The effect of curvature angle and rotational speed on the cyclic fatigue of three types of rotary instrument (In vitro): comparative study

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ABSTRACT

Background: The fracture of instruments within root canal during endodontic treatment is a common incidence, fracture because of fatigue through flexure occurs due to metal fatigue, this study aimed to assess the effect of curvature angle and rotational speed on the cyclic fatigue of different type of Endodontic NiTi Rotary Instruments and compare among them.
Materials and method: Three types of rotary instruments with tip size 0.25: ProTaPer F2 (Densply, Malifier) Revo-S SU(0.06 taper, MicroMega) and RaCe system (0.06 taper, FKG, Dentaire), Forty file of each instrument were used within two canals with angle of curvature (40°&60°)at two speed (250&400)RPM, twelve group were formed for all instruments(total number=120),ten file for each group. The testing canals customized within stainless steel block covered with glass face, the time to fracture recorded and the mean of cycles to fracture (MCF) detected for each instrument. Data were analyzed statistically by ANOVA, LSD and Independent T-test at 5% significant level.
Result: there was a highly significant difference of curvature angle and significant difference of rotational speed on the fracture resistance of instruments. RaCe revealed the best fracture resistance followed by ProTaper then Revo-S that showed the less resistance.
Conclusion: The rotary instruments more prone to fracture when used at more curvature angle and higher rotational speed, as well as the rotary instruments differ from each other according to manufacturing process, taper, cross section and other factors.
Key words: Cyclic fatigue, curvature angle, rotational speed. (J Bagh Coll Dentistry 2013; 25(1):38-42).

INTRODUCTION

Rotary nickel-titanium (NiTi) instruments have become very popular during the last years because most of them seem to be safe when used according to the manufacturers' guidelines; they had ability to enlarge root canals rapidly, and are well suited for preparing severely curved root canals [(1)]. NiTi instruments have increased flexibility, wider elastic limits and superior resistance to bending and torsional failure compared to stainless steel (SS) instrument. They considered suitable for negotiating curved canals and reduce the risk of transportation, zipping, stripping or ledging the canal. The use of these instruments in rotary motion, offers the possibility for more effective and predictable root canal preparation [(2)]. In1988 Walia et al. developed and tested the first NiTi file by milling a nitinol wire blank into size 15file [(3)].

Walia et al. found these hand instruments possessed advantageous bending and torsional properties, which they attributed to low modulus of elasticity. Further ingenuity led to hand-piece-driven rotary systems with superior canal centering ability and reduced preparation time, as compared with SS hand instruments. There are several rotary file systems with differing designs, techniques, and tapers present [(3)].

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Flexural fatigue and torsional overload have been identified as the main reasons for rotary NiTi instrument failure, both of which might contribute to fracture depending on canal curvature, instrument design, and diameter. Continuous rotation of instruments in curved root canals requires the instrument to flex during each rotation, resulting in cyclic compression and tension, which in turn produces material fatigue [(4)].

MATERIALS AND METHOD

Three brands of rotary instruments with tip size 25were used: ProTaper (F2, variable taper), Revo-S (SU, .06 taper) and RaCe (0.06 taper). Forty instruments for each type were tested within two artificial canals with different curvature angle (40° and 60°), at different rotational speed (250and 400) RPM. Twelve groups were formed, ten instrument for each group. Cyclic fatigue testing was conducted with the instrument rotating freely within an artificial canal defined by both the angle and radius of curvature according to Pruett et al. [(5)]. Instrument were tested within two canals (60°and40°angle of curvature)with radius of curvature for both canals was 5 mm and the width of canal was 1.5 mm in a SS block covered with a swiveling glass cover allowed visualization the file rotating in the canal and the removal of broken instruments after fracture. A marker of permanent red ink placed at19mm on the glass cover of metal block to standardize instrument placement [6]. The dental hand-piece was mounted upon a surveyor that allowed for precise and simple placement of each instrument inside the artificial canal, ensuring three-dimensional alignment and positioning the instruments to the same depth for standardization [7].

