The Effect of Temperature on Cyclic Fatigue of Nickel-titanium Rotary Endodontic Instruments

Amandeep Dosanjh, DDS, MS, Susan Paurazas, DDS, MHSA, MS, and Mazin Askar, BDS, MS

Abstract

Introduction: This study examined the effect of different temperatures on the cyclic fatigue of nickel-titanium rotary files. **Methods:** Three groups of nickel-titanium rotary files (EF group [EdgeFile; EdgeEndo, Albuquerque, NM], VB group [Vortex Blue; Dentsply Tulsa Dental Specialties, Tulsa, OK], and ESX group [ESX; Brasseler USA, Savannah, GA]) of size 25 with a .04 taper and 25-mm length were tested in a metal block that simulated a canal curvature of 60° and a 5-mm radius curvature. The block was submerged in a water bath filled with water at 3°C, 22°C, 37°C, and 60°C. At each temperature, 30 files from each group were rotated at 500 rpm in the block. The number of cycles to fracture (NCF) was calculated. Statistical analysis was completed using a 1-way analysis of variance with significance at $P < .05$. **Results:** VB group showed a significant decrease in NCF as the temperature increased from 3°C to 60°C. The ESX group showed a significant decrease in NCF as the temperature increased from 3°C to 37°C. The EF group showed a significant increase in NCF from 3°C to 22°C and a significant decrease in NCF from 22°C to 37°C. For each temperature, the EF group showed higher NCF than the VB group, which showed higher NCF than the ESX group. **Conclusions:** In this *in vitro* study, temperature was found to significantly affect the cyclic fatigue of nickel-titanium rotary files. At each tested temperature, NCF was the highest for the EF group followed by the VB group and lowest for the ESX group. Future cyclic fatigue studies should be conducted at body temperature. *(J Endod 2017;43:823–826)*

Key Words

Cyclic fatigue, files, nickel-titanium, temperature

Significance

The majority of studies to determine the number of cycles to fracture of endodontic rotary NiTi files have been conducted at room temperature. *In vivo*, these files function within the canal near body temperature, and this can affect the results.

Nickel-titanium (NiTi) endodontic rotary files possess superelasticity, which is of great benefit during instrumentation of curved endodontic canals (1). These instruments have an austenite phase at higher temperatures and, upon cooling or applying stresses, can transform into the martensite phase. This phase transition allows for greater flexibility. The transition phase temperatures of files can differ depending on the alloys and heat treatments used for processing (1).

A pilot study conducted at the University of Detroit Mercy, Detroit, MI, in 2015 showed EdgeFile files (EdgeEndo, Albuquerque, NM) have significantly greater cycles to fracture compared with Vortex Blue files (Dentsply Tulsa Dental Specialties, Tulsa, OK) and EndoSequence files (Brasseler USA, Savannah, GA) in a simulated 60° curve in a metal block at room temperature. Heated sodium hypochlorite (NaOCl) irrigant has been shown to be advantageous for disinfection (2, 3). The use of heated 1% NaOCl solution at 60°C was found to have significantly greater dissolution capacity of human pulp tissue compared with 20°C solution (2). Additionally, heated NaOCl at 45°C showed greater killing of *Enterococcus faecalis* than at 20°C (2). Clinically, this heating may cause the NiTi file to transition toward the stiffer austenite phase. This can make the file more susceptible to fatigue crack propagation compared with a NiTi file predominantly in the martensite phase (4). Cooling can allow for greater flexibility of NiTi. Nitinol stents were shown to be more easily mounted and removed once cooled with ice water at 4°C because of increased pliability of the stent once cooled (5).

The increased ductility of a file in its martensite phase allows it to be highly elastic. This also improves damping properties, resistance to crack growth due to fatigue, and provides a higher resistance to cyclic fatigue (4). The use of heated or cooled irrigants may favor the NiTi phase transition of the instrument toward a more austenitic or martensitic phase, respectively, which can affect its cycles to fracture.

