Influence of surface grooves orientation on the cyclic fatigue resistance of NiTi wire

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ABSTRACT

Objective: this study tested the null hypothesis that the surface grooves orientation does not influence the NiTi wire cyclic fatigue. **Material and methods:** Segments of NiTi wire (Moreli, Sorocaba, Brazil) measuring 30mm and with a 0.40mm of diameter were used. Grooves were created in the longitudinal direction, at 45 degrees and 90 degrees. The wire was analyzed with SEM and the roughness was quantified by interferometry. The number of cycles until fracture (NCF) was determined by the cyclic fatigue test. **Results:** the roughness between 45 and 90 degrees groups presented differences ($p<0.05$). The group without grooves presented the highest NCF ($p<0.05$). The group with 45 degrees grooves presented better NCF in comparison to the group with 90 degrees ($p<0.05$). **Conclusions:** the direction of the grooves influences the fatigue life. The NCF increases with the reduction of the angle of the grooves in relation to the long axis, regardless of the depth of the grooves.

Keywords: Dental Alloys. Surface Properties. Physical Properties

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Introduction

The NiTi instruments revolutionized endodontics because of their superior mechanical properties. They have higher flexibility than stainless steel, offering more suitable conditions to shape the root canal. The root canals prepared with NiTi instruments show less change in shape, less incidence of complications and iatrogenias, such as canal transportation, ledge formation, zips and perforations. These instruments are essential for the mechanical shape of curved and/or atresiated canals.[1,2]

Despite the advantages of NiTi endodontic instruments in root canal instrumentation with complex anatomy, these instruments present a high risk of fracture when used in curved channels. This is the main concern of the professionals during their use, as it may compromise the prognosis of the treatment.[3]

It is important that the professional have knowledge about the mechanical properties of the instruments which he works to get the best of them and reduce the number of failures. Many variables influence the mechanical behavior of the endodontic instruments of NiTi, even if we compare them with similar instruments, a small difference between the variables may influence the results obtained in the mechanical tests performed.[2,4-8]

Several factors may influence the mechanical properties of the endodontic instruments, such as variations in the dimensions, shape, taper, manufacturing process, chemical composition of the alloy and surface finish (grooves, burrs and microcavity). As a consequence, NiTi wires with identical characteristics were used in this study to eliminate the influence of the variables.[5-13]

To the best of the authors knowledge, there is no study in the literature demonstrating the correlation of grooves orientation with the cyclic fatigue without the influence of others variables. The aim of this study was to test the influence that surface grooves orientation has on the cyclic fatigue life of NiTi wires. The null hypothesis tested was that the surface grooves orientation does not influence the cyclic fatigue of NiTi wire.

Material and methods

NiTi wire with superelastic characteristics at room temperature (Moreli, Sorocaba, Brazil) and a diameter of 0.40 mm was used on this study. Thirty segments of wire, measuring 30mm were used. They were initially washed with acetone using an ultrasonic apparatus Soniclean 2 (Sanders, Santa Rita do Sapucai, Brazil) before the SEM and roughness analysis. The 30 segments were divided into 3 groups as follows:

» Group 1 (n=10) - wires without grooves (Fig.1A).

» Group 2 (n=10) - surface grooves were created on the wire with 45 degrees inclination to the long axis (Fig. 1B).

» Group 3 (n = 10) - surface grooves were created on the wire with 90 degrees inclination to the long axis (Fig 1C).

