INFLUENCE OF CYCLICAL FATIGUE ON TORSIONAL FRACTURE MORPHOLOGY IN ENDODONTIC INSTRUMENTS

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ABSTRACT
Cyclical fatigue may influence the appearance and propagation of the type of fracture of an endodontic instrument.
The aim of this study was to assess the influence of cyclic fatigue on morphological features of torsional fracture in Pathfile nickel-titanium rotary instruments for surgical preparation in endodontics.
Thirty new Pathfile instruments (Dentsply- Maillefer.Ballaigues-Switzerland) diameter .13 and taper .02 were randomly divided into 5 groups (n=6). Twenty-four of them were subject to cyclical fatigue by continuous rotation using a stainless steel cylinder with internal bore 0.5 mm, length 25 mm, with a curve of 45 degrees and radius 8 mm at 5 mm from the tip, at 300 rpm and 1 Ncm torque for different times: A: 15 sec, B: 75 sec, C: 150 sec and D: 300 sec, while the fifth group was kept as a control (group N). As a second step, the instruments were rotated at 2 rpm and 1 Ncm torque, with their apical 3 mm fixed in a resin block until they suffered torsional fracture. The fracture surfaces were analyzed using a conventional high-vacuum scanning electron microscope (Phillips mod. 515) at 400x. All instruments had ductile fracture areas of different sizes. The ductile fracture areas were measured as percentages of the total area of the instrument by means of Golden Ratio (Softonic) software for measuring images.
The data obtained were analyzed statistically using one-way variance analysis followed by Tukey's multiple comparison test. There were significant differences among groups regarding cyclic fatigue time and fragile fracture area (P<0.001). Comparison of percentages shows five significant differences between N/C; N/D; A/D; C/N and C/A. No other comparison was significant. It is concluded that the increase in cyclical fatigue to which the rotating PathFile instrument is subject significantly increases the percentage of ductile fracture area produced by torsion.

Key words: *fatigue fracture, torsion mechanical, endodontics.*

INFLUENCIA DE LA FATIGA CÍCLICA EN LA MORFOLOGÍA DE LA FRACTURA POR TORSIÓN EN INSTRUMENTOS ENDODÓNTICOS

RESUMEN
La fatiga cíclica puede influir en el nacimiento y propagación del tipo de fractura de un instrumento endodóntico.
El objetivo del presente trabajo fue evaluar la influencia de la fatiga cíclica en las características morfológicas de la fractura por torsión en instrumentos de níquel titanio rotatorio Pathfile, empleados para la preparación quirúrgica en endodoncia.
Se utilizaron 30 instrumentos nuevos, Pathfile (Dentsply-Maillefer. Ballaigues-Suiza) de calibre .13 y .02 de conicidad que fueron divididos aleatoriamente en 5 grupos (n=6). Fueron sometidos a fatiga cíclica por rotación continua un total de 24 instrumentos empleando un tubo cilíndrico de acero inoxidable de calibre interno 0.5 mm y 25 mm de longitud con una curvatura de 45 grados y 8 mm de radio a 5 mm de su extremo apical, a 300 rpm y 1 Ncm de torque en diferentes tiempos: A: 15 seg), B: 75 seg, C: 150 seg) y D: 300 seg, conservándose el quinto grupo como control absoluto (grupo N). En un segundo paso los instrumentos fueron rotados a 2rpm y 1 Ncm de torque fijándose los 3 mm de su punta en un bloque de resina, hasta producir su fractura por torsión. Las superficies de fractura fueron analizadas en un microscopio de barrido convencional de alto vacío. Phillips mod. 515 a 400x. Todos los instrumentos presentaron un área de fractura ductil de diferente tamaño. Se midieron las áreas porcentuales correspondientes a zonas de fractura ductil en relación al área total del instrumento utilizando un programa Golden Ratio (Softonic) de medición de imágenes.
Los datos obtenidos fueron analizados estadísticamente por medio del análisis de varianza de una vía y posteriormente el test de Tukey de comparaciones múltiples. Se presentaron diferencias significativas entre los grupos de tiempo de fatiga cíclica y el área de fractura frágil (P<0.001). La comparación entre porcentajes registra cinco diferencias significativas entre N/C; N/D; A/D; C/N Y C/A. Ninguna otra comparación resultó ser significativa. Se concluye que el aumento de la fatiga cíclica al que es sometido el instrumento PathFile rotatorio aumenta significativamente el porcentaje de área de fractura dúctil producida por torsión.