The purpose of this study was to examine the effect of temperature changes on the cyclic fatigue of EdgeFile, Vortex Blue, and ESX (Brasseler USA) rotary NiTi instruments tested in a metal block submerged in a water bath.

Materials and Methods

One hundred twenty NiTi rotary endodontic files were used for each of the 3 experimental file groups: the EF (EdgeFile files), VB (Vortex Blue files), and ESX (ESX files) groups. All files were size #25 with a .04 taper and 25-mm length, and were sterilized before use. The entire length of each file was placed into a simulated canal in a metal block, which was submerged in a water bath. The simulated canal was open to the water,

From the Department of Postgraduate Endodontics, University of Detroit Mercy, Detroit, Michigan.

Address requests for reprints to Dr Amandeep Dosanjh, Department of Postgraduate Endodontics, University of Detroit Mercy, 2700 Martin Luther King Jr Blvd, Detroit, MI 48208-2576. E-mail address: andydosanjh@gmail.com

0099-2399/$ - see front matter

http://dx.doi.org/10.1016/j.joen.2016.12.026

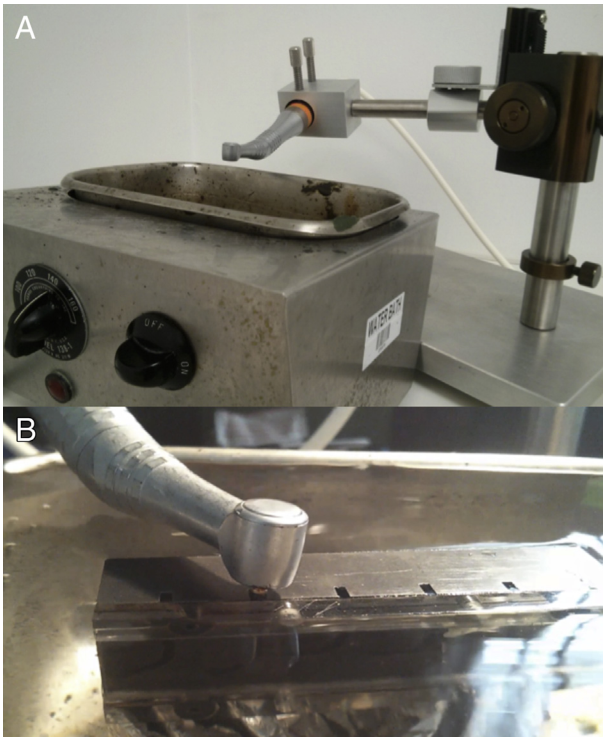

Figure 1. Experimental setup showing (*A*) water bath and electric motor setup and (*B*) a metal block with simulated canal submerged in water with an experimental file inserted.

allowing the file to be exposed to the experimental temperature of the water in the water bath. The files were rotated at 500 rpm (which is within the recommended range of rotational speeds in the directions for use of each file system) with the use of an endodontic motor (E3 Torque Control Motor [Dentsply Tulsa Dental Specialties]). The metal block was made of tempered 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. A digital thermometer was used to measure the temperature of the water, and the water temperature was allowed to equilibrate for a few minutes before initiating testing of each file. Within each group of 120 files, files were randomly subdivided for testing at 4 different temperature cycles, with 30 files per temperature cycle. The 4 different temperature cycles were ice water (3° ± 0.5°C), room temperature (22° ± 0.5°C), body temperature (37° ± 0.5°C), and hot water (60° ± 0.5°C). Pictures of the setup are shown in Figure 1*A* and *B*. A video record was made of each file rotation, and time to fracture was recorded in seconds. This was identified by visual fracture (Fig. 2*A* and *B*) and/or audible sound of fracture. Time to fracture was converted into number of cycles to fracture (NCF).

