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Effect of cyclic torsional preloading on cyclic fatigue resistance of ProTaper Next and Mtwo nickel—titanium instruments

Influenza della torsione sulla resistenza alla fatica ciclica di strumenti in Ni-Ti

Eugenio Pedullà [a,*], Fabio Lo Savio [b], Gianluca Plotino [c], Nicola Maria Grande [c], Silvia Rapisarda [a], Gianluca Gambarini [c], Guido La Rosa [b]

[a] *Department of Surgery, University of Catania, Catania, Italy*
[b] *Department of Industrial Engineering, University of Catania, Catania, Italy*
[c] *Department of Endodontics, 'Sapienza' University of Rome, Rome, Italy*

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KEYWORDS
Cyclic fatigue resistance;
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Abstract
Aim: To evaluate the influence of different torsional preloads on cyclic fatigue resistance of endodontic rotary instruments made by conventional nickel—titanium (NiTi) or M-Wire.
Methods: Eighty new Mtwo (#25/0.06) (Sweden & Martina, Due Carrare, Padova, Italy) and ProTaper Next X2 (Dentsply Maillefer, Ballaigues, Switzerland) were used. The Torque and distortion angles at failure of new instruments ($n = 10$) were measured and 0% ($n = 10$), 25%, 50%, and 75% ($n = 20$) of the mean ultimate torsional strength as preloading condition were applied according to ISO 3630-1 for each brand. The twenty files tested for every extent of preload were subjected to 25 or 50 torsional cycles ($n = 10$). After torsional preloading, the number of cycles to failure was evaluated in a simulated canal with 60° angle of curvature and 5 mm of radius of curvature. Data were analyzed using 2-way analysis of variance. Scanning electron microscope (SEM) was performed to evaluate the fracture surface of each fragment.

* Corresponding author at: Via Cervignano 29, 95129 Catania, Sicily, Italy. Tel.: +39 339 2613264.
E-mail: eugeniopedulla@gmail.com (E. Pedullà).

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Results: ProTaper Next X2 reduced their cyclic fatigue after 25 or 50 cycles of every torsional preloading (25%, 50%, and 75%) ($P < 0.01$). Cyclic fatigue of Mtwo was reduced by 50 cycles of every torsional preloading and only after the 75% of preload for 25 cycles ($P < 0.01$).
Conclusions: Torsional preloads reduced the cyclic fatigue resistance of M-wire and conventional (as ProTaper Next and Mtwo) NiTi rotary instruments except for Mtwo with 25% or 50% of torsional preloading.

PAROLE CHIAVE
Resistenza alla fatica ciclica;
precarico torsionale;
frattura strumenti in Nichel-Titanio;
M-wire;
frattura torsionale.

Riassunto
Obiettivo: Scopo del lavoro è stato valutare l'influenza di diversi precarichi torsionali sulla resistenza a fatica ciclica degli strumenti rotanti endodontici in nickel-titanio (NiTi) convenzionale o M-Wire.
Metodi: Sono stati utilizzati ottanta Mtwo (# 25/0,06) (Sweden & Martina, Due Carrare, Padova, Italia) e ProTaper Next X2 (Dentsply Maillefer, Ballaigues, Svizzera): La coppia e l'angolo di distorsione necessari per la frattura di strumenti nuovi (n = 10) sono stati misurati e un valore pari a 0% (n = 10), 25%, 50% e 75% (n = 20) della resistenza torsionale media finale è stata applicata come condizione di precarico secondo la norma ISO 3630-1 per ogni marca. I venti file testati per ogni tipologia di precarico sono stati sottoposti a 25 o 50 cicli torsionali (n = 10). Dopo precarico torsionale è stato valutato in un canale simulato, con 60° di angolo di curvatura e 5 mm di raggio di curvatura, il numero di cicli a frattura (NCF). I dati sono stati analizzati mediante analisi della varianza a 2 vie. Microscopia elettronica a scansione (SEM) è stata eseguita per valutare la superficie di frattura di ciascun frammento.
Risultati: I ProTaper Next X2 hanno ridotto la loro resistenza a fatica ciclica dopo 25 o 50 cicli di ogni precarico torsionale (25%, 50%, e il 75%) ($P <.01$). La resistenza a fatcica cilcica degli strumenti Mtwo è stata ridotta da 50 cicli di ogni precarico torsionale e solo dopo il 75% di precarico per 25 cicli ($P <.01$).
Conclusioni: Il precarico torsionale ha ridotto la resistenza alla fatica ciclica di strumenti in NiTi convenzionale e M-wire (come Mtwo e ProTaper Next) ad eccezione degli Mtwo che hanno subito il 25% o il 50% di precarico torsionale.

