Effect of Fatigue on Torsional Failure of Nickel-Titanium Controlled Memory Instruments

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Abstract

Introduction: The purpose of this study was to understand how fatigue affects the torsional properties of both traditional nickel-titanium (NiTi) and NiTi controlled memory (CM) files. **Methods:** Typhoon (TYP; Clinician's Choice Dental Products, New Milford, CT) 25/.04 and 40/.04 rotary files in both NiTi and CM were tested to obtain the mean number of cycles of failure (N_f) using a 3-point bending apparatus. New files were then precycled to 4 conditions (0%, 25%, 50%, and 75% of the N_f), and torsional resistance tests were performed. Each file was exposed to torsional stress until failure, and at that point the torque and distortion angles were measured. The fracture surface of each fragment was examined with a scanning electron microscope. **Results:** TYP CM files had an N_f 7 times higher than that of TYP files ($P < .05$). No difference in torque between the CM files and the conventional NiTi files of either file size was detected ($P > .05$). The torque of the size 40/.04 files was significantly higher than the torque of the size 25/.04 files ($P < .05$). In the 40/.04 files group, TYP files in the 75% precycling group had a significantly lower torque than files in the group with no precycling ($P < .05$), whereas slight precycling (25%) significantly reduced the distortion angle on TYP CM files ($P < .05$). The CM files of both sizes had a significantly higher distortion angle than the corresponding NiTi files ($P < .05$). The fractured files in the precycling groups showed the typical pattern of torsional failure. **Conclusions:** Within the same amount of precycling (25%, 50%, and 75%), the cyclic fatigue life of TYP CM instruments was significantly higher than that of the TYP instruments. However, the torque value of TYP CM was similar to TYP files. The larger instruments were not only less resistant to cyclic fatigue but were affected most by prestressing of both TYP and TYP CM files. *(J Endod 2014;40:562–565)*

Key Words

Controlled memory, endodontic, fatigue, nickel-titanium instrument, torsion

In the mid-1990s, nickel-titanium (NiTi) instruments were introduced to clinical practice, and in a few years they became the dominant type of root canal instrumentation in many countries. NiTi instruments are made of a superelastic alloy, which allows the files to follow the curvatures of canals better than steel instruments. Experimental and clinical evidence suggests that the use of NiTi instruments with rotary movement results in improved preparation quality (1, 2). Despite numerous advantages, there is concern about the incidence of instrument fracture during root canal preparation (3, 4).

It has been reported that fracture of a NiTi instrument may occur from either torsional or flexural fatigue or both in combination (3, 5). The following factors contributing to instrument failure have been described: the skill level of the operator, instrumentation technique, instrument design, instrument size and radius of curvature, surface condition, rotation rate, and so on (4–8). Torsional fracture occurs when the torque resulting from the contact between the instrument and canal wall exceeds the torsional strength of the instrument or when the instrument tip is locked in a canal while the rest continues to rotate. Fracture caused by flexural fatigue occurs when a rotary endodontic instrument that has already been weakened by metal fatigue is placed under stress. For a better understanding of the fracture mechanism, several factors must be considered, but the simulation of all these factors in laboratory conditions is difficult (3, 6, 8–10). Therefore, these factors are frequently considered separately.

Heat treatment (thermal processing) is 1 of the fundamental approaches toward adjusting the transition temperatures of NiTi alloys and affecting the fatigue resistance of NiTi endodontic files (9, 11–15). Several novel thermomechanical processing and manufacturing technologies have been developed to optimize the microstructure of NiTi alloys. Recently, NiTi rotary instruments (Typhoon CM; Clinician's Choice Dental Products, New Milford, CT) made from NiTi wire subjected to proprietary thermomechanical processing (controlled memory [CM] wire) have been introduced into the market. The CM wire technology has made the NiTi instruments more resistant to cyclic fatigue than conventional superelastic NiTi instruments (16, 17). It is expected that thermomechanically treated NiTi instruments maintain the same torsional properties as conventional superelastic NiTi instruments (18). It is likely that torsional and fatigue forces happen simultaneously during root canal preparation, but little information is available on the subject. Moreover, how previous exposure to fatigue may affect the properties of thermomechanically treated wire, such as CM files, has been unknown. Therefore, the aim of this study was to evaluate the effect of cyclic fatigue on torsional failure of Typhoon CM instruments.

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TABLE 1. The Number of Revolutions until Fracture of Typhoon NiTi and CM Files at a Curvature of 46° with a 9.5-mm Radius in Water Condition

Files	Size 25/.04[a]	Size 40/.04[b]
Typhoon NiTi[c]	579 ± 119	320 ± 52
Typhoon CM[d]	3968 ± 632	2143 ± 307

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

Materials and Methods

The fatigue testing protocol has been described previously and was reproduced throughout the experimental period (16, 17). Briefly, each NiTi instrument was constrained to a curvature by 3 rigid, stainless steel pins; a calibrated digital photograph of the curvature was taken. The instrument was then allowed to rotate at 500 rpm (as recommended by the manufacturers) until fracture. The fatigue life, or the total number of revolutions to failure, was recorded.

NiTi rotary instruments of Typhoon (TYP, Clinician's Choice Dental Products) and Typhoon CM were subjected to rotational bending at a curvature of 46° with a 9.5-mm radius in deionized water at the temperature of 23° ± 2°C. Only a 16-mm length from the tip of the instrument was immersed in the liquid medium during the test to avoid galvanic action between the instrument and its handle (17). The fatigue resistance of size 25/.04 and 40/.04 TYP and TYP CM instruments was tested. Each group included 12 instruments. In order to evaluate the effect cyclic fatigue may have on torsion, cyclic preloading was performed on the files under 4 conditions. In other words, 12 files of each type and size were exposed to 0%, 25%, 50%, or 75% of their respective mean fatigue life at 500 rpm.

