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Screw-in forces during instrumentation by various file systems

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Objectives: The purpose of this study was to compare the maximum screw-in forces generated during the movement of various Nickel-Titanium (NiTi) file systems. ***Materials and Methods:*** Forty simulated canals in resin blocks were randomly divided into 4 groups for the following instruments: Mtwo size 25/0.07 (MTW, VDW GmbH), Reciproc R25 (RPR, VDW GmbH), ProTaper Universal F2 (PTU, Dentsply Maillefer), and ProTaper Next X2 (PTN, Dentsply Maillefer, n = 10). All the artificial canals were prepared to obtain a standardized lumen by using ProTaper Universal F1. Screw-in forces were measured using a custom-made experimental device (AEndoS-*k*, DMJ system) during instrumentation with each NiTi file system using the designated movement. The rotation speed was set at 350 rpm with an automatic 4 mm pecking motion at a speed of 1 mm/sec. The pecking depth was increased by 1 mm for each pecking motion until the file reach the working length. Forces were recorded during file movement, and the maximum force was extracted from the data. Maximum screw-in forces were analyzed by one-way ANOVA and Tukey's *post hoc* comparison at a significance level of 95%. ***Results:*** Reciproc and ProTaper Universal files generated the highest maximum screw-in forces among all the instruments while M-two and ProTaper Next showed the lowest ($p < 0.05$). ***Conclusions:*** Geometrical differences rather than shaping motion and alloys may affect the screw-in force during canal instrumentation. To reduce screw-in forces, the use of NiTi files with smaller cross-sectional area for higher flexibility is recommended. (*Restor Dent Endod* 2016;41(4):304-309)

Key words: Continuous rotation; Geometry; Nickel-titanium file; Reciprocating; Screw-in force

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Introduction

Motor-driven nickel-titanium (NiTi) endodontic instruments are thought to shape root canals more effectively than stainless steel files. In comparison to conventional stainless steel files, it has been shown that NiTi instruments are two or three times more flexible and have more torsional fracture resistance.[1] Using NiTi instruments during root canal shaping may even allow better preservation of the root canal anatomy.[2,3]

Mechanical performance of an endodontic file is mainly governed by its geometric configuration,[4-6] which not only affects the chance or risk of separation but also leads to the generation of different amounts of stress on the root canal wall during shaping.[6-10] During rotary preparation, contact between the instrument and dentin creates internal stresses in the instrument and a reaction torque in the root dentin. The

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cutting edges take the form of a spiral in the longitudinal aspect. If they are sharp and aggressive, they dig into the dentin producing even greater stresses in both the instrument and root dentin. While this force is essential for achieving the cut and removal of dentin, the spiraling configuration can cause an apical driving force (screw-in effect) that is a tactile sensation of the rotary file being pulled into the canal in an apical direction. If not resisted deliberately, this may result in the inadvertent over-extension of the instrument beyond the apical foramen.[11] Accidental over-preparation of the apical foramen may significantly weaken the roots and create apical root cracks.[12] Consequently, clinicians need to hold the hand-piece firmly or adopt a brushing action to prevent the instrument from pulling into the canal suddenly.

This screw-in phenomenon was reported to occur more frequently when using a rotary instrument with active cutting edges.[11,13] This might be explained by the sharp cutting edge engaging and guiding the file into the canal along the dentin wall. It may cause over-instrumentation beyond the apical foramen, and consequently a bigger apical foramen than the actual file tip size (diameter of D0) at working length. In addition, it may lead to a 'taper lock' effect and the instantaneous increase of torsional stress on the file, which may increase the risk of instrument fracture.[14] Undoubtedly, a separated file and/or over-instrumentation of the canal may reduce the success rate of endodontic treatment.[15]

Various NiTi rotary instrument systems made of different alloys with characterized geometric shapes and/or different kinematic movements are available. In terms of geometry, a reduced contact with the dentinal wall by off-centered cross-sectional design, which is incorporated in the instruments of ProTaper Next (Dentsply Maillefer, Ballaigues, Switzerland) and Revo-S (Micro-Mega, Besançon, France), might reduce screw-in forces.[16] Screw-in forces is clinically important for preventing unintended over-instrumentation and reducing the risk of apical crack formation. Therefore, this study compared the screw-in forces of various instruments during their movements.

