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Study on Finite Element Models of Heroshaper, ProTaper and Mtwo Endodontic File Segments

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Abstract *:* Endodontic files are used for shaping and cleaning purpose during the root canal treatment of infected tooth. These files are made from nickel-titanium orthodontic wire alloy or Nitinol that has high strength and more flexibility as compared to stainless steel. The aim of present research work is to study flexibility of Heroshaper, ProTaper and Mtwo endodontic file segments when subjected to torsion and bending loads and to identify most flexible cross section using finite element method. Non linear material behaviour is considered during the analysis. Various results are obtained in form of equivalent von-Mises stress, which are presented in the form of contours & charts. Discussion is presented on suitability of cross section under bending and torsional loads and effect on flexibility of endodontic file.

Key words : Endodontic files, Finite element method, Nitinol, Root canal treatment.

INTRODUCTION

Endodontic files are surgical instruments used by dentist while performing root canal treatment. These tools are particularly used to clean and shape the root canal of infected tooth. These files are made from nickel-titanium orthodontic wire alloy or Nitinol which facilitates instrumentation of curved canal. Nickel-titanium (NiTi) rotary instruments have become a mainstay in clinical endodontics because of their exceptional ability to shape root canals with fewer procedural complications. Nitinol has high strength and is very flexible, but firm enough to resist excessive bending and torsion as compared to stainless steel. Files made from NiTi are more flexible than stainless steel. The flexibility of endodontic files not only depends on the material but also on the geometry. There are various NiTi files available that are made from different cross sections.

Finite Element Method is an analytical technique which enables to study the effects of geometrical and material variations under load and internal mechanical process. Finite element analysis shows areas of internal stress concentration and consequently predictions can be made of possible failure. Finite element method is widely used in analyzing endodontic file to understand their behavior under different loading conditions.

BACKGROUND:

A study by N. Raj Vikram [1] illustrates that a variety of sophisticated procedures and equipment are used in the field of dentistry, which are based on basic concepts of engineering. A composition of finite (countable) number of elements forms the basis for finite element analysis (FEA). The analysis shows areas of internal stress concentration and consequently predictions can be made of possible failure.

A study by Wakabayashi [2] illustrates that the nonlinear finite element analysis has become an increasingly powerful approach to predict stress and strain within structures in a realistic situation that cannot be solved by conventional linear static models. Further development of the nonlinear FEM solutions is encouraged to gain a wide range of mechanical solutions that would be beneficial for dental and oral health science.

Walia, [3] and Thompson [**] presented the investigation of the bending and torsional properties of Nitinol root canal files. They found that Nitinol files were two to three times more elastic flexibility in bending and torsion, as well as superior resistance to torsional fracture, compared with stainless steel files manufactured by the same process.

A study by Berutti [4] compared the mechanical behavior of two nickel-titanium rotary instruments (ProTaper and ProFile) by applying the finite element analysis method to produce a numerical evaluation. The ProFile model was found to be more elastic than the ProTaper model. Under equal loads, the ProTaper model showed lower and better distributed stresses than the ProFile model.

A study by Diogo Montalv [5] compares two NiTi rotary instruments with similar geometries and equal cross sections, ProFile GT (GT) and a GT Series X(GTX). GTX file was more flexible and capable of stress relief at the most critical section than GT file.

A study by R. Khapre [6] shows comparison of two endodontic file systems namely ProTaper and Twisted. Full length models were analyzed using finite element method under similar loading conditions. It was found that twisted file model shows greater displacement as compared to ProTaper file model. Force-displacement curve also proved that the Twisted file model is more flexible than the ProTaper file model. Base on literature the objective of this paper is formulated to compare three commonly used endodontic file system namely Heroshaper, ProTaper and Mtwo.

