontics because of its superelasticity and shape memory. It produces endodontic instruments with superior flexibility and resistance to cyclic fatigue compared with stainless steel alloys (1). However, instrument fracture is still a concern, because it might jeopardize the treatment outcome (2). It has been proposed that instrument fracture is caused by cyclic fatigue and/or torsional failure (3). Cyclic fatigue occurs when the instrument rotates in a curved canal, developing repetitive compression/tension cycles in the region with greatest curvature until fracturing occurs. Torsional failure takes place if the torque obtained from the contact between the canal wall and the instrument exceeds the instrument's torsional strength (3).

The properties of NiTi instruments are derived from a phase transformation from austenite to martensite, which occurs because of a stress application and/or temperature decrease (1, 4). At a temperature higher than the transformation temperature range, the NiTi alloy is composed mainly of austenite with high hardness and low flexibility, whereas at a lower temperature, it consists mainly of martensite and exhibits reduced hardness and higher flexibility (5, 6).

Because fracture resistance is a crucial mechanical property influencing the performance of NiTi rotary instruments during root canal preparation, significant enhancements in manufacturing processes through thermal treatments and alteration of instrument geometry have been made (7, 8). Moreover, Jamleh et al (9) reported that the surrounding temperature influences the cyclic fatigue resistance of the superelastic stock NiTi instruments. They found that resistance to cyclic fatigue was less at a simulated body temperature than at a lower temperature. ProTaper Gold (PTG; Dentsply Sirona, York, PA) was introduced to the market in 2014 using geometries of ProTaper Universal instruments (Dentsply Sirona) but with enhanced metallurgical

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properties through a heat treatment manufacturing process of NiTi. The PTG instruments show different stress-strain distribution patterns, transformation behavior, and fatigue behaviors, resulting in improved flexibility and cyclic fatigue resistance (8). Based on the PTG instrument's phase transformation behavior, different environmental temperatures led to different fatigue behavior (8).

Moreover, it is recommended to flood the canal with an endodontic irrigant such as sodium hypochlorite (NaOCl). NaOCl is used in concentrations between 0.5% and 6% for its antimicrobial and tissue-dissolving activities (10), especially at elevated temperatures (11). However, the fatigue life of NiTi instruments might be affected by the surrounding medium and its concentration (12–14).

Performing the experiment at a controlled temperature that is close to the body temperature might be more clinically pertinent. Furthermore, the effect of the irrigant's concentration along with different surrounding temperatures was not adequately addressed on heat-treated files. Thus, the purpose of this investigation was to determine the effects of NaOCl at a simulated body temperature with different concentrations on the cyclic fatigue of PTG instruments and compare them with room temperature and 60°C temperature. The null hypothesis stated that the NaOCl concentration and temperature have no influence on the cyclic fatigue resistance of PTG.

Methods

One hundred thirty-five PTG F2 (Dentsply Sirona) instruments were divided equally into 9 groups (n = 15 per group). All instruments used were 25-mm long. Before the experiment, the instruments were inspected for defects and deformities at high magnification (13.6×) (Zeiss Pico; Carl Zeiss MediTec, Dublin, CA); none were excluded.

Cyclic fatigue testing was performed using artificial canals milled in stainless steel blocks using a laser micromachining technique with dimensions larger than the dimensions of the PTG F2 by a 0.1-mm width (15). The canals had a curvature angle = 60°, a curvature radius = 5 mm, and a center of curvature located 5 mm away from the instrument tip. The artificial canal was covered with glass to prevent instrument slippage and to determine the time at which the instrument fractured.

The block was fixed inside a recipient that was filled with distilled water, 2.5% NaOCl, or 5.25% NaOCl. The temperature was preset at 25°C, 37°C, or 60°C, with a tolerance limit of 1°C.

