Fatigue Resistance of a 3-dimensional Conforming Nickel-Titanium Rotary Instrument in Double Curvatures

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Abstract

Introduction: Fatigue resistance of ProFile, Vortex Blue, and TRUShape files in artificial single curvature and in 2 different artificial double curvature canals was evaluated. **Methods:** Three files (ProFile, Vortex Blue [size 20/.06], and TRUShape [size 20/.06*v*]) were subjected to fatigue tests in a single curvature (group 1: 60° curvature) and 2 different double curvatures (group 2: 60° and 30° curvatures; group 3: two 60° curvatures). The time to fracture and the total number of cycles to failure were recorded. The fracture surfaces of the fragments were examined with a scanning electron microscope. **Results:** All files had significantly higher fatigue resistance in a single curvature canal than in the double curvature canals. In a single curvature group, the time to fracture of TRUShape and ProFile was longer than in Vortex Blue files. In both double curvature groups, TRUShape had the longest time to fracture among all files. The fatigue resistance (the time to fracture and number of cycles to failure) of ProFile and Vortex Blue was lower in group 3 than in group 2 ($P < .05$). However, there was no significant difference in fatigue resistance of TRUShape in the double curvature groups. The length of the fragment of TRUShape was longer than in Vortex Blue and ProFile files in group 3 ($P < .05$). **Conclusions:** The fatigue performance of TRUShape is different in double curvature canals, compared with conventional nickel-titanium rotary files. The fatigue resistance of TRUShape was superior to ProFile and Vortex Blue in double curvature canals. *(J Endod 2016;42:961–964)*

Key Words

Double curvatures, fatigue resistance, nickel-titanium instrument, ProFile, TRUShape, Vortex Blue

Nickel-titanium (NiTi) endodontic instruments were introduced more than 2 decades ago. Since their first appearance, instrument design has changed considerably; progress has been made in manufacturing as well as alloy processing. Although NiTi files have been shown to be 2–3 times more flexible than same-size stainless steel files, additional metallurgical benefits have been identified by using heat treatment (1–4). Heat treatment, either before or after machining, serves to create a more optimal phase transition point between martensite and austenite phases (4–8). Some studies (2, 3, 8) have shown that NiTi instruments made of thermomechanically treated alloy have significantly improved fatigue resistance compared with those made of conventional superelastic NiTi alloys that have not been exposed to similar thermal treatments.

NiTi rotary instrument failures in the clinic are mainly caused by cyclic fatigue, which sometimes occurs when a NiTi instrument rotates in a curved root canal (9, 10). During rotation, the instrument material is alternatively subjected to compressive and tensile stresses (11). Such stresses may initiate crack formation and propagation, eventually leading to failure (9). A straight root canal extending the entire length of the root is uncommon. The curvature may be a gradual curvature of the entire canal, a sharp curvature of the canal near the apex, or a gradual curvature of the canal with a straight apical ending. Double curvatures in the form of *S* also occur, particularly in molar teeth. In a single curvature canal, the degree and radius of curvature affect the fatigue life of files (11). Recently, studies (12, 13) demonstrated that the fatigue resistance of NiTi files in double curvature canals was lower than in single curvature canals.

Reducing the likelihood of instrument separation has been 1 of the main goals of manufacturers of rotary NiTi instruments, aiming at improved safety through innovative design and manufacturing processes. Currently, TRUShape (Dentsply Tulsa Dental Specialties, Tulsa, OK) has been introduced into the market as a novel type of heat-treated NiTi instrument. The heat treatment is applied after flutes are ground into blanks from commercially available NiTi to shape the long axis of the file into characteristic bends (14). The file set includes instruments with tip sizes of #20, #25, #30, and #40. The long axis of the file creates an S-curve, and the apical 2 mm of the file has a .06 taper. However, because of the specific shape, the overall taper of the instrument is variable. According to the manufacturer, the maximum fluted diameter for all TRUShape sizes is limited to 0.80 mm along with a regressive taper, which means that between the apical 2 mm and the shank, the average taper of TRUShape is less than .06. All instruments have the same symmetric triangular cross section. According to the manufacturer, these instruments enable dentin preservation during root canal shaping to maintain the integ-

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rity of the root structure. So far there is no information available on fatigue resistance in TRUShape files. Therefore, the purpose of this study was to evaluate and compare the fatigue resistance of ProFile (Dentsply Tulsa Dental Specialties), Vortex Blue (Dentsply Tulsa Dental Specialties), and TRUShape files in artificial single curvature canals and in 2 different artificial double curvature canals.

Materials and Methods

Instruments of ProFile, Vortex Blue (size 20/.06), and TRUShape (size 20/.06*v*) were subjected to fatigue tests inside. Each group included 12 instruments. The fatigue testing protocol has been described previously (13). Briefly, 3 types of artificial canals carved in stainless steel, all with the same size and taper of 30/.06, were used for the tests: a single curvature canal (group 1: 60° curvature, 5-mm radius) and 2 double curvature canals (group 2: a 60° coronal curvature with a 5-mm radius and an apical 30° curvature with a 2-mm radius; and group 3: a 60° coronal curvature with a 5-mm radius and a 60° apical curvature with a 2-mm radius). The ProFile and TRUShape were used at 300 rpm as recommended by the manufacturer, whereas the Vortex Blue files were used at 500 rpm until fracture. To reduce the friction between the files and the metallic canal walls, synthetic oil (Boyle Midway, Toronto, Canada) designed for lubrication of mechanical parts was applied. The time to fracture (seconds) was recorded and multiplied by the number of rotations per minute to obtain the total number of cycles to failure (NCF). The length of the fragments was measured by using a stereomicroscope at ×10 magnification (Microdissection; Zeiss, Bernried, Germany).

