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# Simulated Evaluation of Tooth Fracture Resistance during Instrumentation with Single-and Multi-file Rotary Systems

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**ABSTRACT**

**Introduction:** Use of rotary files in root canal preparation is inevitable due to their high speed and reduced duration of treatment. However, microcracks and even root fracture may sometimes occur in teeth where canal(s) is/are prepared using these devices. The purpose of the current study was to compare NeoNiti single-file with RaCe multi-file rotary systems. **Materials and Methods:** An accurate scanner designed detailed three-dimensional file models, and a simulated model was developed using canal-specific features; including dentin thickness, root canal length, taper rate and root canal curvature. Cleaning and shaping conditions were simulated with appropriate speed and crack conditions for both types of files on the computer. Strain accumulation sites in the root dentin wall where microcracks was likely to occur were simulated and investigated. Abaqus and ANSYS software were used to perform finite element simulations. **Results:** RaCe files with 0.04 taper caused the lowest level of stress (34.33 MPa) to the simulated canal. Conversely, the highest level of stress (62.35 MPa) was applied by 8% NeoNiti file to the simulated canal. **Conclusions:** Based on the present experimental study, it can be concluded that RaCe multi-file rotary system may better be used in endodontic therapy, and the risk of microcracks in the tooth wall is less than that of NeoNiti single-file rotary system.

**Keywords:** Instrumentation; Rotary System; Simulation; Tooth Fracture

## Introduction

Successful endodontic treatment requires detection of all root canals and their complete cleaning and obturation [1]. Root canal preparation is one of the critical factors in endodontic therapy [2]. The efficient cleaning and shaping of root canal system are the most important mechanical and biological goals of root canal treatment [3]. During endodontic therapy, the root becomes prone to dentinal damage, which can cause dentinal microcracks or even fracture. The fractures are the most common complaints during endodontic therapy [4] Root fractures are the errors which seem often irreparable, lead to tooth extraction and can continue to cause dentinal microcracks [5]. Thus, subsequent stresses would be continuously applied to the tooth to develop cracks/fissures and eventually result in a vertical root fracture [5]. Root fractures may occur due to microcracks created in different stages, *e.g.* use of various files, biomechanical preparation and obturation techniques. On the other hand, re-treatment processes may develop microcracks [6]. The extent of dentinal damage can be affected by factors; such as tooth's physical properties, the techniques of root canal preparation or the applied instruments [7]. Moreover, developed microcracks have significant relationships with root canal preparation and filing techniques [8].

Many highly accurate instruments are available, including manual/hand and rotary nickel-titanium (NiTi) files [9]. Since the introduction of rotary NiTi instruments, it has been shown that several NiTi systems can maintain the original shape of the canal, reduce errors and prepare the root canal faster [10, 11]. Numerous NiTi rotary systems have been introduced and differ mainly in their cutting edge and taper

