



Do NiTi Instruments show Defects before Separation? Defects caused by Torsional Fatigue in Hand and Rotary Nickel-Titanium (NiTi) Instruments which Lead to Failure during Clinical Use

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ABSTRACT

Aims: Visual and microscopic evaluation of defects caused by torsional fatigue in hand and rotary nickel titanium (NiTi) instruments.

Materials and methods: Ninety-six NiTi greater taper instruments which were routinely used for root canal treatment only in anterior teeth were selected for the study. The files taken include ProTaper for hand use, ProTaper Rotary files and Endowave rotary files. After every use, the files were observed visually and microscopically (Stereomicroscope at 10x) to evaluate the defects caused by torsional fatigue. Scoring was given according to a new classification formulated which gives an indication of the severity of the defect or damage.

Statistical analysis: Data was statistically analyzed using KruskalWallis and Mann-Whitney U test.

Results: Number of files showing defects were more under stereomicroscope than visual examination. But, the difference in the evaluation methods was not statistically significant. The different types of defects observed were bent instrument, straightening/stretching of twist contour and partial reverse twisting. Endowave files showed maximum number of defects followed by ProTaper for hand use and least in ProTaper Rotary.

Conclusion: Visible defects due to torsional fatigue do occur in NiTi instruments after clinical use. Both visual and microscopic examinations were efficient in detecting defects caused due to torsional fatigue. This study emphasizes that all files should be observed for any visible defects before and after every instrumentation cycle to minimize the risk of instrument separation and failure of endodontic therapy.

Keywords: NiTi endodontic instruments, ProTaper for hand use, ProTaper Rotary, EndoWave, Torsional fatigue.

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INTRODUCTION

Shaping and cleaning of root canal system is an important phase of pulp space therapy. The clinical goal of pulp space therapy is to satisfy biological and mechanical objectives. Biologic objective includes total debridement and disinfection of the root canal system. Mechanical objective includes developing a continuous tapering conical form of the canal and maintaining the original shape and position of the apical foramen (Schilder, 1974).¹

In 1988, Walia et al introduced NiTi endodontic files which had special properties like superelasticity and shape memory. NiTi files have 2 to 3 times more elastic flexibility in bending and superior resistance to torsion compared to stainless steel files.⁴ Apart from these special features, NiTi files have excellent biocompatibility and are highly resistant to corrosion.²

Fracture of NiTi files can occur with or without any visible defects of previous permanent deformation. Fatigue on a file is under the direct influence of stress occurring on a file during its use in root canal.² Fatigue of NiTi endodontic instruments can occur under two circumstances:

1. Flexural fatigue
2. Torsional fatigue

Flexural fatigue is caused by work hardening and metal fatigue that occurs when the file is used in a curved canal (Sotokawa 1988). When a file is used in curved canal, each rotation causes an instrument to undergo one complete stress cycle of tension and compression. This form of stress is called cyclic fatigue (Purett et al 1997) which occurs at the

point of maximum flexure of the shaft and it is the most destructive form of stress. Such fatigue mechanisms initiate microscopically within the elastic limit of the metal and, therefore, not visible for visual inspection with naked eye.¹

Torsional fatigue is the stress built up in a file during its rotation in the canal. It is further categorized into two types:

- a. Dynamic torsional fatigue occurs from frictional forces caused by resistance of dentin to cutting by the file.⁴
- b. Static torsional fracture occurs by continuous rotation of the file at one end while the other end stops spinning as seen, when a section of the file is locked in place while the handpiece continues to rotate.⁴

MATERIALS AND METHODS

Ninety-six NiTi greater taper Rotary and hand endodontic files were observed under microscope at 10× magnification before and after every clinical use.

Materials used

- *Group I:* ProTaper for hand use—S1, S2, F1
- *Group II:* ProTaper Rotary—S1, S2, F1
- *Group III:* Endowave files—Assort Kit consists of four files.

File 1 has constant 8% taper, tip size of 35, standard length of 19 mm. Files 2, 3 and 4 have a constant 6% taper with corresponding to size of 20, 25 and 30, length of 25 mm.

Selection of Specimen

The files taken for observation were according to the following criteria:

Inclusion Criteria

- Files used exclusively on upper and lower anterior teeth.
- Files should not have any manufacturing defect (evaluated under stereomicroscope at 10× magnification before use).

Exclusion Criteria

- Files used on teeth with open apex.
- Files used on teeth with developmental abnormalities in root canal shape.
- Files used on teeth with internal resorption.