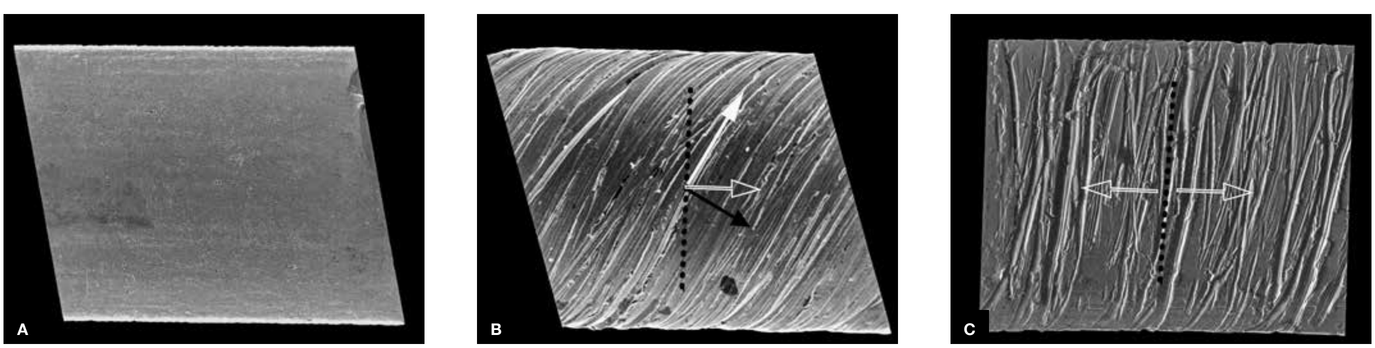

Figure 1. Scanning electron microscope images of wires surfaces with 500X magnification showing: the wire as received without grooves (**A**), with grooves at 45 degrees (**B**) and with grooves at 90 degrees. (**C**) The dashed lines represent the direction of crack propagation. The white arrows without filling represent the main stress. The filled white arrow represent the stress component dissipated inside the grooves, and the black one the component that open the crack.

Groove preparation:

For groups 2 and 3, the wire segments were activated with a 6:1 reduction handpiece (Sirona Dental Systems GmbH, Bensheim, Germany), with the aid of an adapter (Fig 2C), powered by a torque-controlled motor (Silver Reciproc; VDW) at 250rpm and 120gcm. The grooves were prepared with granulation sandpaper 60 (Norton, Guarulhos, Brazil) at 90 degrees and 45 degrees, according to their group. The sandpaper were cut in square shape with sides of 2 cm and fixed with an orthodontic rubber around the wire. To make the pattern of 90° the motor was driven without wire movement. To make the 45° grooves the wire was driven by the endodontic motor, and pulled in a speed of 30 mm/min from the inside of the assembly (sandpaper and elastic). This vertical movement was conducted by a universal testing machine EMIC DL 200 MF (Londrina, PR, Brazil). For both groups the motor was driven for 5 seconds.

Scanning electron microscopy (SEM) analysis

The surface morphology of the groups was analyzed by a SEM (FEG Quanta 250, Eindhoven Netherlands), to observe the grooves orientation.

Roughness

The wire segments were evaluated with an optical profilometer (Zygo 7100 Profilometer, Middlefield, CT). This equipment allows accurate three-dimensional roughness measurement using the interferometric technique. The variations of the measured depths were up to 0.1 μm. The samples from each group were evaluated in three different regions. This test is non-destructive, requires no specimen preparation and is fast.[12]

Cyclic fatigue test

The number of cycles to failure was evaluated by a cyclic fatigue test. The wire segments were rotated at the speed of 300 rpm to the right and torque of 120 gcm, with the same set (contra-angle and motor) described for groove preparation. To perform the rotating bending test simulating clinical use, a 20 mm long artificial metal channel with an arc of 9.42 mm, R = 6 mm and 1.5 mm internal diameter located at the end of the channel was used. This configuration promotes to the segments a cyclic stress with alternating loading of traction and compression in the region of curvature.[9] The time until the instrument fracture was record and the number of cycles was calculated using the following formula:

NCF = (300/60) x t.

NCF - Number of cycles to fracture

t - time until the instrument fracture

The wire segment was inserted to the contra-angle hand piece and motor-driven through an adapter developed for the test (Fig 2). The wire diameter was selected to to allow as little mismatch as possible between the wire and the adapter. The wire segments fit tightly into the socket with the adapter, it was immobilized at 5 mm from one end of the 30 mm wire, allowing a length of 25mm for the cyclic fatigue test.

Statistical analysis

The Kolmogorov-Smirnov normality tests were performed in the groups to verify if the data presented a normal distribution (bell shaped distribution). The groups presented normal distribution, therefore a parametric test was used. Data were analyzed using analysis of variance test (ANOVA), considering the 95% (a=5%) confidence interval and Student-Newman-Kells (SNK) multiple comparisons test was used to verify differences between groups.

Results

Roughness (Ra)

The values of Ra (Roughness average) obtained in the evaluation with the optical profilometer of the surfaces of NiTi wire is shown in table 1. The images obtained in the profilometer are seen in figure 3. Comparing the roughness of the NiTi wire, it was observed that the group with 90 degrees grooves had lower average Ra.

Cyclic fatigue test

The cyclic fatigue test of the NiTi wire was performed to determine the average number of cycles (NCF) until the fracture of the sample. The obtained results are shown in the table. Comparing the numbers of cycles until the fracture, it was observed that NiTi wire with grooves at 45 degrees presented a higher number of cycles to fracture with significant statistical difference in relation to the group with the grooves at 90 degrees.

