EFFECT OF CROSS-SECTIONAL AREA OF 6 NICKEL-TITANIUM ROTARY INSTRUMENTS ON THE FATIGUE FRACTURE UNDER CYCLIC FLEXURAL STRESS: A FRACTOGRAPHIC ANALYSIS

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ABSTRACT

This study aimed to assess the influence of different cross-sectional area on the cyclic fatigue fracture of Ni-Ti rotary files using a fatigue tester incorporating cyclical axial movement. Six brands of Ni-Ti rotary files (ISO 30 size with .04 taper) of 10 each were tested: Alpha system (KOMET), HeroShaper (MicroMega), K3 (SybronEndo), Mtwo (VDW), NRT (Mani), and ProFile (Dentsply). A fatigue-tester (Denbotix) was designed to allow cyclic tension and compressive stress on the tip of the instrument. Each file was mounted on a torque controlled motor (Aseptico) using a 1:20 reduction contra-angle and was rotated at 300 rpm with a continuous, 6 mm axial oscillating motion inside an artificial steel canal. The canal had a 60° angle and a 5 mm radius of curvature. Instrument fracture was visually detected and the time until fracture was recorded by a digital stop watch. The data were analyzed statistically. Fractographic analysis of all fractured surfaces was performed to determine the fracture modes using a scanning electron microscope. Cross-sectional area at 3 mm from the tip of 3 unused Ni-Ti instruments for each group was calculated using Image-Pro Plus (Imagej 1.34n, NIH). Results showed that NRT and ProFile had significantly longer time to fracture compared to the other groups ($p < .05$). The cross-sectional area was not significantly associated with fatigue resistance. Fractographycally, all fractured surfaces demonstrated a combination of ductile and brittle fracture. In conclusion, there was no significant relationship between fatigue resistance and the cross-sectional area of Ni-Ti instruments under experimental conditions. [J Kor Acad Cons Dent 34(5):424-429, 2009]

Key words: artificial steel canal, cross-sectional area, fatigue resistance, fractographic analysis

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I. Introduction

In the continuous search for improvement of endodontic instruments, the greatest innovation introduced in the last decade was the development of nickel-titanium (Ni-Ti) rotary files. The Ni-Ti rotary files exhibit super-elasticity and can prepare root canals with a suitable taper and flow compared to stainless steel hand files and with less apical aberrations.[1-3] Despite the evident advantages, the Ni-Ti rotary files can undergo unexpected fracture as a result of shear or fatigue failure in curved root canals, with the latter being implicated in more than one-third of those instruments fractured clinically.[4-6] Many factors have been implicated in the fatigue fracture of the Ni-Ti rotary files. Of these, the instrument designs and the cross-sectional area can affect the magnitudes of stress and strain when subject to torsion or bending.[7-9] Recently, Ni-Ti rotary instruments are available in a variety of cross-sectional shapes such as a triangle (ProFile, K3, and HeroShaper), modified rectangle (NRT and Mtwo), and pentagon (Alpha System). To date, there has been few studies on how Ni-Ti rotary instruments

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with different cross-sectional shapes behave when subjected to rotational-bending, a deformation mode similar to an engine-file rotating in a curved root canal, but the effect of cross-sectional shapes on the cyclic fatigue fracture is still controversial.[7-12] Several studies have been performed to evaluate the cyclic fatigue in a dynamic model incorporating axial oscillating motion.[13,14] This not only provides a better clinical simulation than the static model, but these studies also demonstrated that the axial (pecking) motion significantly lengthens the life span of the rotary files.[15] Fractography can be broadly defined as the science of observing, measuring and interpreting a fractured surface topography. When material failure involves actual breakage, fractography can be used to identify the fracture origin, the direction of crack propagation, the failure mechanism, materials defects, and the nature of the stresses.[16]

Therefore, this in vitro study aimed to assess the influence of different cross-sectional shapes of Ni-Ti rotary files on the flexural fatigue fracture in a dynamic model and to determine the fracture patterns of broken file surfaces through a fractographic analysis using a scanning electron microscope.

Ⅱ. Materials and methods

Six experimental groups were allocated according to 6 brands of Ni-Ti rotary instruments of 10 each. The instruments tested were Alpha System (KOMET, Culver, Germany), HeroShaper (Micro-Mega, Besançon, France), K3 (SybronEndo, CA, USA), Mtwo (VDW, Munich, Germany), NRT (MANI, Utsunomiya, Japan), and ProFile (Dentsply, Ballaigues, Switzerland). All the instruments were #30/.04 in size and 25 mm in length. Fatigue testing was carried out in a fatigue tester (Denbotix, Bucheon, Korea) that allows the files to rotate freely inside an artificial stainless-steel canal and also allows the handpiece to move vertically (Figure 1). Each file was mounted on an electric motor (Aseptico, WA, USA) using a 1:20 reduction contra-angle handpiece. The instrument was rotated at 300rpm inside an artificial canal. An artificial canal was made out of stainless steel with an inner diameter of 1.05 mm, 10 mm in length, angle of 60°, and a radius of curvature of 5 mm. A continuous, 6 mm axial oscillating motion was applied at 0.5 cycles per second to simulate a clinical pecking motion. The apparatus can control the pecking distance, oscillation speed and set starting and ending point. The starting point was set at the apical end of the canal

