Comparative Analysis of Nickel-Titanium Rotary Endodontic File Systems

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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 compare to stainless steel. This study compares two endodontic file systems namely ProFile and Twisted. These files models are analyzed using finite element method under similar loading conditions. Non-linear material behavior is considered during analysis and stress distribution is obtained under torsional and bending loading conditions. The obtained results are presented in form of stress contours and rigidity curve. Based on results obtained, it was found that the Twisted file system is more flexible as compared to ProFile system.

Keywords: Endodontic files, Nitinol, Finite element analysis, ProFile system, Twisted file system

1. Introduction

Human teeth is composed of three vital layers namely, the enamel (outermost layer), followed by, dentin (intermediate layer) and lastly the pulp which is encased in pulp chamber covered by enamel and dentin. For, pulp tissue to remain healthy and maintain the tooth in vital condition there are root canals inside the root of the teeth which provides the blood circulation to the pulp tissue and helps it to remove noxious stimuli (ex- microorganisms) which can endanger its vitality. Whenever the caries process invades the pulp it undergoes inflammation and the patient's starts complaining of continuous pain which may hamper its normal day to day activities (Unable to eat and sleep). If left, untreated it leads to the death of pulp tissue and may further complicate the condition of the patient.

In such state there exist two treatment options for the patient – extraction of the tooth or the root canal treatment. Extraction is generally an invasive procedure and is not readily accepted by the patient. Thus the Root canal treatment (RCT) is undertaken to save such teeth. In root canal treatment access to the pulp chamber is gained after removing enamel and dentin layers and later on the infected pulp tissue is removed followed by proper shaping and cleaning of the root canal systems. For shaping and cleaning purpose, various rotary file systems are available in the market today.

The present study is aims at comparison of two endodontic file systems based on their structural analysis. As these files are continuously rotating within the complex geometry of root canal, they are subjected to bending moments and torsion. Sometimes these files are blocked within the canal and in some cases even break due to development of higher stresses. Therefore this study is carried out on two endodontic files using well known finite element method illustrated in Zienkiewicz and Taylor (1989) and Bathe (1996). Both loading conditions namely torsional moment and bending moments are considered for the finite element analysis.

2. Background

Various types of file systems are used for canal cleaning and shaping purpose during Root Canal Treatment (Figure. 1). As the canal anatomy is complex (Figure. 2), it is difficult to operate with rotary instruments made from rigid material, like stainless steel, in curved canal geometry. The endodontic instrument must be strong at the same time should be flexible in order to follow the natural anatomy of the root canal. Nickel-titanium orthodontic wire alloy also known as Nitinol fulfils these requirements. According to Walia, et al. (1988) and Thompson (2000), files made from Nitinol are more flexible, strong and provide more ease in operation. Berutti, et al. (2003) and Subramaniam, et al. (2007) gave the stress-strain characteristics of Nitinol as shown in Figure 3. It can be seen from Figure 3 that the Nitinol is highly flexible and can handle larger strains, this helps in cleaning and shaping of the root canal system.

Berutti, et al. (2003) and Subramaniam, et al. (2007) presented the comparative study of two Nitinol endodontic root canal files namely ProTaper and Profile. Detailed finite element analysis was presented on two file models by applying bending moments and torsion. Study shows that

ProFile model is more elastic than ProTaper model. It also shows that ProFile model has very short transformation phase where as ProTaper model has long transformation phase. It also concludes that ProTaper is very useful in cleaning and shaping of narrow and curved canals whereas ProFile model is handy in final phase of shaping and cleaning. Study suggests that use of both files together, with tapered cross-sections, can give better results in root canal treatment.

Figure 1: File System

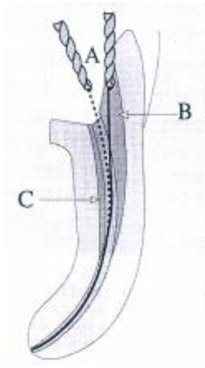


Figure 2: Canal Anatomy

3. Material Characteristics

The endodontic instruments are made from nickel-titanium orthodontic wire alloy or Nitinol. Figure 3 shows the stress-strain characteristics of Nitinol. It can be seen from Figure 3 that the behavior of Nitinol is highly non-linear. The characteristics curve of Nitinol 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 flat. In this transition phase, very small stress produces large strain that makes Nitinol super-elastic in this 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 metal till breaking point, where gradual increase in strain can be observed with increase in stress. It can be noted that the Nitinol is highly flexible and can handle larger strains, this helps in cleaning and shaping of the root canal system.

