Original Article

Comparative evaluation of stress distribution against the root canal wall at three different levels using novel NiTi rotary files – A finite element analysis

Rimjhim Singh, Sandeep Dubey, Palak Singh, Praveen Singh Samant, Suparna Ganguly Saha[1]

Department of Conservative Dentistry and Endodontics, Babu Banarasi Das College of Dental Sciences, Babu Banarasi Das University, Lucknow, Uttar Pradesh, [1]Department of Conservative Dentistry and Endodontics, Index Institute of Dental Sciences, Indore, Madhya Pradesh, India

Abstract

Background: Recent innovations in the physical and mechanical features of endodontic file systems have diminished the prospect of stress generation and fracture risk in novel endodontic files.

Aim: The purpose of this research was to comparatively evaluate the stress distribution of recently introduced endodontic rotary files with distinct features and metallurgy at three different levels of the root canal wall by finite element analysis.

Materials and Methods: Forty endodontic files were used in this experiment after being inspected through a scanning electron microscope for any surface deformities. Based on their metallurgy and design, the scanned files were divided into four groups, each with 10 samples: Group A-2Shape files, Group B-F360, Group C-One Curve, and Group D-TruNatomy. To assess the mechanical behavior of these files, the stress produced by computer-aided models of these instruments on the dentinal wall of a simulated root canal was numerically analyzed using ANSYS® 15 Workbench finite element software.

Results: A one-way ANOVA was used to assess all the raw data with *post hoc* Tukey analysis, the Shapiro–Wilk test, and Levene's test. F360 files exerted the maximum stress on the dentinal wall, while TruNatomy files exerted the least stress at all the distinct levels of dentinal walls.

Conclusions: There was no statistically significant variation in the stress generated between the four groups. Therefore, it can be concluded that improvements in rotary file design and metallurgy have the potential to reduce the stress during canal shaping and the risk of instrument breakage during clinical use.

Keywords: Computer-aided design; finite element analysis; nickel-titanium; one curve; rotary files; TruNatomy

INTRODUCTION

The efficacy of root canal therapy depends on its chemomechanical preparation using mechanical instruments, which are augmented with antimicrobial irrigants. For this crucial stage of root canal treatment, numerous instruments and approaches have been manufactured and illustrated by their manufacturers.[1,2]

The introduction of conventional NiTi rotary instruments has minimized procedural errors and simplified the chemomechanical preparation step of endodontic therapy. Treatment outcomes are affected mostly when a NiTi rotary instrument breaks inside the canal. Hence, fracture prevention is of paramount significance.[3] The documented

Address for correspondence:
Dr. Sandeep Dubey,
Department of Conservative Dentistry and Endodontics,
Babu Banarasi Das College of Dental Sciences, BBD Green City, Faizabad Road, Lucknow - 227 015, Uttar Pradesh, India.
E-mail: sandeepdubey.mds@gmail.com

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frequency rate for fractured rotary instruments is 1.3% to 10%, of which cyclic fatigue accounts for 44.3% and torsional fatigue for 55.7%.[4] The frequency of separation increases correspondingly with increased canal curvature, rising from 7% in straight canals to 35% in averagely curved canals and 58% in highly curved ones.[5] Galal and Hamdy[6] noted in their investigation that additional variables in endodontic files, such as raw materials, manufacturing techniques, and design features, have a significant effect on the separation of instruments as they control the amount of compressive and tensile stress imposed on them. Therefore, new endodontic file systems with upgraded metallurgy and designs are continuously being introduced in the market, aiding clinicians to finish endodontic therapy more promptly and with fewer procedural errors.

The 2Shape file system (Micro-Mega, Besancon, France) has a triple helix cross-section, utilizing one secondary edge and two main cutting edges for debris removal and enhanced cutting efficiency.[7] The F360 file system (Komet, Brasseler GmbH and Co., Lemgo, Germany) is made from conventional, super-elastic NiTi alloy. It has a narrow core and a thin, double S-shaped cross-section.[8,9]

The One Curve (Micro Mega, Besancon, France) is a new file system produced by C-wire technology and has a controlled memory and a variable cross-section design to enhance the centering ability in the apical third of the canal wall.[10] TruNatomy (TN; Dentsply Sirona, Maillefer, Ballaigues, Switzerland) endodontic files are recently introduced NiTi systems constructed with 0.8-mm NiTi wire. They feature a parallelogram design with an off-center cross-section. These files have a lesser probability of separation, as claimed by the manufacturer.[11,12]

With new technology, clinicians have a comprehensive diversity of endodontic file systems with superior mechanical qualities available, but the risk of fracture still exists. There have not been many studies up to this point evaluating the significance of the design and metallurgy of these new NiTi rotary instruments and how they affect the development of stress during the instrumentation inside the root canal.

