Influence of Surface Roughness on the Fatigue Life of Nickel-Titanium Rotary Endodontic Instruments

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Abstract

Introduction: The goal of the present study was to evaluate the influence of surface grooves (peaks and valleys) resulting from machining during the manufacturing process of polished and unpolished nickel-titanium BR4C endodontic files on the fatigue life of the instruments. **Methods:** Ten electropolished and 10 unpolished endodontic files were provided by the manufacturer. Specimens were from the same batch, but the unpolished instruments were removed from the production line before surface treatment. The instruments were evaluated with a profilometer to quantify the surface roughness on the working part of the instruments. Then the files were subjected to rotating bending fatigue tests. **Results:** Analysis with the profilometer showed that surface grooves were deeper on the unpolished instruments compared with their electropolished counterparts. In the rotating bending fatigue test, the mean and standard deviation for the number of cycles until fracture (NCF) were greater for instruments with less pronounced grooves. Student *t* test revealed significant differences in all tests ($P < .05$). **Conclusions:** The results from the present study showed that the depth of the surface grooves on the working part affected the NCF of the instruments tested; the smaller the groove depth, the greater the NCF. *(J Endod 2016;42:965–968)*

Key Words

Fatigue, roughness, surface finish

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Endodontic files, especially those of smaller diameter, pose manufacturing challenges and generally present surface defects and roughness resulting from the machining process. These defects on the working part of the instruments may be manifested as grooves, pits, and burrs.

Grooves are observed as "peaks and valleys" on the working part surface of the majority of instruments evaluated by scanning electron microscopy (SEM). During the manufacturing process of endodontic instruments by machining, the grinding tool works perpendicularly to the metal blank, shaping the material into the desired dimensions and finish of the working part. The grooves left by the machining process are parallel milling marks perpendicular to the long axis of the nickel-titanium (NiTi) wire (1, 2).

Several studies have demonstrated that the presence of grooves on the metal surface may lower the number of cycles to fatigue fracture (NCF) of endodontic files (1–5). Furthermore, some studies have shown that these surface grooves on endodontic files may act as stress concentration points, decreasing their resistance to fatigue fracture (2, 6). Cracks commonly initiate in the valleys of the surface grooves; this is followed by nucleation, growth, and propagation (2, 3, 5, 6). However, other authors report that the surface finish does not affect the fatigue resistance of endodontic instruments (7–9). These conflicting results may be related to failure to detect the presence of grooves on the surface of the working parts of the instruments tested.

Electropolishing is a method of surface finishing used by the manufacturers to remove surface defects that remain after manufacturing of NiTi instruments by machining (1, 2). The goal of the present study was to evaluate the influence of surface groove depth on the fatigue resistance of electropolished and unpolished BR4C NiTi files (FKG, La Chaux-de-Fonds, Switzerland) subjected to rotating bending tests.

Materials and Methods

Instrument Dimensions

BioRace NiTi rotary endodontic instruments size BR4C, with nominal size of 0.35 mm at D0, taper of 0.02 mm/mm, and total length of 25 mm, were used in this experiment. Ten of the instruments provided by the manufacturer had the working part electropolished, and the other 10 instruments had no surface treatment. Specimens were from the same batch, with unpolished instruments being removed from the production line before surface treatment.

Surface Finish

Before the fatigue tests, instruments were evaluated by using a scanning electron microscope (FEG Quanta 250, Eindhoven, Netherlands) to analyze the surface finish of the working parts of the polished and unpolished specimens under ×150 and ×500 magnification.

The roughness (Ra) of the working parts of the polished and unpolished files was quantified by using a New View 7100 Profilometer (Zygo Co, Middlefield, CT). The New View is an interferometric non-contact 3-dimensional surface measurement system.

The profiler gives ultra-precise 3-dimensional analyses of any surface and rapidly measures heights from 0.1 nm to 1.0 mm, with vertical resolution as low as 0.1 nm.

Roughness was quantified at the apical, middle, and coronal thirds of the instruments; 3 measurements were performed per third in randomly selected areas, totaling 9 measurements per instrument. The groove depth value for each instrument was established as the means of the 9 measurements.

Cyclic Fatigue

An artificial canal was made out of a cylindrical tube of stainless steel with inner diameter of 1.4 mm, total length of 19 mm, arc located between the 2 straight segments of the canal, and curvature radius of 6 mm. The arc measured 9 mm, the longest straight segment was 7 mm, and the shortest straight segment was 3 mm. The curvature radius of the artificial canal was measured by taking into account the concave surface of the interior of the tube (Fig. 1).

A stainless steel apparatus was constructed with a square base and a vertical axis. The vertical axis contained a structure that allowed for the fixture and movement of the micro motor/contra-angle. At the apparatus base, a bench vise was used to hold the stainless steel tube. A gap at the base of the apparatus allowed for the movement of the bench vise in a horizontal direction, allowing for a coincidence between the axis of the instrument and the straight part of the stainless steel canal. During the test, the artificial canal was filled with glycerin to reduce the friction of the instrument against the canal wall and to minimize the release of heat.