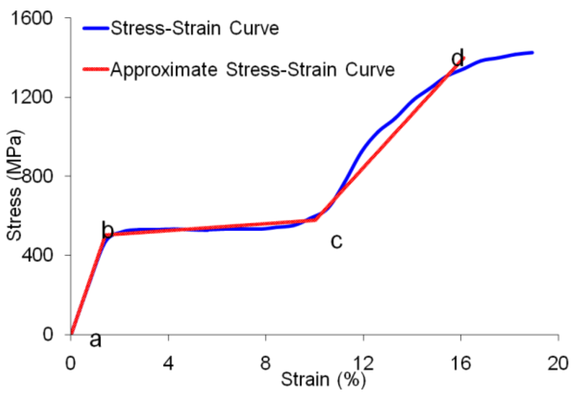
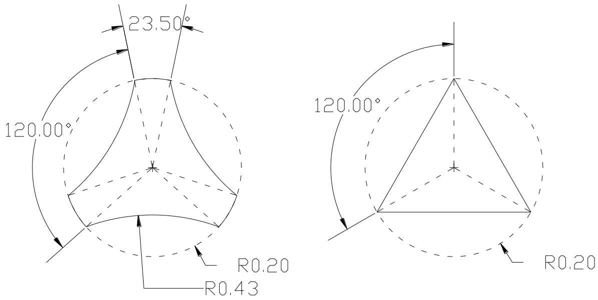


Figure 3: Stress-strain characteristics (actual and approximated) of Nitinol (Berutti, et al. 2003 and Subramaniam, et al. 2007)

While performing finite element analysis, the stress-strain behavior of Nitinol is approximated by three lines a-b, b-c, c-d as shown in Figure 3. The Young's modulus of these three portions is 35,700 MPa, 860 MPa, and 11,600 MPa respectively. The approximate Poisson's ratio of 0.3 is considered for Nitinol during the analysis.

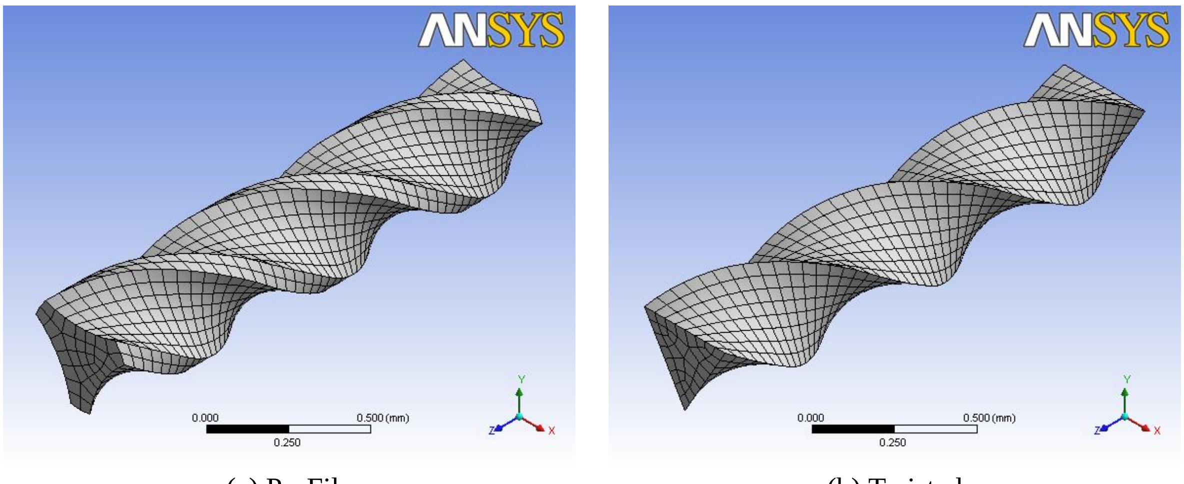


ProFile Model Twisted Model

Figure 4: Cross sections of two files

4. Finite Element Analysis

Two files namely ProFile and Twisted are analyzed using ANSYS Workbench software. At first, the geometry of these two files are created using Design Modeller feature of ANSYS Workbench. The cross sections of these two files are shown in Figure 4. These cross sections are described within a circumferential diameter of 0.4 mm. Three dimensional geometric model of each file is created by rotating the cross section by 360° over the length of 1.8 mm as per the procedure given by Berutti, et al. (2003) and Subramaniam, et al. (2007). In order to have appropriate comparison between these files, segment of equal length and diameter is considered while creating finite element model. The taper of file is not included while creating finite element model. This is done intentionally in order to compare results obtained from present analysis with results available in literature by Berutti, et al. (2003) and Subramaniam, et al. (2007).