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NiTi Characteristics

Fig. 1 shows the stress-strain characteristics of NiTi. As behavior of NiTi is highly non linear, the characteristics curve of NiTi can be divided into three parts a-b, b-c, c-d. In the first part (a-b), stress strain relationship is linear and alloy is in a more stable crystalline phase. This phase is called as austenitic phase. In the second part (b-c), stress strain relationship is also linear but almost horizontal. In this phase, very small stress produces large strain that makes NiTi super elastic. This phase is known as transition phase. In the third part (c-d) stress strain relationship is highly non linear. This phase is called as martensitic phase. It shows typical stress strain relationship for alloy till breaking point, where gradual increase in strain can be observed with increase in stress.

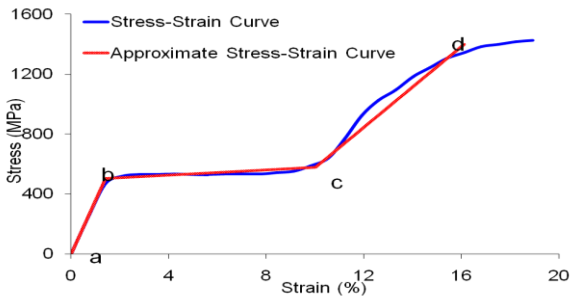


Fig 1: Stress-Strain Characteristics (actual and approximated) of Nitinol

METHODOLOGY

Before analyzing three endodontic files namely Heroshaper, ProTaper and Mtwo, 3D solid model is prepared for each file segment of length 1.8 mm and 0.4 mm diameter as shown in Fig. 2. These 3D models are then discretized by using medium sized mesh. Further, finite element analysis is carried out using ANSYS for torsional and bending moment considering non-linear effect of Nitinol. For torsional loading condition, the model was provided a fixed support at one end and applied an angular rotation of 20 degrees in Z-direction at other end. In bending loading condition, the model was provided a fixed support at one end and applied an angular rotation of 20 degrees in X-direction at other end. Transient finite element analysis is also carried out on file modes to understand the torsional rigidity. Von-Mises stresses distribution is obtained from the bending, torsional and transient analysis.

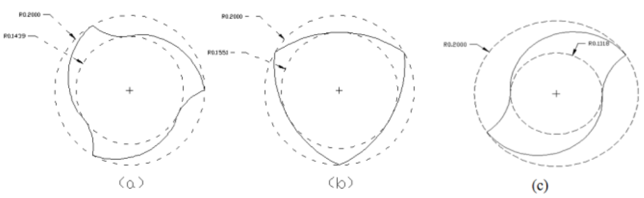


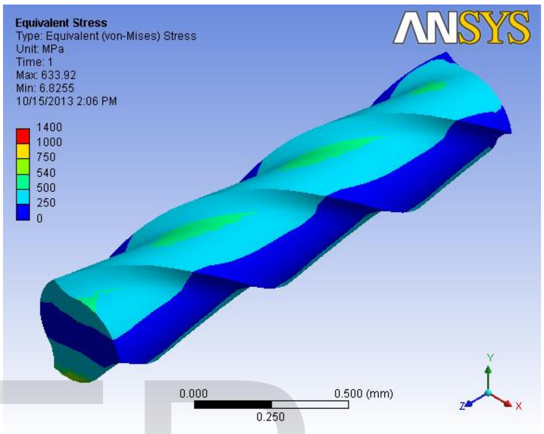
Fig 2: Cross-sections of (a) Hero (b) ProTaper (c) Mtwo endodontic file

Results & Discussion

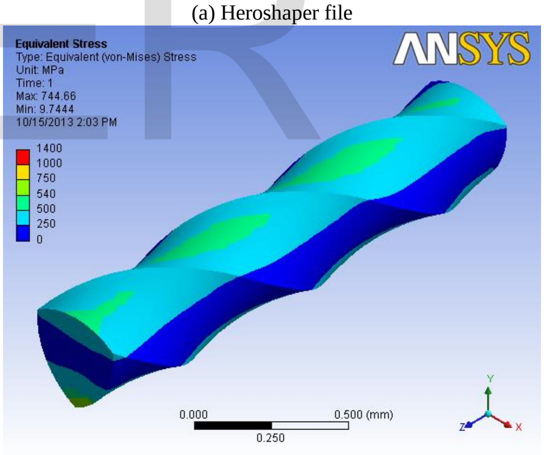
After creating 3D finite element model, it was observed that the cross-sectional area of Mtwo file model is minimum as compared to other file models (see Table I). It was also observed that other geometric properties like volume, core radius and mass moment of inertia is also minimum for Mtwo file model as compared to all models.