Consequently, the objective of this *in vitro* study was to evaluate the stress distribution of innovative endodontic rotary files with various cross-sections and metallurgy at three distinct levels of the root canal using finite element analysis.

MATERIALS AND METHODS

The current research was authorized by the university ethics committee. The sample size was determined using G Power software, version 3.0 (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). The effect size was 0.50 (alpha value of 0.05, power of 95%); the predicted minimal sample size (n) was 40 samples. Four distinct groups of rotary files were made based on the criteria of cross-sections and metallurgy, with a fixed taper of 4% ($n = 10$).

Initially, files were cleaned with 70% w/v ethanol. Investigations of surface irregularities of files were conducted using a scanning electron microscope (Carl Zeiss Microscopy Ltd., EVO-SEM MA15/18, GmbH, Oberkochen, Germany) with high resolution [Figure 1]. Files with any surface deformation were eliminated from the study.

Formation of a three-dimensional model of rotary files

These unique NiTi files were scanned using exocad software (exocad GmbH, Align Technology, Inc. company, Darmstadt, Hessen, Germany), and real-size images in three dimensions were obtained. Later, a geometrical model of rotary files was designed using a three-dimensional (3D) computer-aided design (CAD) program. Solidworks version 2013 software (Dassault Système Solidworks Corp., Waltham, Massachusetts, United States) converted the obtained stereolithography files into initial graphics exchange specification format, which was then used by Analysis System (ANSYS) Workbench 15.0 (Canonsburg, Pennsylvania, United States) to recreate a 3D model of each instrument for investigation. These files had a 25-mm standard length, a 16-mm working length, and a taper of 4% [Figure 2a].

Formation of a three-dimensional model of a root canal

A 3D model of a root canal was formed with a length of 16 mm, a 6 mm radius, and an apical foramen with a diameter of 0.5 mm using ANSYS Workbench 15.0 software. The creation of the mesh was done using Solidworks version 2013. Thus, 3D brick elements and nodes were created for 3D finite models of root canals [Figure 2a].

According to the literature, the distinctive material features of each type of NiTi were attributed to the engineering data feature of ANSYS software.[13-16] The data were transmitted to a mechanical module for analysis with the application of load and boundary conditions after being assigned for geometry and material properties.

Files were inserted into the curved root canal with a 45° curvature and then rotated at 180° for three times at a rate of 300 rpm and a torque of 1.5 Nm.[17] The displacement of nodes was determined, and then the stress was measured at a point where the displacement of nodes was at its maximum [Figure 2b]. Each sample was assessed individually depending on its cross-section and material characteristics. The von Mises stress formula was then employed to evaluate the stress produced on the instrument, and the resulting means were recorded for statistical analysis [Figure 2c-f].