Materials and Methods

In this study, four kinds of instruments made of different alloys and with different kinematic movements were used (Figure 1): Mtwo size 25/0.07 taper (MTW, VDW GmbH, Munich, Germany), Reciproc R25 (RPR, VDW GmbH), ProTaper Universal F2 (PTU, Dentsply Maillefer) and ProTaper Next X2 (PTN, Dentsply Maillefer). MTW, PTU, and PTN are used in a continuous rotation motion while RPR is moved in a reciprocating motion. PTU and MTW are made using conventional NiTi alloys, M-wire was utilized to manufacture PTN and RPR. All the instruments have a tip size of ISO #25 but with different apical taper of a few millimeters: PTU and RPR have an 8% apical taper, MTW has a 7% apical taper, and PTN has a 6% apical taper. Ten files were used for each instrument group.

Forty simulated canals in resin blocks (Dentsply Maillefer) were used in this study (n = 10). The simulated canal had a curvature of 30° according to the Schneider method,[17] and working length of 16 mm by 0.5 mm short from the canal exit under a stereomicroscope (Leica S6D, Leica Microsystems, Wetzlar, Germany). Before shaping with the designated files, the canals in resin blocks were instrumented to form a pre-enlarged canal lumen using NiTi instruments in the following sequence: glide path preparation with ProGlider (Dentsply Maillefer), pre-enlarging with ProTaper Universal S1, S2, and F1. During the instrumentation, canals were irrigated thoroughly, and the patency was checked using a size 10 K-file (M access, Dentsply Maillefer).

A custom-made device (AEndoS-k, DMJ system, Busan, Korea) was used to measure and record screw-in forces during file movement (Figure 2). When the blade of instrument is lodged into the root canal, the simulated

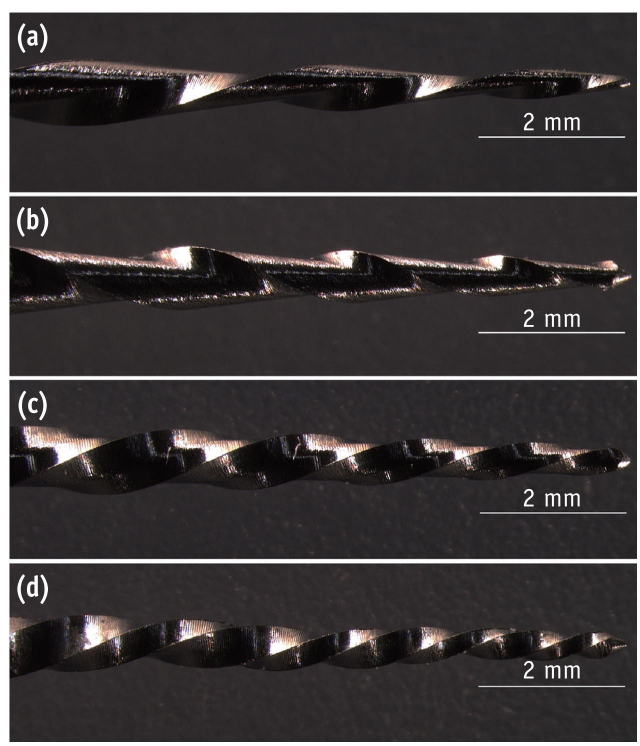

Figure 1. Longitudinal geometries of the instruments showing helical angle and pitch length. (a) Mtwo size 25/0.07; (b) Reciproc R25; (c) ProTaper Universal F2; (d) ProTaper Next X2.

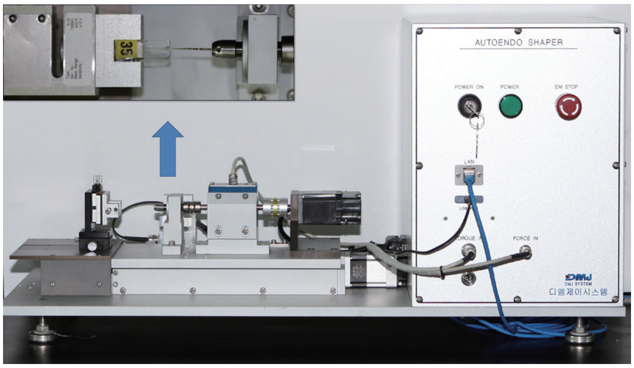

Figure 2. A custom-made test device (AEndoS-*k*, DMJ system, Busan, Korea). Simulated canal, force sensor and engine-driven motor unit are shown in box.

canal was lifted up in the opposite direction against that of file's active direction. At this moment, coronal movement of the simulated canal causes the tension in compression/tension sensor. This tension was referred as screw-in effect, and the force was measured. Each simulated canal in pre-enlarged resin block and designated file were connected to the device, and the file was moved in continuous rotation or reciprocating motion automatically (Figure 2). The rotation speed was set at 350 rpm for all groups and the reciprocating angles were set as 170 degrees counterclockwise and 50 degrees clockwise for the RPR group. The reciprocating angle was set depending on previous study.[18] The files were automatically moved to working length (16 mm) with a pecking motion of 4 mm distance and the crosshead speed was set at 1 mm/sec. The pecking depth was increased 1 mm for every one pecking motion until the file reach the working length. The forces were recorded during the file movement, and the maximum force was extracted from the data. Prior to automatic instrumentation of continuous pecking motions, the canal was filled with distilled water for lubrication.