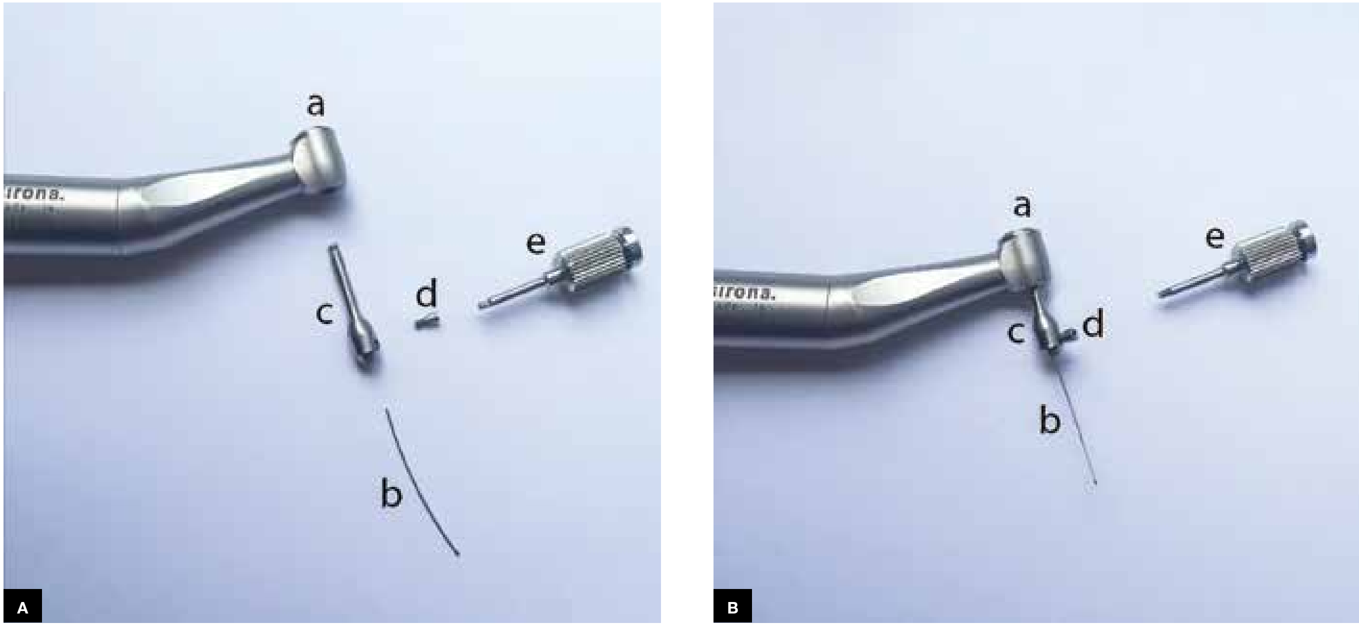

Figure 2. NiTi wire adaptation for cyclic fatigue test. Detached components (**A**), and assembled components (**B**). Motor handpiece (a), NiTi wire segment (b), adapter (c), adapter side screw (d), screw wrench (e).

Table 1. Roughness and cyclic fatigue results.

Grooves orientation	Roughness Ra (µm)	Cyclic Fatigue	
		NCF	Time (s)
Absent	0.10 ± 0.02[a]	1776.6 ± 314.4[a]	355.32[a]
45 degrees	0.55 ± 0.10[b]	625.8 ± 114.3[b]	125.16[b]
90 degrees	0.42 ± 0.09[c]	424.9 ± 49.5[c]	84.98[c]

Different superscript letters indicate statistically significant difference.

