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A comparison of cyclic fatigue between used and new M*two* Ni–Ti rotary instruments

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Abstract

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Aim To evaluate the cyclic fatigue of M*two* Ni–Ti rotary instruments after controlled clinical use in molar teeth.

Methodology Twenty M*two* instruments of each size were selected and divided into two groups: group A consisted of 10 new instruments (control group); group B consisted of 10 used instruments. Each instrument in group B was used to clean and shape 10 root canals of molar teeth in patients. Cyclic fatigue testing of instruments was performed in tapered artificial canals with a 5-mm radius of curvature and a 60° angle of curvature. In all 140, instruments were rotated until fracture and the number of cycles to failure was recorded. Data were analysed using one-way ANOVA, Tukey's HSD test and independent sample *t*-test to determine any statistical difference; the significance was determined at the 95% confidence level.

Results A reduction of cycles to failure between new (group A) and used (group B) instruments was apparent. A statistically significant difference ($P < 0.05$) was noted between instruments of groups A and B in all sizes with the exception of size 40, 0.04 taper.

Conclusions Clinical use significantly reduced cyclic fatigue resistance of M*two* rotary instruments when compared with an unused control group. However, all the instruments had minimal instrument fatigue when discarded after controlled clinical use.

Keywords: clinical use, cyclic fatigue, M*two* Ni–Ti rotary instruments.

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Introduction

The fracture of instruments within the root canal during root canal treatment is a common incident (Martin *et al.* 2003). Although nickel–titanium instruments are reported to be stronger and more flexible than stainless steel instruments (Walia *et al.* 1988), failure is a concern because these instruments can undergo fracture within their elastic limit and without any visible signs of previous permanent deformation (Pruett *et al.* 1997, Sattapan *et al.* 2000).

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Fracture of instruments used in rotary motion occurs in two different ways: fracture because of torsion and fracture because of flexural fatigue (Serene *et al.* 1995, Sattapan *et al.* 2000, Ullmann & Peters 2005). Torsional fracture occurs when an instrument tip is locked in a canal whilst the shank continues to rotate, thereby exerting sufficient torque to fracture the tip (Martin *et al.* 2003, Peters 2004). Instruments fractured because of torsional loads often carry specific signs such as plastic deformation (Sattapan *et al.* 2000).

Fracture because of fatigue through flexure occurs because of metal fatigue. In this situation, the instrument does not bind in the canal, rather it rotates freely at the curvature generating tension/compression cycles at the point of maximum flexure until fracture occurs (Pruett *et al.* 1997, Haikel *et al.* 1999). When an instrument is held in a static position and continues to rotate, one-half of the instrument shaft on the outside of the curve is in tension, whilst the half of the instrument on the inside of the curve is in compression. This repeated tension–compression cycle, caused by rotation within curved canals, increases cyclic fatigue of the instrument over time and may be an important factor in instrument fracture (Pruett *et al.* 1997).

M*two* endodontic instruments (Sweden & Martina, Padova, Italy) are a new generation of Ni–Ti rotary instruments. The transverse section of the Mtwo is an italic 'S' with two blade-cutting surfaces (Fig. 1) resembling that of the S-file (Dobo-Nagy *et al.* 2002). The helical angle of this file is variable and it increases from the tip to the handle, as does the spiral pitch. The flutes become deeper from the tip to the handle. The helical angle is greater for the larger sizes (fewer flutes for instrument length), and decreases for the smaller sizes (more flutes). The rake angle is negative, and the tip is noncutting. The M*two* instruments are produced also with the cutting part extended more than the conventional 16 mm (Fig. 2); this allows the instrument to cut in the coronal portion of the canals.