During the test, the artificial canal was filled with RC Prep (Premier Dental Co., PA, USA) to reduce the instrument's friction against the canal wall and heat generation. Instrument fracture was visually detected and the time until fracture was recorded using a digital stop watch. The mean and standard deviation values of the fracture time were calculated for each group. Using the SPSS statistical package version 12 (SPSS Inc., Chicago, IL, USA), the difference among the instruments as to their fatigue resistance was analyzed using one way analysis of the variance (ANOVA). Tukey post hoc analysis was used to identify the specific groups that showed significant difference. The level of significance was set at 5%.

For fractographic analysis, all fractured files from

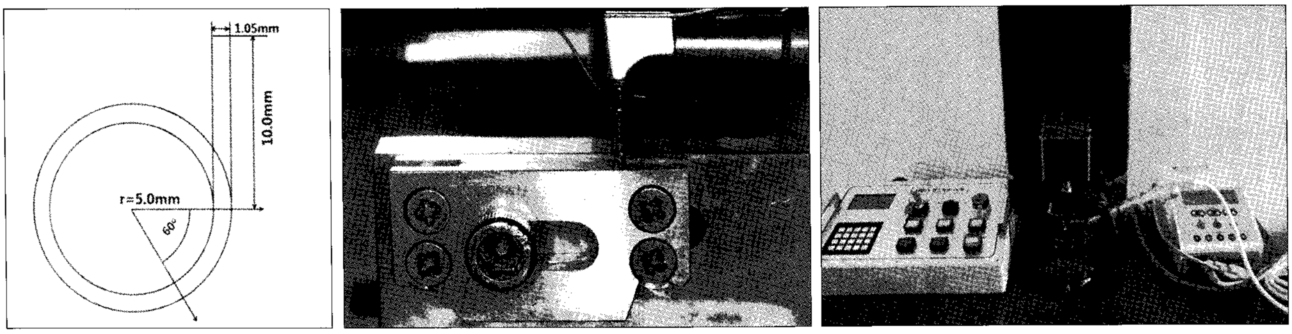

Figure 1. Schematic diagrams and pictures of an artificial canal and a fatigue tester (Denbotix).

each group were photographed using a scanning electron microscope (JSM840A, JOEL, Tokyo, Japan) to determine the modes and patterns of fracture at magnifications of ×200, ×500, and ×1000. In addition, the cross-sectional area of 6 brands of Ni-Ti instruments was determined using SEM photographs as follows. Three new Ni-Ti instruments for each group was embedded in resin and cut at a 3.0 mm from the tip with an ISOmet 11-1180 low-speed saw (Buehler, Lake Bluff, Ill, USA). Then, the specimens were cleaned in an ultrasonic water bath for 15 min. The sections were examined by SEM at a magnification of ×200. The mean cross-sectional area of each file was calculated using Image-Pro Plus software (Imagej 1.34n, NIH, Bethesda, MD, USA). The correlation between the mean cross sectional area and the mean time to fracture of each group was examined using linear regression analysis with statistical significance set to $\alpha=0.05$.

Ⅲ. Results

1. FT (fracture time) measurements

The mean time to fracture for 6 experimental groups was shown in figure 2. For the mean time to fracture, NRT group gave the best values. The mean time to fracture of NRT and ProFile were significantly higher than those of the other groups ($p < .05$), but there was no significant difference between NRT and ProFile. Also, there was no significant difference among Mtwo, K3, Heroshaper, and Alpha System. Different cross-sectional shapes of 6 Ni-Ti rotary instruments and the calculated cross-sectional areas are presented in figure 3. The cross-sectional area of Mtwo file was the smallest, while that of Alpha system was the biggest. The Spearman correlation coefficient was calculated to examine the correlation between time to fracture and the calculated cross-sectional area. The correlation coefficient (r) was 0.035, which revealed no significant relationship between time to fracture and the cross-sectional area of Ni-Ti rotary files tested.

2. Fractographic analysis on the fractured surfaces

Low-magnification SEM photographs showed smooth area of brittle fracture to be the main failure mode at the periphery (Figure 4a), which typically led to a large central region of catastrophic ductile fracture in all fractured samples. The central area of ductile fracture was typically characterized by microvoid formation and dimpling (cup-and-cone fracture, Figure 4b, white arrow). On the contrary, the smooth region at the periphery showed a presence of micro-crack at flute face (NRT, X500, Fig.4c, white arrow), which was considered to act as a trigger point of brittle fracture, and clusters of multiple linear striations (K3, ×1000, figure 4d, white arrow). In addition, the fracture planes at the peripheral border of the cross-section were at different levels from the main fracture plane in most samples.

