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Mechanical behavior of rotary endodontic files in a simulated curved canal using finite element analysis

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Abstract

Aim: The aim of the present study was to evaluate the mechanical behavior of two rotary endodontic files in a simulated curved canal using finite element analysis

Methodology: Two brands of rotary canal shaping instruments (Trunatomy; DENTSPLY Maillefer, and Hyflex CM; Coltene-Whaledent, Allstetten, Switzerland) of size 25mm and taper .04% were scanned with the scanning electron microscope to produce a real-size, 3-dimensional (3-D) model for each. A 3-dimensional model of the simulated root canal with 45° curvature and working length of 16mm and 6mm radius with a 0.5-mm diameter of the apical foramen with a 5% apical taper is created. The finite element simulation was performed by applying an insertion and exertion force of 2.5 N with a constant rotational speed (300 rpm) to analyze the bending stress value for every file was recorded in MPa

Results: The surface of Hyflex CM instrument showed the highest value of force generated in apical 3rd of curved root canal, whereas Trunatomy showed the lowest value.

Conclusion: Within the confinement of this study, it is observed that Trunatomy files exhibited least stress and minimal deformation in the simulated curved canal compared to coltene hyflex cm files using finite element analysis.

Keywords: Niti files, curved canal, finite element analysis

Introduction

In recent decades, nickel-titanium (NiTi) rotary endodontic files have gained increasing popularity over stainless steel files in root canal preparation due to the superelastic behavior of nitinol-based materials. NiTi files present several advantages compared with stainless steel files, such as higher flexibility, fewer canal aberrations, and a shorter procedural duration. However, fracture of NiTi files remains a concern in clinical practice. An instrument might fracture at various levels of stress or strain, with or without any apparent signs of plastic deformation adjacent to the fracture site. This is due to the presence of residual stresses in the instrument after use [1].Two mechanisms of fracture have been proposed, torsional (shear) and flexural (fatigue). There are several contributing factors that affect the fracture of rotary NiTi instruments. To improve the fracture resistance of NiTi rotary files, manufacturers have introduced new alloys with higher mechanical properties [2]. Most rotary NiTi files are fabricated from near-equiatomic NiTi alloys, which contain approximately 55 wt.% nickel [3].

Recently, TruNatomy instruments (TRN) (Dentsply Sirona) has been developed as a novel type of heat-treated NiTi instrument with a special design. The TRN shaping instruments are provided in three different sizes which are small (size 20/.04 taper), prime (size 26/.04 taper) and medium (size 36/.03 taper). It has been claimed by the manufacturer that the three shaping instruments of TRN provide a slim shaping which enhances the debridement due to more space is available by this unique design of the instrument.

The slim NiTi wire design is 0.8 mm instead of up to 1.2 mm of the most other variable tapered instruments. The TRN instruments have off-centred parallelogram cross-section design. It was manufactured by using a special NiTi heat-treated wire that supposed to enhance the flexibility of the instrument. It had been reported that the TRN instruments preserve the structural dentine and tooth integrity due to instrument geometry, regressive tapers and the slim design, along with the heat treatment of the NiTi alloy. However there are no much studies in the literature to assess the mechanical behavior of TRN endodontic file in a curved canal.

A different manufacturer Coltene developed a system, Hyflex CM files produced by an innovative methodology which uses an unique thermomechanical process that controls memory of material, making the files extremely flexible but without the shape memory of other NiTi files. This gives the file the ability to follow the anatomy of the canal very closely, reducing the risk of ledging, transportation or perforation. The instruments were made from a specific nickel-titanium alloy that has been claimed to have a lower percent in weight of nickel (52%). The manufacturer claims that these instruments are up to 300% more fatigue-resistant than instruments made from conventional NiTi wire. The aim of the present study was to evaluate the mechanical behavior of two rotary endodontic files in a simulated curved canal using finite element analysis.

Materials and methods

Two brands of rotary canal shaping instruments (Trunatomy; DENTSPLY Maillefer, and Hyflex CM; Coltene-Whaledent, Allstetten, Switzerland) of size 25mm and taper .04% were scanned with the scanning electron microscope to produce a real-size, 3-dimensional (3-D) model for each.