(a) ProFile (b) Twisted

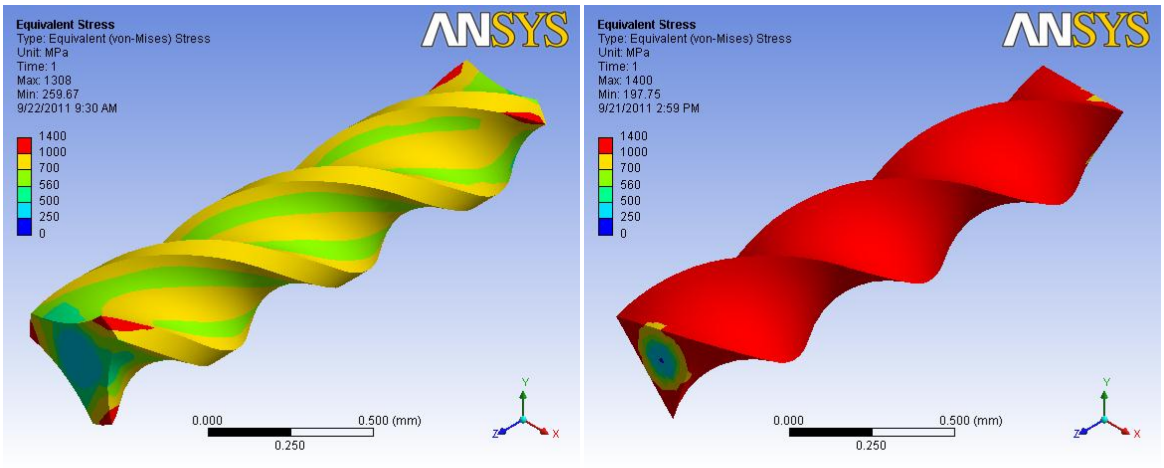
Figure 5: Discretized finite element model of two files

Finite element analysis of these two files is carried out using Simulation feature of ANSYS Workbench. The geometries created using Design Modeller are imported in Simulation feature of ANSYS Workbench for their analysis. During finite element analysis, the non-linear effect (material non-linearity) is incorporated whereas large deformation feature (geometric non-linearity) is ignored. The finite element meshing is carried out using medium size mesh feature with three dimensional elements like brick elements and tetrahedron element. Figure 5 shows the discretized finite element model of two files. The details of nodes and elements used for these file are given in Table 1.

Table 1: Table showing details of meshing of two file

File	*Number of Nodes*	*Number of Elements*
ProFile	*2304*	*1551*
Twisted	*2256*	*1598*

Static structural finite element analysis is carried out on these two file models to understand their bending and torsional behavior. At first, a moment of 2.5 N-mm is applied at one end along z-axis that replicates torsional moment, while the other end is kept fixed. The variation of von-Mises stress due to torsional moment in both file modes is shown in Figure 6. It can be observed that the stress distribution is uniform over the length of model in both the cases. Magnitude of von-Mises stress is below 500 MPa in the region of neutral axis of both file models. In this region, the alloy is in crystalline phase also known as austenitic phase. In case of ProFile model, the exterior part of both files is under greater stresses ranging from 500 MPa to 1000 MPa. In this phase Nitinol's behaviour is super-elastic. Under such stress condition, Nitinol goes through transition phase from austenitic phase to martensitic phase. In case of Twisted file model, the external portion of core of file is under stress ranging from 500 MPa to 1000 MPa. The edges of twisted files are under heavy stresses up to 1400 MPa, which is very close to ultimate tensile strength of Nitinol.

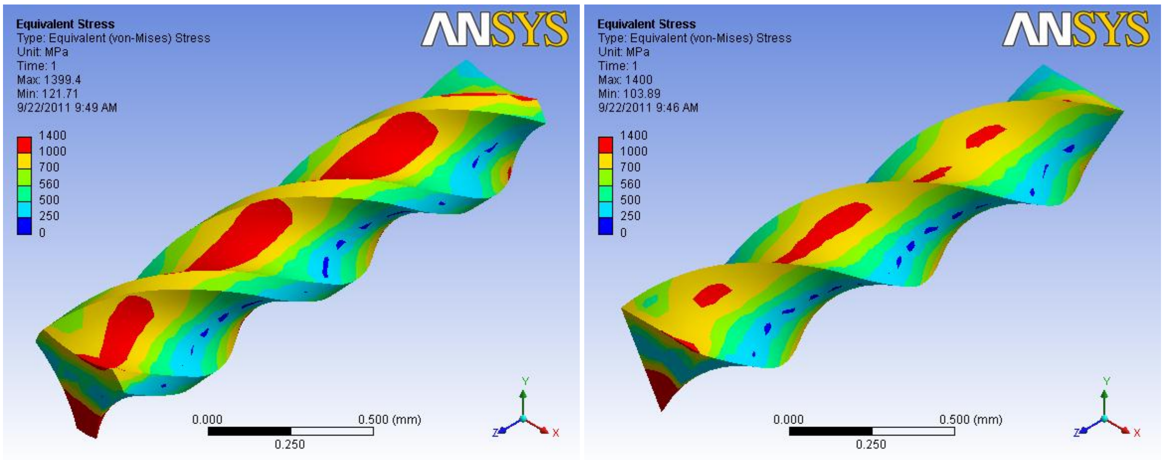


(a) ProFile

(b) Twisted

Figure 6: Distribution of equivalent (von-Mises) stress in two files under application of torsional moment of 2.5 N-mm

