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Fractographic analysis of ProTaper and Mtwo systems: Breakage and distortion in severely curved roots of molars

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Abstract

Aim: This study evaluated the distortion and fracture mode of ProTaper and Mtwo rotary instruments following their use in severely curved root canals in extracted human teeth.

Materials and Methods: A total of 30 mesial canals of mandibular molars were allocated into two groups that were balanced in terms of angle and radius of curvature. Canals were prepared by either ProTaper or Mtwo systems. Each set of instruments was changed after the third canal. Longitudinal and fractographic examinations of the instruments were carried out by scanning electron microscopy. Images were evaluated according to distortion and mode of fracture. Chi-square analysis and Fisher's exact test were carried out at a significance level of $P < 0.05$.

Results: No significant difference was found between fracture and distortion percentage of ProTaper and Mtwo rotary instruments ($P > 0.05$). Fractographic analysis revealed that all of the Mtwo instruments demonstrated torsional failure and all but one of the ProTaper instruments (S1) showed torsional failure.

Conclusion: Fractographic examination of the fractured surface revealed shear fracture was the predominant mode of failure. Root canal curvature was an essential parameter influencing the susceptibility of instruments to fracture.

Key words: Curved canals, fractographic analysis, Mtwo, ProTaper

Introduction

Preparation of curved and narrow root canals is a challenge, as iatrogenic errors may occur, producing defects such as zips, ledges and canal transportation that may adversely impact on root canal morphology and the outcome of root canal treatment.[1,2] Nickel-titanium (Ni-Ti) rotary instruments, opened a new perspective in canal preparation due to their superelasticity[2-4] with the potential to maintain the original root canal morphology,[5,6] reduce transportation and the creation of aberrations,[7] resulting in more satisfactory root canal preparations.

Despite the advantages of Ni-Ti rotary instruments, intracanal fracture is a procedural accident that may occur with these instruments during clinical use[8] with the potential to jeopardize the outcome of root canal treatment.[2,9] Visible defects in instruments are divided into fracture or non-fracture with plastic deformatio.[10] Non-fracture plastic deformations include unwinding and reverse winding with tightening of the spirals and are classified as torsional failure.

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Fractures of rotary instruments can be classified into two modes of failure; torsional/shear fracture and flexural/fatigue fracture.[10,11] Torsional fracture occurs when a part of the instrument is engaged and interlocks inside the canal while the rest of it continues to rotate.[10,12] Applying excessive force apically during instrumentation to negotiate the narrow apical parts of the root canal system might cause such a failure,[10,13] as would failure to create and maintain a glide path.[14]

In a curved canal, a continually rotating instrument is subjected to tension on the outside of the curve whereas the inner surface is in compression.[11] Flexural fracture occurs when the instrument exceeds the elastic limit at the point of curvature.[1] However, evaluation of the mode of failure of rotary Ni-Ti files is more complicated, as both flexural and torsional failure may occur at the same time.[15]

In order to prevent fracture of Ni-Ti instruments, manufacturers continue to introduce new designs with varying tapers, rake angles, cross-sections and blade designs.[1,16] At the same time, no consensus has been agreed on the number of times that a Ni-Ti instrument may be used.[10,12] Although single-use of endodontic instruments is recommended[17,18] there are no guidelines on the usage of instruments in a multirooted tooth with severely curved canals. The purpose of this laboratory study is to evaluate distortion and fracture modes of ProTaper and Mtwo Ni-Ti rotary instruments following their use in severely curved root canals in extracted human teeth.

Materials and Methods

Root canal selection

A total of 30 severely curved mesiobuccal and/or mesiolingual canals of mandibular molars were selected. Following extraction, teeth were immersed in 5.25% sodium hypochlorite (NaOCl) solution for 30 min to remove organic residue and after rinsing were kept in 10% formalin until use. Exclusion criteria for root canal selection were:

1. Internal or external resorption, obstruction, fracture or crack;
2. Incompletely formed apices;
3. Root canals wider than a size 10 K-file could negotiate.

In all specimens, a standard access cavity was prepared using diamond burs and then a size 10 K-file (Mani, Japan) was inserted into one mesial canal and a radiograph exposed to facilitate measurement of canal curvatures. Root canals were divided according to the angle (α) and radius (r) of curvature. To determine the angle of curvature, a line was drawn parallel to the long axis of the canal and a second line was drawn from the apical foramen to intersect with the first line along the long axis of the canal according to Schneider's method.[19] Radius of curvature was measured by the method described by Pruett *et al.*[11] Canals with the angle of curvatures ranging from 40° to 90° and radii being 2 ± 1 mm were selected. The specimens were allocated into two groups that were balanced in terms of angle and radius of curvature; each group contained 15 canals. The mean curvature of the two groups was; group 1; 64.3° (r: 1.40 mm) and group 2; 64.4° (r: 1.41 mm).