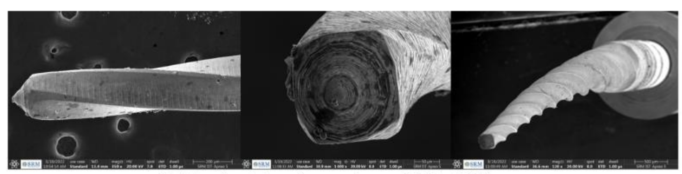

Fig1- Scanning electron microscopy images of Hyflex CM file

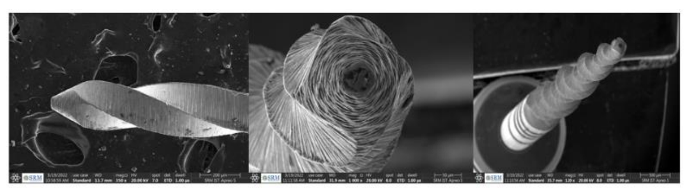

Fig2- Scanning electron microscopy images of Trunatomy file

To build the file's 3D model, the file cross section was drawn in 2D with the help of the SEM images using computer-aided design programs CAD (SolidWorks software package). The 2D file with (.prt) extension was converted into stereolithographic (.stl) extension to be readable by programming software (MATLAB software). Building of 3D model in form of sections was performed by MATLAB software using the following data: taper of the file, change in pitch length, and cross section. After building of the 3D model on MATLAB, the file model was imported to computer-aided design programs CAD (SolidWorks software package). The file (.stl) extensions were converted to (.prt or .sldprt) to be edited by computer-aided design programs CAD (SolidWorks software package). Finishing of the file 3D model was performed by building the tip and the handle of the file using computer-aided design programs CAD (Solid Works software package). Using computer-aided design programs CAD (SolidWorks software package) FE model for the file was done. The meshing of the model was done by (Cosmos, SolidWorks software package) using linear, six-node trihedral elements. The final FE model of the HyFlex instrument consisted of 5268 elements with 9206 nodes.

Fig 3- Designing of rotary files using CAD software

Mathematical Simulation of Root Canal

Another 3D-FE model was constructed for a root canal 13 mm long with a curvature of 45-degree angle and 6 mm radius. The model of the canal had an apical foramen of 0.50 mm diameter and about 5% apical taper. The behavior of the two brands of NiTi file was analyzed numerically in an FE package (ABAQUS V6.5-1; SIMULIA, Providence, RI) to simulate the bending and torsional conditions during root canal shaping. The file was inserted to the full length of the simulated root canal and the stress distribution on the surface and within the instrument was evaluated.

The finite element simulation was performed by applying an insertion and exertion force of 2.5 N with a constant rotational speed (300 rpm) to analyze the bending stress value for every file was recorded in MPa

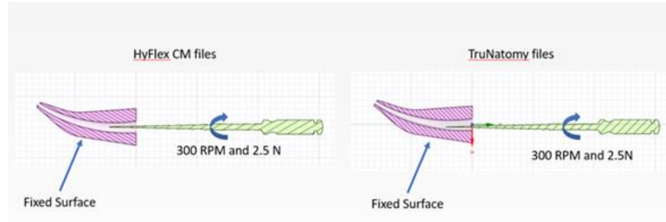

Figure 4:

Diagrammatic representation showing insertion and exertion of the files in the simulated curved canal

Results

The surface of Hyflex CM instrument showed the highest value of force generated in apical 3rd of curved root canal, whereas Trunatomy showed the lowest value. Forces seen on surface of Hyflex CM were 172.31 Mpa and on Trunatomy file were 126.06 Mpa. During insertion into the canal, all files experienced a force, but to varying degrees, along the direction of its longitudinal axis, pulling it apically as well as a reaction torque from root canal wall. The value of the force become constant (with slight fluctuations) once the full length of the canal was reached. After the instrument was withdrawn from the canal and assuming complete recovery of the elastic strains, residual stress could be noticed along the length of all instruments, with the location of such maximum stress corresponding well with that of maximum curve of the canal.

