Journal of Dental Sciences (2017) xx, 1–6

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.e-jds.com

Journal of Dental Sciences

ORIGINAL ARTICLE

# The geometric effect of an off-centered cross-section on nickel–titanium rotary instruments: A finite element analysis study

Jung-Hong Ha [a], Sang Won Kwak [b], Antheunis Versluis [c], Chan-Joo Lee [d], Se-Hee Park [e], Hyeon-Cheol Kim [b*]

[a] *Department of Conservative Dentistry, School of Dentistry, Kyungpook National University, Daegu, South Korea*
[b] *Department of Conservative Dentistry, School of Dentistry, Dental Research Institute, Pusan National University, Yangsan, South Korea*
[c] *Department of Bioscience Research, College of Dentistry, University of Tennessee Health Science Center, Memphis, TN, USA*
[d] *Dongnam Regional Division, Korea Institute of Industrial Technology, Jinju, South Korea*
[e] *Department of Conservative Dentistry, College of Dentistry, Gangneung-Wonju National University, Gangneung, South Korea*

Received 30 September 2016; Final revision received 17 November 2016
Available online ■ ■ ■

**KEYWORDS**
bending stiffness;
cross-section;
geometry;
nickel–titanium rotary file;
off-center;
torsional resistance

**Abstract** *Background/purpose:* Geometric design dictates the mechanical performance of nickel–titanium rotary instruments. Using finite element (FE) analysis, this study evaluated the effects of an off-centered cross-sectional design on the stiffness and stress distribution of nickel–titanium rotary instruments.

*Materials and methods:* We constructed three-dimensional FE models, using ProTaper-NEXT type design (PTN) as well as three other virtual instruments with varied cross-sectional aspect ratios but all with the same cross-sectional area. The cross-sectional aspect ratio of the PTN was 0.75, while others were assigned to have ratios of 1.0 (square), 1.5 (rectangle), and 2.215 (centered-rectangle). The PTN center of the cross-section was '$k$', while others were designed to have $0.9992k$, $0.7k$, and 0 for the square, rectangle, and centered-rectangle models, respectively. To compare the stiffness of the four FE models, we numerically analyzed their mechanical response under bending and torque.

*Results:* Under the bending condition, the square model was found to be the stiffest, followed by the PTN, rectangle, and then the centered-rectangle model. Under the torsion, the square model had the smallest distortion angle, while the rectangular model had the highest distortion angle.

---

* Corresponding author. Department of Conservative Dentistry, School of Dentistry, Pusan National University, Geumo-ro 20, Mulgeum, Yangsan, Gyeongnam, 50612, South Korea.
*E-mail address:* golddent@pusan.ac.kr (H.-C. Kim).

http://dx.doi.org/10.1016/j.jds.2016.11.005

Please cite this article in press as: Ha J-H, et al., The geometric effect of an off-centered cross-section on nickel–titanium rotary instruments: A finite element analysis study, Journal of Dental Sciences (2017), http://dx.doi.org/10.1016/j.jds.2016.11.005

*Conclusion:* Under the limitation of this study, the PTN type off-centered cross-sectional design appeared the most optimal configuration among the tested designs for high bending stiffness with cutting efficiency while rotational stiffness remained similar with the other designs.

## Introduction

Various kinds of nickel–titanium (Ni-Ti) systems have been introduced into the market. Over 2 decades, the development and innovations in the design of rotary Ni-Ti instruments has led to new concepts in design and metal alloys.[1–3] Despite these advancements, the fracture of Ni-Ti instruments remains a hot topic due to the nature of its use in endodontic procedures.[4,5]

During a session of root canal enlargement, the instrument is exposed to various levels of stress or strain, which can lead to plastic deformation and the generation of internal residual stress within the instrument. Accumulation of internal residual stress and damage can subsequently result in instrument fracture. The degree of accumulating damage varies depending on the geometric design of the instrument and the forces exerted on the root dentin may jeopardize its integrity.[6,7]

