Abstract

Introduction: The purpose of this study was to examine the effect of different temperatures (3˚C, 22˚C, 37˚C, and 60˚C) on cyclic fatigue of three different nickel-titanium rotary files. **Methods:** Three groups of nickel-titanium rotary files (EdgeFile [EdgeEndo, Albuquerque, NM], Vortex Blue [Dentsply Tulsa Dental Specialties, Tulsa, OK], and ESX [Brasseler USA, Savannah, GA]) of size #25 with .04 taper and 25 mm length were tested in a metal block that simulated a canal curvature of 60˚ and 5 mm radius of curvature. The block was submerged in a controlled-temperature water bath filled with water at 3˚C ± 0.5˚C, 22˚C ± 0.5˚C, 37˚C ± 0.5˚C, and 60˚C ± 0.5˚C. Thirty files from each experimental group were tested in the block at each of the four temperature cycles, and rotated at 500 rpm. Time to file fracture was recorded, and converted to number of cycles to fracture (NCF). Statistical analysis was completed using a one-way ANOVA with post-hoc Tukey test. **Results:** Vortex Blue files showed a significant decrease in NCF as temperature increased from 3˚C to 60˚C. ESX files showed a significant decrease in NCF as temperature increased from 3˚C to 37˚C. EdgeFile files 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 tested, EdgeFile files showed higher NCF than Vortex Blue files, and Vortex Blue files showed higher NCF than ESX files. **Conclusions:** In this *in vitro* study, temperature was found to have a significant effect on the cyclic fatigue of the NiTi rotary files tested. At each tested temperature, NCF of EdgeFile files was higher than NCF of Vortex Blue files, which was higher than NCF of ESX files. Future cyclic fatigue studies should consider being conducted at body temperature.

Keywords: temperature, cyclic fatigue, nickel-titanium, files

Introduction

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 in 2015 showed EdgeFile files to have significantly greater cycles to fracture compared to Vortex Blue and EndoSequence files in a simulated 60˚ curve in a metal block at room temperature. Heated NaOCl (sodium hypochlorite) 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 *E. faecalis* than at 20˚C (2). Clinically this heating may cause the NiTi file to transition towards the stiffer austenite phase. This can make the file more susceptible to fatigue crack propagation compared to a NiTi file predominantly in the martensite phase (4). Cooling can allow for greater flexibility of nickel titanium. Nitinol stents were shown to be more easily mounted and removed once cooled with ice-water at 4˚C, due to increased pliability of the stent once cooled (5). One study used NiTi wire to create rotary instruments, and tested them at three different temperatures; a higher number of cycles to fracture was seen at 10˚C compared to 50˚C (6). Another study tested a variety of rotary NiTi files available in the market at 20˚C and 37˚C, and found a decrease in the number of cycles to fracture at 37˚C compared to 20˚C (7).

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 a higher resistance to cyclic fatigue (4). The use of heated or cooled irrigants may favor the NiTi phase transition of the instrument towards 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 rotary NiTi instruments, tested in a metal block submerged in a water bath.

Materials and Methods

One hundred twenty nickel-titanium rotary endodontic files were used for each of the three experimental file groups: EF (EdgeFile files; EdgeEndo, Albuquerque, NM), VB (Vortex Blue files; Dentsply Tulsa Dental Specialties, Tulsa, OK), and ESX (ESX files; Brasseler USA, Savannah, GA). All files were size #25 with .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 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 (Tulsa E3 motor). The metal block was made of tempered steel with a milled canal that simulated a 60˚ canal curvature and 5 mm radius of curvature, and a width of 1.5 mm. A digital thermometer was used to measure the temperature of the water before initiating testing of each file. Within each group of 120 files, files were randomly subdivided for testing at the four different temperature cycles, with 30 files per temperature cycle. The four 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˚C ± 0.5˚C). A picture of the setup is shown in Figure 1. A video record was made of each file rotation, and time to fracture was recorded in seconds. This was identified by visual and/or audible sound of fracture. Time to fracture was converted into NCF.

