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ANALYSIS OF FULL LENGTH FINITE ELEMENT MODEL OF PROFILE AND TWISTED ENDODONTIC FILES

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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. Full length 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 bending loading conditions. The obtained results are presented in form of stress contours. Comparison of these file is presented based on distribution of stress across the length of files and force-displacement curves.

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, torsion and sometimes combination of both. 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). Emphasis is given on bending conditions only as they are contribution to higher stress generation for the finite element analysis presented here.

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.

Figure1:File System

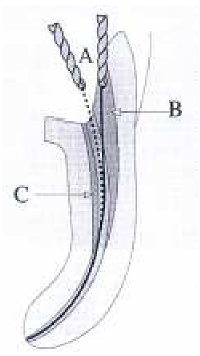


Figure 2: Canal Anatomy

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.

Diogo and Francisca (2011) presented comparison of two Nickel-Titanium files namely ProFile GT and ProFile GT Series X.

Both files are made from Nickel-Titanium alloys but have slightly different stress-strain behavior as they are manufactured through different process. They carried out finite element analysis on two full length file models of ProFile GT and ProFile GT X using commercial software ANSYS. Both models are analyzed for bending as well as torsion. Their analysis shows that ProFile GT X file is more flexible as compared1 to ProFile GT file.

Khapre and Shinde et al. (2011) presented comparison of two NiTi files namely ProFile and Twisted file models. They used finite element based ANSYS Workbench software for the analysis of segment of these files models for bending and torsional loads. They concluded that Twisted file model is more flexible than ProFile model. They also presented rigidity curve for both the file models obtained by performing transient finite element analysis.

Khapre and Shinde et al. (2012) presented a study on comparison of two Nitinol endodontic files namely Protaper and Twisted file. They carried out the analysis using commercial software ANSYS 11.0 on full length file models subjected to lateral load and displacement applied at the tip. They found that the twisted file model shows greater displacement as compared to ProTaper file model for same amount of load. They also presented the load-displacement curve that confirms that the Twisted file model is more flexible than the ProTaper file mode.

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 behaviour 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.

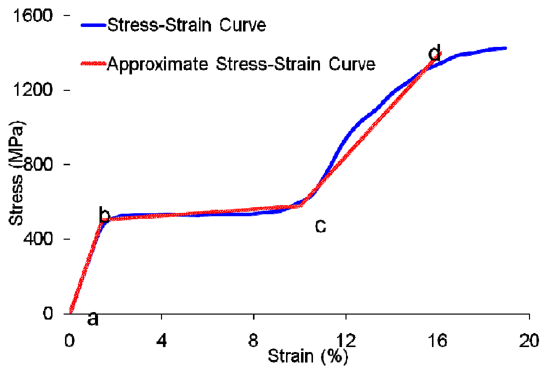
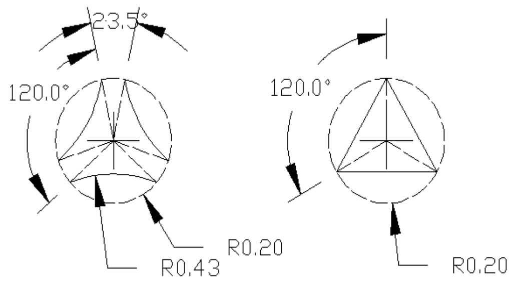


Figure 3: Stress-strain characteristics (actual and approximated) of Nitinol (Berutti, et al. 2003 and Subramaniam, et al. 2007)

While performing finite element analysis, the stress-strain behaviour 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.

