In Vitro Assessment of Torque and Force Generated by Novel ProTaper Next Instruments during Simulated Canal Preparation

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Abstract

Introduction: The purpose of this study was to assess torque and force for simulated canal preparation with a new root canal instrument, ProTaper Next. **Methods:** Six sets of ProTaper Next Instruments (X1–X5) were used to prepare 36 artificial canals. Files were divided into 6 groups. Different settings of rotations per minute (250, 300, and 350 rpm) and numbers of in-and-out movements to reach working length (3 or 4 insertions [ins]) were applied in each group (250 rpm/3 ins, 250 rpm/4 ins, 300 rpm/3 ins, 300 rpm/4 ins, 350 rpm/3 ins, and 350 rpm/4 ins) by using an automated torque bench. Peak torques (Ncm) as well as positive and negative forces (N) were registered. Analysis of variance and Tukey post hoc tests were applied. Preliminary data for angle and stationary torque at failure were also obtained and compared with peak torque for each instrument. **Results:** Significant differences in peak torque ($P < .0001$), positive force ($P < .002$), and negative force ($P < .0001$) were found for ProTaper Next instruments overall. X2 showed the highest torque with all settings. X5 showed the highest positive force in all groups. X1 and X2 showed the highest negative forces for all groups except for 350 rpm/4 ins. Significantly lower torque ($P < .0001$) and positive force ($P < .007$) were measured in the group 350 rpm/4 ins for all instruments except for X4. In contrast, X1 showed a significantly lower negative force for 350 rpm/4 ins. Torque at failure according to American Dental Association no. 28/ISO 36030-1 was lower for X1, X2, and X3 than torque during simulated canal preparation ($P < .0001$). **Conclusions:** Under the conditions of this study, using ProTaper Next at 350 rpm and with 4 in-and-out movements resulted in lowest levels of peak torque as well as positive and negative forces. *(J Endod 2013;39:1615–1619)*

Key Words

Nickel-titanium, ProTaper Next, torque, simulated preparation

Nickel-titanium (NiTi) rotary instruments are increasingly used in root canal preparation. Development continues to design rotaries that render shaping not only easier and faster but are also more likely to lead to improved outcomes, compared with stainless steel hand instruments (1). However, despite increased flexibility and torsional strength compared with stainless steel instruments (2), NiTi rotary instruments still seem to have a risk of fracture in the clinical situation (3, 4).

Failure modes of NiTi instruments have been studied extensively (3–9). Flexural fatigue is caused by repetitive compressive and tensile stresses acting on outer fibers of a file rotating in a curved canal; torsional failure occurs when the tip of the instrument binds, but the shank of the file continues to rotate (3). Shear fracture of the material then occurs when the maximum strength of the material is exceeded (7).

The torque generated by a rotating instrument during root canal instrumentation depends on the contact area between the file and the canal walls, the applied apical force, instrument diameter, and preoperative canal volume (10–12). In turn, mechanical properties of endodontic instruments are affected by a variety of factors such as size, taper, design, alloy chemical composition, and thermomechanical processes applied during manufacturing (13–15).

It is believed that there is a strong positive correlation between the maximum torque an instrument can withstand and its diameter (12, 16). It has also been suggested that the cross-sectional shape of instruments affects the stress distribution pattern and thus their torsional resistance (17, 18). Moreover, flexural fatigue developed during curved root canal shaping may decrease the torsional resistance of endodontic instruments (12, 19–21).

ProTaper Next is a novel set of rotary instruments that are designed with variable tapers and an off-centered rectangular cross section. The set includes 5 shaping instruments with overall variable tapers; at the tip, X1 is #17/.04, X2 is #25/.06, X3 is #30/.075, X4 is #40/.06, and X5 is #50/.06. All the instruments are expected passively to follow the canal until the working length (WL) is achieved (22).

Such a single length technique possibly requires greater torsional strength of a given instrument because of greater contact with the dentin walls resulting in high stresses on its entire length (11). However, the system features an off-centered rectangular cross section, which is intended to reduce torsional stress on the instrument (22).