After cyclic preloading to various extents, torsional loading tests were performed in a torsion tester until rupture to establish the mean values of torque to failure and maximum angular deflection (9). The torsion tests were performed according to ISO 3630-1 (19) using a torsion machine. The rotation speed was set clockwise to 2 rpm. Before testing, each instrument handle was removed at the point where the handle is attached to the shaft. The end of the shaft was clamped into a chuck connected to a reversible geared motor. Three millimeters of the instrument's tip were clamped in another chuck with brass jaws to prevent sliding. The torsional load and distortion angle were recorded until the file broke.

The fracture surfaces of all fragments were examined under a scanning electron microscope (Stereoscan 260; Cambridge Instruments, Cambridge, UK). The region in which the dimple area could be found was outlined on the photomicrograph for fatigue failure groups and measured with ImageJ 1.4 g software (National Institutes of Health, Bethesda, MD) on each photomicrograph. The results were analyzed using the *t* test, 1-way analysis of variance, or post hoc analysis using software (SPSS for Windows 11.0; SPSS, Chicago, IL) when necessary at a significance level of $P < .05$.

Results

In both size 25/.04 and size 40/.04, TYP CM instruments subjected to fatigue testing had a significantly higher number of revolutions before failure when compared with conventional NiTi TYP instruments (Table 1) ($P < .05$). Also, the fatigue resistance of the size 25/.04 group was higher than that of the size 40/.04 group in both TYP and TYP CM instruments (Table 1) ($P < .05$).

In size 25/.04, there was no difference in torque between the CM files and the conventional NiTi files (Table 2) ($P > .05$). The torque of the size 40/.04 files was significantly higher than the torque of the size 25/.04 files ($P < .05$). There was no significant difference of torque value and distortion angle on both TYP CM and TYP instruments of size 25/.04 between the precycling and no precycling groups. In the 40/.04 TYP group, the 75% precycling group had a significantly lower torque than the no precycling group ($P < .05$). Within the TYP CM 40/.04 group, the preloading groups (25%, 50%, and 75%) had a smaller distortion angle until fracture compared with the no preloading group ($P < .05$). The CM files of both sizes had a significantly higher distortion angle than conventional NiTi files of both sizes ($P < .05$).

Fractographically, in instruments failed by fatigue only, TYP CM instruments had a higher number of multiple crack origins than TYP files (Fig. 1*A*). Also, the areas occupied by the dimple region of the total surface area of the fractured cross-sections in these files were smaller in TYP CM instruments (Fig. 1*A*) than in TYP instruments (Fig. 1*B*). After the torsion tests, all fracture surfaces revealed the typical pattern of torsional fracture characterized by circular abrasion marks and skewed dimples near the center of rotation (Fig. 1*C–F*).

Discussion

The aim of this study was to provide deep insight into the effect of cyclic fatigue on torsional failure of Typhoon CM instruments by varying the amount of cyclic preloading. Cyclic fatigue of NiTi rotary instruments has been studied extensively under simulated conditions (20). The fatigue resistance of TYP CM files has been evaluated as an isolated process. Limited information about torsional resistance is available about the thermomechanically treated TYP CM files. The torsional property of another CM instrument (Coltène Hyflex CM; Coltène Whaledent, Cuyahoga Falls, OH) manufactured from a similar alloy has been reported recently (21). It is known that rotary instruments experience both cyclic fatigue and torsional stress simultaneously when actively cutting dentin in curved canals (22). However, there is a scarcity of reports that examine the combined effect of these 2 factors on instrument fracture. In the present study, the third millimeter from the tip was selected on

TABLE 2. Resistance to Torque of Typhoon NiTi and CM Files after Cyclic Precycling of the mNCF

	Size 25/.04						Size 40/.04					
	Typhoon CM			Typhoon NiTi			Typhoon CM			Typhoon NiTi		
Cyclic preloading of mNCF	N_f	Torque[g] (N· mm)	Distortion Angle[a] (°)	N_f	Torque[g] (N· mm)	Distortion Angle[b] (°)	N_f	Torque (N· mm)	Distortion Angle[c] (°)	N_f	Torque (N· mm)	Distortion Angled (°)
0	0	3.85 ± 0.47	792 ± 50	0	3.63 ± 0.89	500 ± 61	0	11.29 ± 0.78	924 ± 108[e]	0	13.38 ± 2.60[g]	412 ± 37
25%	992	3.56 ± 0.40	743 ± 58	147	3.30 ± 0.33	486 ± 39	536	12.16 ± 1.14	750 ± 60[f]	80	12.12 ± 1.59	430 ± 44
50%	1984	3.36 ± 0.35	747 ± 75	290	3.44 ± 0.36	479 ± 36	1072	12.13 ± 1.11	738 ± 106[f]	160	12.43 ± 1.38	417 ± 36
75%	2976	3.33 ± 0.66	778 ± 93	434	3.48 ± 0.44	482 ± 25	1608	11.26 ± 1.52	712 ± 109[f]	240	10.63 ± 1.38[h]	447 ± 44

mNCF, mean number of cycles to fracture; N_f, the total number of revolutions to failure; NiTi, nickel-titanium.

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