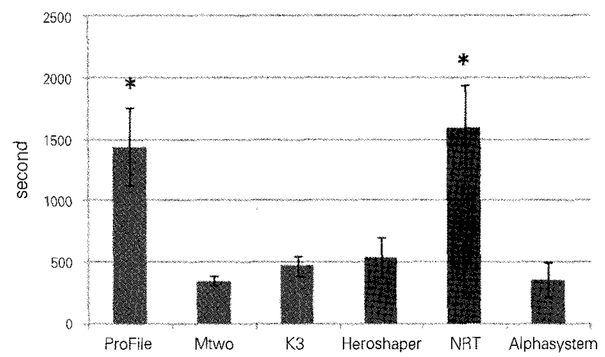

Figure 2. Standard deviation and mean values of time to fracture of 6 Ni-Ti files (second).

* Statistically significant ($p < .05$).

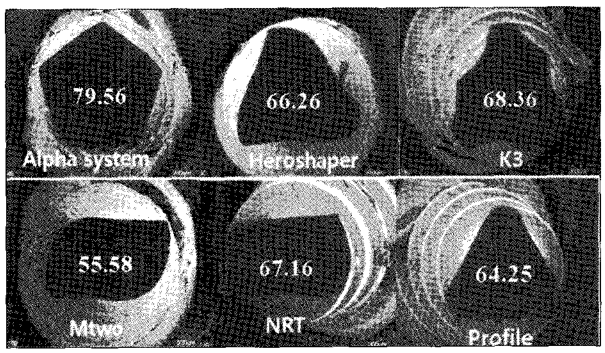

Figure 3. SEM views of cross-sectional shapes of 6 Ni-Ti rotary instruments and the calculated cross-sectional area at 3 mm from the tip(×200).

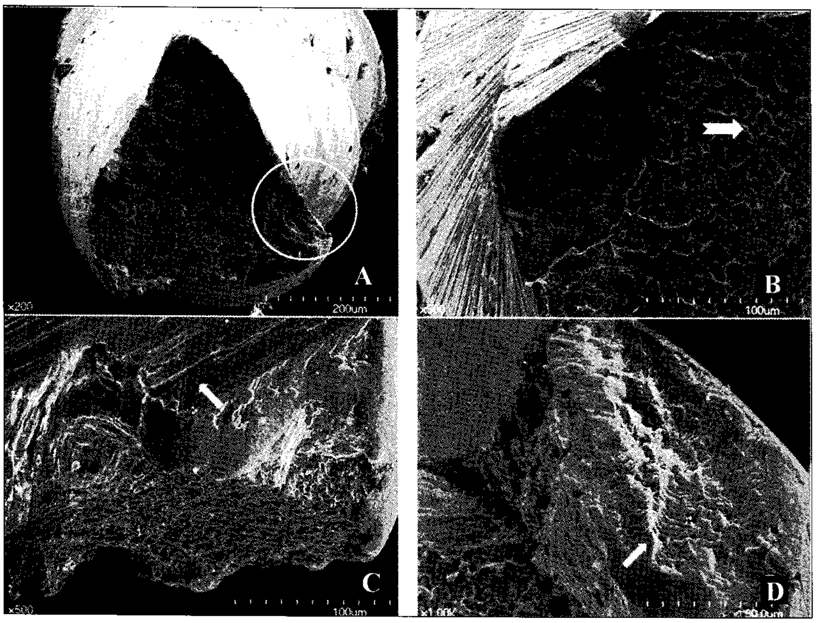

Figure 4. A photograph of fractured surface of NRT instrument (A, × 200) and the magnified view (round circle) showing the presence of micro-crack at lateral surface (C, white arrow, ×500) near the separated tip region. A photograph of fractured K3 instrument showing dimples at central area (B, white arrow, ×500). Evidence of brittle fracture is present as reflected by the multiple linear striations of on the peripheral fractured surface of K3 instrument (D, white arrow, ×1000).