Introduction

Unexpected nickel—titanium (NiTi) rotary instrument separation during use is a concern[1—4] and has a potential effect on the outcome of treatment.[5]

Many variables might contribute to file separation, but the 2 main causes are cyclic fatigue and torsional fatigue. Each has been adequately defined in endodontic literature[6,7] and clinically, cyclic fatigue seems to be more prevalent in curved root canals, whereas torsional failure might happen even in a straight canal.[8]

Although both these failure modes probably occur simultaneously in a clinical situation,[6] studies have found cyclic fatigue to be the primary cause of file separation.[9]

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.[10,11]

Instrument fractured by fatigue rotates freely in a curvature, generating tension/compression cycles at the point of maximum flexure until the fracture occurs.[12]

Manufacturers are constantly attempting to improve files. M-wire was recently introduced as innovative systems that have a higher cyclic fatigue resistance than conventional NiTi. The M-wire NiTi, as the novel file system ProTaper Next (Dentsply Maillefer, Ballaigues, Switzerland), is subjected to thermomechanical processing resulting in a reported increased flexibility.[13,14]

Many fracture simulation studies of NiTi files have been conducted separately for a cyclic fatigue or torsional failure test.[6,15] Only few studies have tried to correlate these 2 factors of fracture.[16—19] Some reports[16,17] have found that the cyclic preloading (preuse) of NiTi rotary files would reduce the torsional resistance significantly. However, to date, few studies with contrasting findings have investigated the potential effect on cyclic fatigue resistance by torsional preloading.[18,19] In particular, no studies have investigated the influence of torsional preloading on cyclic fatigue resistance of endodontic rotary instruments made by traditional NiTi or M-Wire as Mtwo (Sweden & Martina, Due Carrare, PD, Italy) and ProTaper Next.

The aim of this study was to evaluate the effect of different torsional preload on the cyclic fatigue resistance of NiTi rotary instruments made by NiTi or M-Wire.

Materials and methods

A total of 160, 25-mm-long, new files Mtwo and ProTaper Next X2, eighty for each brand and all size #25 with a 0.06 taper were tested. Ten instruments for every brand were torsionally tested until fracture to estimate their mean ultimate torsional strength. Four torsional preloading conditions were

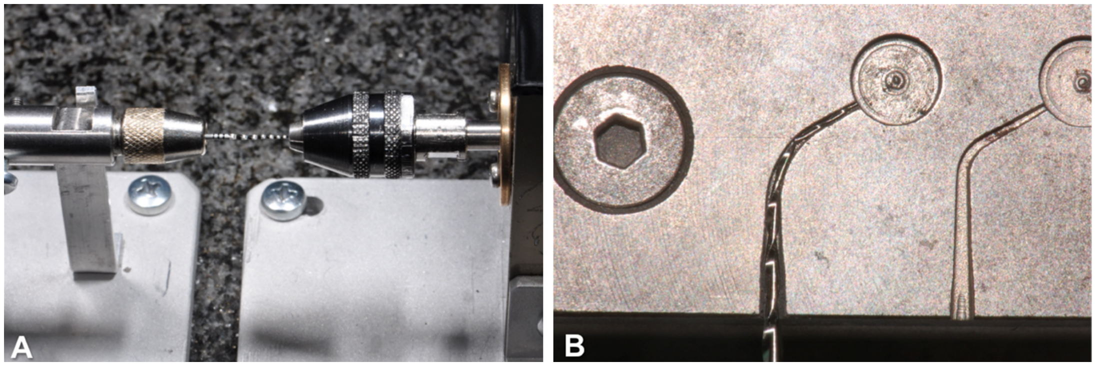

Figure 1 Custom-made torsional device produced following the ISO 3630-1. (A) ProTaper Next X2 clumped at 5 mm from the tip by the chuck. (B) Mtwo #25/.06 instrument broken at 5 mm from the tip after the cyclic fatigue test using an artificial canal.

applied to the remaining instruments of each brand: 0% or no preloading ($n = 10$) and 25%, 50%, and 75% of the mean ultimate torsional strength ($n = 20$ each). The twenty files tested for every extent of torsional preloading were subdivided in two subgroups ($n = 10$) on the basis of the number of preloading cycles performed (25 or 50 torsional cycles). The torsional load until fracture and established torsional preloads were applied using the same custom-made device produced following the ISO 3630-1 (Fig. 1A).