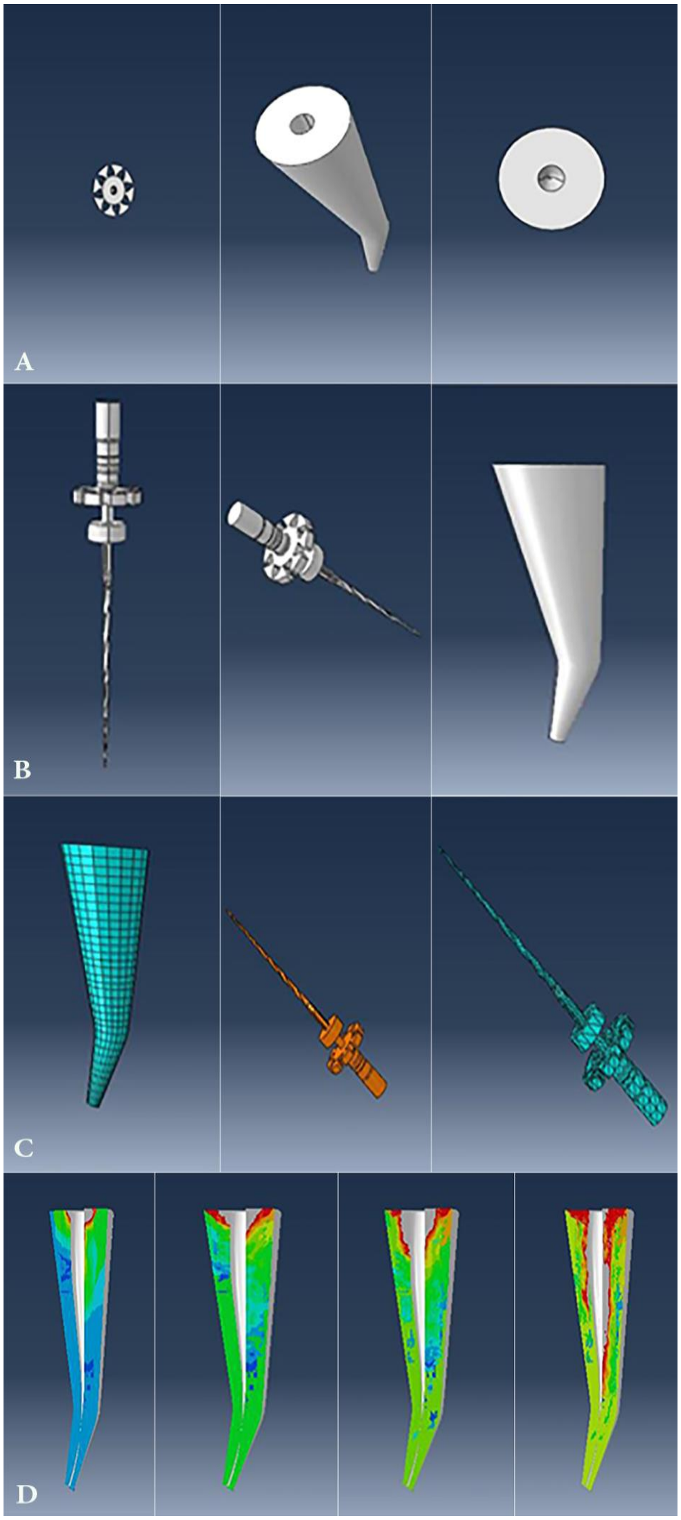


*Figure 1.* A) Canal design for file placement. The original structure of the canal examined element simulation; *B)* RaCe file 25/0.04 designed in the finite element simulations; *C)* Simulated canal mesh. (1) Canal mesh used in finite element simulations. (2) 4% RaCe file canal mesh used in finite element stimulations; *D)* Stress level applied to the canal wall during simulation

degree. These NiTi rotary systems have demonstrated clinical advantages; *e.g.* time saving, cutting efficiency and greater flexibility compared to manual instruments; although they seem to increase intracanal friction and stress [12-14]. Additionally, NiTi files do not tend to change/modify the canal shape during root canal preparation and reduce the tendency to transport the apical foramen [15]. Single file NiTi rotary systems have entered the market for root canal preparation [16] and are a more suitable/attractive option in comparison to rotary files due to their advantages; e.g. cost-effectiveness and easy preparation, reducing the number of files consumed and lessening file fatigue [17-20]. NeoNiTi (Neolix, Charters, la-Foret, France) is a single file system with a non-homogenous rectangular cross section and multiple tapers. The type of motion is a 360-degree rotation. In a study by Moazzami *et al.*, it was indicated that NeoNiti and Reciproc systems were clinically safe to use [21, 22].

On the other hand, RaCe files (FKG Dentaire, Lachaux-de Fonds, Switzerland) are of the most conventional multi-file NiTi rotary systems with variable cutting edge, triangular cross-section, positive cutting angle and high resistance [23]. During the root canal cleaning, the root canal fractures may occur in high stress and resistance areas. Computer simulation modeling is recruited as a suitable replacement for the tooth, which helps to detect areas with potentially high fracture risk [24, 25].

