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Comparative Evaluation of Forces Generated by Two Different Rotary Endodontic File: A Finite Element Study

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Abstract

Aim: Aim of the study is to evaluate the lateral forces acting on the instruments in the apical 3rd of curved canal with two Nickel Titanium rotary systems.

Methodology: two brand of instruments Protaper F2 and Mtwo were scanned with micro computed tomography to produce a real-size, 3-dimensional (3-D) model and were compared with each other. The stresses on the instrument during simulated shaping of the root canals were analyzed numerically using a 3 D finite element package and taking into account the nonlinear mechanical behavior of the NiTi material.

Results: Mtwo file shows lower 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 two files, it was observed that different instrument designs would experience an unequal degree of force generation in the canal, as well as reaction torque from the root canal wall will be different.

Keywords: Finite element analysis; NiTi rotary files; Protaper; Residual stresses, Stress distribution

Introduction

Nickel-titanium (NiTi) alloy manual and rotary endodontic instruments have revolutionized endodontics. The NiTi rotary instrument rotates continually within the root canal system and is subject to structural fatigue and ultimately failure because of two principal types of stress: bending stress and torsional stress [1,2]. The durability of a NiTi rotary instrument is directly proportional to the working stress it undergoes [3-5], and this is closely related to the number of cycles performed [2]. Clinician who has performed endodontics has experienced a variety of emotions ranging from thrill to an upset such as the procedural accident of breaking an instrument. During root canal preparation procedures, the potential for instrument breakage is usually present. Nickel-titanium instruments have been marked to overcome the shortcomings of broken instruments in curved canals. NiTi alloy has the advantages of super elasticity and the shape memory effect compared to stainless steel instruments [6]. Different brands of NiTi rotary system have been introduced to the market, each having a different design for its cross-sectional shape, helical angle [7]. Most commonly used materials are Stainless steel and Nickel-Titanium alloys. Historically root canal instrumentation have been involved the use of stainless steel hand files. Numerous investigations have shown that the preparation of curved root canals with stainless steel instruments frequently results in undesirable aberrations such as elbows, zips, and danger zones [8]. Increasing the resistance to fatigue fracture has been a focus in the design of recent NiTi rotary systems. The design feature can affect the mechanical behavior [9].

File Name	Limitations	Strength
Mtwo	Results in undesirable aberrations such as elbows, zips	Resistance to fatigue fracture and flexibility.
Protaper	Broken instruments in curved canals	Very aggressive and fast

The Mtwo endodontic instruments have two blades and feature a large groove between them. This design reduces the core diameter and increases the flexibility. The increasing pitch allows a more delicate cutting action at the apex and a more aggressive one in the coronal portion of the file. The double cutting edge geometry of Mtwo instruments whose cross section does resembles an S-Instrument, an instrument with a similar geometry and a smaller cross section surface than a triple cutting edge with convex geometry [10]. Bending stress depends on the original anatomy of canal and therefore cannot be influenced significantly by the clinician. Conversely, the endodontist can reduce or decrease the intensity of torsional stress. Although bending stress is one of the most significant in terms of fatigue excessive torsional stress is the main cause of instrument breakage [11]. In endodontology, using the FEM method, the parameters of the geometry of the structure such as the post design, along with the magnitude and direction of the load can be changed easily in simulation that is a significant advantage over experimental methods [12].

Materials and Methods

Mechanical Property of NiTi

In present study the nonlinear mechanical behavior of NiTi material is similar to the one reported by others [13]. The model stress-strain behavior of NiTi alloy comprises a linear elastic deformation of the parent phase, followed by the elastic and then the plastic deformation of the martensitic phase. Elastic strains and the transformation strain are mostly reversible, but the plastic strain is not [13,14]. The mechanical properties entered for the NiTi material in the analysis were Young's modulus 36 GPa and the Poisson's ratio is 0.3. The critical stress at the beginning of the forward phase transformation was taken 504 MPa and at the end point of recoverable strain was 755 MPa [14].

Simulation of the Root Canal Treatment Shaping

To carry out this simulation on the finite element model, a 3D FE model was constructed for a root canal 14mm long with a curvature of 45 degree angle and 6 mm radius as standard. The model root 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 FE package (ABAQUS 8.0) to simulate the bending conditions during root canal treatment shaping. The files were inserted to the full length of the simulated root canal model, and the stress distribution on the surface and also within the instruments was evaluated. The virtual rotation of instrument was fixed at 240 rpm. The force exerted by file in the lateral direction was evaluated mathematically on the software.