Table 1: Properties of endodontic file models

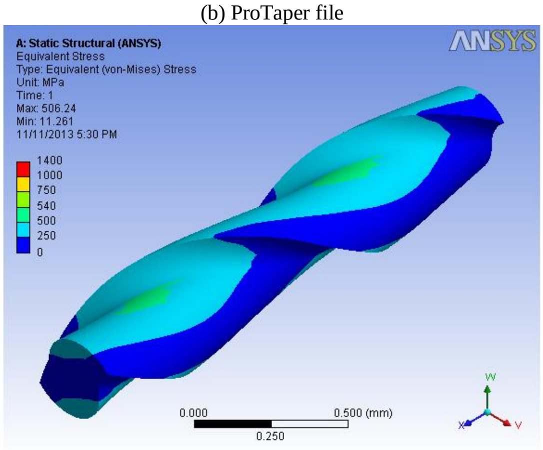
Properties	Heroshaper	ProTaper	Mtwo
Area (mm^2)	0.088977	0.090798	0.0723
Perimeter (mm)	1.1459	1.1079	1.0616
Length of file (mm)	1.8	1.8	1.8
Volume (mm^3)	0.16023	0.16342	0.12913
Outer Radius (mm)	0.2	0.2	0.2
Core Radius (mm)	0.1439	0.1551	0.1118
Nodes	3358	3312	2159
Elements	2610	2632	396
Mass Moment of Inertia Ix ($kg \cdot m^2$)	2.8233e-013	2.8799e-013	2.2555-013
Mass Moment of Inertia Iy ($kg \cdot m^2$)	2.8233e-013	2.8799e-013	2.2556-013
Mass Moment of Inertia Iz ($kg \cdot m^2$)	1.4784e-014	1.5163e-014	1.0099-014
Density of Nitinol (kg/m^3)	6450		



(a) Heroshaper file



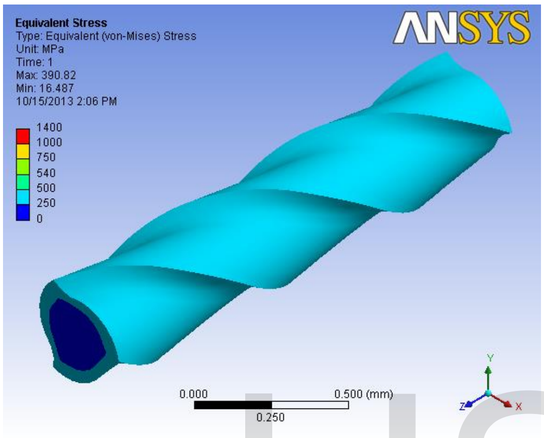
(b) ProTaper file



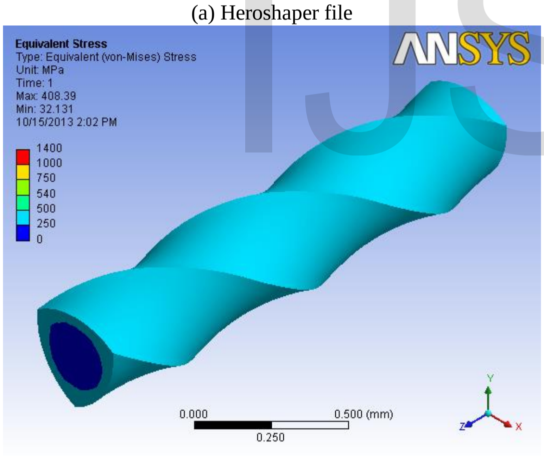
(c) Mtwo file

Fig 3: Von-Mises stress distribution for bending (rotation about x = 20°)

