Low Environmental Temperature Influences the Fatigue Resistance of Nickel-titanium Files

Ya Shen, DDS, PhD,[*†] *Xiangya Huang, DDS, PhD,*[‡] *Zhejun Wang, DDS, PhD,*[*] *Xi Wei, DDS, PhD,*[‡] *and Markus Haapasalo, DDS, PhD*[*]

Abstract

Introduction: The purpose of this study was to evaluate the effect of different temperatures (0°C, 10°C, 22°C, 37°C, and 60°C) on the cyclic fatigue life of nickel-titanium (NiTi) files using a new fatigue test model in zirconium oxide. **Methods:** Three superelastic NiTi files (EndoSequence [Brasseler USA, Savannah, GA], ProFile [Dentsply Tulsa Dental Specialties, Tulsa, OK], and K3 [SybronEndo, Orange, CA]), and 3 heat-treated (K3XF [SybronEndo], Vortex [Dentsply Tulsa Dental Specialties], and HyFlex CM [Coltene-Whaledent, Allstetten, Switzerland]) NiTi files, all size 25/.04, were subjected to cyclic fatigue tests inside a novel, artificial ceramic canal with a curvature of 60° and a 5-mm radius. The model was immersed in water at 5 different preset temperatures. The number of cycles to failure (NCF) was recorded, and the fracture surface of the fragments was examined by a scanning electron microscope. The data were analyzed using 2-way analysis of variance with the significance level at 0.05. **Results:** When the temperature was reduced from 60°C to 0°C, the NCF significantly increased from over 2 to 10 times for the NiTi file groups ($P < .01$). K3XF had the highest fatigue resistance of all files at 0°C ($P < .05$). Vortex files had the highest NCF at 10°C–60°C. The NCF of heat-treated files was significantly higher than superelastic NiTi files at 10°C and 20°C ($P < .05$). There was no significant difference in the NCF of HyFlex CM at 0°C and 22°C. There was little difference in the fractographic appearance among different temperatures, except that the fraction area occupied by the dimple region of some instruments at 0°C was slightly smaller than at 60°C. **Conclusions:** Cooling down to low temperatures may be an interesting strategy to improve the fatigue resistance of rotary NiTi files. *(J Endod 2017;■:1–4)*

Key Words

Ceramic canal, fatigue resistance, nickel-titanium instrument, temperature

Significance

Fatigue resistance of NiTi files reduces when the temperature increases from 0°C to 60°C. Cooling down to low temperatures may be an interesting strategy to improve the fatigue resistance of rotary NiTi files.

The nickel-titanium (NiTi) alloy consists of nickel and titanium in a nearly equal atomic ratio. NiTi is called an exotic metal because it does not conform to the typical rules of metallurgy. The NiTi alloy has special properties such as shape memory and superelasticity (1, 2). Fatigue failure of nitinol material is a constant subject of discussion. Because it is the material of choice for applications requiring high level of flexibility, it is often exposed to much greater fatigue strains than other metals. Although the strain-controlled fatigue performance of nitinol is superior to all other known metals, fatigue failures have been observed in the most demanding applications (1). Rotary root canal instruments manufactured out of an NiTi alloy have proven to be well suited for root canal therapy. NiTi rotary shaping files have reduced the numbers of iatrogenic instrumentation complications that often occurred with endodontic steel files (3). However, the separation of NiTi files can still occur as a result of fatigue failure and torsional fracture. Studies found that cyclic fatigue is 1 of the main reasons for the fracture of endodontic rotary files used clinically (4–6).

To reduce the risk of intracanal fracture caused by cyclic fatigue, new file designs and manufacturing methods have been developed (7, 8). Thermal processing procedures that modify the microstructure of NiTi alloys are 1 of the most fundamental approaches that affect the fatigue resistance of NiTi endodontic files (9–13). In 2009, ProFile Vortex files (Dentsply Tulsa Dental Specialties, Tulsa, OK), the "next generation" in the ProFile file (Dentsply Tulsa Dental Specialties) series, were introduced. These files are manufactured from M-Wire, which had undergone a proprietary treatment. CM Wire (DS Dental, Johnson City, TN) is a novel NiTi alloy with flexible properties that was introduced in 2010. CM NiTi files have been manufactured using a special thermomechanical process that changes the properties of the material, making the files extremely flexible but without the shape memory of other NiTi files. HyFlex CM rotary files (Coltene-Whaledent, Allstetten, Switzerland) are made from NiTi CM-wire. Another thermal process was used for the production of K3XF files (SybronEndo, Orange, CA) subsequent to the grinding process. The manufacturer claims that K3XF provides clinicians with the basic features of the original K3 (SybronEndo) plus a new level of flexibility and resistance to cyclic fatigue with the proprietary R-phase technology. Previous studies (9, 13, 14) have shown that NiTi files made of thermomechanically treated alloys have a significantly improved fatigue

From the *Division of Endodontics, Department of Oral Biological and Medical Sciences, Faculty of Dentistry and †Department of Materials Engineering, The University of British Columbia, Vancouver, British Columbia, Canada; and ‡Department of Conservative Dentistry and Endodontics, Guanghua School of Stomatology, Guangdong Province Key Laboratory of Stomatology, Sun Yat-Sen University, Guangzhou, China.