Three samples of fractured instruments of each file type and curvature groups were randomly selected for scanning electron microscope (SEM). The fractured files were cleansed in absolute alcohol in an ultrasonic bath, and fractographic examination of the fractured surfaces was performed by using an SEM at magnifications of ×200–1000 operating at 3 kV (Helios NanoLab 650; FEI, Eindhoven, The Netherlands).

The normality of the data was tested by Kolmogorov-Smirnov test. The data for the time to fracture, NCF, and fragment length were analyzed statistically by using two-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 means of the results. All analyses were performed at a significance level of $\alpha = 0.05$.

Results

Kolmogorov-Smirnov test showed that the data for the time to fracture and NCF were normally distributed. All files had significantly longer fatigue life in a single curvature canal than in the double curvature canals (two-way analysis of variance; $P < .05$) (Table 1). In a single curvature group (group 1), the time to fracture of TRUShape and ProFile was longer than that of Vortex Blue files (Table 1) ($P < .05$). In both double curvature canals, TRUShape had the longest time to fracture among all files ($P < .05$). The NCF of Vortex Blue files was higher than that of ProFile and TRUShape files in a single curvature (Table 1) ($P < .05$). ProFile and Vortex Blue had higher NCF in group 2 than in group 3. There was no significant difference in the NCF of TRUShape files between groups 2 and 3.

The mean length of broken fragments of ProFile and Vortex Blue files in single curvature canals was significantly longer than that of fragments in double curvature canals (groups 2 and 3) (Table 2) ($P < .05$). Half of the ProFile files in group 2 fractured in the area of the first curvature and half in the area of the second curvature. All TRUShape files in group 2 fractured in the area of the first curvature, and most of TRUShape files in group 3 (9 of 12) fractured also in the first curvature. The fragments of TRUShape files were longer than those of Vortex Blue and ProFile files in group 3 ($P < .05$). The SEM topographic appearance of the fracture surfaces showed typical features of cyclic fatigue, including crack initiation area(s) and the presence of fatigue striations and a fast fracture zone with dimples (Fig. 1). There was little difference in the fractographic appearance between the 3 files.

Discussion

The fatigue resistance in the present study was measured both as the time to fracture and as the number of revolutions until fracture (Table 1). This is important because the files have different rotational speeds. The fatigue resistance of heat-treated NiTi files in a single curvature canal has been studied extensively (2, 3, 8, 11, 15–18), and several devices and methods including a metal tube (2, 3, 11–13, 16–18) and 3-point bending pins (8, 19) have been used. The artificial canals for the fatigue test in the present study were custom-made to secure close fit without binding. Vortex Blue and TRUShape files as 2 types of heat-treated NiTi files were chosen for the fatigue test. In addition, ProFile instrument is one of the classic NiTi rotary instruments manufactured from nitinol SE 508. Therefore, the ProFile instrument was chosen as a standard made by conventional NiTi alloy. Recently, some studies (16, 19, 20) compared the fatigue behavior of files with identical design manufactured from different alloys or after different thermal treatments in a single curvature. The results showed that instruments made from heat-treated NiTi wire had significantly higher fatigue resistance than the conventional NiTi wire files with the same design. However, one study (21) showed that heat-treated size 20/.06 NiTi files made of M-Wire (GT series X instrument; Dentsply Tulsa Dental Specialties) did not have higher fatigue resistance (time to fracture and the number of revolutions until fracture) when compared with conventional superelastic NiTi files (K3; SybronEndo, Orange, CA). These contradictory results might be caused by different test conditions. Another explanation may be that small

TABLE 1. Time to Fracture (seconds) and NCF of Size 20/.06 ProFile, Vortex Blue, and TRUShape* Files in Simulated Canals with a Single Curve and 2 Different Types of Double Curves

File	Time to fracture (seconds) ($n = 12$)			NCF (mean ± standard deviation) ($n = 12$)		
	Single curvature ($\theta = 60°$)	Double curvature ($\theta1 = 60°$, $\theta2 = 30°$)	Double curvature ($\theta1 = 60°$, $\theta2 = 60°$)	Single curvature ($\theta = 60°$)	Double curvature ($\theta1 = 60°$, $\theta2 = 30°$)	Double curvature ($\theta1 = 60°$, $\theta2 = 60°$)
ProFile	163 ± 20[a]	85 ± 34[c]	59 ± 5[e]	817 ± 35[f]	427 ± 170[h]	290 ± 16[j]
Vortex Blue	134 ± 13[b]	80 ± 7[c]	62 ± 6[e]	1113 ± 108[g]	666 ± 60[i]	516 ± 52[h,k]
TRUShape	165 ± 22[a]	103 ± 13[d]	111 ± 19[d]	841 ± 80[f]	516 ± 66[h,k]	557 ± 97[k]

Different superscript letters indicate statistically significant difference ($P < .05$).

*Vortex Blue was used at 500 rpm and other files at 300 rpm.