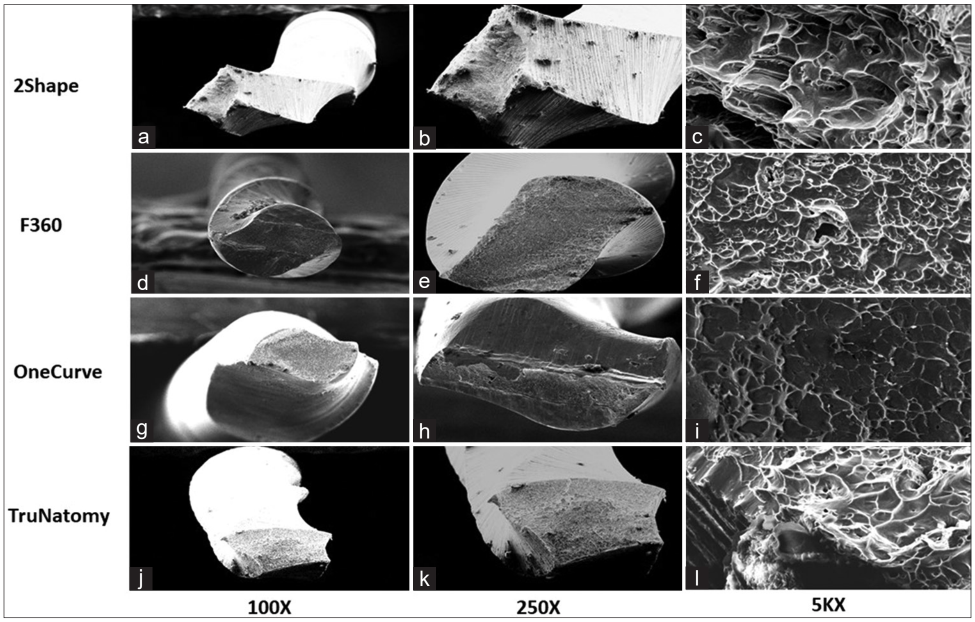

Figure 1: Scanning electron microscope images of endodontic rotary files (a, b, and c) 2Shape files (d, e, and f) F360 files (g, h, and i) OneCurve files (j, k, and l) TruNatomy files: at a magnification of 100X, 250X, and 5KX, respectively

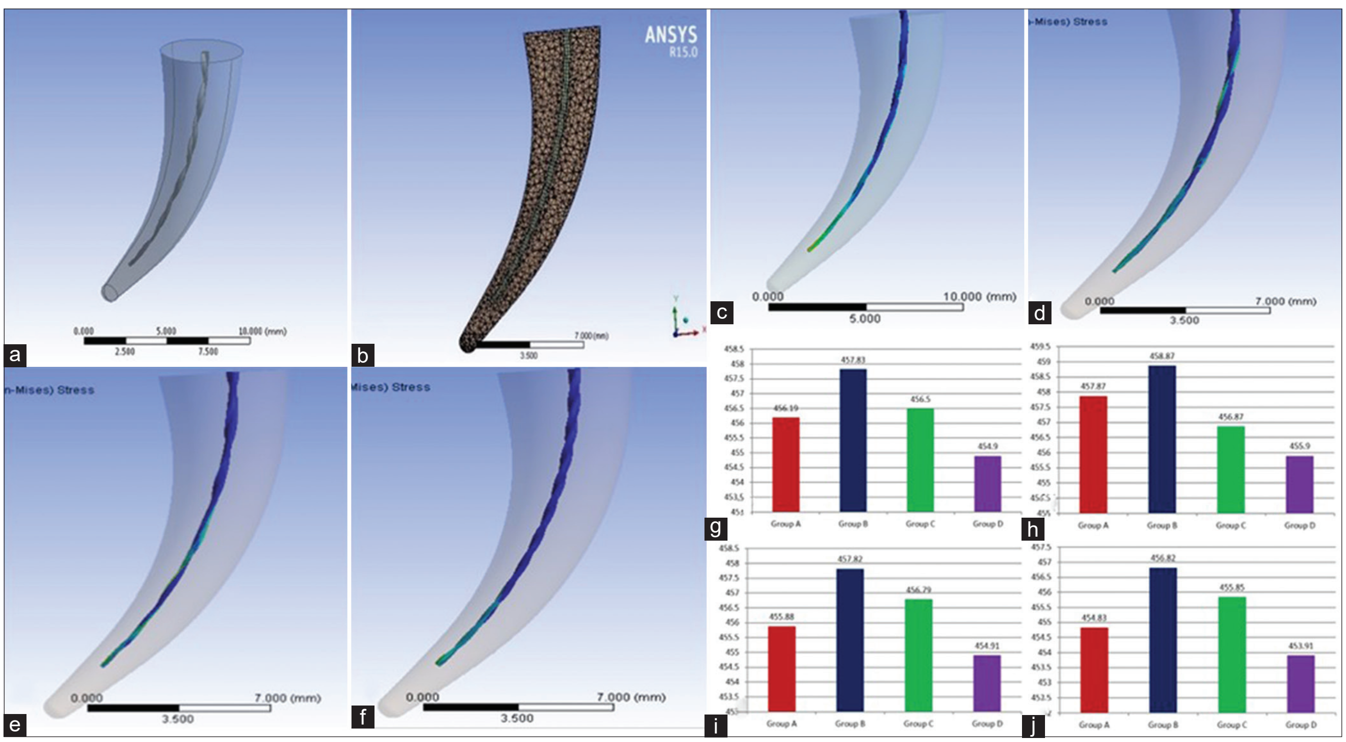

Figure 2: Computer-aided design model (a) Root canal and rotary file, (b) Mesh, Finite element analysis (c) 2Shape, (d) F360, (e) One Curve, and (f) TruNatomy files, respectively. Standard deviations of stress produced (g) Average stress at all distinct levels (h) Apical one-third; (i) Middle one-third; (j) Coronal one-third (a $P > 0.05$ is nonsignificant when assessed using one-way ANOVA for all groups)