The present study aimed to compare NeoNiti single-file and RaCe multi-file NiTi rotary systems in creating microfractures and/or fractures in the simulated teeth.

## Materials and Methods

The finite element simulation of NiTi rotary files interaction inside the canal was made of teeth with an angle of 30 degrees using Abaqus software (John Wiley & Sons, Inc. Hoboken, New Jersey, USA). Having an apical curvature with an angle of 30 degrees using Abacus software was in the following order:

A) Canal design for file placement: to model this part, a structure was created according to Figure 1A, where the angle of the end part equalled 30 degrees. The canal material used in this study was dentin. After defining the canal's structure with an apical curvature having an angle of 30 degrees, the characteristics of canal were assigned. In this stage, properties were determined, e.g. constants of density and elasticity. According to previous investigations, the canal density was 2100, Young's modulus value was 14.7 GPa, the canal Poisson's ratio was 0.31 and the canal cross-section was defined circular.

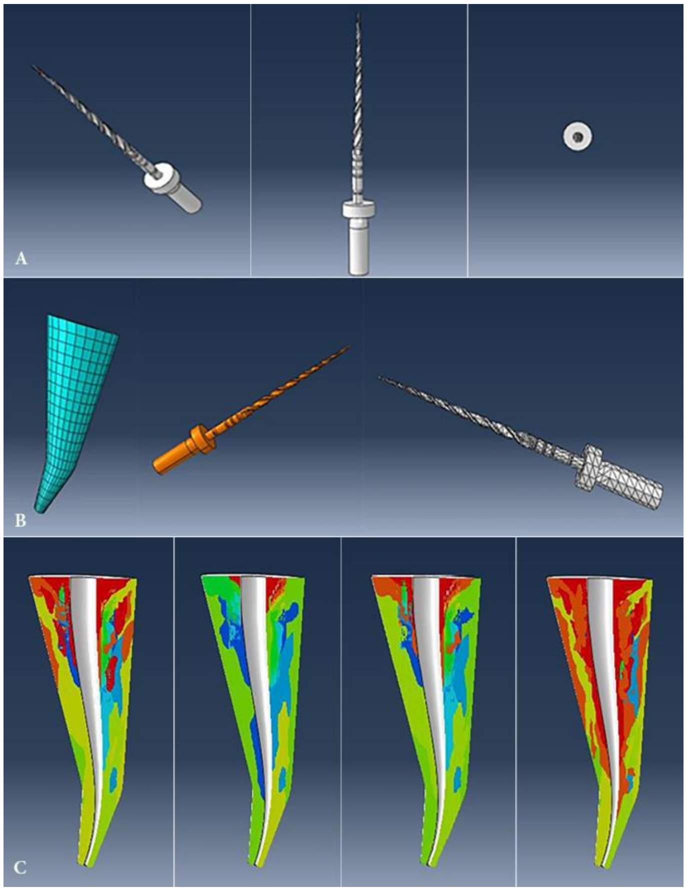


*Figure 2.* *A)* NeoNiti file with 0.08 taper designed in the finite element simulations; *B)* Simulated canal mesh. (1) Canal mesh used in finite element simulations. (2) NeoNiti file with 0.08 taper canal mesh used in finite element stimulations; *C)* The level of stress applied to the canal wall during simulation

The Johnson-Cook model was used to determine the properties of plasticity in finite element simulations. Computationally, the Johnson-Cook model can be defined using the following equation:

$$\overline{\epsilon}_f^{pl} = \left[d_1 + d_2 \exp(d_3 \frac{p}{q})\right]\left[1 + d_4 \ln(\frac{\dot{\overline{\epsilon}}^{pl}}{\dot{\epsilon}_0})\right]\left(1 + d_5 \hat{\theta}\right)$$