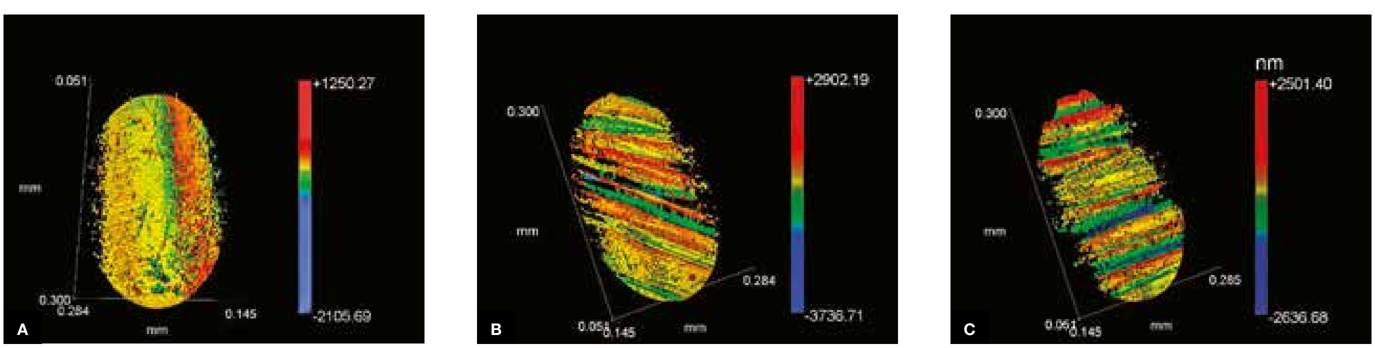

Figure 3. NiTi wires surface finish obtained by interferometry. Wires without grooves (**A**), prepared to obtain 45 degrees grooves (**B**) and 90 degrees grooves (**C**).

Discussion

Results available in the literature show that the surface defects of the endodontic instruments reduce their mechanical behavior. Small defects on the surface of the instruments become stress concentration points and are likely to be nucleation regions of fatigue cracks.[14-17] The objective of this work was to determine the influence of the direction of surface defects (grooves) on the fatigue strength of the NiTi alloy used in the manufacture of endodontic instruments. To eliminate the influence of the variables derived from the manufacturing process of the mechanized endodontic instruments, groups of NiTi wires with grooves made in different directions and with controlled depth were used.

Statistical analysis of the roughness results indicated difference in the value of Ra between the groups. The wires with grooves at 45 degrees presented greater roughness. Although there is a statistical difference at the depths of the grooves at 45 degrees and 90 degrees, this difference (0.13 μm) can be considered negligible. This result indicates that the methodology used in making the grooves was adequate and it was possible to analyze the influence of the groove direction only on the fatigue fracture of the wires parts.

Due to the lack of consensus in the literature on the influence of the surface finish of the endodontic instrument, the great dispersion of the results and the difficulty of isolating each parameter as the only variable, NiTi wires parts with similar morphological characteristics were evaluated, differing only in the directions and depths of the grooves produced. Comparing the numbers of cycles up to the fracture, it was observed that the fatigue life of the 90 degrees grooved wires was shorter (424.9 cycles) and the non-grooved wires presented more cycles (1776.6) to fracture.

The higher number of cycles to fracture of the group with 45 degrees grooves than 90 degrees grooves can be explained by the analysis of the tensile stress generated on the wires surface. Figure 1B and 1C shows the stress states that occurs at the wire surface during rotation inside the simulated metallic canal. The region of the wire located at the canal curvature is subjected to alternating traction and compression stresses at each full rotation.[18] When the stress is tractive it favors the nucleation of cracks, which occurs preferentially inside the grooves. On the other hand, the non-grooved wires do not have areas with stress concentration and the time for fracture is higher due to lower crack nucleation.

The fatigue life of the wires with 90 degrees grooves is 24% of the life of the wires without grooves. This result shows that surface defects reduce the lifetime of the NiTi alloy subjected to the rotary bending test. Regarding the influence of the direction of the groove, the life of the wires with 90 degrees grooves fracture with 68% of the time to occur with the fracture of the wires with 45 degrees grooves.

The results found in the cyclic fatigue test should not be applied directly to endodontic instruments, since the instruments have defects in several directions. During the endodontic practice the clinician uses an instrument without having a true idea of the quantity, quality and orientation of defects present in NiTi endodontic instruments used during the treatment and these factors have influence in the safety of the treatment. The results of the present work showed that the quality of the surface finish influences the fatigue life of the NiTi alloy. These results corroborate several studies, which shows that poor surface finish reduces the number of cycles required to fracture endodontic instruments.[12,17,19]

However, some authors reported that surface finishing is not a factor that influences the fatigue fracture of endodontic instruments.[20,21] Probably, these authors came to this conclusion because they did not consider other variables that might had interfered in their results, such as different morphologies of the compared instruments, lack of standardization of the cross section, differences in the chemical composition of the alloys, among others. The analysis of the NiTi wires with grooves prepared in a single direction allows the isolation of this the variable related to the surface finish.

Although the wire surface with grooves at 90 degrees, showed lower Ra values than the wires with grooves at 45 degrees, the fatigue life was lower ($p < 0.05$). It can be concluded that the direction of the grooves was a variable that overlapped the roughness being a more important factor.

Conclusions

Within the present results, it can be concluded that surface finish defects reduced the cyclic fatigue life of NiTi specimens. The roughness is not the only factor that influence the fatigue life, the direction of the grooves also has impact in the fatigue comportment of NiTi specimens.

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