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Influence of Thermomechanical Treatment on the Mechanical Behavior of Protaper Gold versus Protaper Universal (A Finite Element Study)

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Keywords: Finite element analysis; Mechanical behaviour; NiTi rotary file; Thermomechanical treatment

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Abstract

AIM: To compare and evaluate the influence of thermomechanical treatment of Protaper Gold file versus Protaper Universal file during testing of bending and torsion using finite-element analysis.

METHODS: Two nickel-titanium NiTi rotary files (ProTaper Gold and ProTaper Universal) were used in this study. The files were imaged using stereomicroscope to produce 3D models. The behaviour of the instrument during bending and torsion was numerically analysed in CAD/CAM software package.

RESULTS: Under bending, ProTaper, Gold showed higher flexibility and flexural resistance than ProTaper Universal. The highest stress was related at the cutting edge of both files. While during testing of torsion, the maximum amount of stresses was related to the base of the flutes in both files. ProTaper Gold showed higher torsional resistance than the ProTaper Universal file.

CONCLUSION: Thermomechanical treatment improved the mechanical response (bending and torsional resistance) of NiTi files.

Introduction

During root canal treatment, different types of rotary file systems are used for cleaning and shaping. The root canal system has complex anatomy with different angles of curvatures, so root canal preparation with rigid stainless-steel instruments may lead to more canal aberrations. Recently, nickel-titanium (NiTi) rotary files have been widely used due to the superelastic behaviour of nitinol base material [1].

However, the fracture of rotary files during cleaning and shaping remains the major concern in endodontic practice. The file could fracture at different levels of stress, even without any signs of plastic deformation near the fracture site; this is due to the residual stress in the file after being used. These residual stresses could affect the durability of the file if it were used repeatedly [2]. Thus, flexibility and torsional resistance are important properties that could affect the mechanical performance of NiTi files during root canal preparation [3]. NiTi files fracture during root canal preparation due to either flexural or torsional fatigues. When the file is moved in a curved canal, it will be subjected to repeated cycles of compression and tensile stresses so that flexural fatigue could occur, while when the files' tips were locked in the walls of the canal while the shank was in continuous rotation, torsional failure could occur [4].

The mechanical response of NiTi alloy under different clinical situations is determined by the relative proportions and characteristics of the microstructure of NiTi alloy. Thus, the manufacturer improved the mechanical properties of NiTi instruments using new techniques [5]. Thermomechanical treatment is one of the recent approaches for changing the transition temperatures of NiTi alloys to improve the fatigue resistance of NiTi endodontic files [6].

ProTaper Gold file (PTG; Dentsply, Tulsa Dental Specialties, Tulsa, OK, USA) has similar geometry as ProTaper Universal file (PTU; Dentsply Maillefer, Ballaigues, Switzerland). Both files have a progressive taper and a convex triangular cross-section design. However, PTG instruments have been subjected to thermomechanical heat treatment that resulted in the production of a file with advanced metallurgy. PTG has a 2-stage transformation behaviour with high Af temperatures while PTU instruments have 1-stage transformation [7], [8].

Hence, this study aimed to compare the influence of the thermomechanical heat treatment on the mechanical behaviour of Protaper gold versus ProTaper Universal using Finite Element Analysis.

Methods

Real-size digitised models of two NiTi rotary instruments with same cross-sectional geometry but with different heat treatment were selected for this study: ProTaper Gold instruments (PTG; Dentsply, Tulsa Dental Specialties, Tulsa, OK, USA) and ProTaper Universal (PTU; Dentsply Maillefer, Ballaigues, Switzerland). The PTG and PTU files were of size 25, .08 variable taper.

The files were imaged and measured using stereomicroscope (Technical 2, Carl Zeiss JENA) at X 5, X 10 and X 16 magnifications to obtain a detailed shape to obtain an accurate measurement of the files (Figure 1).

