

THE FRACTURE EVALUATION OF NiTi SMA ENDODONTICS FILES.

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Abstract:

The purpose of this study was to evaluate the fracture resistance and the fracture surface of NiTi SMA engine-driven endodontics files submitted to clockwise torsion. The maximum angular deflection and the maximum torque were analyzed without axial loading. The helical plastic deformations and the fracture surface morphology were evaluated by Scanning Electron Microscopic (SEM). The results showed that there was a significant statistical difference in the maximum fracture torque and no statistical difference for the angular deflection for the analyzed files. In relation to the maximum torque at the instant of the fracture, one of the brand presented better performance than the other. According to SEM evaluation, all the files showed ductile fracture morphology.

Key words: endodontics files, NiTi, SMA, torsion fracture.

INTRODUCTION

Nickel-titanium (NiTi) endodontic instruments have been introduced to facilitate the instrumentation of curved canals. NiTi Shape Memory Alloys (SMA) instruments have the combination of good biocompatibility, good mechanical strength, and specific properties, such as the shape memory effect (SME) and superelasticity (SE). NiTi instrument can bend far more than stainless-steel instruments before exceeding their yield point⁽¹⁾. This flexibility is an important property that allows the preparation

of curved canals while minimizing deviation⁽²⁾. Despite this increased flexibility, fracture is still a concern to NiTi instruments, and they have been reported to undergo unexpected fail⁽³⁾.

The behaviour of NiTi alloys is associated with the stress-induced transformation of the β parent phase, austenite, with the B2 cubic crystal structure, to martensite, with a monoclinic B19' structure. Appropriate chemical composition and thermomechanical treatments are required in order to stress-induces the martensitic transformation in NiTi alloys⁽⁴⁾.

The NiTi alloys, with an approximately equiatomic composition, have in addition to high resistance and excellent biocompatibility some special features: the SME and SE. The SME occurs in specific conditions in which the metal is deformed at a certain temperature, the shape recovery temperature is higher than the temperature of deformation. To recover the original shape it is necessary to heat the material above the shape recovery temperature, A_F . At SE state as far as the shape recovery temperature is lower than the deformation temperature the shape is recovered when the load is released without heating.

The fatigue life of a rotary endodontic instrument could be related to the degree to which it is flexed when placed in a curved root canal, with greater flexures leading to a shorter expected life^(5,6). Torsional fracture occurs when the tip or some part of the endodontic file is hindered in a canal while the instrument shaft continues to rotate. In this case, the elastic limit of the metal is exceeded leading to plastic deformation followed by fracture^(7,8). Many factors can affect the torsional strength of endodontic files, such as taper, instrument design, alloy composition and stiffness, manufacturing, flexibility, and rotation direction⁽⁹⁾.

The objective of this study was to compare the performance of the NiTi SMA engine-driven endodontic instruments, when submitted to clockwise torsion test. The evaluated properties were: the angular deflection up to fracture and the maximum torque of the fracture. Also it was evaluated the fracture surface and the shape of spiral of the cutting edge near the immobilizing point of the endodontic instrument after the mechanical testing.

EXPERIMENTAL PROCEDURE

Nickel-titanium rotary files (#15 and #35, length of 25 mm) with cross section on the shape of triple helix and triple U. The NiTi rotary files K³ Endo (Sybron Endo –

USA) and Profile (Dentsply-Maillefer - Switzerland) were tested. Ten files of each size were tested in clockwise (CW) rotation. Therefore, 20 files from each manufacturer were tested.

A torsion without axial load was applied to the files with a device attached to Universal Mechanical Testing Machine Emic DL 10000 (Emic Equipments and Systems for Tests Ltd, São Paulo). This apparatus was similar to the one used by others studies^(10,11) (figure 1).



Fig. 1 – Device attached to Universal Mechanical Testing Machine.

The load and the displacement of the thread up to the fracture of the instruments were registered continuously by a microcomputer attached to the testing machine. A chart of the load versus displacement was obtained.

The determination of the angular deflection and the obtained displacement were converted through the formula:

$$AngularDeflection(^{\circ}) = \frac{displacement(mm)}{2\pi R(mm)} \times 360^{\circ}$$

The maximum torque at the fracture was calculated through the formula:

$$MaximumTorque(N.m) = MaximumLoad(N) \times R(m)$$

After fracture occurrence, the SEM analysis (JEOL, model ISM 5800 IV) was carried out to evaluate any possible alterations of the spirals of the cutting edge

together with the point of immobilization and the surface characteristics of the fracture.

To obtain the micrographies, a differentiated magnification was adopted to the spiral of the cutting edge near the fracture, as well as the morphological characteristics of the fracture surface. To analyze the shape of the spiral photomicrographies, a lower magnification (60 to 200X) was applied. For the analysis of the morphological characteristics of the fracture surface, the photomicrographies were taken at the magnification of 2000X.

RESULTS

The obtained charts were used to calculate the angular deflection and the maximum torque up to the fracture. The results are shown in table 1.