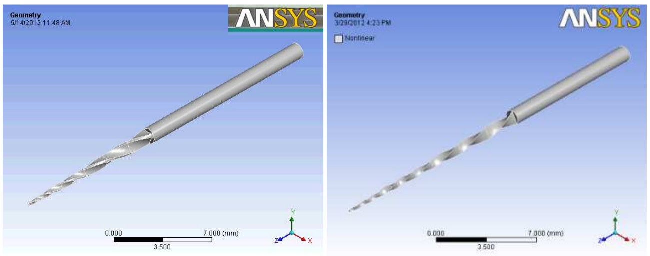


(a) ProFile (b) Twisted

Figure 4: Cross sections of two files at tip

FINITE ELEMENT ANALYSIS

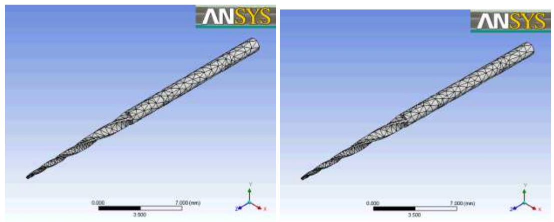
Two files namely ProFile and Twisted are analyzed using ANSYS Workbench software. At first, the geometry of these two files are created using Design Modeller feature of ANSYS Workbench. The cross sections of these two files at their tip are shown in Figure 4. Three dimensional geometric models of both files were created by rotating the cross section over the length of 2.7 mm. The ProFile and Twisted model was created by rotating its cross-section by 360° with number of rotations as 3. In order to generate the tapered files, the cross-sectional area is linearly increased after every rotation so that the final file model has tip diameter as 0.2 mm and edge diameter as 1.2 mm. Three dimensional file models of both file are shown in Fig. 5.



(a) ProFile (b) Twisted

Figure 5: Three dimensional 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 tetrahedron element. Figure 6 shows the discretized finite element model of two files. The details of nodes and elements used for these file are given in Table 1.



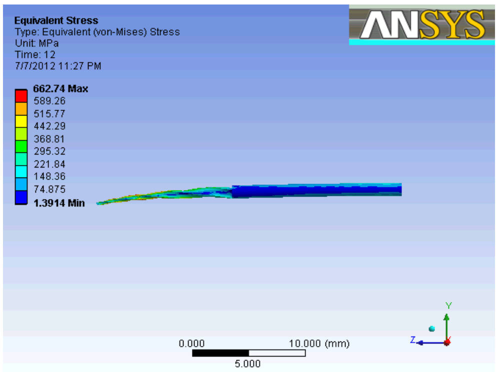
a) ProFile b) Twisted

Figure 6: Discretized finite element model of two files

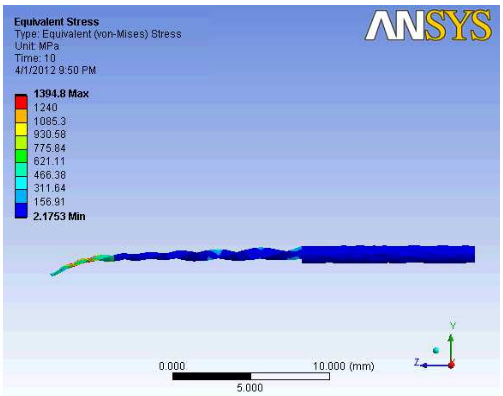
Table 1: Table showing details of meshing of two file

File	Number of Nodes	Number of Elements
ProFile	2325	1014
Twisted	477	820

Static structural finite element analysis is carried out on these two file models to understand their bending behaviour. At first, a force of 1 N is applied at tip of file model in the direction of y-axis keeping the other end fixed that creates bending moment. The variation of Von-Mises stress due to bending moment in both file modes is shown in Figure 7. High stress concentration can be observed near the tip region of both the file. It was also observed that the maximum Von-Misses stresses generated in Twisted file model are greater than the ProFile file model. It can be seen that the material near the tip region of both file model is in the martensitic phase and very close to ultimate tensile strength of Nitinol i.e. 1400 MPa.



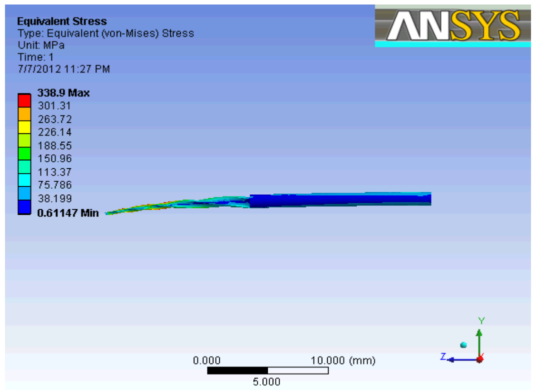
(a) ProFile



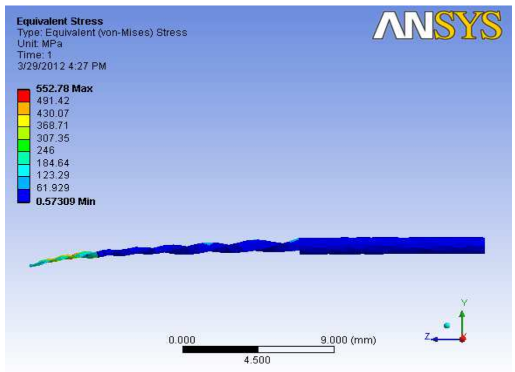
(b) Twisted

Figure 7: Distribution of equivalent (Von-Mises) stress in two files under application of force of 1 N at tip