The Stainless Steel block also mounted and fixed by bench vise to prevent its movement and to obtain fixed relation between the block and the surveyor through hand-piece. Each canal filled with glycerin completely to the coronal orifice of the canal, before introducing each instrument to the required length (19mm) inside a canal to reduce friction and heat release [8]. The electric motor adjusted to the desired speed (250 or 400) RPM and fixed by surveyor to follow the curvature of the canal then operated. In order to make standard tests, no pecking motion was used, however the authors are aware that in normal clinical practice it is possible to use the pecking technique to increase fatigue resistance [9].

The time to fracture recorded then the number of cycles to fracture (NCF) calculated by multiplying the time to fracture in minute by the speed used (RPM). The data were collected and analyzed using software program (SPSS18) for statistical analysis. One way analysis of variance (ANOVA) and LSD test were used to determine whether there was statistical difference among the mean of cycles to fracture for rotary instruments used. Independent t-test was used to evaluate the significant of variance between two speeds at the same curvature as well as between two curvatures at the same speed for each rotary instrument.

RESULTS

Descriptive statistical analysis showed that the highest Mean of Cycles to Fracture (MCF), more fracture resistant, represented by C1(RaCe) 625.41cycle when the curvature angle used 40°at 250 RPM speed followed by A1(ProTaper) in the same curvature and speed had 526.18 cycles, while the lowest mean of cycles to fracture expressed by B4 (Revo-S) 259.99 cycle when the angle of curvature was 60° at 400 RPM followed by A3(ProTaper) in the same curvature and speed which had 335.99 cycle, as in Bar chart (Fig.1.)

Between the two curvature (40° and 60°)for each rotary instrument used at both speed (250 or 400) RPM statistically there was high significant difference (Table 2), at the same time between the two speed used (250 and 400) RPM at constant curvature (40 or 60) the relation was significant for each rotary instrument used (Table 3).

The statistical difference among three instrument used at both speed and angle of curvature was highly significant Table 4 , In LSD Table 5 for all tests used the higher MCF showed by RaCe followed by proTaper then Revo-S (B). Thus RaCe (C) was the more fracture resistant followed by proTaper (A) and then Revo-S (B).

DISCUSSION

The artificial canals used were prepared from SS to resist wearing by friction. The instruments used in this study were: ProTaper, Revo–S and RaCe In this study it's clear that at both speed used the MCF decreased when the angle of curvature increased from 40° to 60° as in Table 1and there was a highly significant differences between the two curvatures at both speed as in Table 2. This result was in consistent with previous studies Ankrum et al. [11], Kitchens et al. [12], Lee et al. [13].

Ankrum et al. [11] showed that the great care should be taken when instrumenting severely curved canals due to the higher breakage expected as a result of increased stresses placed on the file when curvature angle increased. Kitchens et al. [12] revealed that the number of rotations before failure occurs depends on the angle at which the file was rotated; Lee et al. [13] attributed that to the increase in the maximum stress level in the files.

At both angle of curvature used (40°&60°) when the speed increased from 250 to 400RPMthe MCF decreased, statistically between the two speed there was a significant difference as in Table 3 that was in agreement with Martin et al. [9], Lopes et al. [8], De-Deus et al. [14].

Martin et al. [9] conclude that increased rotational speeds augment the rubbing of file within the canal lead to file fracture more readily. Lopes et al. [8] showed that in a cyclic fatigue the higher speeds produce more heat, thereby induce a faster increase in the instrument temperature, leads to a rapid increase in surface tension, causing fatigue fracture. This finding came in contrast with Kitchens et al. [12] who found that the speed per second did not affect the number of rotations to fracture, because the critical number of rotations will occur sooner at higher speed. This contrast in result may be attributed to the high speeds used by Kitchens et al. [12] (350-600) RPM or due to the difference in methodology because they used straight non covered groove within metal block and the change in curvature obtained from the change in direction of file used not change in curvature of groove. This result disagrees with Gao et al.[15] may be to the abrupt angle of curvature (90°) used in their study.