The fracture occurred near the point of immobilization at the tip of the instruments ($\pm 3\text{mm}$).

Angular deflection

The parametric Student's t-test was applied to the obtained data with 95% of confidence interval, t-value = 0,667 with p = 0,513 and t-value = -1,556 with p = 0,137. It was revealed that there was no significant difference between the averages of the tested groups, from which there was a variation when comparing the brands and the diameters of the K³ Endo # 15 (Group I A) and ProFile # 15 (Group II A) instruments in relation to the maximum angular deflection. The same results were observed between the instruments K³ Endo # 35 (Group I B) and ProFile # 35 (Group II B) in relation to the maximum angular deflection (table 1).

Maximum torque

The parametric Student's t-test was applied to the obtained data, with 95% of confidence interval, t-value = 7,912 with p = 0,000 and t-value = 11,796 with p = 0,000. It was revealed that there was a highly significant difference between the averages of the tested groups. Concerning to brand, K³ Endo # 15 (Group I A) it supported higher torque up to fracture when compared to ProFile # 15 brand (Group II A). The same results was presented when it was compared instruments K³ Endo # 35 (Group I B) and ProFile # 35 (Group II B) in relation to the maximum torque (table 1).

	Angular deflection		Maximum torque	
	Average (°)	Standard deviation	Average 10 ⁻³ N.m	Standard deviation
Group I A K³Endo #15	676,40	101,60	4,95	5,73
Group II A ProFile #15	637,20	155,70	2,99	5,58
Group I B K³Endo # 35	818,00	69,94	18,48	9,58
Group II B ProFile # 35	886,90	121,40	14,03	7,50

Table 01 – Average and standard deviation values of the angular deflection and maximum torque

SEM Analysis

When seen at lower magnification (60 to 200X), all the fractured instrument presented smooth fracture surfaces and perpendicular to their axis. Plastic deformations of the spirals occurred near the fracture surface as shown in figure 2. There was a reversion in the direction of the spirals in relation to its original direction when the files were submitted to clockwise torsion. At higher magnification (2000X), it was observed that the fracture surface presented typical ductile fracture presenting microvoids with varied shapes (figure 3). At the border of fracture surface, the microvoids were broaden and with small depth. In the cutting edge there were observed dimples and grooves patterns from machining.

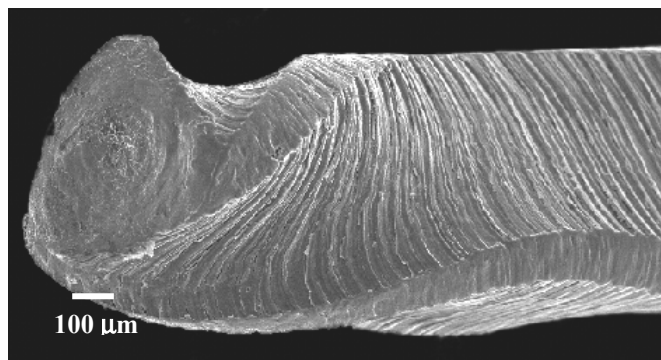


Fig 2 – Representative morphology of an endodontic file (ProFile # 15) after mechanical testing, showing the reversion in the direction of the helix. (SEM original magnification - 200X).

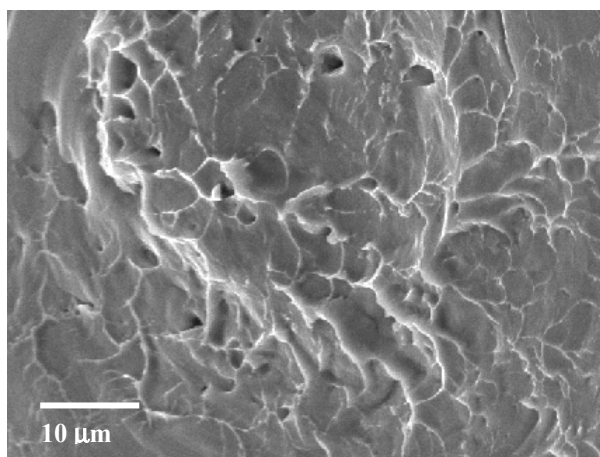


Fig. 3 – Representative surface fracture morphology of an endodontic file surface (K³ Endo # 15), showing the presence of microvoids with varied shapes (SEM original magnification - 2000X).

DISCUSSION

In this study, the evaluation of the angular deflection and the maximum torque were developed in agreement with the ANSI/ADA Specification number 28, 1989. The test for the evaluation of the torque shows to the professional the maximum load that may be applied to the instrument.

In the evaluation of the mechanical resistance of the instruments in the torsion test, some different parameters may be used. For some authors^(10,13), the main parameter is the maximum angular deflection that acts as a factor of safety in relation to the fracture of the instrument. Larger the angular deflection of an endodontic instrument, the larger will be its toughness and plastic deformation before starting the

fracture process. This material's feature is a factor of safety because it goes beyond the limit of resistance to the fracture by torsion of the material⁽¹⁴⁾.