The fatigue tests were carried out on a static model. The instruments were driven by an engine (Satelec Endo Dual Motor; Acteon, Mérignac, France) at 300 rpm with a 16:1 reduction handpiece (W&H Dentalwerk, Bürmoos GMBH, Bürmoos, Austria) and introduced into the canal until the tip touched a shield positioned at the end of the canal. This shield was removed thereafter because its main purpose was to standardize the distance the instrument penetrated in the artificial canal.

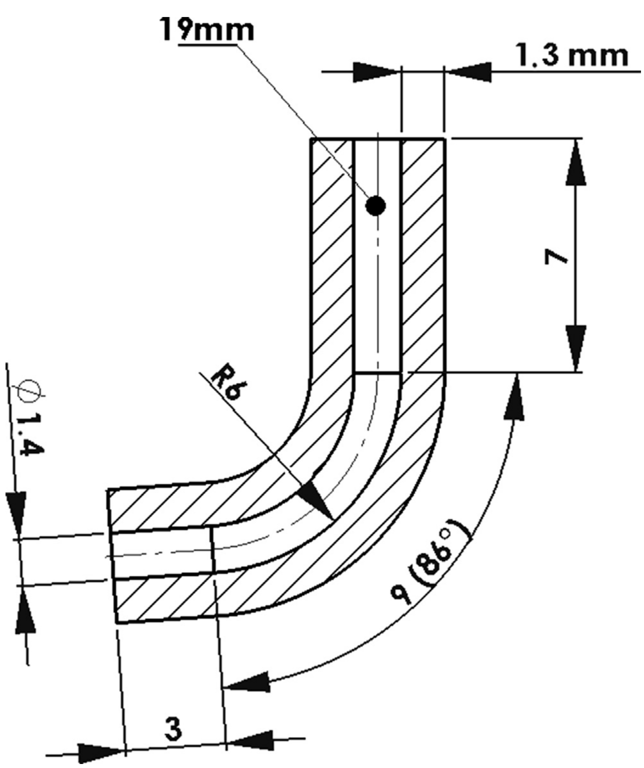

Figure 1. A schematic representation of the artificial canal used in the cyclic fatigue test.

Subsequently, the BR4C instruments of each group (polished and unpolished) were worked in clockwise rotation at nominal speed of 300 rpm until fracture. The time to fracture was measured by the same operator by using a digital stopwatch (Leroy Hanson Co, Inc, Sioux City, IA) and was established when there was visual observation of instrument separation. The number of cycles was obtained by multiplying the rotational speed by the time (in seconds) until the fracture of each instrument occurred.

The fracture surface and the helical shaft of fractured instruments were analyzed by means of SEM (FEG Quanta 250; FEI, Eindhoven, Netherlands) to determine the type of fracture, presence of fatigue cracks, and plastic deformation in the helical shaft.

Statistical Analysis

Data obtained from the NCF and from the roughness of the polished and unpolished BioRace BR4C instruments were statistically analyzed by Student t test at a significance level of 5%.

Results

SEM analysis revealed that the surface of the working part of all unpolished instruments exhibited prominent vertical machining marks. On the other hand, polished instruments showed smooth surfaces, with limited presence of manufacturing marks (Fig. 2).

Roughness measurements showed that groove depth was greater on the surface of unpolished files compared with polished files (Fig. 3). The groove depth (Ra) on the surface of unpolished instruments (Ra = 3.3619 μm) was 14% greater than that of the polished instruments (Ra = 2.9448 μm).

Data obtained revealed statistically significant differences in the roughness (Ra) of the working parts of the polished and unpolished BioRace BR4C instruments ($P < .05$).

Because statistical analysis demonstrated that there was a significant difference between the 2 groups when it comes to the roughness of the instruments ($P < .05$), one group could be regarded as having high roughness, and the other has low roughness. Consequently, data from the NCF analysis can be interpreted as the influence of the roughness on the resistance of the cyclic fatigue.

The means and standard deviations of the time and NCF occurred are shown in Table 1. Polished instruments displayed a significantly higher number of cycles to fracture when compared with unpolished instruments ($P < .05$). The NCF of polished instruments was 117% greater than that of unpolished files.

SEM analysis showed that the fracture surface of both polished and unpolished BR4C instruments had morphologic characteristics of ductile fracture. No plastic deformation occurred in the helical shaft of the instruments tested.

Discussion

In the present study, only 1 type of instrument was selected, with the aim to eliminate additional variables such as shape and dimensions of the instrument, material, hardness, and cutting ability because these variables could interfere with the results of the test. Accordingly, the only difference between the instruments tested was their surface finish (electropolished or unpolished).

The rotating bending test was selected to evaluate the resistance to fatigue fracture. A clinical study would be inconclusive because of the impossibility of controlling all of the anatomic variables involved.