Address requests for reprints to Prof Markus Haapasalo, Division of Endodontics, Department of Oral Biological and Medical Sciences, UBC Faculty of Dentistry, 2199 Wesbrook Mall, Vancouver, BC, Canada V6T 1Z3. E-mail address: markush@dentistry.ubc.ca

0099-2399/$ - see front matter

https://doi.org/10.1016/j.joen.2017.11.004

resistance compared with those made of conventional superelastic NiTi alloys that have not been exposed to similar thermal treatments. Clinically, endodontic instruments are used to prepare the root canal in the presence of an irrigant solution. Published studies (15, 16) have shown that those heat-treated NiTi files that have been examined for fatigue both in a dry condition and liquid have all shown higher fatigue resistance in liquid. Several studies (17, 18) on irrigating solutions have shown that increasing the temperature of sodium hypochlorite to 60°C significantly increases the rate of soft tissue dissolution. However, new studies (19–22) have reported that the increased temperature during use reduced the fatigue life of NiTi files in water. Therefore, the aims of this study was to evaluate the effect of 5 different temperatures (0°C, 10°C, 22°C, 37°C, and 60°C) on the cyclic fatigue life of conventional superelastic and heat-treated NiTi files using a new fatigue test in zirconium oxide model.

Materials and Methods

Six nickel-titanium rotary instruments (size 25/.04), EndoSequence (Brasseler USA, Savannah, GA), ProFile, K3, K3XF, HyFlex CM, and Vortex were subjected to cyclic fatigue tests in a novel ceramic artificial canals model (23). The ceramic artificial canals were milled in an InCoris ZI zirconium oxide disc (Dentsply Sirona, Bensheim, Germany) using the inLab MC X5 Digital CAD/CAM System (Dentsply Sirona). The size of the artificial canal was 30/.06 with a curvature of 60° and a 5-mm radius (23). The model was fixed in a glass container filled with 300 mL distilled water. To achieve the desired temperatures, the glass container was filled with ice water at 0°C ± 0.5°C or placed on a hot plate until the water temperature was stabilized at 10°C ± 1°C, the room temperature at 22°C ± 1°C, the body temperature at 37°C ± 1°C, or a high temperature of 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 each NiTi file was introduced into the ceramic canal and immersed in the liquid medium during the test. Each test group included 12 instruments. The EndoSequence, ProFile, and K3 files were rotated at 300 rpm, and the K3XF, HyFlex CM, and Vortex files were allowed to rotate at 500 rpm as recommended by the manufacturer until fracture. A digital video at a fixed distance and magnification was recorded to detect file breakage. 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 (NCF).

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, 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 NCF and fragment length of the instruments at different temperatures were analyzed statistically using 2-way analysis of variance (SPSS for Windows 11.0; SPSS, Chicago, IL). Post hoc multiple comparison (Tukey test) was used to isolate and compare the mean of the results. All analyses were performed at a 95% confidence level.

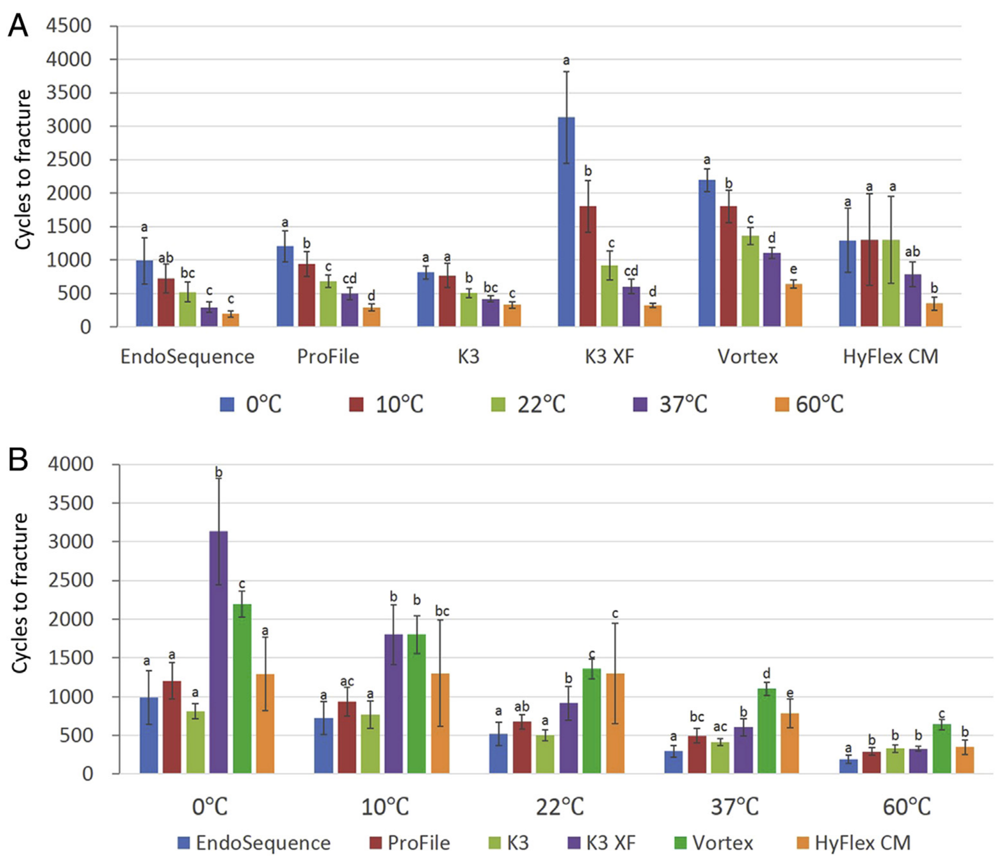

Figure 1. (*A* and *B*) The NCF of 6 NiTi files at different temperature(s). Different letters indicate statistically significant differences between different temperatures for each group ($P < .05$).