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Supported by the Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG), Belo Horizonte, MG, Brazil, and Pró-Reitoria de Pesquisa da Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brazil.

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0099-2399/$ - see front matter

http://dx.doi.org/10.1016/j.joen.2013.07.014

These instruments are manufactured from so-called M-Wire raw material, which was shown to possibly extend fatigue life beyond conventional NiTi alloy (23).

Currently there are no data available on torque and force during canal preparation with ProTaper Next used according to the current Directions for Use. Hence, the aim of this study was to determine baseline peak torque as well as positive and negative forces among ProTaper Next instruments during simulated canal preparation. Also, different rotations per minute (rpm) and insertion settings were compared to suggest the optimum speed and overall handling those instruments should be subjected to during their use in root canal treatments.

Materials and Methods

Six sets of ProTaper Next Instruments (X1, X2, X3, X4, and X5) were used to prepare 36 simulated root canals in plastic blocks (A 0177; Dentsply Maillefer, Ballaigues, Switzerland) in a standardized fashion.

According to rotational speed (250, 300, or 350 rpm) and insertion pattern (3 or 4 insertions [ins]), rotaries were divided into 6 groups (250 rpm/3 ins, 250 rpm/4 ins, 300 rpm/3 ins, 300 rpm/4 ins, 350 rpm/3 ins, and 350 rpm/4 ins).

Canals were initially lubricated with liquid soap and instrumented by the same operator throughout the study. Sizes #10 and #15 K-files were used to confirm a glide path and to establish WL, which was set at 16 mm.

Subsequent tests were run in a standardized automated fashion in a torque-testing platform, which has been described in detail earlier (16, 20). In brief, plastic blocks were secured into a rigid holder that was attached to a strain gauge connected to a pre-amplifier (A&D 30; Orientec, Tokyo, Japan). The bench was then configured to determine torque and force during canal preparation. A torque sensor (MTTRA 2, with amplifier Microtest; Microtec Systems, Villingen, Germany) and a motor (Type ZSS; Phytron, Gröbenzell, Germany) were mounted on a stable metal platform, which moved along a low friction guide rail for a width of approximately 5 cm. A linear potentiometer (Lp-100; Midori, Osaka, Japan) was attached to the sliding platform to record linear movements.

Following preliminary experiments 2 sequences for instrument insertion were programmed to allow fully automated canal preparation: reaching WL with 3 more aggressive or 4 less forceful instrument insertions. These patterns were the same for all 5 ProTaper Next sizes.

The sequence originally recommended by the manufacturer was followed to shape the simulated canals; X1–X5 were used to WL. Before each use and on completion of simulated shaping procedures, instruments were inspected for plastic deformation.

Peak torques (Ncm) as well as positive and negative peak forces (N) were registered by using the custom-made Endotest software package (16) and collected for off-line analysis.

For comparison, an initial analysis of torsional limits of ProTaper Next was performed with 6 samples of each instrument. Stationary torque (Ncm) and angle (°) at failure during clockwise rotation were tested according to American National Standards Institute/American Dental Association Specification no. 28 (ISO3630-1) by using the same torque-testing device. In accordance with this specification, a soft brass chuck was fitted to the specimen holder, and the apical 3 mm of each instrument was secured. Rotation was set at 2 rpm, and torque was recorded in relation to angular deflection with an accuracy of 0.5° until failure.

Data for peak torque as well as positive and negative peak forces were found to be compatible with normal distribution, and standard deviations of subgroups were similar. Results were analyzed with analysis of variance, and when it showed significant differences, Tukey post hoc tests were used to compare subgroups.

One-sample *t* test was also used to compare peak torque during simulated canal preparation with stationary torque at failure for each individual instrument.