In another case, a moment of 2.9 N-mm is applied at one end along x-axis that replicates bending moment, while the other end is kept fixed. The variation of von-Mises stress due to bending moment in both file modes is shown in Figure 7. It can be observed that the stresses are very less in the region of neutral plane exists in central region both file models. In both file models, the magnitude of stress increases as the distance from neutral plane increases. These stresses are tensile/compressive in nature at top/bottom portion of file (similar to cantilever beam). The stresses generated in both file models are in the range of 500 MPa to 1400 MPa that shows the presence of transition phase from austenitic and martensitic phase, as well as fully developed martensitic phase in the region of flutes between blades.



(a) ProFile (b) Twisted

Figure 7: Distribution of equivalent (von-Mises) stress in two files under application of bending moment of 2.9 N-mm

The stress distribution obtained for ProTaper file model subjected to bending moment and torsional moment is compared with the stress distribution available in literature Berutti, et al. (2003) and Subramaniam, et al. (2007). It was found that the obtained results match well with the literature.

Transient finite element analysis is carried out on these two file models to understand their torsional rigidity. The analysis is carried out on two file models by applying torsional moment of 4.0 N-mm is applied at one end, while the other end is kept fixed. This analysis is carried out keeping time at the end of analysis as 40 seconds. Moment applied is kept as a function of time and step size of 1 second is considered during analysis. Automatic time stepping feature is also used during the analysis in order to get accurate results in minimum time duration. Rotation is measured at every time step and rigidity curve is plotted as shown in Figure 8. It can be seen that the nature of rigidity curve is same for both file models. In both the file models, the rigidity curves are almost horizontal in the initial phase. This indicates that the Nitinol is in austenitic phase, where stress is directly proportional to strain. It can also be seen that the rigidity of twisted file model is less than ProFile model in austenitic phase. It can also be observed that ProFile model remain in austenitic phase for higher magnitude of moment where as Twisted file model looses austenitic phase and moves towards martensitic phase prior to ProFile model.

After following horizontal path, sudden drop in rigidity is noted in both file models. This phase is the transition phase where large strain can be handled by Nitinol for lesser magnitude of stress. It can be observed that this transition phase is occurs earlier in twisted model as compare to ProFile model. The rigidity for both file models is nearly same in when they reach martensitic phase. The twisted file model has slightly less rigidity as compare to ProFile model in martensitic phase also. Both file models exhibits constant increase in rigidity in martensitic phase.

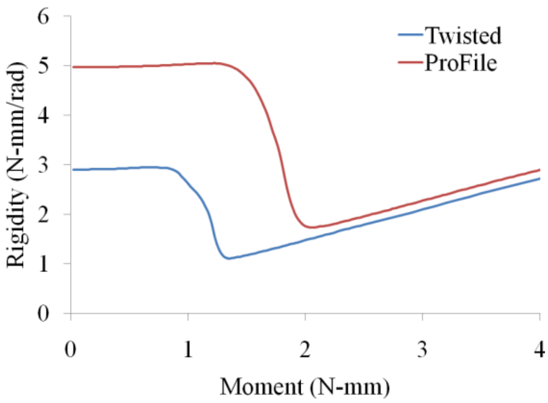


Figure 8: Moment rigidity curve for two files under application of torsional moment of 4.0 N-mm

5. Conclusion

After performing finite element analysis on two file models, the obtained results are presented in forms of stress contours (Figure 6 and Figure 7) and rigidity curve (Figure 8). Both file models shows complex stress distribution when subjected to torsional moment as well as bending moment. For same magnitude of torsional moment, the magnitude of stresses developed in twisted file model is more than the magnitude of stresses developed in ProFile model. It was found that ProFile model is more rigid as compare with twisted file model. It was also found that the rigidity curve pattern of both file models is same but their values are different. This is due to different geometric properties of file models like cross-sectional area and moment of inertia. As twisted file is more elastic than ProFile model, it allows dentist to operate with more ease in curved canals during the process of final shaping and cleaning.

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