Palabras clave: *fractura por fatiga, torsión mecánica, endodoncia.*

INTRODUCTION

PathFile instruments (Dentsply-Maillefer- Switzerland), designed for continuous rotary instrumentation are made from machined nickel-titanium alloy, which makes them highly flexible and elastic. They come in three sizes: .13 .16 .19, and have quadrangular cross-section, inactive tip and constant 2% taper, making them the tool of choice for maintaining apical permeability when the instrument needs to rotate freely and repeatedly within the lumen of the root canal, and therefore the main requirement is that it should be resistant to cyclic fatigue[1].

The design of a rotary instrument affects its performance because it conditions its resistance to cyclic fatigue and torsion resulting from friction, two factors determining plastic deformation or fracture during use[2,3,4]. Fracture or fatigue failure is usually related to plastic deformations, which in turn are associated to shear stress. Plastic deformation originates at the surface in the form of small surface cracks and uneven chipping. Although components eventually break due to the application of excessive stress, this overload occurs as a result of a sum of factors which are precisely those that should be identified in the analysis of the failure. In the presence of fluctuating loads, stress concentration produces elastic-plastic cyclical deformation which initiates a fatigue crack, which ultimately causes ductile or brittle metal fracture.

Ductile fracture occurs after intensive plastic deformation and is characterized by slow crack propagation. Fragile fracture occurs along crystallographic planes called fracture planes and the crack propagates rapidly.

A scanning electron microscope is the most appropriate instrument for examining the surfaces because it has higher resolution and field depth then an optical microscope. These qualities are needed to reveal topographical details of the fracture surfaces under study[5,6]. The causes of failure by fracture can be analyzed through the interpretation and characterization of the fracture surface of the material[7].

The aim of this study was to assess the influence of cyclic fatigue on the morphological characteristics of the fracture by torsion in Pathfile nickel-titanium rotary instruments used for endodontic root canal surgical preparation.

MATERIALS AND METHODS

A device was made consisting of a 25 mm long cylindrical stainless steel tube with an internal bore of 0.5 mm and a 45 degree bend with 8 mm radius located at 5 mm from one end. The opposite end was fixed to the plastic lid of 5 ml a test tube. The assembly was fixed to a base to allow handling and prevent it from moving during the experiment.

A total 30 new Pathfile instruments (Dentsply- Maillefer.Ballaigues-Switzerland), gauge .13, designed for rotary instrumentation were removed from their packaging and divided randomly into 5 groups of 6 instruments. The instruments were subject to constant speed while fully inserted within the steel tube at 300 rpm and 1 Ncm torque, using an XSmart electric motor (Dentsply –Maillefer. Ballaigues-Switzerland) for different lengths of time: 15 seconds (Group A), 75 seconds (Group B), 150 seconds (Group C) and 300 seconds (Group D). The fifth group was kept as a control without fatigue (Group N).

Then each instrument was fixed by its apical three millimeters in a block of composite resin. The resin block was placed in a fixed clamp and the instrument was mounted on an electronically modified contra-angle handpiece driven by an electric motor (XSmart – Denstply, USA), which provided 2 rpm at a torque of 1 Ncm. The instruments were subjected to continuous rotation until they were fractured.

The fracture surfaces obtained were observed at 400X under a high-vacuum SEM Phillips mod. 515. The images showed an irregular, variable central area corresponding to the ductile fracture morphology characterized by dimples (Figs. 1-3).

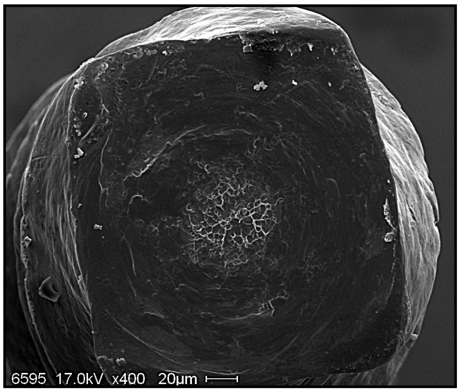

Fig. 1: Fracture surface of a specimen from the control group.