RESULTS

All the obtained values were statistically analyzed using IBM SPSS statistical software version 23.0 (IBM Corporation, Armonk, New York, USA). The descriptive statistics encompassed the mean and standard deviation (SD), and the threshold of significance was set at 5%. A one-way ANOVA was used to compare the mean score variances among groups, and *post hoc* Tukey analyses were performed subsequently. The data distribution and variable homogeneity were scrutinized using the Shapiro–Wilk test and the Levene test, respectively. The data of all four groups–Group A-2Shape, Group B-F360, Group C-One curve, and Group D-TruNatomy–were found to be homogeneous and normally distributed. SD and mean values were calculated for each variable [Figure 2g-j].

The TruNatomy model exhibited minimum stress in all three areas of the root canal, i.e. 454.90 MPa. In comparison to the 2Shape file model, the One Curve file model displayed more stress generation at the coronal (455.85 MPa) and middle (456.79 MPa) levels, and a minimum stress distribution compared to the 2Shape file model, whereas at the apical level, the One Curve file model generated less stress (456.87 MPa) than the 2Shape model (457.87 MPa). The F360 model exerted the maximum stress (457.83 MPa) on the dentinal wall among all the tested files [Table 1]. According to the tests, there were no statistically significant differences in the parameters between all four groups.

DISCUSSION

In the modern world of competitive endodontics, a practitioner must understand the fundamental biological and mechanical principles of instruments. Separation of instruments in the root canal is a frequent procedural error made during endodontic therapy. It can diminish the efficiency of clearing the obstructed debris from the canal, thus decreasing the healing of the periapical lesions.[18,19] In this study, the finite element method was used to evaluate the mechanical behavior and stress distribution of endodontic rotary instruments under a controlled simulated condition. This method is advantageous as it enables a clear assessment of every single geometrical design parameter.

Based on a study by Basheer Ahamed *et al*.[17] and Kim *et al*.,[20] a simulacrum of a root canal was created to relate both bending and torsion and produce a combined loading instead of applying an external force. As opposed to earlier research, which relied on an external source to produce stress.

According to the present study, TruNatomy files generated a stress of 454.90 MPa [Table 2], which was determined to be the least when compared to other files at the distinct levels. The reason for the lowest stress generated by these files is very likely owing to their distinctive design, which substitutes 0.8 mm NiTi wire for 1.2 mm NiTi wire, their regressive taper, and their off-center cross-sectional design. Previous research had shown that the dentinal wall experiences less stress when the central core area is smaller.[21,22] Martins *et al*.[23] found that the eccentricity of the file caused the local stress to relax, which led to stress reduction with bending. Conversely, the findings of the study by Galal and Hamdy[6] were in opposition to the explanation; they claimed that the eccentric cross-section of files increased stress production. The manufacturing process of TruNatomy, which involved special heat treatment, may also be responsible for the minimal stress, and this agrees with the study conducted by Elnaghy *et al*.,[24] who found that the production of internal stress decreases when NiTi files are heat treated both during and after fabrication.

The One Curve file yielded a stress of 456.50 MPa on the dentinal wall, which is slightly more than the 2Shape file (456.19 MPa). The reason could be due to its variable cross-section. As Ghoneim[25] observed, these endodontic files, with different cross sections, resulted in more removal of dentin, which can be due to more stress concentration. Kim *et al*.[26] stated in their study that the minimum dentin thickness in a root canal wall is a result of a higher concentration of root stress.

