Comparative Evaluation of Stress Distribution in Experimentally Designed Nickel-titanium Rotary Files with Varying Cross Sections: A Finite Element Analysis

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Abstract

Introduction: Single cross-sectional nickel-titanium (NiTi) rotary instruments during continuous rotations are subjected to constant and variable stresses depending on the canal anatomy. This study was intended to create 2 new experimental, theoretic single-file designs with combinations of triple U (TU), triangle (TR), and convex triangle (CT) cross sections and to compare their bending stresses in simulated root canals with a single cross-sectional instrument using finite element analysis. **Methods:** A 3-dimensional model of the simulated root canal with 45° curvature and NiTi files with 5 cross-sectional designs were created using Pro/ENGINEER Wildfire 4.0 software (PTC Inc, Needham, MA) and ANSYS software (version 17; ANSYS, Inc, Canonsburg, PA) for finite element analysis. The NiTi files of 3 groups had single cross-sectional shapes of CT, TR, and TU designs, and 2 experimental groups had a CT, TR, and TU (CTU) design and a TU, TR, and CT (UTC) design. The file was rotated in simulated root canals to analyze the bending stress, and the von Mises stress value for every file was recorded in MPa. Statistical analysis was performed using the Kruskal-Wallis test and the Bonferroni-adjusted Mann-Whitney test for multiple pair-wise comparison with a *P* value <.05 (95 %). **Results:** The maximum bending stress of the rotary file was observed in the apical third of the CT design, whereas comparatively less stress was recorded in the CTU design. The TU and TR designs showed a similar stress pattern at the curvature, whereas the UTC design showed greater stress in the apical and middle thirds of the file in curved canals. All the file designs showed a statistically significant difference. **Conclusions:** The CTU designed instruments showed the least bending stress on a 45° angulated simulated root canal when compared with all the other tested designs. *(J Endod 2018;44:654–658)*

Key Words

Bending stress, cross-sectional design, finite element analysis, nickel-titanium rotary file

Significance

A combination of 3 cross-sectional designs in single-file geometry can provide higher stress resistance in curved canals, which aids clinicians in preventing instrument separation.

Rotary endodontics has become an integral part of cleaning and shaping procedures because of the inherent properties of nickel-titanium (NiTi). NiTi instruments offer excellent flexibility and improved cutting efficiency, thereby preserving root canal anatomy. Over the past decade, technological improvements in the field of endodontics have seen the evolution of surplus rotary instruments and instrumentation techniques. Despite these advantages, NiTi rotary instruments are vulnerable to fracture because of cyclic and torsional fatigue (1).

To overcome these drawbacks, new manufacturing techniques have been incorporated in NiTi rotary instruments to improve physical and mechanical properties for better clinical performance (2). Currently, various modifications have been made for enhancing the fatigue resistance of NiTi rotary files such as controlled memory M-Wire technology and R-phase heat treatment (3). Because of improved NiTi metallurgy, many of the older instruments lost their favor with dentists, leading to migration toward newer file systems. In recent years, single-file NiTi rotary instruments have been gaining attention because of the difficulty in choosing the appropriate system for different root canal morphologies and the time consumed with multiple instrumentation procedures. The use of single files prevents possible cross contamination and reduces cyclic fatigue with improved metallurgy (4).

The mechanical performance of NiTi instruments is mainly determined by manufacturing processes and geometric design. Torsional stiffness and bending flexibility are the 2 most essential features required in any rotary file, which determines file performance in clinical use (5, 6). Various studies have shown that the stiffness and flexibility of an endodontic file are dependent on the geometric design such as taper, helix angle, cross-sectional design, tip diameter, and length (6–9). Most of the single-file NiTi systems have been manufactured with a single cross-sectional design, making the instrument either rigid or flexible. Berutti et al (6) compared the cutting efficacy and flexibility of the U-shaped cross-sectional design with a triangular shape and reported that the latter is more resistant to bending forces. He also stated that

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the convex triangular design is appropriate in the initial canal shaping phase (coronal and middle third), whereas the triple U is suitable for the final stage (apical third) of shaping (7). This theoretic concept of NiTi rotary instruments can be analyzed using finite element analysis (FEA), which is an engineering method for the numeric analysis of complex structures based on their material properties. Kim et al (10) evaluated geometric differences between 3 NiTi instruments on their stress distribution under bending and torsional condition using FEA. In recent years, single-file systems with multiple cross sections have been introduced into the market, such as One Shape (Micro-Mega, Besancon Cedex, France), WaveOne (Dentsply, Surrey, UK), and Hyflex EDM (Coltene Whaledent, Altstatten, Switzerland). Those manufacturers claim that the different cross-sectional design can improve the fracture toughness, flexibility, and cutting efficiency of the files. However, there is scarce scientific evidence proving the significance of the cross-sectional design in curved root canals.

This study was intended to create 2 new experimental, theoretic single-file designs with combinations of triple U (TU), triangle (TR), and convex triangle (CT) cross sections and to compare their bending stresses in simulated root canals with the files of 3 single cross-sectional designs using FEA.