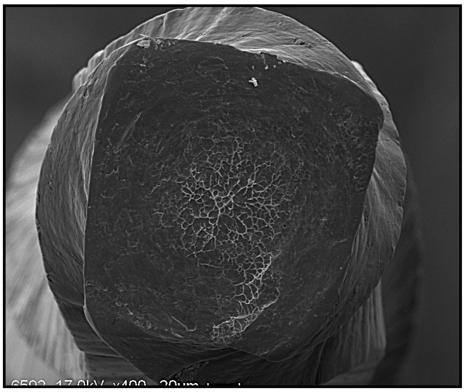

Fig. 2: Fracture surface of a specimen from Group D.

The images were analyzed using Golden Ratio (Softonic) software for measuring photographs by pixels. We determined the center of the instrument and measured the major and minor radii of the ductile fracture areas and their opposite radii. These four values were averaged and used as the mean radius for determining the ductile fracture surface of each instrument. The circular area of the instrument was determined by using radius to the free side. The percentage of fracture area in the total instrument area was calculated (Fig. 4). Data were put into tables for analysis.

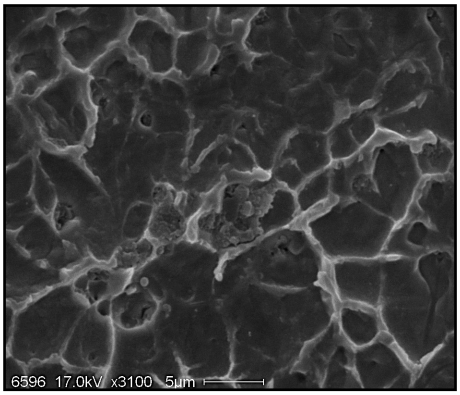

Fig. 3: Dimple area characteristic of the ductile fracture 3100X.

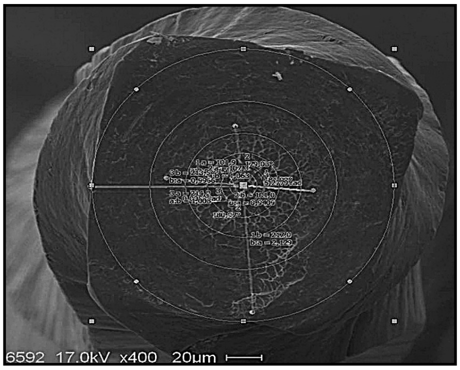

Fig. 4: Measurement procedure.

RESULTS

Table 1 shows one example of data collected for Group A.

Figure 5 shows mean values of percentages of fracture area in the total instrument area for each study group. The fracture area increases with increasing cyclic fatigue time.

One-way Kruskal-Wallis test applied to the results showed significant differences among groups (P<0.001) (Table 2).

The Tukey multiple comparison test was used to determine the difference between groups (Table 3). Comparison of percentages shows five significant differences among groups N/C, N/D, A/C, A/D Y C/D. No other comparison was significant.

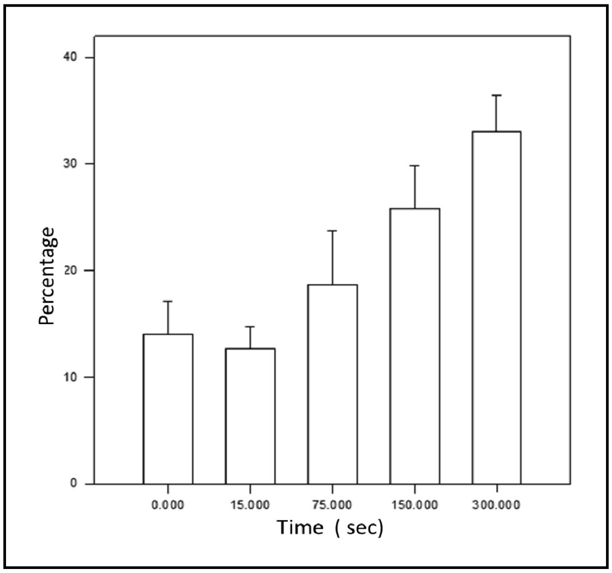

Fig. 5:Percentages of fracture area in the total instrument area for each study group. The fracture area increases with increasing cyclic fatigue time.

