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RESEARCH ARTICLE

LATERAL FORCES EXERTED BY TWO ROTARY NITI FILES: A COMPARATIVE FINITE ELEMENT STUDY

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ABSTRACT

Aim: Aim of the study is to evaluate the lateral forces on the instrument in the apical 3rd of curved canal with two Nickel Titanium rotary systems.
Methodology: One brand of instrument ProTaper F2 was scanned with micro computed tomography to produce a real-size, 3-dimensional (3-D) model and was compared with Anexas (designed by author). The stresses on the instrument during simulated shaping of the root canals were analyzed numerically by using a 3 D finite element package, taking into account the nonlinear mechanical behavior of the NiTi material.
Results: Anexas shows lowest values for force generation in the apical 3rd of canal as compared to Protaper which shows higher values.
Conclusion: With FE simulation of root canal shaping by 2 files, it was observed that different instrument designs would experience unequal degree of force generation in canal, as well as reaction torque from the root canal wall.

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INTRODUCTION

In recent years, nickel-titanium (NiTi) alloy rotary endodontic instruments have revolutionized endodontics. The NiTi rotary instrument rotates continually within the root canal and is subject to structural fatigue and ultimately failure because of two principal types of stress: bending stress and torsional stress (Sotokawa, 1988; Pruett *et al.,* 1997). The durability of a NiTi rotary instrument is directly proportional to the working stress it undertakes (Zuolo and Walton, 1997; Yared *et al.,* 1999; Gambarini, 2001), and this is closely related to the number of cycles performed (Pruett *et al.,* 1997). Every clinician who has performed endodontics has experienced a variety of emotions ranging from the thrill-of-the-fill, to an upset such as the procedural accident of breaking an instrument. During root canal preparation procedures, the potential for instrument breakage is always present. When instrument breakage occurs, it immediately provokes despair, anxiety, and then the hope that nonsurgical re-treatment techniques exist to liberate the instrument from the canal (Parashos *et al.,* 2006). In routine endodontics a clinician may encounter with many procedural errors and obstacles including file fracture which may alter the course of treatment at any stage (Torabinejad and Lemon, 2002). Canal curvature is suspected to be the predominant risk factor for instrument failure because of flexural stresses and cyclic fatigue (Peters, 2004; Hulsmann *et al.,* 2005). The improved flexibility of instruments made of nickel titanium has been shown to produce improved preparation shapes compared to stainless steel (Serene *et al.,* 1995). Various brands of NiTi rotary system have been introduced to the market, each having a slightly different design for its cross-sectional shape, helical angle, and "radial lands" (Hata *et al.,* 2002). Various parameters that affect canal-centering ability:

1. Alloys used in manufacturing instruments
2. Instrument design
   - Cross-section
   - Taper
   - Tip

Increasing the resistance to fracture has been a focus in the design of new NiTi rotary systems. The design can affect the mechanical behavior (Kim *et al.,* 2010). ProTaper system (Dentsply, Switzerland) has a convex triangular cross-section. This design along with progressive taper present in the instruments, results in reduced contact area between dentin and the cutting blade of the instrument (Clauder and Baymann, 2004). Rotary instruments such as ProTaper (Dentsply Maillefer, Ballaigues, Switzerland) have a modified cross-sectional design that resembles a K-File configuration compared to other rotary instruments. It cuts dentine more electively and reduce torsional loads (Maitin *et al.,* 2013). Anexas is a new file design by the author, this cad design of

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the file is variable pitch and variable taper, the cross section of the file is asymmetrical , helical angles are accentuated. The tip is non cutting half spiral. Most rotary NiTi instruments have tip designs that confer poor cutting capability. If the tip encounters a portion of canal smaller than its diameter, the instrument tends to lock, and torque rises rapidly. If torque reaches a critical level, the instrument undergoes structural failure (Gambarini, 2010; Yared *et al.,* 2002). In endodontics using the FEM technology, the parameters of the geometry of the structure such as the material properties, along with the magnitude and direction of the load can be changed easily in simulation, which is a great advantage over experimental methods (Roylance, 2000).

MATERIALS AND METHOD

Mechanical Property of NiTi

In this study the nonlinear mechanical behavior of NiTi material is similar to the one reported by others (18), was taken into account in this study. Briefly, the model stress-strain behavior of NiTi alloy comprises a linear elastic deformation of the parent phase, followed by elastic and then the plastic deformation of the martensitic phase. The elastic strains and the transformation strain are mostly reversible, but the plastic strain is not (Xu *et al.,* 2006; Wang, 2007). The general mechanical properties entered for the NiTi material in the analysis were Young's modulus 36 gigapascals (GPa) and the Poisson's ratio is 0.3. The critical stress at the beginning of the forward phase transformation was taken as 504 MPa and at the end point of recoverable strain was 755 MPa (Wang, 2007).

Simulation of the root canal shaping

To carry out this simulation mathematically on the finite element model, a 3D-FE model was constructed for a root canal 14mmlong with a curvature of 45-degree angle and 6 mm radius. The model canal had an apical foramen of 0.25 mm diameter and about 5% apical taper. To carry out study the behavior of the 3 brands of NiTi files were analyzed numerically in a Finite element package (ABAQUS 8.0) to simulate the bending conditions during root canal shaping. The files were inserted to the full length of the simulated root canal in model, and the stress distribution on the surface and within the instruments was evaluated. The virtual rotation rate was fixed at 240 rpm for all rotary instruments. The force exerted by file in the lateral direction was evaluated mathematically.