Results

One-way analysis of variance with a post hoc Tukey test was used to compare the cyclic fatigue of the instruments at different temperatures. The results are graphically shown in Figure 3. When the temperature cycle increased from 3°C to 22°C, the average NCF significantly ($P < .01$) decreased for both the VB and ESX groups, from 4842 (standard deviation [SD] = 1136) and 932 (SD = 163) to 2062 (SD = 358) and 466 (SD = 66), respectively. However, the NCF significantly ($P < .05$) increased for the EF group from 6185 (SD = 2143) to 7243 (SD = 2088). When the temperature cycle increased from 22°C to 37°C, all files showed a significant ($P < .01$) decrease in the NCF to averages of 1233 (SD = 218), 271 (SD = 55), and 1675 (SD = 384) for the VB, ESX, and EF groups, respectively. Further increasing the temperature from 37°C to 60°C caused a significant ($P < .01$) reduction in the NCF for the VB group to an average of 651 (SD = 111). The ESX and EF groups also had reductions in their NCF to respective averages of 218 (SD = 45) and 901 (SD = 201), but these were not statistically significant. At each temperature, the EF group had a significantly ($P < .01$) higher NCF than the VB group. The VB group had a significantly ($P < .01$) higher NCF than the ESX group.

Discussion

The findings of this study showed that temperature has a significant effect on the NCF for all rotary NiTi endodontic files tested. This is in agreement with previous studies (6, 7) in which increasing the temperature was found to decrease the NCF. In one study, NiTi rotary

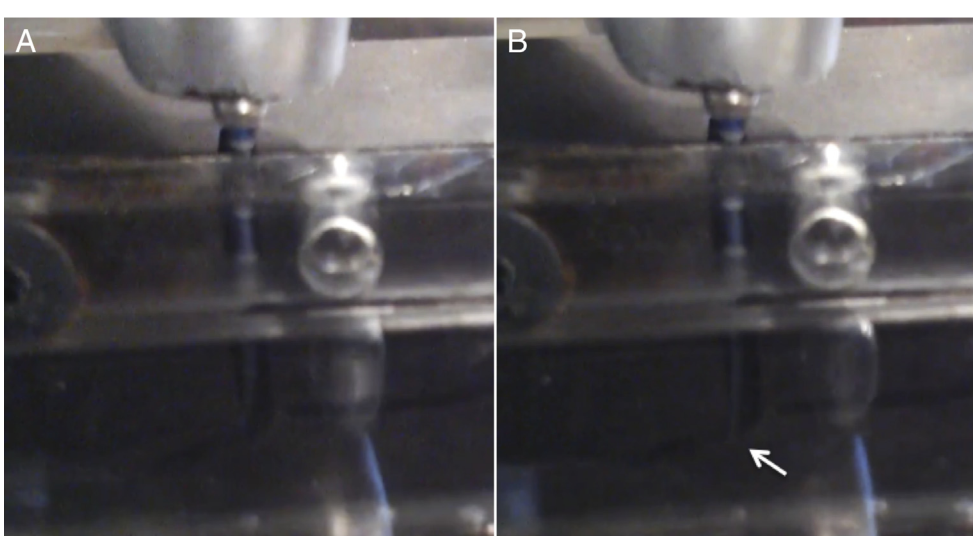

Figure 2. An image of a file rotating in a simulated canal (*A*) before file fracture and (*B*) after file fracture. The *white arrow* points to the site of fracture.