The maximum angular deflection of the K³ Endo and ProFile instruments, varied in relation to the brand and their diameters, with no statistically significant difference amongst instruments of same nominal diameter (size) of both brands. Even though, to some studies^(10,15) the maximum angular deflection in the fracture, for hand instruments of NiTi, has decreased with the increase of the nominal diameter of the endodontic instrument. Other author observed that the angular deflection is not influenced by the increase of the nominal diameter of the instrument⁽¹⁶⁾. This feature may be explained by the fact that all the efforts to standardize the dimensions of the endodontic instruments, could present discrepancy in dimensions of the instruments even with the same number. Besides, they could have deficient surface finishing presenting dimples and microvoids occurred during the manufacturing process and they act as stress concentrator interfering directly in the obtained results of such endodontic instruments when submitted to mechanical tests⁽¹⁷⁾.

As to the maximum fracture torque, it was possible to verify statistical differences for the two brands tested with different diameter, increasing with the increase of the nominal diameter of the endodontic instrument. Similar results were obtained in other studies^(10,13,14). The source of those differences is related variation in transversal cross section, and consequently, with the need of a higher load to fracture the instruments of a higher size. It was verified that the K³ Endo instruments needed a higher maximum torque at the moment of the fracture than the ProFile instruments. This may explain the better performance of triple helix K³ Endo file, which has a larger nucleus when submitted to a torsion effort that promotes the stress distribution progressively between the angle of the cutting edge and the canal file (figure 4). Consequently, in this region the stress may be more evident. To a transversal cross section of a triple U instrument (ProFile) (figure 5), which has a smaller nucleus, the stress is concentrated in the canal file much closer to the center line of the instrument than in triple helix⁽¹⁸⁾. This explain the better performance of triple K³ Endo in relation to triple U Profile.

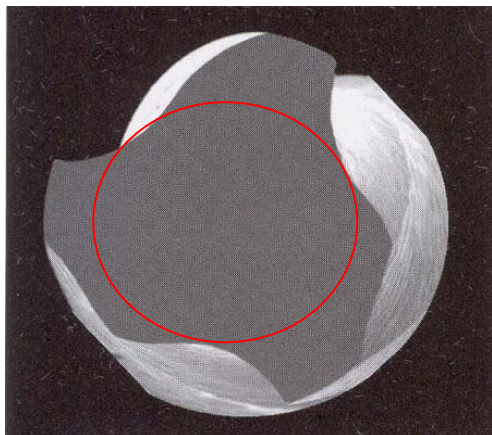


Fig. 4 – Representative micrograph of the K³Endo instrument with triple helix cross section (Lopes et al¹⁹., 2004).

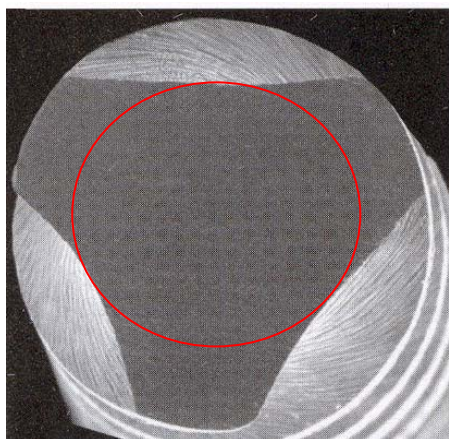


Fig. 5 – Representative micrograph of the ProFile instrument with triple U cross section (Lopes et al¹⁹., 2004).

In the qualitative evaluation through the SEM of all samples, there was a plastic deformation of the instrument's spirals, represented by the reversion of the original direction, near to the point of fracture ($\pm 3\text{mm}$). Concerning the direction of the rotation, it is possible to affirm that the reversion indicated that the clockwise rotation is in agreement with some works^(10,20) that presented similar results, in clinical studies.

The frequency of fracture of the NiTi SMA engine-driven endodontic instruments during the preparation of the root canal may be reduced, according to the instrument's manufacturing with a better control of material quality, more demanding evaluation of the dimensions and a better surface finishing. As to the used materials, the chemical composition of the NiTi alloy, may alter, with the objective of producing harder and more flexible metal alloys, without the need of losing the capacity of

cutting the instrument. An alternative would be the use of a hard coating on the instruments⁽¹⁷⁾. With these procedure it is probable that there will soon be more resistant and more reliable instruments.

CONCLUSIONS

According to the results, it's conclude that:

- In relation to the maximum angular deflection, there was a variation when comparing the brands (K³ Endo and ProFile) for the same diameters instruments;
- For maximum torque there was a significant difference between the averages of the tested groups with better performance of K³ Endo brand compared to ProFile brand;
- At lower magnification (60 to 200X), all the fractured instrument presented smooth fracture surfaces and perpendicular to their axis. There was a reversion in the direction of the spirals in relation to its original direction when the files were submitted to clockwise torsion;
- At higher magnification (2.000X), it was observed that the fracture surface presented typical ductile fracture presenting microvoids with varied shapes.

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