Fatigue Resistance of Nickel-titanium Instruments Exposed to High-concentration Hypochlorite

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Abstract

Introduction: The purpose of this study was to introduce a new fatigue test model that simulates the clinical situation for evaluating the corrosion effect of 5.25% sodium hypochlorite (NaOCl) on nickel-titanium (NiTi) files and to evaluate the effect of 3 different temperatures (22°C, 37°C, and 60°C) on the cyclic fatigue of these files. **Methods:** Three NiTi files (size 25/.04), K3 (SybronEndo, Orange, CA), K3XF (SybronEndo), and Vortex (Dentsply Tulsa Dental Specialties, Tulsa, OK), were subjected to cyclic fatigue tests inside a novel artificial ceramic canal with a curvature of 60° and a 5-mm radius. A 19-mm-long file segment from the tip was introduced into the canal and immersed in water or 5.25% NaOCl at 3 different temperatures, and the number of revolutions to fracture (N_f) was recorded. The fracture surface of all fragments was examined by a scanning electron microscope. Data were analyzed using univariate analysis of variance with the significance level at 0.05. **Results:** The N_f of Vortex files was the highest followed by K3XF and K3 ($P < .05$) at all conditions. The N_f of all files was highest at 22°C and lowest at 60°C ($P < .05$). However, no difference in N_f was detected in Vortex files between 22°C and 37°C. The N_f of all files in 5.25% NaOCl was shorter than that in water although there was no statistically significant difference. No pitting or crevice corrosion was observed on the fracture surface. **Conclusions:** NaOCl, 5.25%, does not significantly affect the fatigue behavior of NiTi files. The fatigue resistance should be tested under specific temperature conditions. The austenite finish temperature of a file is important in determining the fracture risk at body temperature. *(J Endod 2017;■:1–5)*

Key Words

Ceramic canal, corrosion, fatigue resistance, nickel-titanium instrument, sodium hypochlorite, temperature

Significance

NaOCl, 5.25%, does not significantly affect the fatigue behavior of NiTi files. The fatigue resistance should be tested under specific temperature conditions.

Despite their popularity, a concern with the use of nickel-titanium (NiTi) rotary files is the possibility of unexpected separation. Two different mechanisms may lead to NiTi rotary fracture: cyclic fatigue and torsional fracture (1–3). When a rotary file undergoes repeated compression and extension in a curved canal, this can cause work hardening of the metal, which causes cyclic fatigue and an increased risk of fracture. NiTi file failures in the clinic are mainly caused by cyclic fatigue (2–4). The fatigue life of a file can be expressed as the number of loading cycles required to initiate a fatigue crack and to propagate the crack to critical size (5, 6). Fatigue crack growth rates in NiTi alloys have been reported to be significantly greater than in other metals of similar strength (7). Therefore, it is not surprising that several studies have been published in recent years with a focus on the fatigue resistance of different NiTi files (4–6,8–12). All of these studies have attempted to simulate the rotation of the instrument within a curvature to determine how long it lasts before the fracture occurs.

Root canal instrumentation is recommended to be performed with sodium hypochlorite (NaOCl) as an irrigant in the canal(s) and a reservoir in the pulp chamber. NaOCl has antimicrobial and tissue-dissolving activity (13, 14), but it can also cause the corrosion of metals. NiTi instruments come into contact with NaOCl during instrumentation, which raises the question of the impact of such short-term contact on the integrity of the files. The events potentially leading to complete separation of file fragments begin on the file surface as crack initiation. Because environmental conditions are also known to affect crack initiation, a role possibly played by a corrosive irrigating solution, NaOCl is of interest. Surface corrosion starting as pitting and crevice corrosion could have an impact on the file's ability to withstand fatigue stress. NaOCl is commonly used in concentrations between 0.5% and 6%. Although the corrosive behavior of NaOCl on NiTi instruments has been studied (15–21), the fatigue test was performed after a passive exposure of the instruments to NaOCl for different time periods (15–18) or while instruments were immersed in a low concentration of NaOCl (ie, 1.2%) (19–21) to avoid the corrosion of the test models, which typically are or contain metallic parts such as stainless steel. Zirconia found in nature is a highly hard material that has been given the nickname "ceramic steel" (22). The interest in using zirconia dioxide as a biomaterial is based on its mechanical

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strength as well as its chemical and dimensional stability and elastic modulus similar to stainless steel (22).