Each file was clamped at 5 mm from the tip using a chuck connected to a torque-sensing load cell, after which the shaft of the file was fastened into an opposing chuck able to be rotated with a stepper motor. Each file shaft was rotated in the clockwise direction at a speed of 2 revolutions per minute until file separation or the preset torque value (25%, 50%, and 75%). When the preset torque value was achieved, the motor automatically moved in counterclockwise direction, at the same rotational rate, until the instrument returned in the original position (i.e., strain = 0). This motion was repeated until the preset number of repetitions (25 or 50) was reached. The torque load (Ncm) and angular rotation (°, degrees) were monitored continuously by using a torsiometer (Sabri Dental Enterprises, Downers Grove, IL) at room temperature (20 °C ± 1 °C), and the ultimate torsional strength and angle of rotation at failure were recorded.

After torsional preloading, a static model for cyclic fatigue testing was conducted in an artificial curved canal of a custom-made device already used in many published studies.[8,12,15,20] The artificial canal was manufactured by reproducing the instrument's size and taper and it had 5 mm radius of curvature (measured at the internal concave surface of the artificial canal), 60° angle of curvature measured according to the Schneider's method,[21] a center of curvature at 5 mm from the end of the canal and a curved segment of 5 mm in length (Fig. 1B). The files were activated by using a 6:1 reduction handpiece (Sirona Dental Systems GmbH, Bensheim, Germany) powered by a torque-controlled motor (Silver Reciproc; VDW, Munich, Germany) at a speed of 300 rpm. To reduce friction between the instrument and the metal canal walls, a special high-flow synthetic oil designed for the lubrication of mechanical parts (Super Oil; Singer Co Ltd, Elizabethport, NJ) was applied. All instruments were rotated until a fracture occurred. The time was recorded and stopped when a fracture was detected visually and/or audibly.

The number of cycles to failure (NCF) for each instrument was recorded. The length of the fractured file tip was measured by using a digital microcaliper (Mitutoyo Italiana srl, Lainate, Italy).

The fracture surfaces of all fragments were examined under a Scanning Electron Microscope (SEM) (ZEISS Supra 35VP, Oberkochen, GmBH, Germany) looking for topographic features of the fractured instruments.

NCF data were analyzed by using 2-way analysis of variance and the Bonferroni post hoc test (Prism 5.0; GraphPad Software, Inc., La Jolla, CA) at 0.05 as level of significance.

Results

The mean torque load and angle of rotation until fracture are presented in Table 1.

Every amount (75%, 50% and 25%) of torsional preloading significantly decreased the cyclic fatigue resistance of all nonpreloaded (0%) ProTaper Next X2 either after 50 or after 25 cycles ($P < 0.0001$ and <0.001 respectively). Every amount of torsional preloading reduced cyclic fatigue resistance of the new Mtwo 25/0.06 after 50 cycles ($P < 0.01$). However, only Mtwo instruments preloaded at 75% of the maximum torsional strength showed a reduced cyclic fatigue after 25 cycles ($P < 0.05$) (Table 2).

Table 1 Mean torque (Ncm) and angle of rotation (°) of instruments tested.

Instrument	Torque (Ncm)				Angle of rotation (°)			
	Mean	Standard deviation	Min	Max	Mean	Standard deviation	Min	Max
ProTaper Next X2	1.30[a]	0.20	0.92	1.70	262.24[c]	20.61	220	285
Mtwo #25/.06	0.94[b]	0.15	0.77	1.18	348.73[c]	71.43	235	430

Different superscript letters indicate statistic differences among groups ($P < 0.05$).

Table 2 Number of cycles to failure (NCF) (mean ± standard deviation) after different percentage and cycles of torsional preloading.