In this study two brand of NiTi instrument, ProTaper F2 (Size 25 variable taper, Dentsply Maillefer) and Mtwo (size 25, 0.06 taper, VDW Gmbh Germany) were 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 and Mtwo instruments. After obtaining the 3D data it was converted into the STL format for the study to be performed mathematically, 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 carry out the study and a 3D model of each instrument was reproduced accurately. In this study a mesh of linear, 8-noded, hexahedral elements was now laid over the instrument in software to produce a 3D model for entry into FE analysis. The model for Protaper has 2850 elements and 5783 nodes for M Two it has 2392 elements and 5211nodes.

Results

In this *invitro* study while inserting file into the simulated 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 external surface. The force acting on the surface of the endodontic instrument was assessed in an engineering software ABACUS and ANSYS packages. The results showed that ProTaper instrument showed higher value of lateral forces acting on the surface of the file as compared to the MTwo file in the apical third section. The amount of force exerted by ProTaper was found to be 191 grams as compared to 144 grams exerted by MTwo file. The values of the force became more or less constant once the full length was reached in the simulated canal. The stress acting on the file was also analyzed. It was found that in ProTaper, the file experienced stress till 7 mm from the tip while the MTwo file experienced stress up to 6 mm only.

File Name	Lateral Forces	Stress on File
MTwo	144 grams	6 mm
Protaper	191 grams	7 mm

Discussion

A large number of articles have been published on the application of the virtual reality technology in orthodontics [15], restorative dentistry [16], orthognathic surgery [17], and implantology [18], with encouraging results. This is an effort to apply the virtual reality technology in endodontics for accurate force measurements. Since the last decade NiTi rotary instruments have been gaining popularity among general dentists and endodontic specialists. But at the same time there has been an increasing concern about the instrument fracture during the use of rotary files, as evidenced by the amount of reports on this problem [19,20]. Detailed examination of fracture instruments under electron microscope basically two types of fracture mechanisms was identified:

a. Fatigue failure characterized by numerous patches of the linear fatigue-striation marks and
b. Torsional failure characterized by the circular abrasion marks on the fracture surface [21,22]. Examination of the instrument longitudinally and microscopically would reveal the actual cause of failure [23].

But frankly the actual cause of instrument fracture could not be determined satisfactorily by such inspection of broken instruments, since 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.

That's why a mathematical simulation is used here to estimate the stress distribution and residual stresses on the instrument. In dental research to study 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 for study of generated stresses. In Finite Element analysis, a large structure is divided into a large number of small simple shaped elements and small nodes, for which individual deformation (strain and stress) can be easily calculated than for the whole undivided large structure as such. By solving the deformation of all the small elements simultaneously and mathematically in a program, the deformation of structure as a whole can be assessed [24]. Hence the 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 surface [25].

In our study the amount of force exerted by the MTwo file was 144 grams while the amount of force exerted by ProTaper file was 191 grams. The amount of lateral forces exerted by the ProTaper file was found to be much greater as compared to that of MTwo. Similarly the force acting on the file goes upto 7mm in ProTaper and 6mm in MTwo file. MTwo file with a variable taper and variable pitch. 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. It should also be kept in mind that during the manufacture of NiTi instruments, small machining scratches and grooves are invariably left on the surface of these fine instruments. These surface imperfections can serve as notches that would eventually concentrate the stress, limiting the instrument's fatigue life span. The high concentration of stresses at the cutting edge of ProTaper files might cause these machining defects to become microcracks. Crack like characters at the cutting surfaces have been a frequent observation in clinically used Pro Taper instruments.

Conclusion

Within the limitations of this FEM study, it can be easily seen that lot of stresses were generated on surface of Protaper files compared to MTwo. The same results were depicted with the forces acting on the total length of file. Protaper had high lateral stresses compared to MTwo. It can be concluded that each instrument would experience unequal degree of screw in tendency depending on its design, 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 these residual stresses for various instrument designs, so the operator needs to analyze cross sectional design and taper of each files for their use.

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