Ⅳ. Discussion

Many manufacturers have developed and designed new Ni-Ti rotary instruments that have different features, such as various cross-sectional shapes, pitches, helix, and tips. The fatigue resistance of endodontic files made of same material and same dimension (size and taper) is entirely dependent on instrument designs (cross-sectional area, pitch, helix, radial land, and/or spirals) and the cross-sectional area is closely associated with file flexibility (stiffness).[12] Therefore, this study compared the cyclic fatigue resistance for 6 Ni-Ti rotary instruments with different cross-sectional configurations. A previous study by Schäfer et al.[17] demonstrated that Ni-Ti rotary instruments with small cross-sectional area showed better results in terms of fatigue resistance. Turpin et al[7] calculated the cross-sectional areas of triple-helix (Hero) and triple-U files (ProFile) and compared bending stresses in these 2 instruments. For identical working diameters, the cross-sectional area of the triple-helix (Hero) was found to be approximately 30% greater than that of the triple-U shaped ProFile. The greater cross-sectional area determined a lower flexibility of the Hero file compared to ProFile, which can explain the poor fatigue resistance in their study. Likewise, Alpha System was more vulnerable to cyclic fatigue due to its large cross-sectional area. Alpha System has five-edged (pentagon) cross-section and its cross-sectional area was the largest among 6 experimental groups. The present result, however, was not consistent with that of Turpin et al.[7] and Schäfer et al.[17] In other words, although Mtwo has the smallest cross-sectional area among the 6 Ni-Ti files tested, Mtwo showed the lowest value of fatigue resistance. A possible explanation might be that Mtwo instrument has a lower number of spirals per unit length. The fewer the spirals a flute has per unit length around the shaft of a file, the more it resists deformation but at the same time the more rigid it becomes.[18]

On the contrary, Yao et al[19] showed that K3 file was more resistant to cyclic fatigue than ProFile although K3 has larger cross-sectional area than ProFile. The authors explained that it may be related to the overall design of the K3 file, that is, the variable core diameter. Tripi et al.[20] also demonstrated in their study that the variable core diameter and the presence of radial lands could explain the high fatigue resistance of K3 instruments. However, the present study showed that the fatigue resistance of K3 instrument was lower than that of ProFile which has a smaller cross-sectional area. This result is consistent with those of the previous studies.[11,12] Therefore, more controlled studies regarding the effect of instrument designs on the fatigue fracture are necessary.

An interesting finding in the present study was that NRT file showed the best value of fatigue resistance although the cross-sectional area was not the smallest. This finding is in agreement with the finding of other authors that Ni-Ti instruments with a triangular-based cross-sectional shapes (ProFile) displayed a higher bending load than those that rectangular-based cross-sectional shapes (NRT).[21] The authors contributed the high flexibility of NRT to the additional heat treatment during the manufacturing process. A previous study also suggested that rectangular shape can allow improvement of file flexibility.[22]

In conclusion, the cross-sectional area is not a determining factor affecting the fatigue resistance of Ni-Ti rotary file. In addition, NRT and ProFile system can be useful for safe instrumentation in curved root canals in the aspects of fatigue resistance.

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국문초록

반복 굽힘 스트레스 하에서 전동식 니켈-티타늄 파일의 단면적의 크기가 피로파절에 미치는 영향 : 파절역학 분석

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본 연구의 목적은 니켈 티타늄 전동파일의 피로 파절에 파일의 단면 형태가 미치는 영향을 평가하고자 하였다. 6 종의 ProFile (Dentsply), Mtwo (VDW), K3 (SybronEndo), HeroShaper (MicroMega), NRT (Mani), Alpha system (KOMET) 니켈-티타늄 전동 파일(ISO 30 size/.04 taper)을 각 10개씩 실험군으로 배정하고 실험을 진행하였다. 니켈 티타늄 전동파일에 반복적인 장력과 압축력을 재현시킬 수 있는 피로파절 실험기(Denbotix)와 연결된 토크 조절 전동모터(Aseptico)에 각 군의 파일을 연결하여 300rpm 속도로 만곡도가 60도이고 5mm 의 반경을 가진 인공 금속 근관 내를 6 mm pecking depth 로 작동시켰다. 각 파일의 파절시간을 측정하고 통계 분석하여 유의성을 분석하였으며, 각 군의 파절된 모든 파일의 파절면을 주사전자현미경을 이용한 fractographic analysis를 통해 파절 역학을 규명하였다. 또한 각 군에서 3 개의 사용하지 않은 새 파일을 clear resin 에 매몰하고 tip에서부터 3mm 지점을 횡절단하여 Image-Pro Plus (Imagej 1.34n, NIH) 소프트웨어로 절단면의 단면적을 측정하고 단면적의 크기와 피로 파절과의 상관성도 평가하였다. 실험 결과 NRT와 ProFile이 다른 실험군에 비해서 유의성 있게 높은 피로 파절 저항성을 보였다 ($P < .05$). 또한 파일의 단면적은 피로파절 저항성과 통계학적인 유의성은 보이지 않았다. Fractographic analysis 결과 모든 시편에서 파절면은 ductile fracture와 brittle fracture가 혼재된 양상으로 나타났다. 결론적으로 니켈 티타늄 전동 파일의 단면적의 크기는 피로파절 저항과는 상관성이 적었다.

주요단어 : 인공 금속근관, 단면형태, 피로파절 저항성, 파절역학 분석