Influence of curvature location along an artificial canal on cyclic fatigue of a rotary nickel-titanium endodontic instrument

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Objectives. This study evaluated the effects of curvature location along an artificial canal on cyclic fatigue (CF) of an Mtwo rotary instrument, verifying the number of cycles to fatigue fracture (NCF) and morphologic characteristics of the fractured instruments.

Study design. CF testing of instruments was performed in artificial canals with curvature radii of 10 mm and arc lengths of 11 mm. Mtwo rotary instruments size 40, 0.04 taper were used in 2 groups (n = 10): group A, curvature positioned on middle part; group B, apical curvature. All instruments were rotated until fracture. The number of cycles to failure was registered. Data were analyzed by independent sample t test. Fractured surfaces and the helical shafts of the instruments were analyzed by scanning electron microscopy.

Results. NCF for groups A and B had significant statistic differences (P < .05). The highest values were found in the group where the curvature was positioned on the apical part of the canal. No plastic deformation was observed on the helical shafts.

Conclusions. The number of cycles to fracture of the Mtwo instruments increased when the arc was changed from the middle to the apical part of the canal. The morphologic characteristics of the fractured surfaces were of the ductile type. (Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011;111:792-796)

A major concern when using rotary engine–driven nickel-titanium (NiTi) endodontic instruments, irrespective of the manufacturer, is the breakage of these instruments because of cyclic fatigue (CF) when used under low-cycle loading.1,2,3

Fracture resistance through fatigue at a low-cycle number refers to the number of cycles that an instrument is able to resist under a specific load condition.1,2,4 Thus, the number of cycles until failure is cumulative and can be obtained through the multiplication of the rotation speed by the time elapsed until fracture owing to CF occurs.1,5,8

The resistance to fracture of an endodontic instrument may be measured in a mechanical test of rotating-bending fatigue. When an endodontic instrument rotates in the interior of a curved canal, within its elastic limits, a mechanical load occurs, represented by alternating tensile and compressive stresses. The cyclical repetition of these loads leads to instrument fracture through low-cycle fatigue.1,9,10

The magnitude of the tensile and compressive forces imposed on the flexed area of the instrument depends on the length of curvature radius, the length of the arc, the diameter of the instrument,1,2,4,8,11 and the position of the canal curvature.11

Necchi et al.,11 using an accurate finite element model for studying rotary endodontic instruments, observed that the change of position of an arc with the same length influenced the presented stress lev-
els, increasing from the apical to the mid root position.

**MATERIAL AND METHODS**

**Mtwo** rotary NiTi endodontic instruments (VDW, Munich, Germany) size 40, 0.04 taper and 25-mm length, were used in this experiment. The instruments were tested for CF fracture at a rotational speed of 280 rpm, comprising 2 test groups (groups A and B) with 10 instruments each. Two artificial curved canals (U-shaped grooves) were machined on stainless steel blocks, with 1.5-mm wide, 2.0-mm deep, total lengths of 23.0 mm, arcs with curvature radii of 10.0 mm and arc lengths of 11.0 mm. In one of the canals (group A), the curve was positioned on the middle part, with 2 straight segments of 6 mm on the extremities (Fig. 1, a). In the other (group B), the arc was located simulating an apical curvature of a root canal, with a straight part of 12 mm (Fig. 1, b). The curvature radii and the arc lengths were measured taking into account the outer arc from the center of the curve (Fig. 1).

A thin and translucent acrylic plate (1-mm thickness) was attached to each canal, allowing visualization of the instrument working in the canal. This device was immobilized in a bench vise #2. A nylon prism was machined to support an electric micromotor and contra-angle at speed reduction of 16:1 (VDW silver, Munich, Germany). Both the bench vise and nylon prism were mounted on an aluminum base, permitting precise and simple placement of each instrument inside the artificial canal, ensuring 3-dimensional alignment and positioning of the instruments to the same depth (Fig. 2).

During the test, the artificial canals were filled with glycerin to reduce the friction of the instruments against the canal wall and to minimize the release of heat. Subsequently, instruments of each group worked in clockwise rotation at nominal speed of 280 rpm until fracture. The exact moment of the fracture was observed under magnification, using a clinical microscope (CEMAPO, São Paulo, Brazil). The time to fracture was recorded with the aid of a video camera tape counter (Sony, Tokyo, Japan) connected to the microscope (please see Video 1 and Video 2, found on the journal’s Web site at http://www.sciencedirect.com/science/journal/10792104).