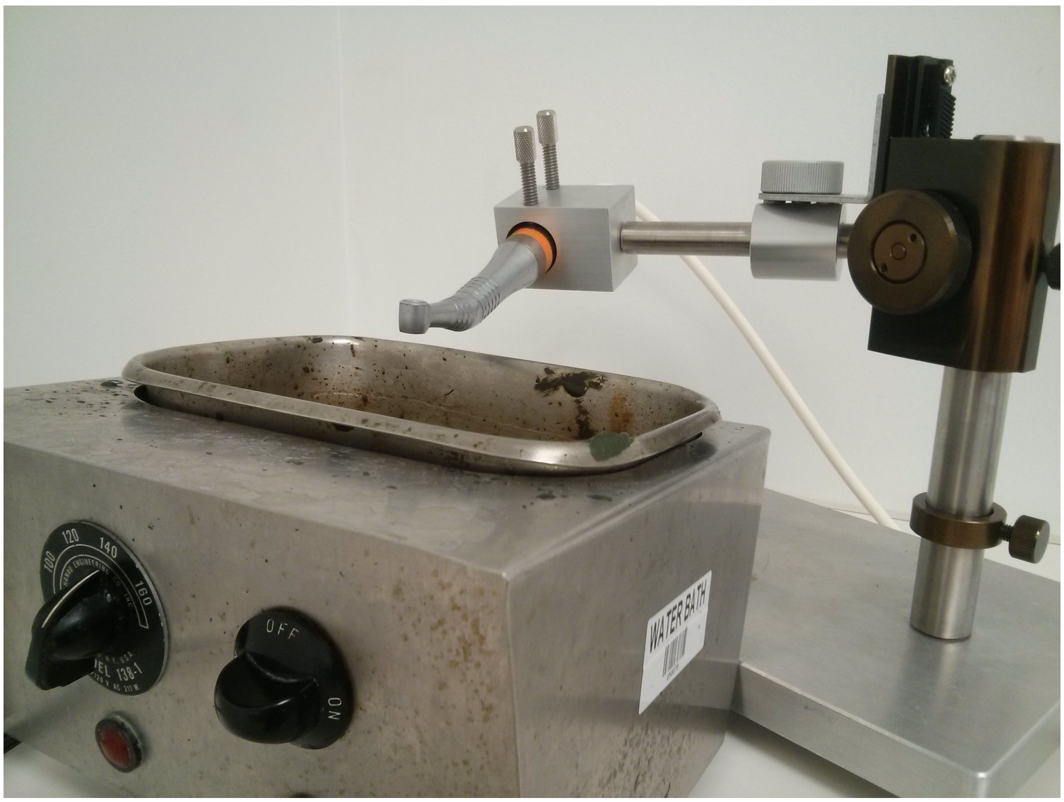

Figure 1. Picture of water bath and electric motor setup

Results

A one-way ANOVA with post-hoc Tukey test was used to compare the cyclic fatigue of the instruments at different temperatures. The results are graphically shown in Figure 2. When the temperature cycle increased from 3˚C to 22˚C, the average NCF significantly ($p<0.01$) decreased for both VB and ESX, from 4842 (SD=1136) and 932 (SD=163) to 2062 (SD=358) and 466 (SD=66), respectively. However, the NCF significantly ($p<0.05$) increased for EF from 6185 (SD=2143) to 7243 (SD=2088). When the temperature cycle increased from 22˚C to 37˚C, all files showed a significant ($p<0.01$) decrease in the NCF, to averages of 1233 (SD=218), 271 (SD=55), and 1675 (SD=384) for VB, ESX, and EF, respectively. Further increasing the temperature from 37˚C to 60˚C caused a significant ($p<0.01$) reduction in the NCF for VB to an average of 651 (SD=111). ESX and EF 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, EF had a significantly ($p<0.01$) higher NCF than VB. VB had a significantly ($p<0.01$) higher NCF than ESX.