RaCe showed more fracture resistance than proTaper and Revo-S and this was in consistent with Kim et al. (16) and Al-Hadlaq et al. (17) who found that the more fracture resistant for RaCe (C) was due to the lower flexural rigidity cross section (triangular) and the near absence of machining marks on the instrument after electro-polishing that when an instrument is machined(being ground), plastic deformation occurs at the surface of the metal, resulting in residual stresses that remain at the surface and removed by electro-polishing, while Barbosa et al. (18) reported that electro polishing did not increase fracture resistance of NiTi files. The more fracture resistant for RaCe than ProTaper in present study was in agreement with Zhang et al. (19), Kim et al. (16) who showed that was related to the less diameter at the point of maximum curvature for RaCe (at D 5 0.55mm, at D 40.49mm for 60° and 40° angle of curvature respectively) than that for ProTaper (at D5 0.60mm , at D4 0.54mm), but this was disagree with Xu et al. (20) who according to finite element found that the cross sections with sharp and fine points (RaCe) may have poorer stress distribution than those with a convex(ProTaper)or triple-helix (Revo-S).The triangular cross-section creates a flat transitional surface from the blade to the sectional area and inertia and thus less fracture resistance.

In this study ProTaper was more fracture resistant than Revo-S and this come in consistent with Necchi et al. (21) who revealed that an instrument with convex triangular cross section (ProTaper) more fracture resistant than asymmetrical triples helix (Revo-S). This may due to a cross-sectional design that distributes the torsional stress well (convex) possessing high flexibility with relatively low reaction stresses on bending would be more suitable for preparing the more severely curved canals.

Ullmann and Peters (22) in contrast with this finding demonstrated that the resistance of an instrument to cyclic fatigue decreases as its diameter increases, because the diameter of ProTaper at D5(0.60 mm) and at D4 (0.54mm) was greater than that of Revo-S at D5 (0.55mm) and at D4 (0.49mm) when the angle of curvature used was 60° and 40° respectively. Increase in diameter causes excessive torsional stress that creates a critical amount of cyclic fatigue that cannot be tolerated by the alloy without rupturing (23). Basrani et al. (24) revealed that to the asymmetric cross-sectional geometry of the Revo-S SU instrument is an innovative feature intended to decrease the stress during root canal preparation and reduce the stress on the instrument and increase fracture resistance.

From Table1, the mean length of fractured fragment of all rotary instrument used in present study was near 4 mm (at 40°) and near 5mm (at 60°) that the point of maximum curvature at the midpoint of arc determined by the angle of curvature and the radius of curvature (25,26). At this point, the stress on the instrument was conceivably greater) 8). There was some difference in length of fractured fragment between different speeds and different curvature. Ullmann and peters (22) attributed this distribution of separated fragment lengths to the manufacturing flaws in some distance to the point of greatest deformation would undergo crack propagation sufficient to ultimately cause instrument separation.

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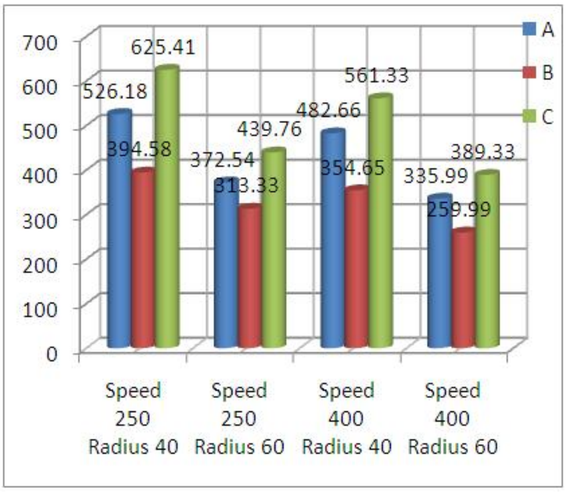