In another case, a displacement of 2 mm in the direction of y-axis is applied at tip of both files, 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 8. It can be observed that the stresses are very high in near the tip of both file models. Magnitude of stress generated in file models indicates that the material is in the transition phase i.e. from austenitic phase to martensitic phase.



a) ProFile



b) Twisted

Figure 8: Distribution of equivalent (von-Mises) stress in two files under application of displacement of 2 mm at tip

The results obtained from finite element analysis of both file models are presented in Table 2. It can be seen from Table 2 that, 1 N force produces very high stresses in both the file models. The maximum Von-Mises stresses generated in Twisted file model is higher in magnitude as compared to maximum Von-Mises stresses generated in ProFile file model. The percentage variation in Maximum Von-Mises stresses was found to be 52.48 %. When a y-direction deflection of 2 mm was applied on both file models, the magnitude of maximum Von-Mises stresses generated in both file models shows 38.69% variation. It can also be observed from Table 2 that the minimum Von-Mises stress generated in both file models under application of force as well as displacement are very less in magnitude.

Table 2: Table showing details of Max./Min. Von-Mises stresses

Load/ Displacement		**Max. Von-Mises Stress**		
		(MPa)		
		Twisted	ProFile	Δ %
Force	1 (N)	1394.8	662.74	52.48
Displacement	2 (mm)	552.78	338.9	38.69
Load/ Displacement		Min. Von-Mises Stress		
		(MPa)		
		Twisted	ProFile	Δ %
Force	1 (N)	2.1753	1.3914	48.75
Displacement	2 (mm)	0.5730	0.6114	-6.68

Table 3 summarizes the results of force/displacement obtained for finite element analysis of both file models. It can be observed that, a force of 1 N produce more displacement in twisted file model as compared to ProFile file model. The percentage variation in displacement was found to be 79.49%. It can also be observed that 2 mm displacement produces a higher magnitude reaction in ProFile file model as compared to Twisted file model. This clearly depicts that twisted file model is more flexible than ProFile file model.

Table 3: Table showing details of Force/Displacement

Load/ Displacement	**Load/**	**Max. Stress**	**Von-Mises**	
	Displacement	(MPa)		
		Twisted	ProFile	Δ %
Force (1N)	Displacement	22.736	4.6627	79.49
Displacement(2mm)	Force	0.2634	0.5271	-50.29

The force-displacement pattern obtained from present analysis is shown in Fig. 9. It can be seen that the force-displacement curve for twisted file model lies exactly below the curve of ProFile file model. This shows that Twisted file model is more flexible than ProFile file model.

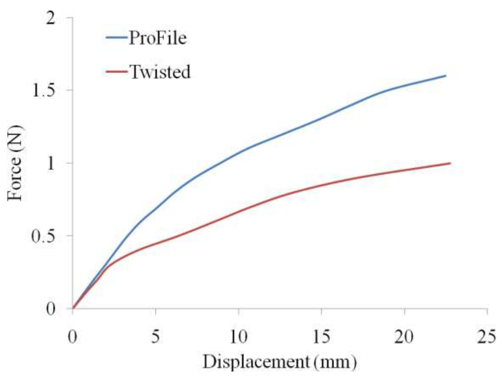


Fig. 9 Force-Displacement behaviour

CONCLUSION

After performing finite element analysis on two file models, the obtained results are presented in forms of stress contours (Figure 7 and Figure 8) and force-displacement curve (Figure 9). Both file models shows complex stress distribution near the tip region when subjected to force as well as displacement. For the same load and boundary conditions, (1N at the tip) the Twisted file was 52.48% more stress than the ProFile file. The force required for a 2 mm deflection of the Twisted file tip is 79.38% than the value needed for the same deflection of the ProFile tip; both the force versus displacement file charts are nonlinear. it was observed that the stress pattern in ProFile was uniform throughout the length of file and in the Twisted files maximum stress occurred at the tip. Force-displacement curve also confirms that the Twisted file model is more flexible than the ProFile file model. Twisted file is more elastic than ProFile model, hence it allows dentist to operate with more ease in curved canals during the process of final shaping and cleaning.

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