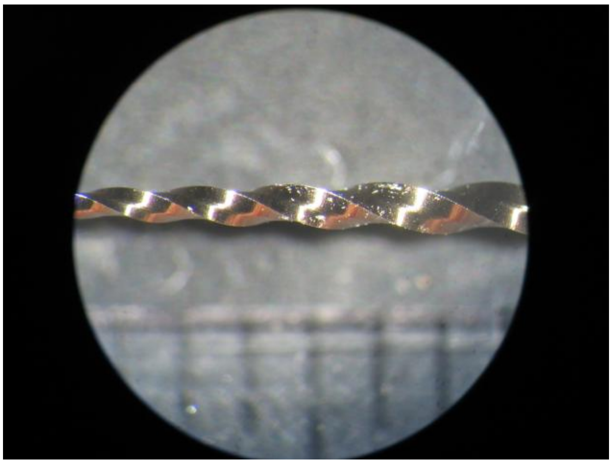


Figure 1: Stereomicroscope imaging for Protaper Gold

The file's cross-section (convex triangular) was drawn in 2D using Computer-Aided Design CAD programs SolidWorks 2012 (Dassault Systèmes SolidWorks Corporation, Waltham, MA, USA) then exported as Stereolithographic (.stl) file format. The building of 3D model in the form of sections was performed by MATLAB (MathWorks, Inc., Natick, Massachusetts, USA) using the following data: variable taper of the file and the change in pitch length (Figure 2 and Figure 3).

Figure 2: 3D model of the file

Using SolidWorks FE model was created and meshed using linear, six nodes trihedral elements. The final FE model of both files consisted of 1850 elements with 3610 nodes.

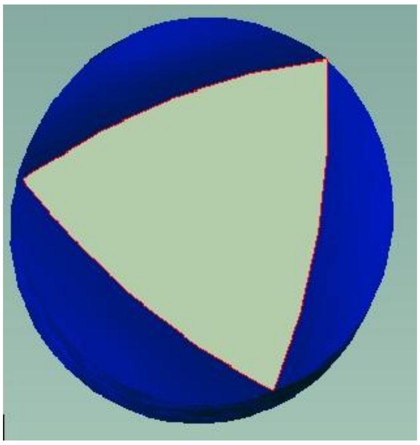


Figure 3: Convex triangular cross-section design of the file's models

The maximum element size was 0.526743 mm, while the minimum element size was 0.105349 mm. The stress-strain behaviour of PTU and PTG file's alloy was obtained from the literature and entered in the SolidWorks.

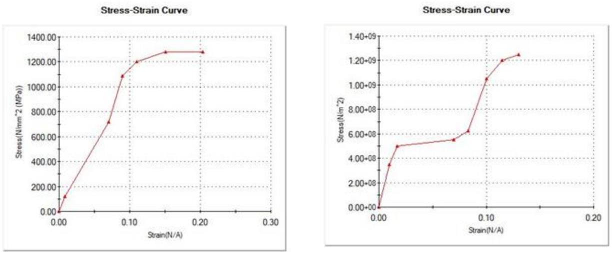


Figure 4: Stress-strain curve for (A); Protaper Gold (B) Protaper Universal files

The Young's modulus of the alloy was 36 GPa and the Poisson's ratio 0.3. (Figure 4 and Figure 5).