Resistance of rotary instruments to cyclic fatigue is affected by the angle and radius of canal curvature and the size and taper of the instrument. Increased severity in the angle and radius of the curves around which the instrument rotates decreases instrument lifespan (Pruett *et al.* 1997, Mize *et al.* 1998, Haikel *et al.* 1999). Similarly, several studies have shown that increased diameter at the point of maximum curvature of the instrument reduces the time to fracture (Serene *et al.* 1995, Pruett *et al.* 1997, Haikel *et al.* 1999, Gambarini 2001a, Melo *et al.* 2002, Peters & Barbakow 2002).

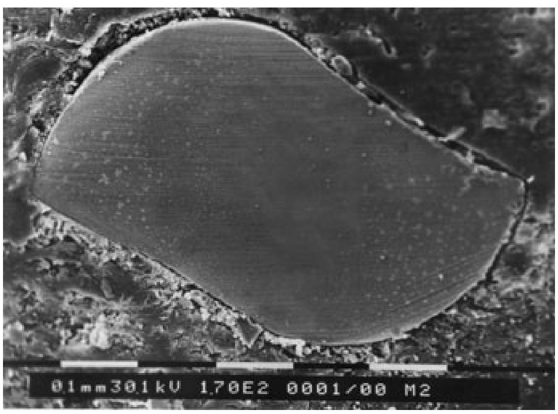

Figure 1 Scanning Electron Microscope micrograph of the transverse cross-section of a M*two* 25/0.06 instrument showing the two cutting edges resulting in an 'Italic S' design (170 x).

Previous clinical cyclic fatigue studies reported that the prolonged clinical use of Ni–Ti engine-driven instruments reduced their resistance to cyclic fatigue. Gambarini (2001a) described a reduction in the lifespan ranging from 35.9% to 62.3% and from 15.2% to 62% (Gambarini 2001b), whilst Yared *et al.* (2000) reported a reduction of the lifespan ranging from 5.1% to 13.5% after clinical usage on molars. Fife *et al.* (2004) showed a progressive decrease in the number of rotations until fracture amongst new, used and extensively used ProTaper instruments with statistically significant difference for instruments S2 and F2.

The aim of this study was to evaluate the cyclic fatigue resistance of new and used M*two* Ni–Ti rotary instruments after controlled clinical use in the root canals of molar teeth.

Materials and methods

Twenty M*two* instruments of the following sizes (size 10, 0.04 taper, size 15, 0.05 taper, size 20, 0.06 taper, size 25, 0.06 taper, size 30, 0.05 taper, size 35, 0.04 taper, size 40, 0.04 taper) were selected and divided into two groups: group A consisting of 10 new instruments of each size (control group); group B consisting of 10 used instruments of each size. Each group B M*two* instrument was used for shaping 10 root canals in the molar teeth of patients.

Canal preparation

Nonsurgical root canal treatment was performed on patients by one endodontist using a standard clinical protocol. The M*two* system consists of eight instruments varying in size and taper: size 10, 0.04 taper, size 15, 0.05 taper, size 20, 0.06 taper, size 25, 0.06 taper, size 25, 0.07 taper, size 30, 0.05 taper, size 35, 0.04 taper, size 40, 0.04 taper (Fig. 2). The size 25, 0.07 instrument was not tested because its specific clinical use was not appropriate in this study.

Sixty maxillary and mandibular human molar teeth undergoing root canal treatment were included. Direct and angled preoperative radiographs of each tooth were exposed using a paralleling technique. Radiographs were evaluated in normal room lighting, using a view box and 3.5X loupes. The radiographs were used to detect canals that merged. In such