Figure 1: Bar chart showing descriptive statistical analysis for cycles to fracture at both speed used (250&400) RPM within two angle of curvature (40° and 60°)

Table1: Descriptive statistical analysis for Cycles and Time to fracture and fragment length.

group	Speed (RPM)	curvature	cycles to fracture		Time to fracture (second)		Fragment length (mm)	
			Mean	±SD	Mean	±SD	Mean	±SD
ProTaper (A1)	250	40°	526.18	27.74	126.3	6.63	4.09	.086
ProTaper (A2)	250	60°	372.54	30.35	89.4	7.29	5.07	.088
ProTaper (A3)	400	40°	482.66	39.40	72.4	5.91	4.10	.075
ProTaper (A4)	400	60°	335.99	42.88	50.4	6.43	5.06	.098
Revo_S (B1)	250	40°	394.58	36.06	94.7	8.65	4.06	.062
Revo_S (B2)	250	60°	313.33	36.89	72.8	7.19	5.04	.060
Revo_S (B3)	400	40°	354.65	38.84	53.2	5.82	4.07	.050
Revo_ S (B4)	400	60°	259.99	43.20	39	6.48	4.97	.088
RaCe (C1)	250	40°	625.41	30.13	150.1	7.23	4.12	.079
RaCe (C2)	250	60°	439.76	39.35	105.4	9.70	5.12	.128
RaCe (C3)	400	40°	561.33	41.19	84.2	6.17	4.12	.034
RaCe (C4)	400	60°	389.33	54.54	58.4	8.18	5.09	.176

Table 2: Independent t-test between two curvature (40° or 60°) at constant speed (250 and 400) RPM for each rotary system

Speed RPM	group	t-test	p-value	Sig.
250	A1&A2	11.816	.000	HS
250	B1&B2	4.980	.000	HS
250	C1&C2	11.843	.000	HS
400	A3&A4	7.964	.000	HS
400	B3&B4	5.152	.000	HS
400	C3&C4	7.958	.000	HS

Table 3: Independent t-test between two speed used (250 and 400) RPM at a constant curvature (40° or 60°) for each rotary system

curvature	Groups	t-test	p-value	Sig
40°	A1&A3	7.96	.011	S
40°	B1&B3	2.38	.028	S
40°	C1&C3	3.97	.001	HS
60°	A2&A4	2.20	.040	S
60°	B2&B4	2.96	.008	HS
60°	C2&C4	2.37	.029	S

Table 4: ANOVA test among rotary instruments: ProTaper (A1), Revo-S (B1) and RaCe (C1) at both speed 250&400 RPM and angle of curvature (40°&60°)

Among three instruments	F-value	P-value	df
A1,B1,C1(250 RPM, 40°)	101.84	.000	2
A2,B2,B2(250 RPM, 60°)	24.92	.000	2
A3,B3,C3(400 RPM,40°)	58.65	.000	2
A4,B4,C4(400 RPM, 60°	18.97	.000	2

Table 5: LSD table for multiple comparison among the rotary instrument used (A, B and C) in different speeds and angles of curvature.

Groups	Variables	Mean difference	p-value	Sig.
At speed 250 , 40° angle	A1-B1	134.295	.000	HS
	A1-C1	-89.236	.000	HS
	B1-C1	-223.532	.000	HS
At speed 250 , 60 ° angle	A2-B2	49.216	.006	HS
	A2-C2	-66.616	.000	HS
	B2-C2	-115.832	.000	HS
At speed 400 , 40° angle	A3-B3	128.041	.000	HS
	A3-C3	-78.666	.000	HS
	B3-C3	-206.708	.000	HS
At speed 400 , 60° angle	A4-B4	75.999	.001	HS
	A4-C4	-53.333	.018	HS
	B4-C4	-129.333	.000	HS