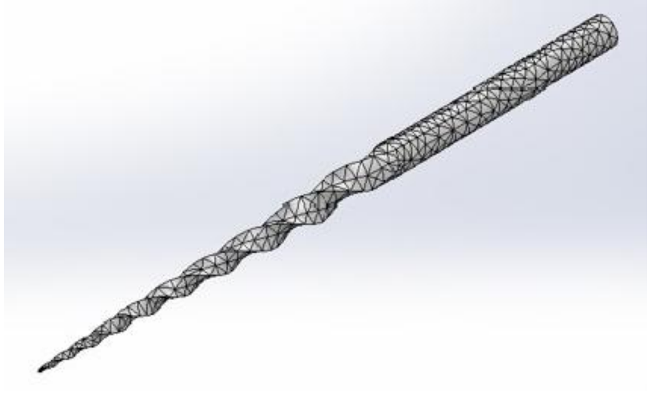


Figure 5: Meshing of the 3D models

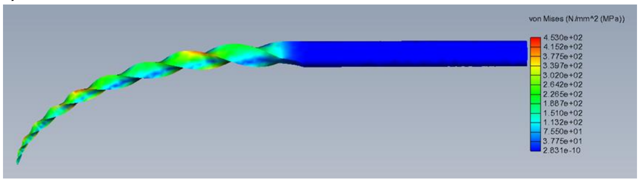
Bending

Using a constant load, bending was simulated by applying a concentrated load of 1 N at the tip of the file with its shaft rigidly held in place. Both the vertical displacement and the von Mises stress distribution was evaluated [9].

Application of a shear moment (torsion)

A sheer moment 2.5 N mm of force was applied to the shaft in a clockwise direction while the last 4 mm of the tip was rigidly constrained. The stress distribution was evaluated [9].

a)



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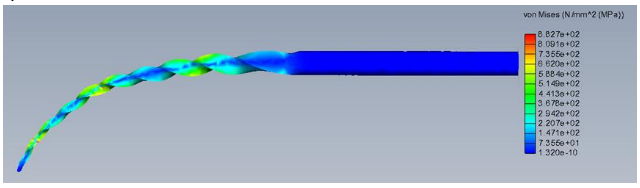
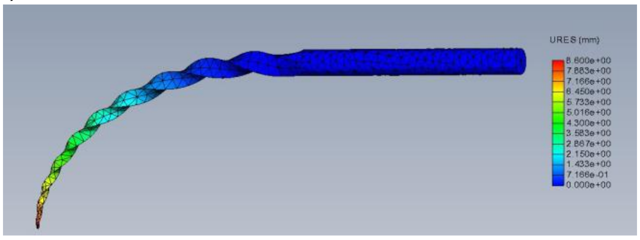


c)



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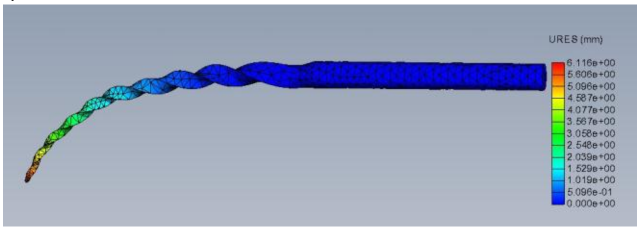


Figure 6: a) Stress distribution during bending of Protaper Gold; b) Stress distribution during bending of Proatper Universal; c) Deflection during bending of Protaper Gold; d) Deflection during bending of Protaper Universal

Results

Bending

Applying load of 1 N at the file's tip, the end deflection for Protaper Gold was 8.6 mm, while ProTaper Universal 6.1 mm, indicating that PTG is more flexible than PTU. Stress analysis showed that the maximum von Mises stress of 453 MPa was related to PTG; while in PTU, the maximum von Mises stress recorded was 882.7 MPa.

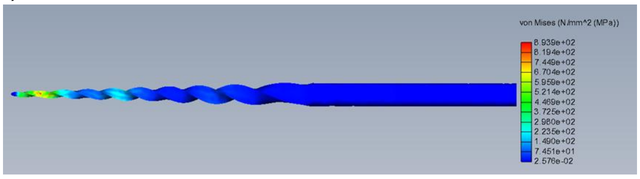
Stress distribution showed that the maximum von Mises stress was related to the cutting edges both in Prptaper Gold and Protaper universal files. The maximum values of stress were recorded in Protaper universal at 4 mm from the tip, while in Protaper Gold it was recorded in the middle and in the last third of the file (Figure 6a, 6b, 6c and 6d).