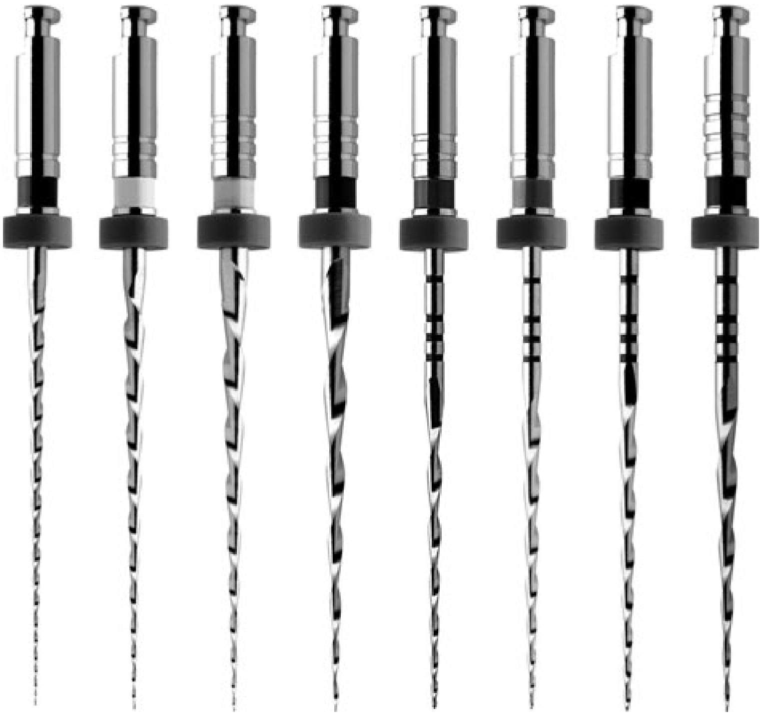

Figure 2 M*two* Ni-Ti rotary instruments (10/0.04, 15/0.05, 20/0.06, 25/0.06, 30/0.05, 35/0.04, 40/0.04, 25/0.07). The first four instruments are represented in the figure in the version with extended cutting portion; the other instruments present the classic length of the portion (16mm).

cases, only one canal was included in the study. Only teeth with mature apices and at least 1 root with a curvature of 10° or greater (Schneider 1971) were included. Molars with apical abrupt curvatures (with a radius of curvature ≤2 mm in the last 3 mm) were excluded. Approximate root canal lengths were determined from the preoperative radiographs. After appropriate anaesthesia, access openings were prepared, the canal orifices located and the cavity irrigated with 5.25% NaOCl. The canals were initially scouted with sizes 08 and 10 hand MMC K-type files (MicroMega, Besançon, France) using the lubricant RC Prep (Premiere, Stone Pharmaceuticals, Philadelphia, PA, USA). The canal working length was determined with the Apit 7 (Osada, Tokyo, Japan) and then confirmed radiographically. Reference points were recorded for each canal.

The M*two* Ni–Ti rotary instruments were used in a 16 : 1 handpiece (Anthogyr, Sallanches, France) in conjunction with a high torque endodontic electric motor (E-Go, Sweden & Martina, Padova, Italy) at 300 rpm. Ni–Ti M*two* instruments were used in a simultaneous technique (Foschi *et al.* 2004) without early coronal enlargement. Instruments were each taken to working length with light apical pressure. As soon as the clinician felt a binding sensation, the instrument was withdrawn 1–2 mm so that it could be worked in a brushing action to selectively remove the interferences and to advance towards the apex. The instruments were used with lateral pressure in order to obtain a circumferential cut and only allowed to rotate at length for a few seconds.

The patency of the apical foramen was checked by passing the tip of a size 08 file through the foramen after each instrument of the M*two* sequence until completion of the root canal shaping. Apical gauging was performed and shaping was considered complete when the apical root canal was enlarged to three sizes larger than the first file that bound at the working length (Weine 2004).

During shaping, each canal was irrigated between each successive instrument with 2.5 mL of 5.25% NaOCl using an endodontic syringe (Naxitip, Ultradent, South Jordan, UT, USA) placed as far into the root canal as possible without binding. The final flush was performed with 5 mL of 17% EDTA solution rinsed out with 5 mL of saline solution. Canals were then dried with paper points and filled.

The canals of each molar were cleaned and shaped at the same appointment. The M*two* instruments were cleaned of all visible debris using an ultrasonic cleaner and sterilized before each use by steam autoclave (Domina Plus, DentaLX s.r.l, Vicenza, Italy) at 134 °C for 10 min.