The number of cycles to fracture was obtained by multiplying the rotational speed by the time until the fracture of each instrument occurred. Data obtained on the number of cycles to fracture of the Mtwo instruments under the rotational speed tested were statistically analyzed by the parametric *t*-sample test with significance level set at 5% (*P* < .05). The fracture surface and the helical shaft of fractured instruments were analyzed by using scanning electron microscopy (SEM) (JSM 58,000: JEOL, Tokyo, Japan) to determine the type of fracture.

**RESULTS**

Table I depicts the mean and standard deviation of the time and the number of cycles to fatigue fracture (NCF) in relation to the curvature position.
along the artificial canal. Statistical analysis showed that there was a significant difference in the number of cycles to fracture between the groups. The number of cycles to fracture was significantly reduced when the instruments were subjected to rotation in the curvature located on the middle of the canal (group A) (Table I).

SEM analysis showed that the fracture surfaces had ductile morphologic characteristics. The presence of dimples with varied forms was identified on these surfaces (Fig. 3).

Plastic deformation was not observed in the helical shaft of the fractured instruments. The different positions of the curvature along the artificial canals did not influence SEM results (Fig. 4).

DISCUSSION

Two instruments have been evaluated for CF under diverse conditions in previous studies, and this test has been considered a simple and reliable approach to determine the fatigue behavior of instruments manufactured from the NiTi alloy. In the present study, an apparatus was used to hold the electric micromotor and thereby eliminate the interference of operator-induced tensions on endodontic instruments during the fatigue test.

Although stainless steel artificial canals have been used in previous studies to standardize measurement parameters (entire lengths of the canals, arcs, and curvature radii), it is important to bear in mind that the actual lengths of arc and radius of the curved canal are not the same as of the instrument positioned inside the artificial canal. On the other hand, in this trial the location of the curve along the canal was absolutely changed, and was positioned on the extremity or middle of the artificial canal, as suggested by Necchi et al.

Because the diameter of the canal was greater than that of the endodontic instrument and a lubricant...
Several studies have used human teeth in the experimental design\textsuperscript{20-23}; however, it is virtually impossible to control the intensity of stress in the rotating-bending area of the instruments when used in human root canals. Differences in the root canal curvature from tooth to tooth represent another important variation. Moreover, there will always be a combination of torsional stress and CF when human root canals are used. To avoid these biases and for better control of variables, artificial metallic canals were used.

The CF resistance is measured by the number of cycles that an instrument can resist during the fatigue test. The numbers of cycles are cumulative and relate to the intensity of compressive and tensile stresses occurring in the bent portion of the instrument. The intensity of stresses is in turn related to the curvature radius, arc length, and instrument size.

To Necchi et al.,\textsuperscript{11} the radius and the position of the canal curvature are the most critical parameters that determined the stress in the instrument, with higher stress levels being produced by decreasing the radius and moving from the apical to the mid root position.

The results gathered from this study clearly show that the change of curvature from the apical to the middle position resulted in a decrease in the NCF of the Mtwo instruments. Therefore, the results of the fatigue tests to the Mtwo files in the laboratory were the Mtwo instruments. Therefore, the results of the middle position resulted in a decrease in the NCF of that determined the stress in the instrument, with the canal curvature are the most critical parameters to control the intensity of stress in the rotating-bending area of the instruments when used in human root canals. Differences in the root canal curvature from tooth to tooth represent another important variation. Moreover, there will always be a combination of torsional stress and CF when human root canals are used. To avoid these biases and for better control of variables, artificial metallic canals were used.

The results gathered from this study clearly show that the change of curvature from the apical to the middle position resulted in a decrease in the NCF of the Mtwo instruments. Therefore, the results of the fatigue tests to the Mtwo files in the laboratory were similar to those reported by Necchi et al.,\textsuperscript{11} studying geometrical models of NiTi and stainless steel ProTaper F1 instruments in a finite element model. This probably happened because with the shift of the arc to the middle of the artificial canal, the maximum point of rotating-bending fatigue was located in a point of larger diameter in the helical conical shaft of the instrument. Therefore, the larger the diameter of helical shaft of an endodontic instrument nears the highest point of tension/compression (close to the middle of the curve), the larger the intensity of the stresses and smaller the NCF of the instrument.

CONCLUSIONS

The number of cycles to failure for the Mtwo instruments, used under rotating-bending conditions within an artificial curved canal, increased with the shift of the curvature from the middle to the apical canal position. No plastic deformation occurred along the helical shaft of the fractured instruments. Fractured surfaces were found to be of the ductile type.

Appendix
SUPPLEMENTARY DATA

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