In this section, the essential constants to define the problem were constants *A, B, n,* and m, which were defined according to the following values: *A*=50000000, *B*=101000000, *N*=0.08, and *m*=0. It is worth noting that in this study, the effects temperature changes are ignored. The strain rate dependence was selected from the Johnson-Cook type and the values of *C* and Epsilon dot zero, which are the most important constants of this part, were defined as *C*=0.03 and 0.001, respectively. To increase the accuracy of simulations, the values related to specific heat and thermal conductivity were defined according to specific heat=12.60. The Johnson-Cook failure model was used to model the damage. The following equation can express this model:

In this damage model, it was necessary to determine the constant coefficients of d1, d2, d3, d4 and d5, with the values of 0.54, 4.89, 3.03, 0.014, and 1.12, respectively, related to the type of canal structure. On the other hand, it was important to define the extent of damage in the canal, thus, the numerical value of this quantity was set to 1 mm after the onset of damage.

$$\sigma^0 = [A + B(\overline{\epsilon}^{pl})^n]\left(1 - \hat{\theta}^m\right)$$

B) File group No. 1 (RaCe size 25/0.04) in the simulations was defined with their structure made of NiTi and explained properties according to a mass density of 6.45 (Figure 1B). Furthermore, Young's modulus of 13 GPa and Poisson's ratio of 340 were used as the setting for elastic properties. No further settings were necessary due to the rigidity of the file in the current study. To continue the simulation, two parts were placed in front of each other. Intracanal penetration of the file caused mechanical changes within the cavity and was associated with the rotary/transfer speed of the file system; in accordance with the manufacturer's instructions. To evaluate the mechanism of the action of the file system within the canal, it was decided to proceed to the output setting and determine the stresses of canal wall during the simulation. Before simulating, the defined structures had to be meshed in order to analyze the results of this process. The simulated canal mesh is shown in Figure 1C.

C) After meshing the structure, the simulation was performed. Levels of stresses applied to the canal walls can be seen in Figure 1D.

D) In this part, via changing the file system to file group No. 2 (NeoNit file size 25/0.08), the stress in the canal sample was examined. The canal used in this simulation was appropriate to the file used. Figure 2B shows the canal mesh designed in the study. Calculation of the level of stresses entered into the canal was modeled in the second structure and indicated more stress in this structure. The stresses applied to the second canal can be seen due to the placement of Neoniti file size 25 and 8%.Taper.

In the next part of this study, by changing the file system to file group No. 3 (25/0.06 RaCe file), the stress in the canal caused by this designed file was examined (Figure 3). The canal used in this simulation was made by the applied file so that the designed canal mesh could be according to Figure 3B.

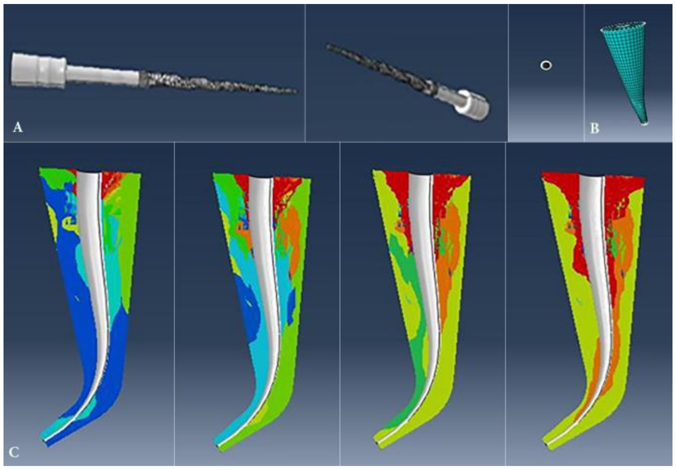

*Figure 3. A)* Race 6% file used in finite element simulation; *B)* Simulated canal mesh. (1) Canal mesh used in finite element simulations. (2) RaCe with 0.06 taper file canal mesh used in finite element stimulations; *C)* The level of stress applied to the canal wall during simulation