The 2Shape files yielded moderate stress on the dentinal wall. It can be explained by their unique asymmetrical triple helix design, progressive and increasing pitch, and deeper flutes to aid a smaller core diameter, because of which stress might have concentrated in a smaller area. This is in accordance with the study of Diemer *et al*.,[27] who found that a triple helix cross-section typically results in less axial stress and deeper flutes, resulting in a smaller core diameter, which causes the stress to be concentrated in a smaller area. Another feature of the 2Shape file is its progressive increasing pitch, which might have resulted in a lesser screw-in effect of the instrument inside the root canal, causing less stress on the dentinal wall. Diemer and Calas also confirmed in their investigation that diminishing the screw-in effect by increasing pitch can minimize torsional stress.[28]

It is to be noted that these files generated less stress than One Curve at the coronal (454.83 MPa), as shown in Table 1, and in the middle thirds (455.88 MPa) [Table 1]. The reason could be attributed to its asymmetrical triple helix cross-section, which would have led to less contact with the root canal and less stress on the walls at the coronal

Table 1: Comparison of stress in the apical, middle, and coronal thirds of modern rotary files

Tested files	Apical one third (MPa)	Middle one-third (MPa)	Coronal one third (MPa)	*P*
2Shape	454.83	455.88	457.87	0.764 (nonsignificant)
F360	456.82	457.82	458.87	0.729 (nonsignificant)
One curve	455.85	456.79	456.87	0.867 (nonsignificant)
TruNatomy	453.91	454.91	455.9	0.756 (nonsignificant)

Table 2: Novel endodontic rotary files: Intergroup comparison

Tested files	Mean (MPa)	SD	SE
2Shape	456.19	1.810	0.57261
F360f	457.83	1.811	0.57273
One Curve	456.50	1.811	0.57273
TruNatomy	454.90	0.616	0.19493

SD: Standard deviation, SE: Standard error

and middle thirds, whereas the One Curve file features an S-shaped cross-section along its active coronal and middle areas, except for the apical 4 mm part, which has a triple helix form. This outcome of the study is consistent with the findings of Gharechahi *et al*.,[29] who examined the stress distribution of files in various canal anatomies and discovered that files with a triple helix design caused less stress and had a better stress distribution than files with an S-shaped cross-section. However, at the apical area, both One Curve and 2Shape have a similar cross-section, i.e. an asymmetrical triple helix design, and One Curve produced lesser stress (456.87 MPa) compared to 2Shape (457.87 MPa) [Table 1]. The reason for reduced stress in One Curve models could be due to their proprietary C-wire heat treatment with controlled memory. Fornari *et al*.[30] claim in their research that this type of design increases friction and loading at the apical area while shaping the root canal. Contrary to our findings, Medha *et al*.[31] examined how forces were distributed in the apical third of curved root canals and discovered that triple helix cross-section reduced internal residual stress.

The F360 rotary files examined in this study produced the maximum amount of stress (457.83 MPa) among all the other tested groups. It can be because of their manufacturing, as they evolved from conventional superelastic NiTi alloys. Due to this, they may continue to be in the austenite phase while being employed in a clinical setting, causing an uneven distribution of stress while recovering their form after instrumentation. The findings of this experiment agree with those of Ba-Hattab and Pahncke,[32] who investigated the shaping capability of the F360 file with different NiTi rotary file systems made from different metallurgy, and they found that the F360 file caused the root canal walls to be under inconsistent amounts of stress. In addition, the S-shaped cross-section of the F360 files may have put extra stress on the dentinal wall. Prados-Privado *et al*.[33] compared the bending and torsion responses of WaveOne, WaveOne Gold, Reciproc, and Reciproc Blue in their investigation. Their findings are consistent with ours showing that an S-shaped cross-section file (the Reciproc file) produced more stress.

The statistical analysis revealed that none of the four tested unique NiTi files significantly increased stress levels. The stress was found to be least at the coronal part of the root canal, followed by the middle part, and to be maximum at the apical area. These outcomes of the present study suggest that a decrease in the radius of curvature of the root canal model may be responsible for the increase in stress from the middle to the apical area following root canal instrumentation.

Designing a finite element model is challenging, intricate, expensive, and time-consuming because it requires a thorough understanding of CAD to accurately mimic the geometric depiction of an endodontic rotary file's parameters and additional knowledge to simulate the mechanical behavior and stress dispersion of rotary files against the dentinal wall. To validate the model employed in this study, additional research is required because there is not a single endodontic tool system that is suitable for all clinical conditions. For preventing fracture during actual use, it is crucial to comprehend how the structural characteristics may impact the amount of stress applied to the endodontic instrument.

CONCLUSIONS

The TruNatomy file distributed the least amount of stress against the simulated root canal wall within the constraints of this study. The findings of this study suggest that modifications to an endodontic file's design (cross-section and core area), along with a postmachining thermomechanical heat treatment, may be more effective ways to reduce the risk of instrument breakage caused by stress distributed during the shaping of curved root canals.

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Conflicts of interest

There are no conflicts of interest.

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