File	Without torsional preloading (0%)	RNTP	Torsional preloading		
			25%	50%	75%
ProTaper Next X2	405 ± 30[a]	25	290 ± 20[c]	272 ± 53[c]	265 ± 37[c]
		50	212 ± 51[c]	220 ± 90[c]	203 ± 65[c]
Mtwo	606 ± 26[b]	25	510 ± 47[d]	502 ± 122[d]	427 ± 101[d]
		50	398 ± 81[d]	403 ± 93[d]	352 ± 98[d]

Different superscript letters indicate statistic differences among groups ($P < 0.05$).

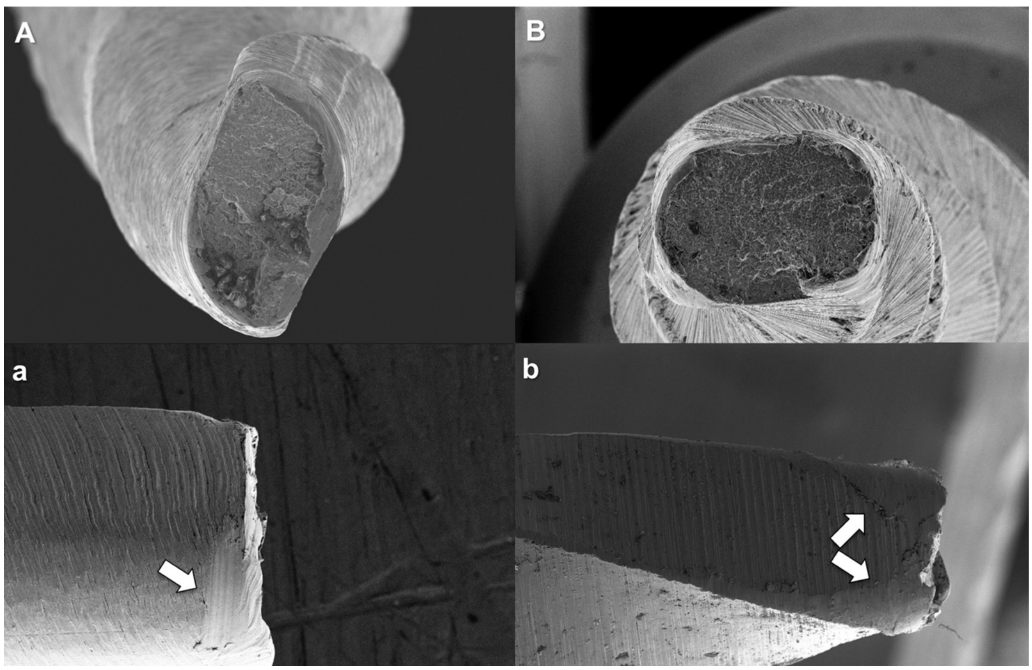

Figure 2 SEM appearances of the torsionally preloaded instruments (75% for 50 cycles) after fatigue test (A,a: Mtwo; B, b: ProTaper Next). (A, B) Fracture surface of preloaded files at 75% of the ultimate torsional strength for 50 cycles and their lateral view (a, b). Dimples involve all fracture surface of torsionally preloaded instruments fractured by cyclic fatigue test. Smoothed borders (white arrows) due to the torsional preload are visible in lateral view.

The length of the fractured files was not statistically different for all of the instruments tested ($P > 0.05$) and it ranged from 4.5 to 6.2 mm (mean = 5.2 mm).

SEM of the fracture surface showed similar features of torsional failure with fibrous dimples at the center of rotation for instruments tested only at torsion. Dimples are visible in all fracture surfaces of the instruments tested for cyclic fatigue. Dimples in the all fracture surface (Fig. 2A and B) and smoothed borders (Fig. 2a and b) were found in the torsional preloaded files broken in the following cyclic fatigue test.

Discussion

Endodontic instruments are subjected to both torsional and flexural stresses during root canal preparation and these types of stress can lead to metal fatigue and failure.[18]

There are only few studies that have investigated either the effect of cyclic fatigue preloading on the torsional resistance[16,17,22] or the effect of torsional preloads on the cyclic fatigue resistance of conventional NiTi instruments. 18,19,23 However, no data have been reported on the influence of torsional preloading on cyclic fatigue of instruments made by different NiTi alloys. Therefore, in this study, M-wire (ProTaper Next) and conventional NiTi files (Mtwo) were compared for the effect of different torsional preloads on their cyclic fatigue resistance.