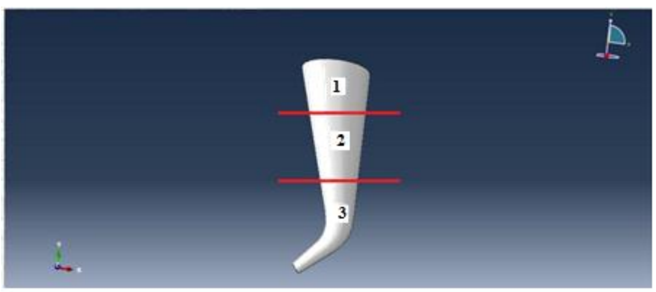

***Figure 4.*** Simulated canal segmentation process to investigate the zone of maximum stress applied to the canal

The stress level was applied to the third structure while using the RaCe file 6%. Simulated canal segmentation process to investigate the zone of the maximum stress applied to the canal is presented in Figure 4.

In the present study, Abaqus and ANSYS software were used to perform finite element simulations. Abaqus is one of the most potent computer-aided engineering software in the field of finite element analysis.

## Results

The present study was performed using finite element method (FEM) to simulate and investigate the intracanal stress. In the current study, the models investigated in the simulations included the two main parts of *(i)* rotary files and *(ii)* target root canal. Three files were used in the simulations, and three simulated canals applied were incompatible with the type of rotary file. However, the material used in the evaluation of finite element was conventional NiTi alloy for RaCe and NiTi M-wire alloy for NeoNiti rotary files.

According to the results, RaCe 4% file caused the lowest level of stress (34.33 MPa) to the simulated canal; while the highest level of stress (35.62 MPa) was applied by NeoNiti 8% file. Table 1 shows the maximum stress level applied by each file. The results were obtained according to the rate and crack recommended by the file manufacturer. The simulated canals were divided into three parts (1/3 coronal, 1/3 middle, 1/3 apical), as shown in Figure 4. According to the stress contour in simulated structures, the maximum level of stress was observed in zone 2 (mid-root zone), and the risk of crack creation in the simulated canals was maximum in zone 2.

## Discussion

The present study was performed to compare the probability of tooth fracture during instrumentation between single- and multi-file rotary systems. The stress level in the inner wall of the canal indicates how the file and the canal interact; according to Figures 1, 2 and 3, it can be seen that the higher the penetration resistance of the file, the higher the level of stress applied to the canal wall. Also according to our result it can be said that the defined prime model (25/0.06 RaCe file) is a more suitable sample for dental use.

Our results demonstrated that the highest level of dentinal stress and damage leading to microcrack occurs in the canal wall via instrumentation with Neoniti single-file system whereas RaCe multi-file system seems to be safer in this regard and may reduce the subsequent potential problems. On the other hand, the taper of final files can affect the amount of stress on the walls; however, further investigations are needed to confirm the issue, especially because only a few studies focused on the above-mentioned issue.

Recently, finit element analysis (FEA) has been introduced as a reliable virtual testing approach to predict the mechanical behaviour of NiTi files through a reverse engineering approach. The reliability of FEA for the prediction of failure was demonstrated by a strict correlation between the results of virtual simulation and in vitro laboratory tests in terms of the

***Table 1.*** Maximum level of stress applied to the simulated canal by different types of rotary files

| Types of rotary files | The maximum level of stress (MPa) |
|---|---|
| No. 1-RaCe file 4% | 33.34 |
| No. 2-(NeoNiti file 8%) | 35.62 |
| No. 3-RaCe file 6% | 34.12 |

number of cycles to failure and of the localization of breaking points of ProTaper Next (Destsply Sirona) instruments. Therefore, FEA could be considered an effective aid for the dynamic analysis and prediction of the mechanical properties of endodontic instruments [25].