Each instrument was carefully examined under the stereomicroscope at 10× magnification (Global G6, St Louis, MO, USA) between uses for signs of plastic deformation or separation. The instruments with any sign of deformation and/or separation were excluded from the study and replaced in order to maintain constant the number of instruments tested for each size in each group ($n = 10$).

Fatigue-testing device

The fatigue-testing device manufactured for this study consisted of a main frame to which was connected a mobile plastic support for the handpiece and a stainless steel block with the artificial canals. The dental handpiece was mounted upon a mobile device that allowed for precise and simple placement of each instrument inside the artificial canal, ensuring three-dimensional alignment and positioning of the instruments to the same depth. Each artificial canal was manufactured reproducing each instrument size and taper, thus providing the instrument with a suitable trajectory (Grande *et al.* 2005). To ensure the accuracy of the size of each canal, a copper duplicate of each instrument was milled increasing the original size of the instrument by 0.2 mm using a computer numerical control machining bench (Bridgeport VMC 760XP3, Hardinge Machine Tools Ltd, Whiteacres, Leicester, UK). The copper duplicates were constructed according to the curvature parameters that were chosen for the study. With these negative molds, the artificial canals were made using a die-sinking electrical-discharge machining process (Agietron Hyperspark 3, AGIE Sa, Losone, Switzerland) in a stainless steel block. The blocks were hardened through annealing. The depth of each artificial canal was machined to the maximum diameter of the instrument +0.2 mm, allowing the instrument to rotate freely inside the artificial canal.

A simulated root canal with an angle of curvature of 60° and radius of curvature of 5 mm was constructed for each instrument. The centre of the curvature was 6 mm from the tip of the instrument and the curved segment of the canal was approximately 6 mm in length. Each artificial canal corresponding to the shape of each different instrument tested was mounted on the stainless steel block that was connected to the main frame.

The artificial canal was covered with a tempered glass to prevent the instruments from slipping out and to allow for observation of the rotating instrument. To permit air cooling of the instrument during the test, the glass was grooved, and an air compressor was attached.

Fatigue testing

Ten instruments for each instrument size of each group were tested, thus, 140 instruments were used in all.

The instruments were rotated at a constant speed of 300 rpm using a 16 : 1 reduction handpiece (Anthogyr, Sallanches, France) powered by a torque-controlled electric motor (E-Go, Sweden & Martina, Padova, Italy).

To reduce the friction of the file as it contacted the artificial canal walls, a special high-flow synthetic oil designed for lubrication of mechanical parts (Super Oil, Singer Co. Ltd, Elizabethport, NJ, USA) was applied.

Each instrument was rotated until fracture occurred. The time to fracture was recorded visually with a 1/100-s chronometer and the number of rotations was calculated to the nearest full number. The time to fracture was multiplied by the number of rotations per minute to obtain the number of cycles to failure (NCF) for each instrument. Mean values were then calculated. The length of the fractured tip was also recorded for each instrument and the mean values were then calculated for each instrument type in each group.

Statistical analysis

To determine any statistical difference amongst the subgroups, the data were subjected to a one-way analysis of variance (ANOVA) and Tukey's HSD test.

To determine any statistical significance between the values of new and used instruments of the same file size, data obtained were subjected to an independent sample t-test. Significance was determined at the 95% confidence level.

Results

No instrument underwent intra-canal failure during clinical use, whilst four size 10, 0.04 taper, three size 15, 0.05 taper and one size 20, 0.06 taper instruments demonstrated visible signs of plastic deformation and were discarded and replaced. Deformations occurred in the apical 4 mm of the instruments.

A reduction of NCF between new (group A) and used (group B) instruments occurred (Fig. 3). Mean values ± SD, expressed in NCF, are displayed in Table 1.