Results

The first set of analyses examined the impact of simulated torque. There were significant differences in peak torque ($P < .0001$) for the different settings. As illustrated in Figure 1, ProTaper Next X2 showed the highest torque (statistically significant in all groups), followed by X1 (statistically significant in groups 250 rpm/4 ins, 300 rpm/3 ins, and 350 rpm/3 ins). See Supplemental Table S1 for raw torque and force data. (Supplemental content is available online at www.jendodon.com.)

Table 1 shows the torque (Ncm) and angle (°) at failure at 3 mm from the tip. Torque at failure was lower for X1, X2, and X3 than torque during simulated canal preparation ($P < .0001$).

There were also significant differences in peak force ($P < .002$) for the different settings. As shown in Figure 2, X5 showed significantly higher peak force (statistically significant in all groups), followed by X4 (statistically significant in groups 250 rpm/4 ins, 300 rpm/4 ins, and 350 rpm/4 ins).

In relation to negative force and as illustrated in Figure 2, the only significant differences that were found were the highest negative force for X1 and X2 when compared with X3, X4, and X5 ($P < .0001$) for all groups except for 350 rpm/4 ins, in which the only file with a different higher significant value was X2.

When results of different groups were compared for each file, significantly lower torque ($P < .0001$) and lower peak force ($P < .007$) were shown in the group 350 rpm/4 ins for all instruments except for X4, which showed significantly lower torque ($P = .001$) and force after 4 insertions but when rotated at 300 rpm ($P < .0001$). X1 showed a significantly lower negative force when it was rotated at 350 rpm and 4 in-and-out movements were used to reach WL ($P < .0001$).

There was no breakage or plastic deformation through visual inspection of any of the rotaries after being used in 6 artificial root canals each.

Discussion

The aim of this study was to provide *in vitro* data that could guide the clinical use of novel ProTaper Next rotary instruments manufactured from M-Wire NiTi alloy (Sportswire, Langley, OK). Specifically, standard parameters such as peak torque and positive and negative forces were measured in simulated clinical conditions. At this time there is no information available for this particular instrument; however, other instruments manufactured from similar alloy have also been investigated recently (15, 23-27).

Plastic blocks with standardized simulated root canals were used in the present experiment, which is similar to previous studies (16, 28). Plastic blocks have been used not only for the assessment of shaping capabilities but also for the cutting behavior of NiTi rotaries (29); however, cutting of dentin varies from cutting plastic material. Nevertheless, torque values obtained during canal preparation in plastic blocks with curved canals were similar to those in mandibular incisors in an earlier study (16).

Another important issue for this type of study that may vary from real dentin and plastic is the "threading-in" effect of files, which is why peak negative force was also tested. The phenomenon of threading-in of a rotary during root canal preparation results in negative force when automatic insertion with a servomechanism such as in the current study is used.