Materials and Methods

Preparation of 3-dimensional Finite Element Models

The 3-dimensional (3D) model of the simulated root canal and NiTi files was created using ANSYS software (ANSYS, Inc, Canonsburg, PA) with program version 17.0 and Pro/ENGINEER Wildfire 4.0 software. Finite element meshing was performed using Solid 186 in ANSYS to create 3D brick elements with 8-node hexahedral elements. This element also supports hyperelasticity, large deflection, and large strain capacity, which are very important properties for the shape memory NiTi alloy.

Material Properties

The geometric file design was created with shape memory and superelasticity similar to NiTi rotary files with properties such as the Young modulus (36 GPa), Poisson ratio (0.3), maximum stress (stress ranges from austenite to martensite: 504–600 MPa and martensite to austenite: 346–250 MPa), and strain (0.07 MPa) (11). The Young modulus of the root canal dentin components was 18.60 GPa with a Poisson ratio of 0.30.

Geometry

Five cross-sectional designs with a single pitch were analyzed. The first 3 groups had single cross-sectional shapes of CT, TR, and TU designs. Next, 2 groups consisted of experimental designs with a combination of all 3 cross sections with the triangle design in the middle third (CT [coronal third], TR [middle third], and TU [apical third] [CTU] and TU [coronal third], TR [middle third], and CT [apical third] [UTC]) as shown in Figure 1*A–E*.

3D Finite Element Model of NiTi Files

All simulated NiTi rotary file models had a standard length of 25 mm with a working surface of 16 mm, a taper of 0.06, a 10 thread pitch, and a tip diameter of 0.25 mm. The final model of the rotary file CT design consisted of 81,385 elements with 20,573 nodes, the TR file consisted of 75,430 elements with 16,750 nodes, the TU file consisted of 96,750 elements with 30,745 nodes, CTU consisted of 149,120 elements with 40,250 nodes, and UTC consisted of 152,432 elements with 42,785 nodes. The z-axis was chosen to be constant to the cross section along the length of the instrument.

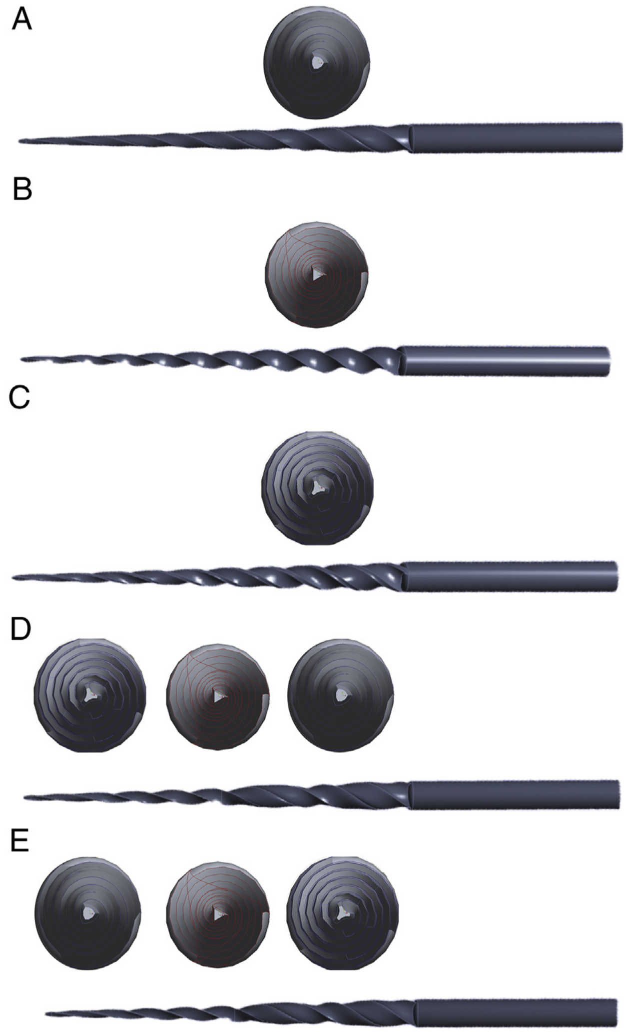

Figure 1. The cross sections of all groups. (*A*) CT, (*B*) TR, (*C*) TU, (*D*) CTU, and (*E*) UTC.

3D Finite Element Model of Root Canal

The root canals were constructed with a 16-mm, 45° root curvature, and a 6-mm radius. The simulated root canals were designed with a 0.5-mm diameter of the apical foramen with a 5% apical taper. The root canals (Fig. 2*A*) were assumed to be homogeneous and isotropic with a linear elasticity consisting of 3000 elements and 3500 nodes.

Loading and Boundary Conditions

The file was inserted to the full length of the simulated root canals, and the stress distribution on the instrument surface was evaluated (Fig. 2*A–E*). The virtual rotation was 180° at a rate of 240 rpm with 2.0 Nm torque at a 45° curvature. Simulations were performed 3 times, and the mean was tabulated for statistical analysis.

Deformation and Stress Analysis

The nonlinear structural analysis took large displacements and strains into account during simulated bending loads and rotations. Flexural stiffness was calculated as the ratio of the bending load to the loading point deflection. Stresses in each integration point (8/element) were recorded at each rotation angle at 0, 3, 6, 9, 12, and 15 mm. Stress