A statistically significant difference ($P < 0.05$) was noted between instruments of groups A and B in all

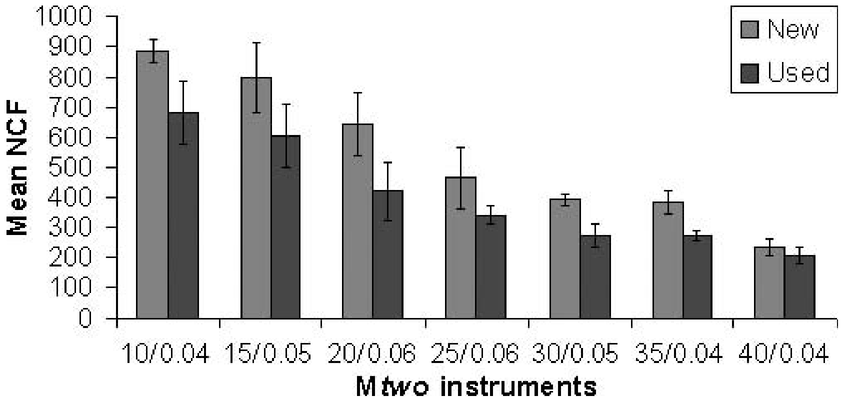

Figure 3 Comparison of the number of cycles to failure (NCF) between different M*two* instruments. Values are expressed as mean ± SD.

sizes with the exception of size 40, 0.04 taper, confirming that multiple clinical uses of Ni–Ti engine-driven instruments reduced their resistance to cyclic fatigue. In fact, a reduction of the lifespan ranging from 13% (M*two* size 40, 0.04 taper) to 34% (M*two* size 20, 0.06 taper) was registered. M*two* size 10, 0.04 taper, size 15, 0.05 taper, size 25, 0.06 taper, size 30, 0.05 taper and size 35, 0.04 taper instruments had a decrease in the lifespan, respectively, of 23%, 25%, 28%, 30% and 27% (Table 1).

Differences were also found for instruments with respect to the effect of size on fatigue failure. Results showed that larger instruments underwent fracture in less time under dynamic stress than smaller ones both in group A and B (Tables 2 and 3).

A statistically significant difference ($P < 0.05$) in the mean length of the fractured fragments after multiple uses occurred for size 25, 0.06 taper instruments only. No statistical difference in the mean length of the fragments was evident with multiple use for the other instruments (Table 4).

The multiple comparison Tukey's HSD test demonstrated a statistically significant difference in the mean length of the fragments between the size 35, 0.04 taper and the other instruments except for size 40, 0.04 taper in group A ($P < 0.05$). In group B, statistically significant differences were found between size 10, 0.04 taper and both size 25, 0.06 taper and size 40, 0.04 taper; size 15, 0.05 taper was also significantly different to size 40, 0.04 taper ($P < 0.05$).

Discussion

The removal of fractured instruments from the root canal is often difficult and occasionally impossible (Suter *et al.* 2005) and may alter the outcome of root canal treatment (Friedman 2002). The prognosis of teeth with fractured instrument retained in the canal has been reported to be lower than that of cases without broken instruments (Strindberg 1956, Grossman 1968, Crump & Natkin 1970, Fors & Berg 1986).

Clinically, the M*two* instruments have a consistent sequence that is reproducible and were thus evaluated for cyclic fatigue resistance after clinical use on molar teeth. The results confirmed that the diameter of the instrument at the point of maximum curvature influenced fatigue life as well as clinical use. That is, NCF decreased as the diameter of the instrument increased (Serene *et al.* 1995, Pruett *et al.* 1997, Haikel *et al.* 1999, Gambarini 2001a, Melo *et al.* 2002, Peters

Table 1 Mean ± SD expressed in number of cycles to failure registered during the cyclic fatigue testing of each instrument and reduction of the lifespan between new and used instruments

Mtwo	10/0.04*	15/0.05*	20/0.06*	25/0.06*	30/0.05*	35/0.04*	40/0.04
Group A (new)	884.8 ± 45.1	802.4 ± 142.8	644.2 ± 132.9	466.6 ± 101.5	394.8 ± 15.4	380.6 ± 44.7	238.6 ± 33.6
Group B (used)	681.2 ± 129.1	604.5 ± 125.4	425.0 ± 35.0	338.1± 58.0	277.0 ± 48.6	276.0 ± 16.8	207.3 ± 36.5
Lifespan reduction	−23%	−25%	−34%	−28%	−30%	−27%	−13%

*Statistically significant difference between the values of new and used instruments of the same file size ($P < 0.05$ independent sample *t*-test).
Minus sign indicates a reduction of the lifespan for used instruments compared with the new ones.