Table 1: Example of data collection for Group A.

Group	Major radius	Minor radius	Opposite major radius	Opposite minor radius	Mean radius	Ductile fracture area	Instrument radius	Total instrument area	% AFD
A1	163,3	57,9	84,1	92,1	99,35	30993,12	241,9	183739,01	16,86
A2	117,8	55,8	88,7	80,1	85,6	23007,91	235,6	174293,11	13,2
A3	144,2	54,9	51,1	68,6	79,7	19945,56	225,4	159528,2	12,5
A4	105,7	50,5	53,9	87,2	74,32	17346	246,9	191413,17	9,06
A5	123,3	56,3	79,5	85,2	86,07	23263,96	243,3	185871,95	12,51
A6	142,2	53,25	59,4	78,8	83,41	21847	238,7	178909,94	12,21

% AFD percentages of ductile fracture in the total area

Table 2: Kruskal-Wallis one way.

Source variation	DF	SS	MS	F	p
Between groups	4	1743,153	435,788	21,635	<0,001
Residual	25	503,570	20,143		
Total	29	2246,723			

Table 3: Tukey Test - All Pairwise Multiple Comparison.

Comparison for factor seg.

Comparison	Diff of Means	p q	P	P<0,050
300 vs 15	20,318	511,089	<0,001	Yes
300 vs 0	19,037	510,390	<0,001	Yes
300 vs 75	14,357	57,836	<0,001	Yes
150 vs 15	13,057	57,126	<0,001	Yes
150 vs 0	11,775	56,427	<0,001	Yes

DISCUSSION

Lopes et al.[8] tested the effect of speed on rotary instrumentation and found that fracture morphology was always ductile. No plastic deformation was observed on the instrument helicoid. It is worth noting that even when no plastic deformation is observed by macroscopic examination, there may be a microscopically detectable ductile fracture.[9]

We agree with Cheung et al., who have questioned the macroscopic view or lateral examination of a separate file, suggesting fractographic analysis techniques.[10]

SEM observation of the fracture surface may provide information on the following parameters, which characterize the breakage of the element: crack propagation mechanism, crack toughness of the material, stress configuration and origin of fracture.[11]

Li UM. et al.[12] tested cyclic fatigue and evaluated the fracture areas using SEM, showing small fatigue fracture areas characterized by sets of parallel lines, called fatigue grooves, and a large final area of ductile fracture with characteristic cavities or dimples.

Our observations show similar morphologies, in agreement with other authors and agreeing with their findings of abrasion marks and dimples determining ductile fracture in the central area.[13]

This type of fracture is typical of materials with face-centered cubic (FCC) crystalline structure, such as NiTi. [9]

These types of fracture are usually mixed, but the relative proportion of the different types is indicative of the material's mechanical crack properties. A material's crack toughness is related to its capacity for plastic deformation and absorbing energy during the fracturing process.[9-11]

In our particular case, the combination with a previous load of cumulative damage by cyclical fatigue showed significant differences between groups, allowing us to infer that this crack toughness is compromised by the imperfections generated in the crystallography and the surface, which initiate rapid fatigue cracks, with the final ductile fracture area being inversely proportional.[7] A small fatigue area at the beginning of breakage and large, fast final fracture area indicate high work stress. Conversely, a large area of fatigue propagation and a small final breakage area indicate rather low stress. Thus, an instrument subject to higher cyclic fatigue will resist lower work stress or torque. This being so, it would be logical to infer that torque requirement should be reduced when using instruments that have been subject to greater cyclical fatigue. An affordable mechanism for detecting irregularities generated by fatigue remains to be determined in order to dispose of damaged instruments before they break unexpectedly.

CONCLUSION

Under the conditions in this study, increasing cyclical fatigue to which the PathFile rotary instrument is subject significantly increases the percentage of ductile fracture area caused by torsion.

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