The use of only low-concentration NaOCl in a real-time corrosion test may give a too optimistic picture of the effect of NaOCl on NiTi instruments. Hence, a fatigue test model allowing high NaOCl concentrations would be useful to mimic the clinical situation for examining the fatigue behavior of NiTi instruments under various conditions. Currently, 2 studies (12, 23) have found that the temperature influenced the fatigue life of NiTi files in water. Therefore, the aims of this study were to introduce a new fatigue test (in zirconium oxide) model that better simulates the clinical situation for the evaluation of the corrosion effect of 5.25% NaOCl on NiTi files and to evaluate the effect of 3 different temperatures (22°C, 37°C, and 60°C) on the cyclic fatigue life of conventional superelastic and heat-treated NiTi files.

Materials and Methods

Three nickel-titanium rotary instruments (size 25/.04), K3 (SybronEndo, Orange, CA), K3XF (SybronEndo), and Vortex (Dentsply Tulsa Dental Specialties, Tulsa, OK), were subjected to cyclic fatigue tests inside a novel ceramic artificial canal model. The ceramic artificial canals were milled in an InCoris ZI zirconium oxide disc (Dentsply Sirona, Bensheim, Germany) using the inLab MC X5 Digital computer-aided design and computer-aided manufacturing (CAD/CAM) System (Dentsply Sirona). The size of the artificial canal was 30/.06 with a curvature of 60° and a 5-mm radius (24). The model was fixed in a glass container filled with 300 mL 5.25% NaOCl (The Clorox Company, Brampton, Ontario, Canada) or distilled water. To achieve the desired temperatures, the glass container was placed on a hot plate until the water temperature was stabilized at the room temperature (22°C ± 1°C), body temperature (37°C ± 1°C), or high temperature (60°C ± 1°C); during all tests, the temperature was measured with an infrared thermometer (Sper Scientific Ltd, Scottsdale, AZ). A 19-mm-long segment from the tip of the instrument was introduced into the ceramic canal and immersed in the liquid medium during the test. Each group included 12 instruments. K3 was rotated at 300 rpm, and K3XF and Vortex were allowed to rotate at 500 rpm as recommended by the manufacturer until fracture. The fatigue life of the time to break (seconds) was recorded and multiplied by the number of rotations per minute to obtain the total number of cycles to failure (N_f). After the test, the detached fragments were collected and rinsed briefly with deionized water, and the length of the fragment was measured using a stereomicroscope at 10× (Microdissection; Zeiss, Bernried, Germany). The fractured instruments (ie, 3 files randomly selected from each group) were further cleaned in an ultrasonic bath in absolute alcohol, and the fractured surfaces were faced upward for fractographic examination using a scanning electron microscope (Helios NanoLab 650; FEI, Eindhoven, Netherlands) operating at 3 kV.

The data for the N_f were verified with the Kolmogorov-Smirnov test for the normality of the distribution and the Levene test for the homogeneity of variances. The data were analyzed statistically using univariate analysis of variance (SPSS for Windows 11.0; SPSS, Chicago, IL). Post hoc multiple comparison (the Tukey test) was used to isolate and compare the means of the results. All analyses were performed at a significance level of $\alpha = 0.05$.

Results

The N_f of the Vortex files was the highest followed by K3XF and K3 both in water and NaOCl at all 3 temperatures ($P < .01$) (Table 1). All 3 files had the highest N_f at 22°C and the lowest at 60°C ($P < .001$). There was no difference (NaOCl) or a smaller difference (water) in the N_f of Vortex files at 22°C and 37°C, whereas the fatigue resistance of K3 and

TABLE 1. The Number of Revolutions until Fracture of Files in Water and Sodium Hypochlorite (NaOCl) at 22°C, 37°C, and 60°C

File	Distilled water			5.25% NaOCl		
	22°C	37°C	60°C	22°C	37°C	60°C
Traditional						
K3	501.54 ± 70.46^{ac}	413.75 ± 46.37^{ab}	328.75 ± 47.87^{b}	433.33 ± 57.89^{ab}	348.33 ± 72.00^{b}	284.17 ± 38.54^{b}
Heat treated						
K3 XF	914.58 ± 215.30^{d}	603.47 ± 112.45^{c}	325.00 ± 30.77^{b}	884.72 ± 242.69^{d}	505.56 ± 73.28^{ac}	293.06 ± 62.45^{b}
Vortex	1356.94 ± 126.87^{e}	1102.78 ± 84.93^{f}	638.89 ± 64.48^{c}	1197.92 ± 64.76^{f}	1098.61 ± 90.65^{f}	609.72 ± 77.59^{c}

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