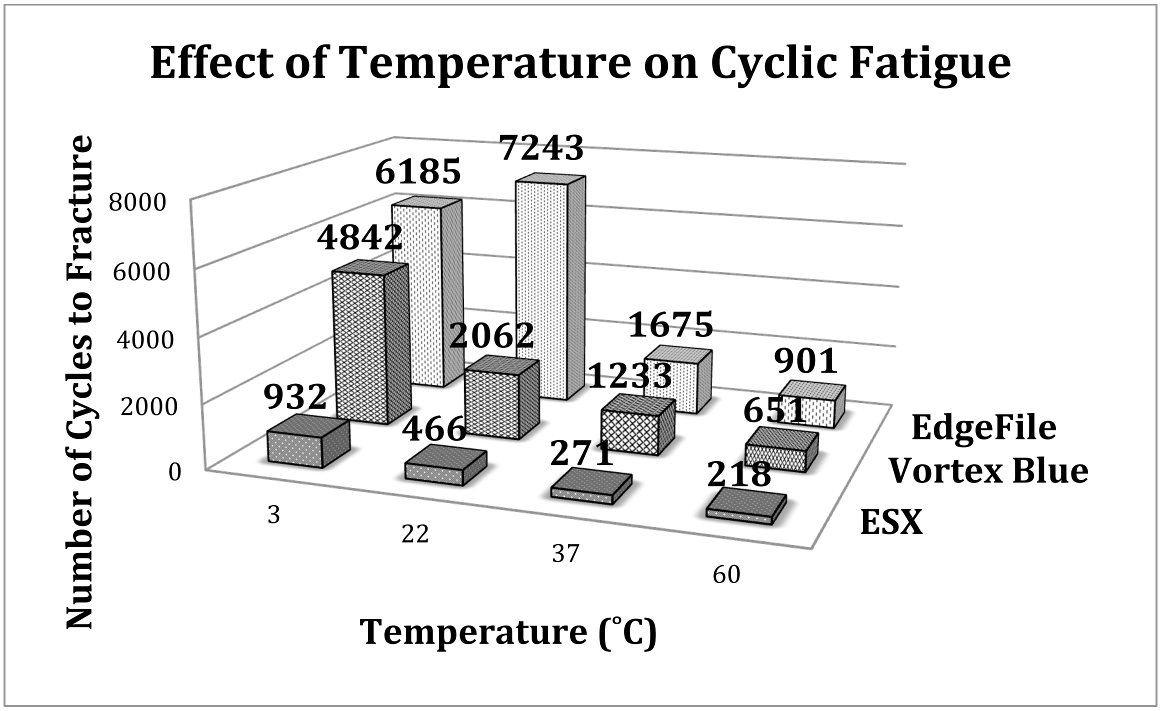

Figure 2. Effect of Temperature on Cyclic Fatigue

Discussion

The findings of this study showed that temperature has a significant effect on the number of cycles to fracture for all rotary NiTi endodontic files tested. This is in agreement with previous studies (6, 7) where increasing the temperature was found to decrease the NCF. However, this 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 where 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 NCF for the ESX and Vortex Blue files nearly halved when the temperature was increased from room temperature to body temperature, while that for EdgeFile files decreased by over four times. This large difference in NCF is apparent when compared to the other files. For example, when compared to Vortex Blue files, at room temperature the NCF of EdgeFile files was over 3.5 times higher. When heated to body temperature, the NCF of EdgeFile files was only 1.35 times higher than Vortex Blue files; however, this was still significant. The metallurgic properties of endodontic files appear to affect their NCF in addition to temperature.

File types were selected to get a variation in metallurgy. The EdgeFile files are predominantly in a martensitic phase at room temperature, which is responsible for their lack of 'shape memory.' Further cooling of the EdgeFile files to 3˚C resulted in a decrease in the NCF. This decrease in NCF may be due to 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. Both the ESX and Vortex Blue files at least doubled their NCF when they were placed in ice water, since they may possess more austenitic phase at room temperature compared to EdgeFile files. By cooling them, they transitioned to a more martensitic phase. The difference in NCF for ESX files from 37˚C to 60˚C was not significant. This may be due to the files 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 EdgeFile files. 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.

Using a heated NaOCl irrigant, however, 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 due to 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), room temperature NaOCl solution injected into a canal increased temperature 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 down 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, since 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.

In conclusion, when placed in a water bath, ESX files 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; Vortex Blue files showed the same, except they continued to have a reduction in NCF to 60˚C. EdgeFile files showed an increase in NCF from 3˚C to 22˚C, and a marked decrease in NCF from 22˚C to 37˚C. There was no statistically significant difference in NCF from 37˚C to 60˚C. At all temperatures, EdgeFile files were found to have significantly higher NCF than Vortex Blue files, which had significantly higher NCF than ESX files. Since 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 interpretation of studies conducted at room temperature.

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