Patency and working length of each canal were determined by passing a size 10 K-file to the canal until the tip of the file was visible through the apical foramen. This length was recorded, and the final working length was established 1 mm short of this recorded length.

Canal preparation

The canals in the first group were instrumented with ProTaper instruments (Dentsply Maillefer, Ballaigues, Switzerland) and the canals in group 2 with Mtwo instruments (VDW, Munich, Germany). Five sets of instruments were used; each being changed after the third use.

The instruments were used with an X-Smart electric motor (Dentsply Maillefer, Ballaigues, Switzerland) with a contra-angle 16:1 reduction rotary handpiece, operating according to the speed and torque values given by the manufacturer. Instruments were used with a slight apical pressure and each instrument was used for 5-10 s with an in and out movement. All instrumentation was performed by a single endodontist.

A glide path was created manually with a size 10 K-file (Mani, Japan). Before use, each rotary instrument was coated with 0.1 ml of RC-Prep (Premier Dental Products, Norristown, PA, USA). Canals of both groups were irrigated with 1 ml of 5.25% NaOCl followed by 0.5 ml of 10% ethylenediaminetetraacetic acid solution after each change of instrument. The final apical preparation was size 25 (group 1: F2 7% taper and group 2: 6% taper) for both of the groups. All instruments were immersed in 1% NaOCl, brushed and ultrasonically cleaned after their final use according to the cleaning protocol of Linsuwanont *et al.*[20]

Evaluation of instruments

The first scanning electron microscope (SEM) (Jeol JSM-T330 SEM, Tokyo, Japan) images of the instruments were taken from the lateral view before use. Instruments were mounted on a stub in a standardized position so that 2-3 mm of their shafts could be observed. After use, two more images were recorded from the tip of the instrument at ×50 and ×200 magnification. All fractured instruments were investigated under SEM to observe the fracture surface in detail and identify any signs of dimples or cracks [Figure 1].

The images, in lateral view, were classified into either torsional or flexural failure according to the description by Sattapan *et al.*[10] After the examination of the fracture surface (fractographic analysis), the images were categorized as either "fatigue" or "shear" failure. Fatigue failure is characterized with a crack initiation site and at higher magnification the presence of "fatigue striations" close to the crack initiation site. Crack initiation is generally associated with a site of high stress concentration, typically a surface defect such as a machining groove. Shear failure tends to show a burnished fracture surface with concentric abrasion rings and often a central area with a dimpled appearance (skewed dimples) where the instrument suddenly ruptures.

Statistical analysis

Statistical analysis of the collected data was performed with statistical package for the social sciences 15.0 statistics software (SPSS, Inc., Chicago, IL, USA). Chi-square analysis and Fisher's exact test were carried out at a significance level of $P < 0.05$.

Results

No significant difference was found between fracture and distortion percentage of ProTaper and Mtwo rotary instruments ($P > 0.05$).

During canal shaping using the ProTaper system (group 1) eight fractures occurred (40%) and three instruments were permanently deformed (15%) [Table 1]. Most of the fractures occurred in the initial shaping file (S1). Furthermore one S1 file and one F1 file were unwound [Figure 1d] and one S1 file showed reverse winding [Figure 1a].

In the Mtwo group, six of the instruments fractured (30%). Most of the fractures occurred in the initial shaping file (size 10, 0.04 taper). In addition, deformation was observed in nine other instruments (45%): One size 10, 0.04 taper, two size 15, 0.05 taper and one size 25, 0.06 taper instruments showed reverse winding and three size 20, 0.06 taper and two size 25, 0.06 taper instruments showed unwinding of the spirals [Figure 1b and c]. None of the instruments from either of the groups fractured during their first use.