In this study a brand of NiTi instrument, ProTaper F2 (Size 25 variable taper, Dentsply Maillefer) was scanned at 2 microns interval in a micro computed tomography machine (phoenix v|tome|x s S&I - 10065) to obtain a real-size, geometric configuration of the protaper instrument. After obtaining the 3D data it was converted into the STL, the data was again converted into IgS format by CREO Parametric 2.0. The noise in the 3D stack of data was suppressed digitally to the maximum possible extent, and a 3D model of protaper instrument was reproduced. A new file design Anexas (size 25, variable taper) to be tested against the existing designs was constructed on the CAD model which was designed in IgS format. A mesh of linear 8noded hexahedral element was laid over the protaper instrument in software to produce a 3D model for entry into FE analysis. The model for Anexas no 25 file consisted of 3547 elements and 5944 nodes and for protaper 2850 elements and 5783 nodes.

RESULTS

In this study while inserting file into the canal, both files experienced a force but to varying degrees along the direction of its longitudinal axis, as well as a reaction on the on the surface of root canal wall this force is same as the force acting on the surface of the file (as per Newton's third law of motion). The force acting on the surface of endodontic instrument is assessed in an engineering software ABACUS and ANSYS. The results showed that Protaper instrument showed higher value of lateral forces acting on the surface of the file as compared to the Anexas file in the apical third section. The amount of force exerted by ProTaper was found to be 191 grams as compared to 153 grams exerted by Anexas file. The value of the force became more or less constant once the full length was reached in the canal. The stress acting on the file is also analyzed. It was found that in ProTaper the file experienced stress till 7 mm from the tip while the Anexas file experienced stress up to 6.5 mm only.

DISCUSSION

A number of articles have been published on the application of the virtual reality technology in orthodontics (Carriere and Carriere, 1995), restorative dentistry (Herder *et al.,* 1996), orthognathic surgery (Wagner *et al.,* 1997), and implantology (Verstreken *et al.,* 1996), with quiet encouraging results. This is an effort to apply the virtual reality technology in endodontics. In the last decade NiTi rotary instruments have been gaining popularity among general dentists and endodontic specialists. But at the same time there is an increasing concern about the instrument fracture during the use, as evidenced by the amount of reports on this problem (Ankrum *et al.,* 2004; Bergmans *et al.,* 2003). If we examine fracture instruments under electron microscope basically two types of fracture mechanisms were identified 1) fatigue failure characterized by numerous patches of linear fatigue-striation marks and 2) torsional failure characterized by circular abrasion marks on the fracture surface (Cheung *et al.,* 2005; Wei *et al.,* 2007). Examination of the instrument longitudinally and microscopically would reveal the cause of failure (Cheung *et al.,* 2005) but the actual cause of instrument fracture could not be determined satisfactorily by such inspection of broken instruments, because it's impossible to assess the amount of force required to fracture this instrument, or the amount of force acting on the files to cause such a catastrophe. So a mathematical simulation is used here to estimate the stress distribution and residual stresses on the instrument. In dental research to analyze the stress of structural objects with complex morphology, strain gauge technique, and finite element method are very commonly used. Finite element analysis has been practically and broadly applied to the field of structural and mechanical analysis. In Finite Element analysis, a large structure is divided into a number of small simple shaped elements and nodes, for which individual deformation (strain and stress) can be very easily calculated than for the whole undivided large structure. By solving the deformation of all the small elements simultaneously and mathematically, the deformation of the structure as a whole can be assessed (Srirekha and Bashetty, 2010). Hence finite element analysis was used in this study. The forces are generated as a result of friction between dentin and the cutting edge of the instruments (Schrader and Peters, 2005). In our study the amount of force exerted by the ProTaper file was 191 grams while the amount of force exerted by Anexas file was 153 grams.

The amount of lateral forces exerted by the ProTaper file was found to be much greater as compared to that of Anexas. Similarly the force acting on the file goes upto 7mm in ProTaper and 6.5mm in Anexas file. The author has designed Anexas file with a variable taper and variable pitch, the cross section of the file is also asymmetrical. This leads to less screwing effect of the file inside the canal due to which there is less lateral and apical forces acting on the file. This leads to less instrument breakages. Anexas file also has variable helical angle which reduces the screwing tendency. All of the features combining make sure that the amount of forces acting on the file is reduced apically as well as laterally. We should also keep in mind that during the manufacture of NiTi instruments, small machining scratches and grooves are invariably left on the surface of these instruments. These surface imperfections can serve as notches that would concentrate the stress, limiting the instrument's fatigue life span. The high concentration of stresses at the cutting edge of ProTaper instrument might cause these machining defects to become microcracks. Crack like features at the cutting surfaces have been a frequent observation in clinically used Pro Taper instruments (Abujudom *et al.,* 1990).

Conclusion

Within the setup of this study, it can be easily seen that lot of stress were generated on surface of Protaper files compared to Anexas. The same results were seen with the forces acting on the total length of file. Protaper had high lateral stresses compared to Anexas. It can be concluded that each instrument design would experience unequal degree of screw in tendency, as well as the reaction torque from the root canal wall. There is a difference in the location for maximum stress concentration and in the value and distribution of the residual stresses for various instrument designs, so the operator needs to analyze cross sectional design and taper of files for their use.

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