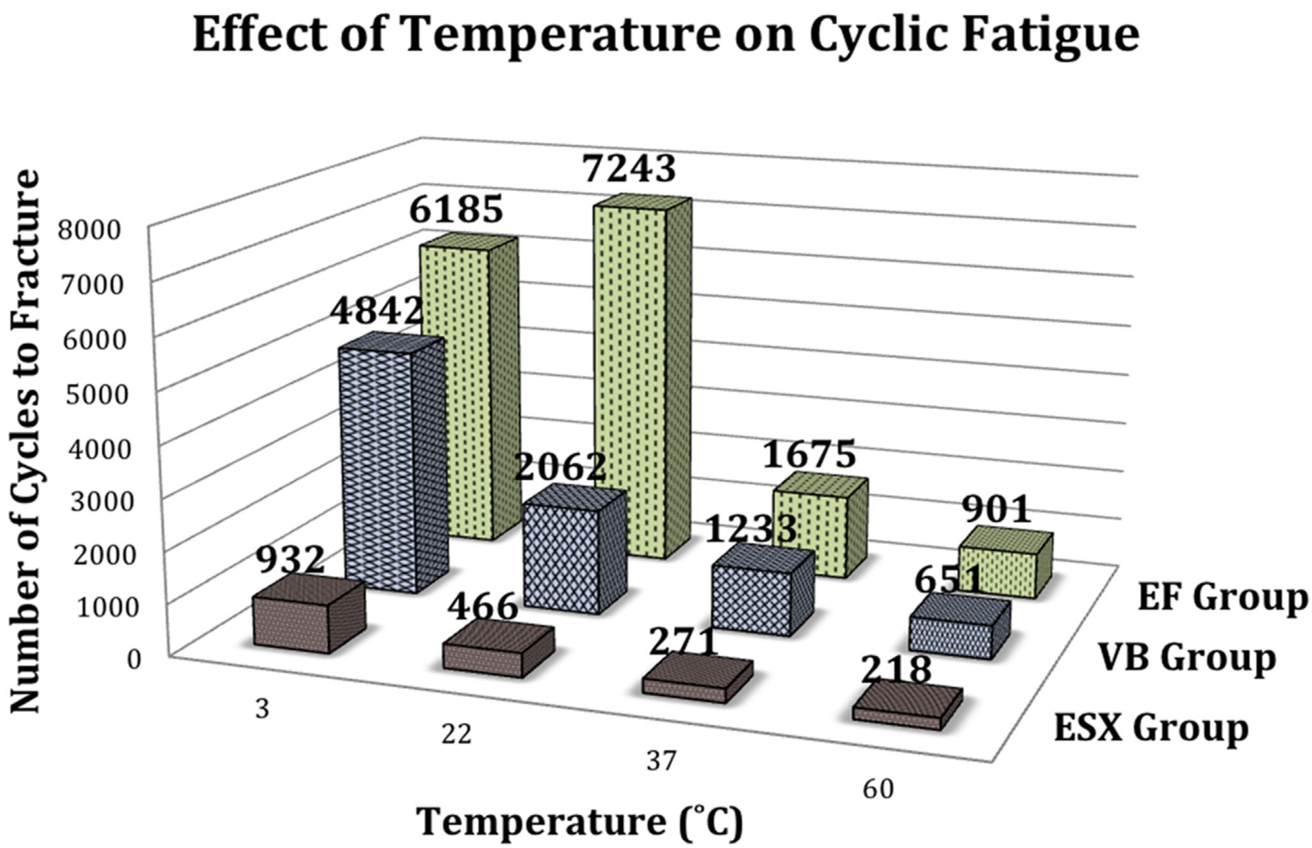

Figure 3. A graphical representation of the averages of NCF versus temperature for tested files.

instruments were made from wire to a tip size of 30 with a .06 taper (6). Eight files were rotated at each tested temperature (10°C, 37°C, and 50°C) until fracture; a lower NCF was observed at 50°C and 37°C compared with 10°C (6). Another study tested a variety of rotary NiTi files available on the market (Hyflex CM [Coltene, Cuyahoga Falls, OH], TRUShape [Dentsply Tulsa Dental Specialties], Vortex Blue, and ProTaper Universal [Dentsply Tulsa Dental Specialties]) with a tip size of 25 at 20°C and 37°C (7). A decrease in the NCF was found at 37°C compared with 20°C for all of the tested instruments (7). However, our study examined a greater variety of temperatures than the other studies. This is of importance because cyclic fatigue studies are usually conducted in an *ex vivo* setting in which temperature is not considered as a variable. Future studies can be made more clinically relevant by being conducted at body temperature instead of room temperature.