CLINICAL PROCEDURE

Rubber dam application was done on teeth being instrumented. Standard access cavity preparations were done and straight line access was achieved and reproducible glide path was established with size 15 hand file. Following access, pulp chamber was filled brimful with either sodium

hypochlorite or a lubricant, such as Glyde root canal conditioner. Biomechanical preparations were done using crown down technique with EDTA as lubricant with access cavity filled with 3% sodium hypochlorite at every stage. Working length was determined. Before instrumentation, the canals were irrigated with sodium hypochlorite. The files were used in a sequential order as advised by the manufacturer. Instrumentation was done using the files in Anthogyr reduction gear handpiece. Low speed of 150 to 300 rpm was used in a brushing motion. Files were used sequentially, moving apically short of the working length. File was removed, cleaned and inspected.

All files were used to a maximum of 20 uses. If any distortion was observed, the files were not used further.

Evaluation of the Files

After every use, the files were ultrasonically cleansed, sterilized and observed by visual and microscopic examination (stereomicroscope at 10× magnification) to see any torsional changes in the files.

Record was maintained to evaluate the number of uses and the changes in the file after each use. To supplement these photographs were taken to maintain an archival record of the observations or defects.

There are many classifications of different types of defects as given by Sotokawa (1988),⁹ Roane and Sabala (1984) and Idomeo Bonetti Filho et al (1998).¹⁰

Although a number of classifications exist, to make the study more useful, a new classification was designed for the benefit of the clinicians to visually and microscopically gauge the torsional fatigue. The advantage of this classification is that it also gives an indication of the severity of the defect or damage.

In this classification, the defects caused by torsional fatigue are divided into two groups depending on the severity of defects as follows:

1. Defects indicating mild damage:
 - a. Bent instrument/tip deformation
 - b. Stretching/straightening of twist contour
 - c. Cutting edge dented
2. Defects indicating severe damage:
 - a. Partial reverse twisting
 - b. Change in length (mm)
 - c. Fracture of the instrument

Utilizing the above classification, following scores were given according to the degree of deformation after observing each file both visually and microscopically after every use.

- 0 – no deformation
- 1 – bent instrument/tip deformation
- 2 – stretching/straightening of twist contour
- 3 – cutting edge dented

- 4 – partial reverse twisting
- 5 – change in length (mm)
- 6 – fracture of the instrument

The scores were tabulated and statistically analyzed using Mann-Whitney U test and Kruskal-Wallis test.

RESULTS

The percentage distribution of various types of defects as observed by different methods of examination, i.e. by visual and stereomicroscopic methods indicate that tip deformation (Fig. 2)/bent instrument (Fig. 1) was seen in 20 files (20.8%) under stereomicroscopic examination, while visual examination showed only 16 files (16.67%) with this type of defect. Stretching/straightening defect (Fig. 3) could be observed in eight files (8.3%) by stereomicroscopic examination, while the defect could be identified in six files (6.25%) by visual examination.

Comparison of the methods of examination of the defects using Mann-Whitney U test showed no statistically significant difference ($p = 0.886$, NS).

The overall frequency distribution of types of defects in all groups taken for observation showed that out of 96 files, 66 files (68.8%) did not show any defects. The most common type of defect was 'bent instrument', the percentage being 20.8% (20 files), this was followed by 'stretching/straightening' 8.3% (8 files) and 'partial reverse twisting' 2.08% (2 file) (Fig. 4). Other types of distortions like denting of cutting edge, change in length and fracture of the instrument were never observed.

The percentage distribution of various types of defects in group I (ProTaper for hand use) showed that out of 32 files used 68.8% (22 files) had no defects and 31.2% (10 files) of files showed defects. The defects observed were bent instruments in 25% (8 files) and showed partial reverse twisting in 6.3% (2 file).

The percentage distribution of various types of defects in group II (ProTaper Rotary) showed that out of the 32 files used 81.3% (26 files) had no defects. Out of the 18.7% (6 files) distorted files, 12.5% (4 files) were bent instruments and stretching/straightening (Fig. 3) was observed in 6.3% (2 files).