The maximum screw-in forces during the instrumentation procedures were statistically analyzed (SPSS ver. 22, IBM Corp., Somers, NY, USA) by using one-way analysis of variance and Tukey's *post hoc* comparison test with a significance level of 95%.

Results

The changes in screw-in forces during the instrumentation procedure are presented in Figure 3 as a representative chart. The forces generated during the pecking motion until the file reaches the working length are presented. The deepest depth in force with negative value indicates the maximum screw-in forces.

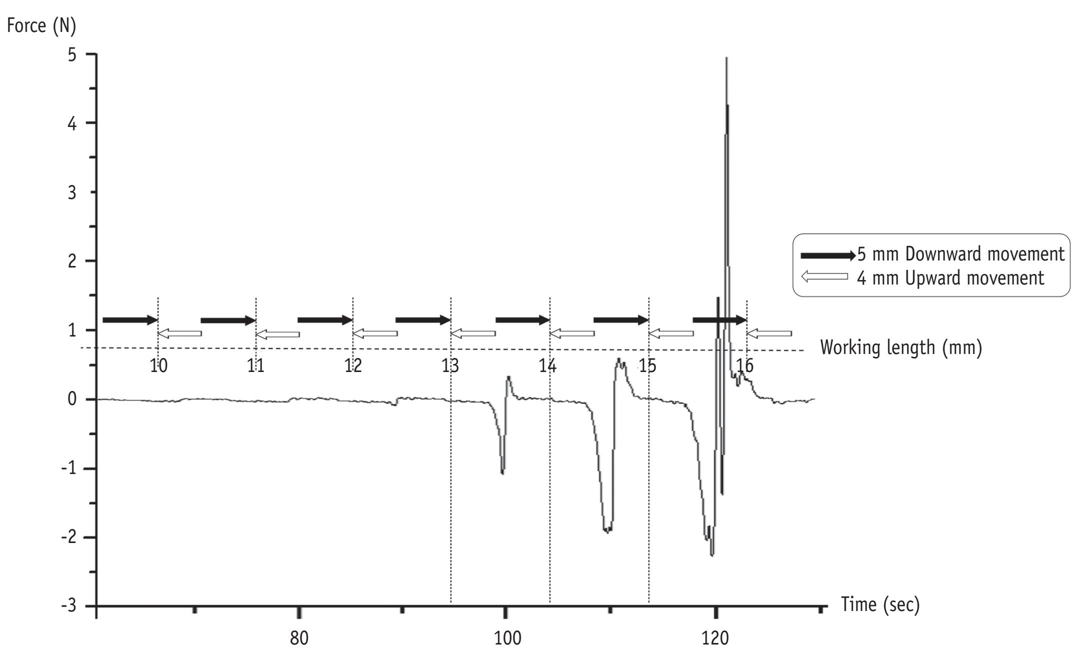

Figure 3. Representative chart of screw-in forces during instrumentation using Reciproc R25. Negative values indicate the screw-in forces and the deepest depth in force with negative value indicates the maximum screw-in forces. Repeating 5 mm downward (black arrow) and 4 mm upward (white arrow) movement, the files approach the working length (16 mm) as the laps of time.

Table 1. Maximum screw-in forces according to the file systems during instrumentation

Group	Maximum screw-in force (N)
Mtwo size 25/0.07 taper	0.532 ± 0.088[a]
Reciproc R25	1.999 ± 0.107[b]
ProTaper Universal F2	1.989 ± 0.322[b]
ProTaper Next X2	0.539 ± 0.108[a]

Different superscript letters indicate significant differences between groups ($p < 0.05$).

The RPR and PTU files had the higher maximum screw-in force among the tested instruments ($p < 0.05$). PTN showed the lowest screw-in force as well as the MTW file ($p < 0.05$, Table 1).