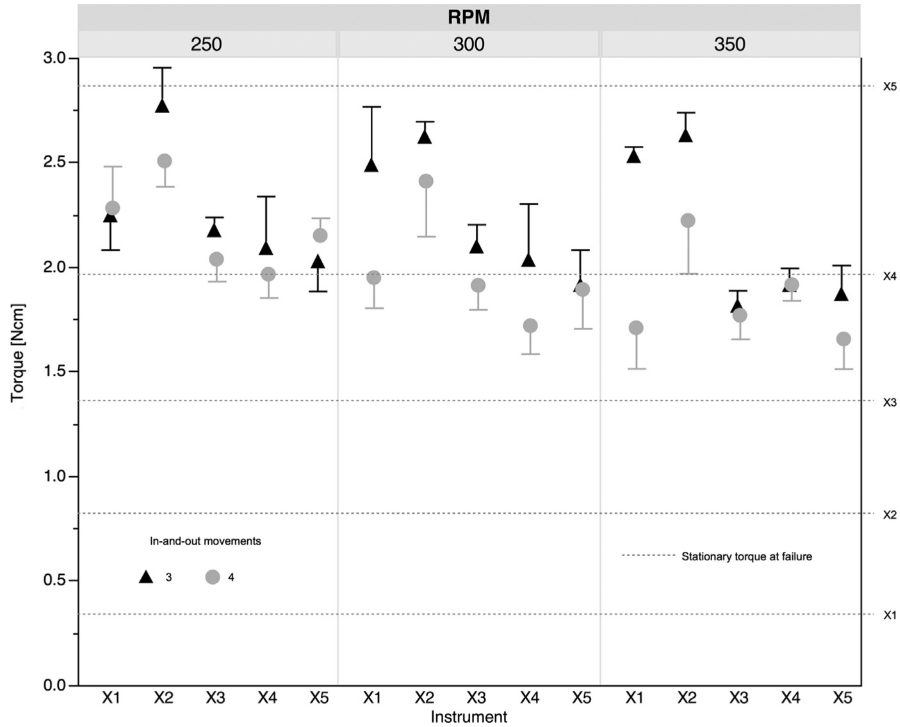

Figure 1. Distribution of mean and standard deviation of peak torque (Ncm) for each instrument according to rotational speed (250, 300, or 350 rpm) and insertion pattern (3 or 4 in-and-out movements). For comparison, mean stationary torque at failure at 3 mm from the tip for each instrument is represented in the *dashed lines*.

A clinician in the same situation would have the sensation that the instrument is pulled into the canal. However, this sensation is exaggerated in simulated canals in plastic blocks. These canals are more homogeneously shaped, which results in more overall wall contact compared with the more irregular shape of canals in human teeth (16). Therefore, caution should be exercised in directly taking *in vitro* data describing threading-in into the clinic; nevertheless, the present data do suggest that the smaller ProTaper Next sizes have a higher potential for threading-in behavior compared with the larger ones.

To observe the torque and force that these instruments are subjected to while shaping a root canal, 6 different groups were created in which 3 levels of rpm and 2 ways to reach the WL (with 3 or 4 depths or advanced movements of insertion) were included. Under the present conditions, ProTaper Next X2 showed the highest values of peak torque in all the groups when compared with other instruments, followed by X1 in some of them.

The present results represent a first impression about the system, but despite the limitations of this initial analysis, it could be inferred that X2 may possibly be the most active instrument in cutting dentin walls. One explanation why measured torque values are lower for X1 compared with X2 lies in the fact that the diameter at the apex of the simulated root canal used was approximately 0.20 mm, and that is a larger size than the diameter that X1 has at the tip (0.17 mm). However, this condition regarding canal size is somewhat comparable to what may occur clinically because the manufacturer suggests the use of Pathfile P1 and P2 before starting with the sequence of ProTaper Next to create a glide path, resulting in an apical diameter of at least 0.16 mm (22).

Interestingly, the expected stationary torque to failure for X1, X2, and X3 was very low, and the mean peak torque generated for the group with the lowest corresponding number (350 rpm/4 ins) was 80% higher. These data are important because they confirm the necessity to perform a careful glide path preparation preceding the use of this rotary system. However, it has to be taken into consideration that this torsional fracture was tested at 3 mm from the tip of the instrument under stationary conditions; dynamic clinical conditions are different, and torsional loading of smaller instrument cross sections as well as additive effects of cyclic fatigue and torque will occur.

In relation to the peak force applied, from the data in Figure 2, it is apparent that instrument X5 showed the highest value compared with all the other instruments in all groups. Again, this result was somewhat expected for an instrument with the largest diameter of the series. According to the study of Peters and Barbakow (16), instruments of larger

TABLE 1. Means ± Standard Deviation of Angular Deflection and Torque at Failure (n = 6 per group)

	Instruments				
	X1	X2	X3	X4	X5
Torque at failure (Ncm)	0.35 ± 0.04[a]	0.82 ± 0.11[a]	1.37 ± 0.06[a]	1.96 ± 0.26[b]	2.87 ± 0.22[c]
Angular deflection (°)	335.33 ± 47.12	290.67 ± 18.41	330.17 ± 20.80	338.50 ± 34.66	424.5 ± 48.33

Differences compared with torque during simulated canal preparation: a, significantly higher; b, no significance; c, significantly lower.