The extent that temperature affects NCF seems to also be affected by the metallurgic properties of the endodontic files. The NCF for the ESX and VB groups nearly halved when the temperature was increased from room temperature to body temperature, whereas that for the EF group decreased by over 4 times. This large difference in NCF is apparent when compared with the other files. For example, when compared with the VB group, at room temperature the NCF of the EF group was over 3.5 times higher. When heated to body temperature, the NCF of the EF group was only 1.35 times higher than that of the VB group; however, this was still statistically significant.

File types were selected to obtain a variation in metallurgy. Files in the EF group are predominantly in a martensitic phase at room temperature, which is responsible for their lack of shape memory. Further cooling of the files in the EF group to 3°C resulted in a decrease in NCF. This decrease in NCF may be caused by a mechanism similar to how traditional metals become more brittle as they cool, causing them to fracture. Heating most likely caused a transition to an austenitic phase, reducing the NCF. Although there was a reduction in the NCF from 37°C to 60°C, this was not found to be statistically significant. Files in both the ESX and VB groups at least doubled their NCF when they were placed in ice water because they may possess a more austenitic phase at room temperature compared with files in the EF group. By cooling them, they transitioned to a more martensitic phase. The difference in NCF for the ESX group from 37°C to 60°C was not significant. This may be caused by the files in the ESX group already being in mostly an austenitic phase at body temperature; consequently, further heating did not have an effect.

Our findings suggest that an irrigant chilled below room temperature seems favorable to increase NCF, except for files that are already in a martensitic phase such as the files in the EF group. Vera et al (8) examined using 2.5°C irrigant *ex vivo* and found that irrigation for 5 minutes resulted in a 10°C decrease in external root temperature after 30 seconds. They concluded that using the chilled irrigant to decrease external root temperature might be a way to reduce inflammation in the periradicular region. In addition to increasing NCF, another benefit of a cold irrigant may be to provide an anti-inflammatory effect.

However, using a heated NaOCl irrigant has been shown to be effective for disinfection and tissue dissolution (2, 3). According to our findings, the use of a heated irrigant during file instrumentation may increase the incidence of file separation because of the reduction in NCF that may result. Furthermore, exposure of NiTi files to heated NaOCl may cause more corrosion, leading to faster separation (9). Therefore, a heated NaOCl irrigant may be best suited as a final step in the irrigation protocol. In an *in vivo* study by de

Hemptinne et al (10), when room temperature NaOCl solution was injected into a canal, the temperature increased to 30.9°C after only 10 seconds. The temperature of a heated solution decreased from 56.4°C to 45.4°C after 5 seconds and took a minute to decrease to 37°C. This rapid equilibration of temperature makes it especially important to test cyclic fatigue of instruments at body temperature instead of at room temperature, because irrigant at room temperature quickly equilibrates to body temperature when used in the root canal space. This experimental model used a metal block to simulate a root canal. The effects of conduction and insulation of heat are likely different in this model than those of root dentin and may be a factor for *in vivo* results.

Notably, this study only examined cyclic fatigue; torsional fatigue and cutting effectiveness of files are also important aspects of a file's performance. Future studies should examine the effects of temperature and file metallurgy on these characteristics. Future studies can also consider using scanning electron microscopic imaging to analyze features of the file fractures.