The handpiece of the endodontic rotary motor (TCM Endo III; Nouvag AG, Lake Constance, Switzerland) was mounted on a device that allowed reproducible and fixed positioning of each instrument inside the canal. The instrument was inserted into the canal 19 mm from its tip. The instrument was rotated according to the manufacturer instructions at 300 rpm until fracturing occurred. The time to fracture was registered in seconds, and the number of cycles to fracture (NCF) was calculated using the following formula: NCF = rpm × time to fracture (seconds)/60. The experimental procedures were performed by a single operator. For the corrosive action of NaOCl, the artificial metallic canal was replaced when any sign of corrosion was observed. The fragment length was measured using a Hirox Digital Microscope (Hirox-USA Inc, Hackensack, NJ). Three fractured instruments from each group were cleaned with absolute alcohol in an ultrasonic bath, and the fractured surfaces were examined using a scanning electron microscope (6360LV Scanning Electron Microscope; JEOL, Tokyo, Japan).

Statistical Analysis

Because the distribution of data was abnormal based on the Shapiro-Wilk test (P = .002), the data were analyzed statistically using the Kruskal-Wallis and Mann-Whitney tests. All statistical analyses were performed using SPSS software Version 22 (IBM Corp, Armonk, NY) at a significance level of 5%.

Results

The means and standard deviations of the NCFs for the PTG F2 instruments subjected to different irrigation concentrations and temperatures are presented in Table 1. PTG F2 instruments in distilled water at 25°C significantly had the highest NCF, whereas those in 5.25% NaOCl at 60°C significantly had the lowest value. Within each testing medium, the results showed that the higher the temperature, the lower the NCF, except for the 2.5% concentration where no statistically significant difference between 25°C and 37°C was found. Moreover, for each testing temperature, the NaOCl lowered the NCF, especially at higher concentrations. The length of the fractured fragments was in the range between 4.1 ± 0.77 and 5.2 ± 0.78 mm.

The fracture surfaces of PTG F2 that appeared at different temperatures and irrigations observed via scanning electron microscopy showed typical features of cyclic fatigue, including 1 or 2 crack initiation areas, the presence of fatigue striations, and a fast fracture zone with dimples (Fig. 1*A–I*). The fracture cross sections of the tested instruments revealed that crack initiation was formed at the cutting edges of the fracture cross sections, with an area of microscopic dimples on the fracture surfaces. None of the tested files showed pitting or crevice corrosion in water or 5.25% NaOCl as evaluated via scanning electron microscopy (Fig. 1).

Discussion

Cyclic fatigue failure is 1 of the proposed mechanisms that might lead to NiTi instrument fracture (3, 16). It has been shown that environmental temperature influences fatigue resistance (9, 17–20). However, investigating the effect of the environmental temperature along with the effect of NaOCl at different concentrations on cyclic fatigue might be more clinically relevant.

In this study, the irrigant's concentration and temperature were shown to greatly influence cyclic fatigue. The fatigue resistance was negatively affected when the irrigating solution was changed from distilled water to NaOCl, especially at higher concentrations (P < .05), and when the testing temperature was increased (P < .05). Huang et al (19) found a similar tendency with K3 (SybronEndo, Orange, CA), K3XF (SybronEndo), and Vortex (Dentsply Tulsa Dental Specialties, Tulsa, OK) instruments with distilled water and 5.25% NaOCl at different temperatures. Thus, the null hypothesis should be rejected.

TABLE 1. The Number of Cycles to Fracture (NCF) of ProTaper Gold F2 under Different Irrigant Concentrations and Temperature Conditions

	25°C (NCF)	37°C (NCF)	60°C (NCF)
Distilled water	1239.1 ± 388.2[a]	962.9 ± 276.0[b]	418.8 ± 114.8[c]
2.5% NaOCl	761.3 ± 270.9[df]	662.3 ± 227.9[d]	325.9 ± 116.9[e]
5.25% NaOCl	877.8 ± 298.0[f]	571.1 ± 172.3[g]	305.6 ± 90.6[e]

Different superscripts indicate statistical significance.