The rotary file systems have different types, including single- and multi-file systems [24]. Single-file rotary system for root canal preparation has recently entered the market [24]. These systems are more suitable and attractive compared to multi-file systems due to their advantages; *e.g.* cost-effectiveness, natural preparation, reduction of file consumption and/or file fatigue [16, 18]. Additionally, there are studies reporting that single-file systems can cause less dentinal damage than multi-file systems; due to more manipulation in the canal by the latter, leading to more stress concentration [26, 27].

Fracture development in radicular dentin is a vexing clinical problem. There is some evidence that dental procedures, such as canal preparation and obturation may contribute to this phenomenon [28]. Using two-dimensional FEA, Versluis *et al.* [29] suggested that rounded canal profiles will help reduce and more evenly distribute stresses within the root, perhaps, reducing fracture susceptibility.

Harandi *et al.* [30] compared the incidence of dentinal crack formation by instrumentation with ProTaper Universal system (rotary, multi-file system), SafeSider (reciprocation movement, multi-file system) and Neolix (rotary, single-file system). They reported that all the instrumentation systems increased the number of micro cracks compared to unprepared teeth, while Neolix rotary single-file system caused highest dentinal cracks [30], is consistent with our study.

In the study carried out by Eken *et al.* [20] used the single-file rotary (OneShape and WaveOne) and the multi-file rotary systems (ProTaper Universal, Mtwo, Twisted File and ProTaper Next). The results of this study indicated that the WaveOne model showed more homogenous stresses when loaded on both sides and the risk of microcracks in the tooth wall is less than other file rotary systems. The results of this study are inconsistent with the results of our study, which may be due to differences in the type of rotary systems used [20]. According to Kim *et al.* [31], there is a relationship between dentinal micro crack formation and instrument design.

RaCe file has a triangular cross-section and around, non-cutting tip. An electrochemical process polishes the cutting edge of the file. Another desirable feature of the file is the lack of locking inside the canal, which is due to the special design of the screws on the body [32].

The Neoniti file has a non-uniform square and rectangular cross-section. This design gives the file a high degree of flexibility. [33]. One of the features of the Neoniti file is the round and passive tip, no intracanal locking, and high fracture resistance [34]. The alloy used to fabricate the RaCe files is the conventional NiTi and has two to three times more flexibility than stainless steel files [14]. Since the introduction of rotary systems, various designs with more desirable features have been expanding [3]. Recently, a new generation of NiTi alloys called M-wire has been introduced to the market, fabricated through a thermomechanical process [27]. The Neoniti files are made of M-wire alloy. The advantages of this alloy over conventional NiTi alloy are lower elastic modulus, higher flexibility, and more excellent resistance to cyclic fatigue, leading to reduced fracture risk [34].

In the current study, the highest levels of stress created in the canal in both single- and multi-file rotary systems were in the root middle third, which was identified/addressed as the starting point of stress and microcrack accumulation. According to the present investigation, although the use of single file rotary systems could save time and reduce the number of files consumed, they might impose more stress on the tooth, cause microcrack in the root middle third and increase the risk of vertical root fracture (VRF). Medha *et al.* [35] conducted an investigation to evaluate the stress level created in the canal during instrumentation using the three rotary files of ProTaper, Revo S, and Hyflex. They showed that the highest level of stress was in the apical third [35], which is inconsistent with the findings of the current study. However, the difference in the outcomes could be due to the differences in instrument design.

In the present study, a canal with an angle/curvature of 30 degrees was simulated; whereas in a clinical situation, there are different types of canals with different degrees of curves. There are limitations to simulating/examining types of canals and their variations in one study.

## Conclusions

Based on the present experimental study, it can be concluded that RaCe multi-file system has more safety and fewer complications in root canal preparation compared to Neoniti single-file system. Consequently, the current study proposes the use of RaCe multi-file rotary system for root canal preparation.

Conflict of Interest: 'None declared'.

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