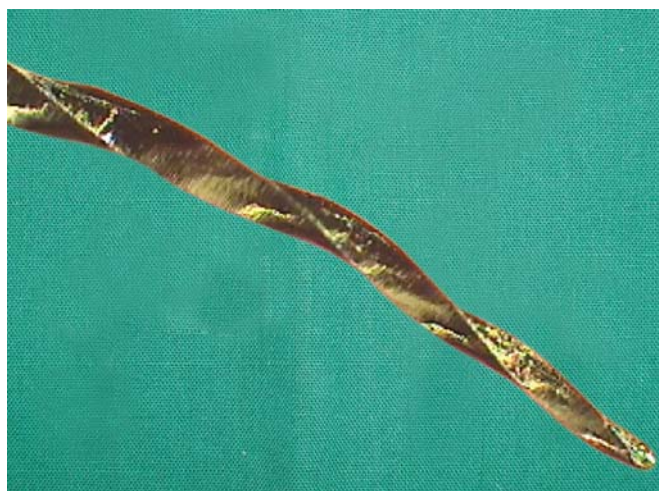


Fig. 1: Bent instrument



Fig 3: Straightening/stretching of twist contour



Fig. 2: Tip deformation



Fig. 4: Partial reverse twisting

The percentage distribution of various types of defects in group III (Endowave) showed that out of 32 files used no defects were observed in 56.3% (18 files). Out of 43.7% (14 files) distorted files, 25% (8 files) were bent instrument and 18.25% (6 files) instruments showed stretching/straightening.

Intergroup comparison of frequency of different types of file distortion between the three study groups using Kruskal-Wallis test showed no statistical significant difference ($p = 0.281$, NS).

The percentage distribution of distorted files used in the upper and lower anterior teeth among all groups showed that, among the 48 files used for instrumentation in upper anterior teeth, 79.2% (38 files) showed no defects. Among the distorted files 16.7% (8 files) were bent instruments and 4.2% (2 file) showed stretching/straightening. Among the 48 files used on lower anterior teeth, 58.3% (24 files) showed no defects, 25% (12 files) were bent instruments, 12.5% (6 files) showed stretching/straightening and 4.2% (2 file) showed partial reverse twisting.

Intercomparison of frequency of file defects among upper and lower anterior teeth using the Mann-Whitney U test showed no statistical significance ($p = 0.098$, NS).

DISCUSSION

One of the primary goals of endodontic therapy is the total removal of pulp tissue, shaping and cleaning of the root canal system and its obturation to obtain a fluid impervious seal with a suitable material.¹¹ The clinical goal of shaping and cleaning the root canal system is complete debridement and development of a continuously tapering conical canal form while maintaining the original shape.¹

The introduction of nickel titanium alloy to produce endodontic instruments has been a major development in endodontics (Walia et al 1988). The unique property of these NiTi files facilitates preparation of narrow and curved canals whilst minimizing procedural accidents or mishaps that were generally associated with stainless steel instruments.¹

The unique low modulus of elasticity of NiTi alloy has allowed these instruments to be used in continuously rotating handpiece for root canal instrumentation. Despite the increased strength and flexibility of NiTi instruments, instrument separation is still a concern and has been reported to undergo unexpected fracture without warning.

In the present study, files were viewed under stereomicroscope at 10× magnification and files without manufacturing defects were selected because manufacturing defects can cause fracture of a new instrument even during the first use (Sattapan et al 2000).

In a study conducted by Sattapan et al (2000), it was observed that the files that broke due to torsion exhibited

signs of deterioration above the point of fracture. On the other hand, the files that broke due to fatigue through flexure did not exhibit defects linked to their subsequent fracture. In curved canals, the files undergo both torsional and flexural fatigue, whereas in straight canals only torsional fatigue is observed. So, in this study, the files used exclusively in the anterior teeth were evaluated to detect defects caused by torsional fatigue alone.

Thus, this study was done to evaluate defects that have occurred only due to torsional fatigue and to analyze the type and frequency of defects in NiTi Rotary endodontic files during routine clinical use after biomechanical preparation and to draw conclusions that provide insight into the patterns of defects in an attempt to minimize risk of instrument's separation within the canals. The study was done *in vivo* conditions to replicate the torque during instrumentation under dynamic, clinically relevant conditions.

Sattapan et al (2000) suggested that all files should be examined after each use to reduce the risk of separation in the root canals. He also stated that minor defects, both manufacturing errors and plastic deformation may not be detected with naked eye and recommended examination of instruments at a magnification of at least 10×. So, various methods used to examine the defects occurring in endodontic files after clinical use were evaluated in this study. The methods of evaluation used were visual examination and microscopic examination at 10× magnification. In the present study, the percentage defects observed under stereomicroscope at 10× magnification was 31.3%, whereas by visual examination, it was 25.0%. The results of the study revealed that two files with defects of bent instrument and one file with stretching/straightening could not be observed by visual examination. This is in accordance with Sattapan et al that all instruments subjected to torsional fracture showed defects.⁶ But when the methods were statistically analyzed, there was no statistically significant difference ($p = 0.886$, NS) between the two methods of examinations used for the study. This is contradictory to the study by Pruett et al (1997)¹² who stated that visual inspection is not a reliable method for evaluating used nickel titanium instruments.