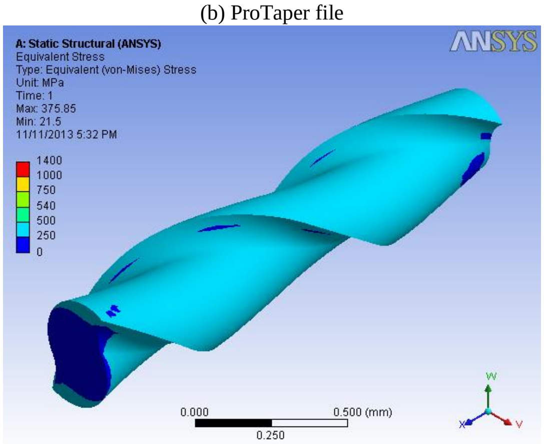
When these models were subjected to rotation of 20° along X-direction (bending), the value of maximum von-Mises stress are generated in Heroshaper, ProTaper and Mtwo are 633.92 MPa, 744.66 MPa and 506.24 MPa respectively (Fig. 3). In case of torsional loading (Fig. 4), these values are found to be 390.82 MPa, 408.39 MPa and 375.85 MPa respectively for Heroshaper, ProTaper and Mtwo file models. Transient torsional analysis is also performed on all three file models and rigidity curve is plotted as shown in Fig. 5. It can be seen from Fig. 5 that ProTaper file shows maximum rigidity in all three phases of Nitinol. It was also found that Mtwo file model shows lowest rigidity value as compared to other two file models. Rigidity of Heroshaper file model is slightly higher than Mtwo file model.



(a) Heroshaper file



(b) ProTaper file



(c) Mtwo file

Fig 4: Von-Mises stress distribution for bending (rotation about x = 20°)

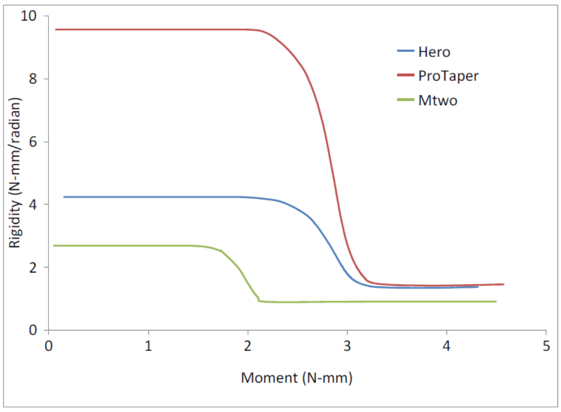


Fig 5: Moment-Rigidity curve

CONCLUSION

Based on the result obtained from finite element analysis, it can be concluded that the Mtwo file model is most flexible as compared to Heroshaper and ProTaper file model.

From the stress distribution diagrams (Fig. 3, and Fig. 4) of file segment it can be observe that von Misses stress distribution is complex when subjected to bending as well as torsional loads. It can also be seen from Fig. 4 that, when file is subjected to torsional loads, the stress is below 500 MPa hence the file is in austensitic phase as well as the stresses are less at the central region and increases as the distance increases from neutral plane. Fig. 3 also shows that when file is subjected to bending loads, the stress is above 540 MPa hence the file is in martensitic phase and stresses are more at the flute region.

From the rigidity curve (Fig. 5), the maximum rigidity of ProTaper, Heroshaper and Mtwo Endodontic File can be observed at 9.7, 4.22, 2.72 N.mm/rad respectively. Hence ProTaper is more rigid than Heroshaper and Mtwo file. Rigidity curve shows horizontal behavior when in austensitic phase then sudden drop in rigidity is observed, this phase is the transition phase the value of rigidity observed at the end of this phase is near about 1.3 N.mm/rad and then the martensitic phase occurs.

Based on the result obtained from finite element analysis, it can be concluded that the Mtwo file model is most flexible as compared to Heroshaper and ProTaper file model.

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