Table 1: Distortion and fracture distribution of ProTaper and Mtwo rotary instruments

Rotary instruments	ProTaper *n* (%)	Mtwo *n* (%)	*P*
Fracture			
Torsional	7 (87.5)	6 (100)	1.000
Flexural	1 (12.5)	0 (0.00)	
Distortion			
Reverse winding	1 (33.3)	9 (45.0)	1.000
Unwinding	2 (66.7)	5 (55.6)	

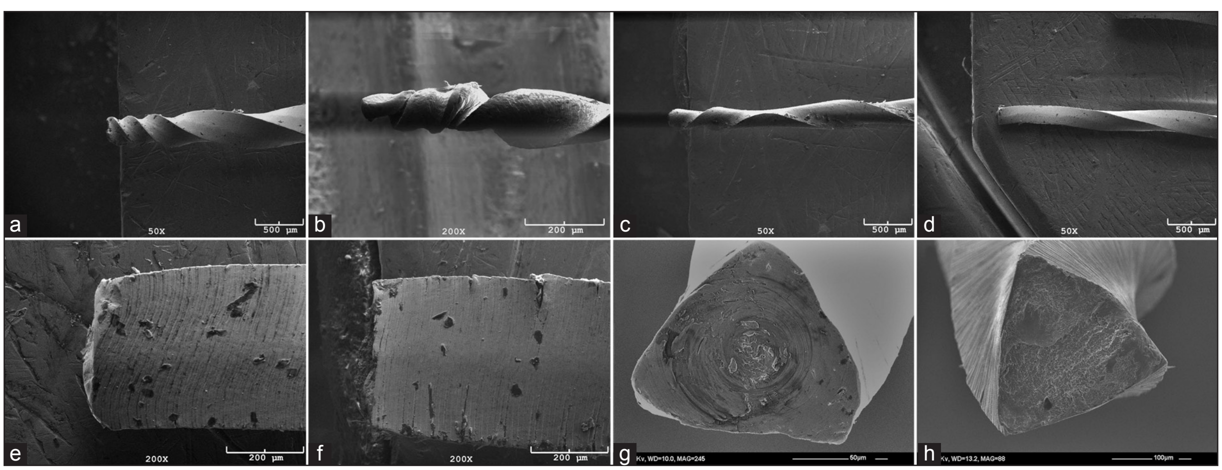

Figure 1: Scanning electron micrographs of ProTaper and Mtwo nickel-titanium files. (a) A ProTaper S1 instrument showing reverse winding and fracture (original magnification ×50). (b) A size 15, 0.05 taper Mtwo instrument showing reverse winding of the spirals (original magnification ×200). (c) A size 20, 0.06 taper Mtwo instrument showing unwinding of the spirals (original magnification ×50). (d) A ProTaper F1 instrument showing unwinding and fracture (original magnification ×50). (e) Longitudinal examination of fractured ProTaper S1 instrument (original magnification ×200). (f) Longitudinal examination of fractured ProTaper F1 instrument (original magnification ×200). (g) Fracture surface of the specimen in *E* showing circular abrasion marks indicating torsional fracture (original magnification ×245). (h) Fracture surface of the specimen in *F* separated because of flexural fatigue (original magnification ×88)

Except for one Mtwo file (size 10, 0.04 taper), which fractured in its middle third, all of the fractures occurred in the apical third of the instruments.

Fractographic analysis revealed that all of the Mtwo instruments demonstrated torsional failure [Figure 2] and all but one of the ProTaper instruments (S1) showed torsional failure [Figures 1f and h]. There was no significant difference amongst groups regarding the mode of failure ($P > 0.05$) with torsional fracture being the predominant mode of failure [Figures 1e and g].

Discussion

This laboratory study evaluated the distortion (unwinding or reverse winding with tightening of the spirals) and mode of failure of ProTaper and Mtwo Ni-Ti rotary instruments in severely curved canals.

Extracted human teeth were used to simulate clinical conditions[21] and each set of instruments was used to shape three root canals in order to simulate a mandibular molar with three curved root canals. Hence the instruments were not sterilized after each use. Despite the variations in the morphology of natural teeth, several attempts were made to ensure comparability of the experimental groups. For example, the mean angle and radius of curvature of the two experimental groups were similar. The angle of canal curvatures was measured according to Schneider's method since it is widely used and is cited in many studies;[1,7,16] the radius of canal curvatures was measured according to the method established by Pruett *et al.*[11]