Torsion

Applying 2.5 Nmm torque to the files showed higher values of von Mises stress in Protaper Universal file (893.9 MPa), while in Protaper Gold file it was 144.1 MPa.

Stress distribution was related to the base of the flutes of both files (Figure 7a and Figure 7b).

a)



b)

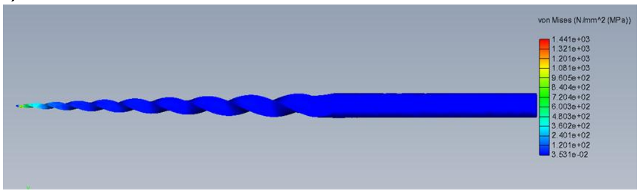


Figure 7: a) Stress distribution during torsional testing of Protaper Universal; b) Stress distribution during torsional testing of Protaper Gold

Discussion

During the last decades (NiTi) files have become widely used because of their superelasticity. However, during the preparation of root canals, NiTi files are subjected to bending and torsional stresses because of the curved anatomy of the root canals and the narrow lumen of the canals. Several factors could affect the stress distribution in NiTi instruments such as the design, alloy, and the heat treatment applied during manufacturing [10].

Deflection under bending reflects the instrument's flexibility, PTG had a greater deflection than PTU, indicating that PTG files possess a higher flexibility. When both files were subjected to 1 N bending, PTG showed more flexural resistance and a lower concentration of stress than PTU file. Under bending conditions, stress distribution in PTG and PTU was near the cutting edge of both files. This was related to the mechanics of bending a triangular cross-section design; this was in full agreement with Kim et al., [9]. As the geometry of both files is the same (from the same manufacturer), the difference in flexural resistance between them is related to the different metallurgy.

The torsional fatigue resulted from friction between the file and the narrow canal. Thus, we examined the torsional resistance under a similar amount of torque rather than a twist-angle [9]. ProTaper Gold has higher torsional resistance than Protaper Universal file. Thermomechanical treatment of Protaper Gold file resulted in increasing its torsional resistance. Stress distribution showed that concentrations of stress were related to the base of the flutes for both files. This stress distribution was related to the convex triangular cross-section design of both files.

Recently, A new era of thermomechanical treatments of the alloy has started to overcome the drawbacks of the traditional NiTi alloy. These new thermal treatments improved mechanical behaviour when compared with conventional superelastic NiTi instruments [11]. Thermomechanical treatment is one of the recent techniques for improving the mechanical performance of NiTi endodontic files [12], [13].

The NiTi alloy has two crystalline phases (austenite and martensite). They have different mechanical properties when the martensitic phase is subjected to heat; it converted to the austenite phase, while in the austenitic phase, the alloy will have shape memory and superelastic characteristics [14].

PTG files have identical design as PTU files, but it developed with thermomechanical treatment. PTG files have 2-stage specific transformation behaviour and high Af temperatures, whereas PTU instruments have 1-stage transformation [7], [15]. This transformation was responsible for the altered mechanical response of PTG instruments. The differences in the fatigue resistance between the PTG and PTU files were related to the presence of martensite, which due to the high transformation temperatures found in the PTG files.

In the present study, the results showed that PTG files have higher flexural and torsional resistance than PTU files. Also, PTG files showed greater flexibility than PTU files. This is due to the thermomechanical treatment of the alloy that altered the mechanical response of the alloy and increased its flexibility. This was in full agreement with Plotino et al., [15] and Hieawy et al., [16] and Aoun et al., [17] who compared the mechanical properties of both PTG and PTU.

In conclusion, the present study evaluated the stress distribution during bending and torsion using FE analysis for two NiTi files of the same design and different metallurgy. With thin the limitations of this study, It was concluded that the thermomechanical treatment improved the mechanical response (bending and torsional resistance) of NiTi files. Further investigations may be needed to investigate the effect of different temperatures on the mechanical behaviour of NiTi file to improve the life span of the files during clinical practice.

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