NCF value of instruments, tested in custom made devices, is usually used to investigate cyclic fatigue resistance.[24–26] On the other hand, the ISO standard 3630-1[16,18,23] is often used to measure torsional strength of NiTi instruments. In this study, cyclic fatigue was measured by NCF testing the files in a custom made device already used in previous study,[8,15,25] while the torsional loads were applied following the ISO Standard 3630-1 modified only for clamping the testing instruments at the D5 than at the D3 level. This modification was performed in order to provide the torsional preloads at the same level of the maximum stress of the subsequent cyclic fatigue where it was used an artificial canal with 5 mm of radius of curvature.

The broken fragment after the fatigue tests showed an average length of 5 mm that coincided with the site of torsional preloading application (at D5).

Although the comparison among the different instruments is difficult to make because of their differences in design and cross-section, in this study, new files without torsional preloads Mtwo showed significantly higher cyclic fatigue resistance than ProTaper Next ($P < 0.001$). On the other hand, new ProTaper Next X2 showed significantly higher value of the mean ultimate torsional strength than Mtwo #25/0.06 ($P < 0.001$). These results are in agreement with a recent study that has reported higher cyclic fatigue resistance of Mtwo than ProTaper Next.[27] Even if no previous studies have compared the torque resistance of Mtwo and ProTaper Next, recently it was reported that instruments made by M-wire as ProTaper Next have higher torsional resistance than instruments made by conventional NiTi as Mtwo[28] (Table 1).

Analyzing the influence of torsion on cyclic fatigue, in agreement with other reports in literature, the number of torsional preload repetitions used (25 or 50 cycles) did not affect the cyclic fatigue resistance of the ProTaper Next after every amount and Mtwo after the 75% of torsional preload.[19] However, Mtwo torsionally preloaded up to the 50% of their maximum torsional strength reduce their cyclic fatigue when 50 cycles was performed, but no after 25 cycles. This finding is probably due to the cross-section and design of Mtwo instruments that are capable to not reduce their cyclic fatigue resistance after a medium torsional stress (up to 50%) applied for a reduced number of cycles (25 cycles).

On the other hand, the extent of torsional pre-loads reduced the cyclic fatigue resistance of the instruments tested especially when 75% of the mean ultimate torsional strength was applied. These results are in agreement with other studies in literature that have shown a reduced cyclic fatigue resistance of conventional NiTi instruments, as K3, after their torsional pre-load.[18,23] However, another recent study has shown that the torsional preloads may improve the cyclic fatigue resistance of conventional nickel—titanium rotary instruments as ProFile and ProTaper F1.[19] These contrasting findings are probably due to the different instruments and methodology used. Moreover in this last study torsional preloads were applied at 5 mm from the tip, but the cyclic fatigue test was performed in an artificial canal with 7.8 mm of radius of curvature; thus, the two stresses were performed in different parts of instruments making it difficult to draw conclusions on the influence of torsional stress on cyclic fatigue of the tested instruments.

The SEM analysis showed typical fractographic appearances of torsional and/or cyclic fatigue fractures similar among the 2 brands tested (Fig. 2). Dimples on the entire fracture surface characterize cyclic fatigue fracture, while torsional failure is characterized by circular abrasion marks and dimples near the center of rotation on the fracture surface.[11,17,29]

In this study, when the cyclic fatigue test was applied after the incomplete torsional test, instruments of all brands showed typical cyclic fatigue fracture pattern at the SEM evaluation. Therefore, in preloaded instruments, as previously reported,[17] the fractographic findings corresponded to those ones due to the last test performed (cyclic fatigue in this report).

Conclusions

Within the limitations of this study, it could be concluded that torsional preloads reduced the cyclic fatigue resistance of conventional and M-wire NiTi rotary instruments except for Mtwo #25/0.06 preloaded by a medium torsional stress for few cycles (25% or 50% of torsional preloading applied for 25 cycles).

Clinical relevance

ProTaper Next are able to resist to high torsional stress whenever they are used in narrow root canals, while Mtwo endures high flexural stress whenever they are used in curved root canals.

Conflict of interest

The authors deny any conflicts of interest.

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