The manufacturing process of Ni-Ti instruments, which includes heat treatment and methods used to realize the geometric shapes, fundamentally determines their mechanical properties.[8–10] Design elements of Ni-Ti instruments have been widely investigated by testing cyclic fatigue and torsional resistances or using finite element (FE) analysis to create controlled conditions.[11,12] It has been demonstrated that the pitch, cross-sectional shape and area determine the flexibility and torsional resistance of the instruments.[11,12]

In the majority of conventional Ni-Ti files, the rotational axis corresponds to the geometric cross-sectional center. An off-centered cross-sectional design was first introduced by Micro-Mega (Besançon, France) in their Revo-S system. More recently, another off-centered cross-sectional design was introduced as the ProTaper Next (PTN; Dentsply Maillefer, Ballaigues, Switzerland). The geometric cross-sectional centers of these instruments are displaced from the instruments' centers of rotation. The manufacturers claim that, compared to conventional concentric instrument designs, the off-centered cross-sectional design creates a snake-like, swaggering movement of the instrument that reduces the stress generation during rotation and screw-in forces by decreasing the instrument's contacts with the tooth's canal wall, while still increasing the space needed for debris removal.[13,14] Current available studies of off-centered design have experimentally examined mechanical performances, such as cyclic fatigue resistance and torsional resistance against fractures.[13,15] However, to the best of our knowledge, no studies have been published that analyzed the effects of off-centered designs on the deformation and stress patterns in the instrument.

The aim of this study was to evaluate systematically the fundamental effects of the off-centered cross-sections on deformations and stresses in Ni-Ti rotary instruments under controlled conditions provided by FE analysis.

## Materials and methods

Four different generalized geometric designs were investigated (Figure 1). The PTN model had the same cross-sectional shape and off-set as ProTaper Next instruments. All four designs had the same cross-sectional area but with different cross-sectional shapes and aspect ratios. The cross-section of PTN was rectangular, with an aspect ratio of 0.75. The degree to which models were off-centered was expressed with respect to the offset $k$ of PTN. The other three models were: (1) square (EXP1-SQ; aspect ratio = 1.00 / an off-center = $0.9992k$); (2) rectangle (EXP2-RT; aspect ratio = 1.50 / an off-center = $0.7k$); and (3) centered-rectangle (EXP3-CR; aspect ratio = 2.215 / an off-center = 0). All instrument models had the same 16-mm long working part and the same external peripheral diameter (1 mm at D16, 0.30 mm at D0). The models were meshed for the FEA with 8-noded hexahedral elements using I-DEAS, version 5 (Siemens PLM Software, Cypress, CA, USA). The final FE models of the PTN consisted of 7104 elements with 9234 nodes. The square design (EXP1-SQ) consisted of 9728 elements with 6909 nodes. The rectangular design (EXP2-RT) consisted of 6624 elements with 10,200 nodes. The centered-rectangle design (EXP3-CR) consisted of 4640 elements with 6660 nodes.

We performed numerical analysis using ABAQUS V6.10-1 (SIMULIA, Providence, RI, USA) to determine the mechanical response and stress distributions in the modeled instrument designs under bending and torsion. The instruments' material properties were modeled using the stress–strain relationship described by Liu.[16] Modulus of elasticity of the austenite phase, the critical stress at the beginning of the transformation to the R-phase, and the Poisson's ratio were 23.5 GPa, 450 MPa, and 0.33 respectively.[17]

Flexural stiffness was calculated as the ratio of bending load and loading point deflection. In this study, the instrument tip was displaced 2 mm. Stresses in each integration point were recorded at each rotation angle during the rotation of 90° considering the symmetry of cross-section (Figure 1E). For the torsional condition, the file was fixed at 4-mm length of the tip, while the file was rotated using a torsional moment of 2.5 Nmm at the end of the shaft (Figure 1F). Reaction force at the file tip was recorded during flexure and distortion angle during torsion.

Please cite this article in press as: Ha J-H, et al., The geometric effect of an off-centered cross-section on nickel–titanium rotary instruments: A finite element analysis study, Journal of Dental Sciences (2017), http://dx.doi.org/10.1016/j.jds.2016.11.005