The overall frequency distribution of different types of defects in files taken for observation showed that, out of 48 files examined, 68.8% did not show any defects. Files indicating mild damage were 29.1% and severe damage was seen in 2.08% of the files. The most common type of defect was 'bent instrument' the percentage being 20.8%, this was followed by stretching/straightening 8.3%. The only defect observed indicating severe damage was 'partial reverse

twisting' in 2.08% of the files. Other types of distortions like denting of cutting edge, change in length and fracture of the instrument were not observed. This is in accordance with Sattapan et al 2000 who stated that signs of permanent deformation were observed in all files that have fractured due to torsional fatigue.³

The overall percentage of defects observed in group I (ProTaper for hand use) was 31.2%, group II (ProTaper Rotary) was 18.7% and, in group III (Endowave), it was 43.7%. Among the study groups, group III (Endowave) showed the highest percentage of defects followed by group I (ProTaper for hand use) and least defects were observed in group II (ProTaper Rotary). The ProTaper instruments have a variable tapered shaft that is designed specifically for selective crown down technique, in which successive instruments selectively prepare different areas of the canal (Clauder and Baumann 2004).⁷ The Mtwo instruments have constant tapered shaft design for use in sequence moving from smaller to larger instruments, where the full length of the canal is approached at the same time, i.e. the simultaneous technique (Foschi et al 2004).⁷ The differential taper in ProTaper instruments causes the files to be actively cutting only in limited portion of the canal but in case of Endowave because of the continuous similar taper, the whole length of the file is in contact with the root canal and leads to more torsional fatigue. This is in accordance with Miyai et al (2006) who stated that the maximum torsional torque and bending load value of Endowave was lower than that of Hero 642 and K3.⁵

The defect indicating severe damage (partial reverse twisting) was observed only in group I (ProTaper for hand use) which may be attributed to the difference in the manner of use between hand and Rotary files, where in the amount of pressure applied was not uniform and may be higher in case of hand instruments leading to severe damage. Sattapan (2000)⁸ stated that apical force applied was generally low (not exceeding 150 gm) when rotary NiTi files were used and in order to reduce the risk of separation due torsional failure in the root canal, apical force should be moderate during instrumentation with NiTi endodontic instruments.⁸

Dynamic torsional fatigue results from frictional forces caused by resistance of dentin to cutting by the file.⁴ Hence, the present study also aimed at evaluating the difference in the frequency of torsional defects in narrow and wide canals. To determine this parameter, the files used exclusively for instrumentation of upper and lower anterior teeth separately were evaluated. It was also observed that defect indicating severe damage was observed in the files used for instrumentation in lower anterior teeth. The comparison of frequency of file defects among upper and lower anterior

teeth using the Mann-Whitney 'U' test showed no statistical significance ($p = 0.098$, NS).

This may be because of the smaller cross-sectional area of the root canals in lower anterior teeth, when compared to upper anterior teeth accounting for greater resistance caused by dentin on the rotating file leading to greater fatigue changes. This has been reinforced by Sattapan et al who stated that the NiTi instruments generated higher torque in smaller than medium canals and the torque was dependent on the tip size and taper of the instrument, and on canal size.⁸

This study shows that visible defects due to torsional fatigue that can be observed by naked eyes do occur in NiTi greater taper endodontic instruments after clinical use, this emphasizes that all files should be observed for any visible defects before and after every instrumentation cycle to minimize the risk of instrument separation and failure of endodontic therapy. It was also observed that the most of the defects caused by torsional fatigue are mild in nature.

CONCLUSION

Within the parameters of this *in vivo* study, the following conclusions may be drawn:

- Visible defects due to torsional fatigue do occur in NiTi greater taper endodontic instruments after clinical use.
- This study emphasizes that all files should be observed for any visible defects before and after every instrumentation cycle to minimize the risk of instrument separation and failure due to torsional fatigue.
- Frequency of defects observed were highest in Endowave followed by ProTaper for hand use. Least number of defects were observed in ProTaper Rotary instruments.
- Files underwent higher fatigue rate in narrower canals and were easily susceptible to failure.

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