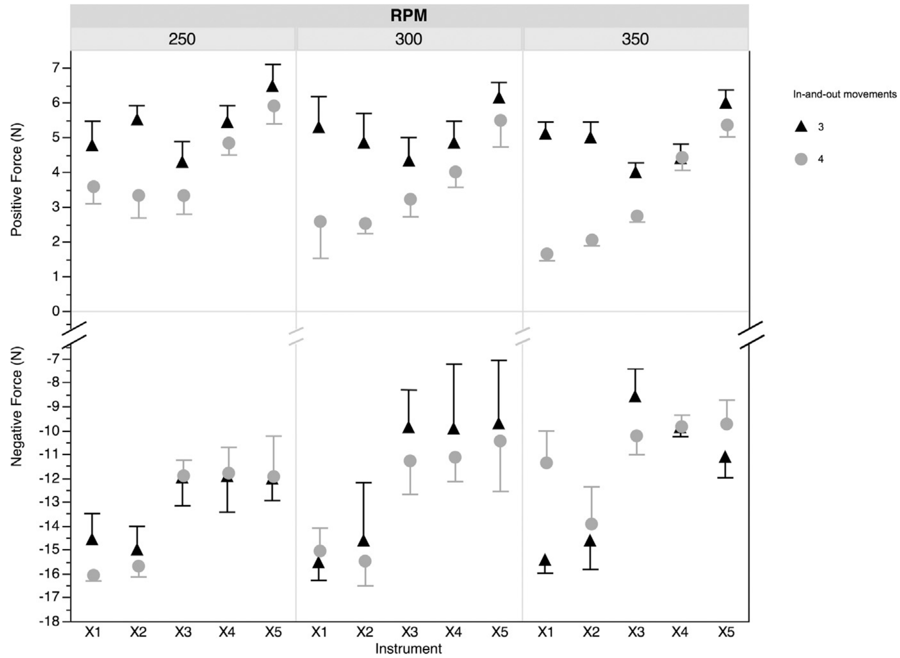

Figure 2. Distribution of mean and standard deviation of positive and negative peak force (N) for each instrument according to rotational speed (250, 300, or 350 rpm) and insertion pattern (3 or 4 in-and-out movements).

diameters require higher apical forces to penetrate deeper into the root canals.

An unexpected result was that despite having greater apical force, the instrument X5 showed low peak torque values in all groups. The expected result would be the greater the force, the greater the necessary torque to cause the instrument to begin to rotate inside the root canal (16). A possible explanation for this inverse relationship may be the fact that the manufacturer claimed that the off-centered rectangular cross section gives the file a different movement through the root canal, changing the envelope of motion and the compressibility of the file.

All instruments were used in an in-and-out motion, and it was apparent that when files were used with 3 such movements to reach WL, significantly more torque and more force were generated than with 4 movements. It seems possible that these results are due to a more passive shaping technique when using four in-and-out movements and a more aggressive technique with three.

In conclusion, under the present experimental conditions of simulated root canal preparation, X2 was associated with the highest torque, whereas X5 showed the highest positive force, and X1 and X2 had the highest peaks of negative force. This finding suggests that special care should be exercised when using X2 because this file may experience significant contact with the canal walls.

Within the limitations of this *in vitro* study, the results also suggest that ProTaper Next instruments should be used at higher rotational speed than previously suggested for other rotaries and with a gentler movement to have the lowest levels of torque. Future experiments should include the use of definite brushing movement as well as dimensional and geometric characterization of ProTaper Next instruments.

Acknowledgments

The authors thank Dentsply-Maillefer for the donation of the instruments used in this study.

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

Supplementary Material

Supplementary material associated with this article can be found in the online version at www.jendodon.com (http://dx.doi.org/10.1016/j.joen.2013.07.014).

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