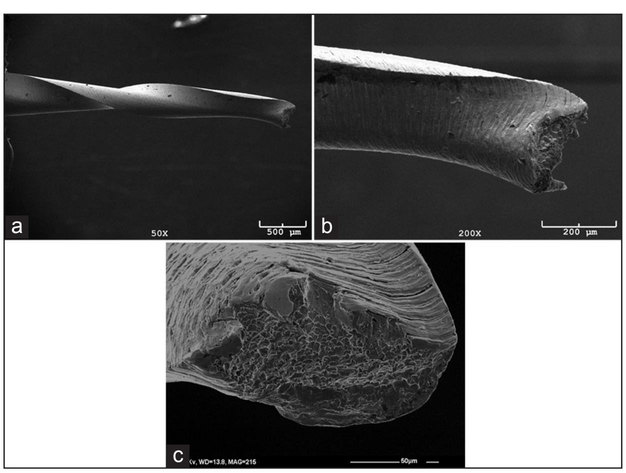

Figure 2: Scanning electron micrographs of (a) A size 15, 0.05 taper Mtwo instrument showing fracture (original magnification ×50). (b) Longitudinal examination of the specimen in *A* (original magnification ×200). (c) Fracture surface of the same specimen separated because of torsional fracture (original magnification ×215)

In the ProTaper group, Sx and F3 instruments were not used so both of the groups contained only 4 instruments in each set. Furthermore, all factors involved in the preparation of the root canals were standardized (operator, method and maximum times of use), to investigate the effect of the curvature on the incidence of overall failure.

The SEM method used for the evaluation of the instruments is convenient as well as provides an accurate image for assessing the deformation of instruments.[4,8,22]

A total of 14 instruments fractured during root canal preparation. Most fractures occurred in the initial instruments (S1 for ProTaper and size 10, 0.04 taper for Mtwo), a finding that is in accordance with the results of previous studies.[10,22,23] Except for one Mtwo file (size 10, 0.04 taper) all of the fractures occurred in the apical third of the instruments. From shank to tip, the diameter of the core material of the instruments decrease as well as the diameter of the apical portion, which might relate to the higher proportion of fractures in the apical parts of the instruments.[1,9,10]

Mtwo instruments demonstrated distortion before they fractured. Even though the final apical size was the same (size 25) for both groups, the final file of Mtwo has an apical taper of 0.06, which is smaller than ProTaper (F2) that has a 0.07 taper. Use of greater taper instruments in the apical region of severely curved canals should be considered carefully because the larger instruments are stiffer and more prone to fracture.[21,24]

Zelada *et al.*[9] reported that the radius of curvature was the most important factor in instrument failure and in canals with very small radius of curvature, the risk of instrument breakage was greater. Grande *et al*.[25] performed cyclic fatigue testing of instruments in artificial canals with radii of curvature of 2 or 5 mm and an angle of curvature of 60, the more abrupt 2-mm radius group had significantly fewer cycles to failure. Even though, in the present study, the angle and radius of curvature were standardized in both of the groups, the specimens in the ProTaper group had more fractures. The differences in the tapers of the tip region and the amount of metal mass might be the reason why there were more fractures in ProTaper group. Cycles to failure of larger instruments were less than for smaller instruments.[10] Thus, they should be discarded sooner than smaller instruments.

All of the fractured Mtwo instruments and all but one of the ProTaper instruments were associated with shear fracture. This finding is different from many studies,[15,26] but the result suggests that a single overload event causing shear fracture is the predominant mode of failure encountered for instrumentation of severely curved canals. Binding near the tip of the files with smaller diameters are more likely to occur because these files are generally used for apical enlargement.[10,22] In other words, the smaller, more fragile tips were more vulnerable.[11] In fact, small size files have been considered as disposable instruments because of the higher possibility of deformation and fracture.[27]

There are several factors contributing to instrument failure; cross-sectional geometry,[28] rotational speed,[13] sterilization procedures,[29] angle of curvature,[13] radius of curvature,[30] as well as operator skill[26,27] and use of corrosive agents such as sodium-hypochlorite.[31] In order to prevent irreversible deformation, it is necessary to take account of the preoperative shape of the canal.[11]

Although a number of studies[11,30,32] have established that, repeated clinical use significantly decreases the flexibility of Ni-Ti rotary instruments, there is no consensus in the literature concerning a recommended number of uses of rotary Ni-Ti instruments. In a severely curved canal, single use may be the only safe recommendation.[3,11]

Conclusions

Several ProTaper and Mtwo instruments fractured or demonstrated deformation. Fractographic examination of the fractured surface revealed that a single overloading event causing shear fracture was the predominant mode of failure. Root canal curvature appears to be an important reason for the fracture of Ni-Ti rotary instruments. Mtwo instruments demonstrated distortion before fracture, which might alert the clinician to discard the deformed instrument to prevent a possible intra-canal fracture.

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