Discussion

Mechanical performance of endodontic file systems depends mainly on their geometric characteristics and metallurgical properties.[4-6,10,19] Previous studies have focused on file designs to understand the instruments' longevity and fracture resistances.[8,19-21] These factors may also affect the forces that are applied to root dentin during shaping.[9,10,22,23] During root canal preparation, a canal is shaped by the contact between the instrument and dentin. These contacts create reaction forces in both the root canal wall and the instrument.[4,10,22] These reaction forces are essential for root canal preparation that cuts the infected dentin and shapes the canal for a lumen to clean and obturate efficiently. However, the associated apical driving screw-in forces can result in an instantaneous loss of instrument control and cause the instrument to pass beyond the working length or apical foramen.[4,11] This may significantly weaken the roots and create apical root cracks.[12] To date, few studies have reported the screw-in effect despite the fact that the screw-in tendency may be harmful to root canal preparation.[13] Therefore, the aim of this study was to compare the screw-in forces of various instruments during their movements.

Various instrument systems (MTW, RPR, PTU, and PTN) with different kinematics, alloys, and shapes were compared with regard to the generation of screw-in forces. PTU is a popular instrument made of conventional NiTi alloy and characterized as an active cutting instrument with a convex triangular cross-section (for the size F2). PTN is a recently introduced system made of M-wire with a unique off-centered rectangular cross-section intended to reduce the contact points with the root canal. RPR is one of the representative reciprocating systems also made of M-wire. RPR has an S-shaped cross-section and two contacts points with the canal wall which is quite similar with the MTW.

We used simulated resin root canals. Although extracted teeth could be used to simulate clinical condition, they have a critical drawback of anatomic deviation. The screw-in forces and reaction torque were highly affected by canal curvatures, which cannot be standardized in natural teeth.[23] There was also a corresponding increase in the screw-in forces with increased root canal curvature (and/or reduced radius) regardless of the cross-sectional configuration and number of threads on the instrument. Under non-standard conditions, the contact point between the canal and instrument cannot be controlled and the results may be distorted.

In the present study, PTU and RPR had the highest screw-in forces. PTU has triangular cross-sectional area that cuts dentin with three-point contact symmetrically, and has larger taper (0.08 taper for F2) compared with PTX (0.06 taper for X2) and MTW (0.07 taper apically). PTU is also made with conventional NiTi alloy. These geometric characteristics increase its rigidity and produce a higher screw-in effect. In contrast, PTN and MTW produced the lowest screw-in force than other two file systems tested. It may be resulted from the smaller taper of PTN and MTW (0.06 and 0.07 taper, respectively) compared with the other instruments (0.08 apical taper for PTU and RPR). Another explanation may be the characteristics of the M-wire, which is more flexible than the conventional NiTi alloy.[24,25] However, only PTN showed less screw-in forces, while RPR showed higher screw-in forces. Therefore, the geometrical factors seemed to be the dominant factor.

A previous study of finite element analysis tested two variables, the cross-section and pitch length of the instrument. This analysis showed that the superior flexibility and smaller diameter of the instrument resulted in lower screw-in force.[23] Versluis *et al.*[8] also reported that the magnitude of the screw-in effect and reaction force on the canal wall were also related to the flexural rigidity of the cross-sectional configuration of the instrument. Slender rectangular cross-sectional instruments (similar with the PTN) which has smaller center-core had greater flexibility and lower screw-in effect than triangular and square cross-sectional instruments.[6,8,23,26] Reciprocating movements may reduce the screw-in effect because a momentary clockwise rotation (opposite direction to active direction) may relieve the stress when the instrument is trapped in dentin during counterclockwise rotation. However, in the present study, RPR showed similar screw-in forces with the PTU (continuous rotating) and higher forces than the PTN and MTW. Therefore, through this study, the difference in kinematic movement was not sufficient to explain this effect.

Recently, manufacturers have developed and introduced various new file systems made of new alloys through heat treatments. Instruments with advanced flexibility through heat treatment may reduce transportation with a reduced reaction force; thus, there may be a reduced risk of cracking or fracturing apical dentin which may jeopardize the prognosis of endodontically treated teeth.[8,10,27] Further study using various instrument systems made of heat treated alloys as well as variety of geometric factors especially in the longitudinal aspect such as pitch are needed.[5,6,8,10,23]

Although the screw-in tendency is harmful to root canal preparation, to date, few studies have reported the screw-in effect.[13] The present study reports practical information for currently used instruments with different kinematics and alloys as well as geometrical characteristics. Over-instrumentation beyond the apical foramen may lead to reduced success rates for endodontically treated teeth.[15] When a screw-in force is generated, torsional stresses on the instrument are also increased instantaneously and thus the risk of instrument fracture may increase.[11] Clinicians should be aware that geometric characteristics may make some instruments more prone to high screw-in forces.

Conclusions

Under the limitations of this study, varying range of screw-in forces was generated according to the instruments' geometries and sizes. Clinicians need to hold the hand-piece firmly to prevent the instrument from being pulled inside the canal

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