S.No	Type	Result	Max.	Min.	Unit
1.	HyFlex CM	Total Deformation	1.3387	0.000	mm
2.		Equivalent Stress	172.31	2.78e-11	MPa
3.		Equivalent Elastic Strain	0.0022	4.51e-16	Mm/mm
4.	TruNatomy	Total Deformation	1.0502	0	mm
5.		Equivalent Stress	126.06	3.66e-11	MPa
6.		Equivalent Elastic Strain	0.0016	6.05e-16	Mm/mm

Table 1- Showing the maximum stresses, total deformation and equivalent elastic strain values during bending and torsion with different metallurgy in a simulated curved canal

Discussion

During the last decade, NiTi rotary instruments have been gaining popularity among general dentists and endodontic specialists. Meanwhile, there is an increasing concern about the instrument fracture during the use, as evidenced by the amount of reports on this problem [4, 5]. By examining fracture instruments under electron microscope basically two types of fracture mechanisms were identified: (I) fatigue failure, characterized by numerous patches of linear fatigue-striation marks and (II) torsional failure, characterized by circular abrasion marks on the fracture surface [6, 7].

Fractographic examination (at high magnification), in conjunction with longitudinal examination, is necessary to reveal features that might indicate the crack origin and the mode of material failure [6]. However, the distribution of stresses along the instrument and any residual stresses that might contribute to instrument breakage would not be revealed in such post mortem examination of broken fragments. It would equally be impossible to measure the stress on the instrument during actual clinical use. Thus, a mathematical simulation was used to estimate the stress distribution and residual stresses on the instrument.

FE models have been proposed to analyze the mechanical performance of endodontic rotary files, isolating the variables independently under controlled settings to facilitate the comparison between the mechanical behavior and stress distribution of existing endodontic rotary files and even to allow the design of new endodontic rotary instruments by reducing time and costs [8]

Although metallurgical properties and metallurgical treatments have been shown to influence the properties of NiTi endodontic rotary instruments, geometrical design has been highlighted to be directly related to the stiffness, clinical efficiency and cutting performance of endodontic rotary files [8]

Arbab-Chirani et al. compared numerically the mechanical behavior of Hero, HeroShaper, ProFile, Wtwo and ProTaper F1 endodontic rotary NiTi instruments under bending and torsional conditions and showed that the different designs for tapers, pitch and cutting blades influence on the bending and torsional mechanical behavior [9]. Baek et al. evaluated the effect from pitch and cross-section design on torsional stiffness of NiTi endodontic rotary instruments and evidenced that torsional deformation and fracture of NiTi rotary files might be reduced by reducing the pitch and increasing the cross-sectional areas rather than the center core area [10].

In this study, FEA served as a mathematical multifunctional technique creating the NiTi design and the curved root canal anatomy. The simulation of root canal dentin used in this study assumes an isotropic, linear elasticity and uniformity in the Young modulus and the Poisson ratio. Histologically, the hardness of dentin decreases from the outer surface to the dental pulp cavity, which makes its mechanical properties not always the same within the dentin. Although geometric models of the instruments were used for this analysis, bending stress and permanent deformation under clinical conditions may differ from this simulation because of the assumed fixed root canal anatomy and weak points in the instruments because of varying cross sections, making it a necessity that calculated values must be verified by in vitro experimental methods.[11]

The evaluation of stress distributions in the present study was done under application of simulated loading to the clinical situations according to the study conducted by Necchiet et al. in 2010.[12] TruNatomy shaping file has an off-centered parallelogram cross-sectional design; it might be speculated that this design could contribute to the higher cyclic fracture resistance of the TN files. In addition, the fact that the TruNatomy file is made of a thin NiTi wire (0.8 mm) might have resulted in decreased stress distribution than the Coltene hyflex files.

The results are in accordance with the previous study by Riyahi et al. 2020 in which it was concluded that Trunatomy files have higher fatigue resistance compared to Protaper Next (Dentsply) and Twisted files (Sybron endo)[13]

Conclusion

Within the confinement of this study, it is observed that Trunatomy files exhibited least stress and minimal deformation in the simulated curved canal compared to coltene hyflex cm files using finite element analysis. It can be concluded that each instrument design would experience unequal degree of screw-in tendency, as well as reaction torque from the root canal wall. Hence the operator needs to analyze cross sectional design and taper of files for their use.

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