In conclusion, when placed in a water bath, files in the ESX group showed a decrease in NCF when heated from 3°C up to 37°C, but no significant difference was seen from 37°C to 60°C; files in the VB group showed the same, except they continued to have a reduction in NCF to 60°C. Files in the EF group showed an increase in NCF from 3°C to 22°C and a marked decrease in NCF from 22°C to 37°. There was no statistically significant difference in NCF from 37°C to 60°C. At all temperatures, files in the EF group were found to have significantly higher NCF than files in the VB group, which had significantly higher NCF than the files in the ESX group. Because the cyclic fatigue of various file types was found to be significantly affected by temperature, future cyclic fatigue studies are recommended to be conducted at body temperature. Consideration should be taken in the interpretation of studies conducted at room temperature.

Acknowledgments

The authors thank Dr. John Braud for help in providing supplies for this project. Also thanks to Brasseler USA, Dentsply Tulsa Dental Specialties, and EdgeEndo for their donations of the endodontic files used for this study.

The authors deny any conflicts of interest related to this study.

References

1. Montalveo D, Alçada FS, Fernandes FM, de Vilaverde-Correia S. Structural characterisation and mechanical FE analysis of conventional and M-Wire Ni-Ti alloys used in endodontic rotary instruments. ScientificWorldJournal 2014;2014:1–8.
2. Sirtes G, Waltimo T, Schaetzle M, et al. The effects of temperature on sodium hypochlorite short-term stability, pulp dissolution capacity, and antimicrobial efficacy. J Endod 2005;31:669–71.
3. Dumitriu D, Dobre T. Effects of temperature and hypochlorite concentration on the rate of collagen dissolution. J Endod 2015;41:903–6.
4. Shen Y, Zhou HM, Zheng YF, et al. Current challenges and concepts of the thermomechanical treatment of nickel-titanium instruments. J Endod 2013;39:163–72.
5. Merkel D, Brinkmann E, Wiens D, et al. *In situ* cooling with ice water for the easier removal of self-expanding nitinol stents. Endosc Int Open 2015;3:51–5.
6. Jamleh A, Yahata Y, Ebihara A, et al. Performance of NiTi endodontic instrument under different temperatures. Odontology 2016;104:324–8.
7. de Vasconcelos RA, Murphy S, Carvalho CA, et al. Evidence for reduced fatigue resistance of contemporary rotary instruments exposed to body temperature. J Endod 2016;42:782–7.
8. Vera J, Ochoa-Rivera J, Vazquez-Carcaño, et al. Effect of intracanal cryotherapy on reducing root surface temperature. J Endod 2015;41:1884–7.
9. Peters OA, Roehlike JO, Baumann MA. Effect of immersion in sodium hypochlorite on torque and fatigue resistance of nickel-titanium instruments. J Endod 2007;33:589–93.
10. de Hemptinne F, Slaus G, Vandendael M, et al. *In vivo* intracanal temperature evolution during endodontic treatment after the injection of room temperature or preheated sodium hypochlorite. J Endod 2015;41:1112–5.

CORRIGENDUM

Corrigendum to 'Antimicrobial Activity and Physicochemical Properties of Calcium Hydroxide Pastes Used as Intracanal Medication' [J Endod 2016;42:1822–1828]

Rafaela Fernandes Zancan, MSc,* Rodrigo Ricci Vivan, PhD,* Marcelo Ribeiro Milanda Lopes, MSc,† Paulo Henrique Weckwerth, PhD,‡ Flaviana Bombarda de Andrade, PhD,* José Burgos Ponce, PhD,§ and Marco Antonio Hungaro Duarte, PhD*

*Department of Restorative Dentistry, Dental Materials and Endodontics, †Integrated Research Center, and §Department of Surgery, Stomatology, Pathology and Radiology, Bauru Dental School, University of São Paulo, Bauru, São Paulo, Brazil; and ‡Pro-Rectory of Research and Graduate Studies, University of Sagrado Coração, Bauru, São Paulo, Brazil.

The authors regret that they mistakenly left out that the article was supported by the State of São Paulo Research Foundation (FAPESP 2014/17473-1).

The authors would like to apologise for any inconvenience caused.