Table 2 Multiple comparison Tukey's HSD test amongst the different new instruments' NCF

NEW	10/0.04	15/0.05	20/0.06	25/0.06	30/0.05	35/0.04	40/0.04
10/0.04	–						
15/0.05	$P > 0.05$	–					
20/0.06	*	*	–				
25/0.06	*	*	*	–			
30/0.05	*	*	*	$P > 0.05$	–		
35/0.04	*	*	*	$P > 0.05$	$P > 0.05$	–	
40/0.04	*	*	*	*	*	*	–

*Statistically significant difference between the subgroups ($P < 0.05$).
NCF = number of cycles to failure.

Table 3 Multiple comparison Tukey's HSD test amongst the different used instruments' NCF

USED	10/0.04	15/0.05	20/0.06	25/0.06	30/0.05	35/0.04	40/0.04
10/0.04	–						
15/0.05	$P > 0.05$	–					
20/0.06	*	*	–				
25/0.06	*	*	$P > 0.05$	–			
30/0.05	*	*	*	$P > 0.05$	–		
35/0.04	*	*	*	$P > 0.05$	$P > 0.05$	–	
40/0.04	*	*	*	*	$P > 0.05$	$P > 0.05$	–

*Statistically significant difference between the subgroups ($P < 0.05$).
NCF = number of cycles to failure.

Table 4 Mean length of the fragments ± SD registered for each instrument (in mm)

Mtwo	10/0.04	15/0.05	20/0.06	25/0.06*	30/0.05	35/0.04	40/0.04
Group A (new)	5.0 ± 0.2	5.1 ± 0.8	5.1 ± 0.4	5.2 ± 0.3	5.2 ± 0.6	5.7 ± 0.1	5.6 ± 0.3
Group B (used)	4.9 ± 0.4	5.1 ± 0.4	5.5 ± 0.5	5.7 ± 0.5	5.2 ± 0.3	5.4 ± 0.7	5.9 ± 0.5

*Statistically significant difference between the values of new and used instruments of the same file size ($P < 0.05$ independent sample *t*-test).

& Barbakow 2002). Only the study by Yared *et al.* (2000) did not support these findings.

This is due to the fact that when a curved root canal instrument rotates, any points within it in the segment subjected to the maximum stress, except those in the centre (neutral axis), are subjected to repeated tensile or compressive strains. The farther away from the central axis, the greater the imposed strain at that point (Craig 1997). This explains why instruments of a larger diameter are affected by fatigue more than smaller ones.

Despite the tendency for larger instruments to undergo fracture in fewer NCF under dynamic stress than a smaller ones, no statistically significant differences were found in some cases (Table 3). The lack of statistical significance between instrument of size 25, 0.06 taper, size 30, 0.05 taper and size 35, 0.04 taper could be explained by the fact that the instruments have the same diameter at the point of maximum curvature because of their tip diameter and taper. Furthermore, Gambarini (2001a) and Haikel *et al.* (1999) reported that instruments with smaller tapers were significantly more resistant to cyclic fatigue than those with larger tapers.

Previous clinical cyclic fatigue studies were performed by Yared *et al.* (1999, 2000), Gambarini (2001a,b) and Fife *et al.* (2004). Although the mean number of rotations-to-breakage of used instruments was less than that of the new ones, Yared *et al.* (1999, 2000) did not demonstrate statistically significant difference between new and used ProFile instruments. Gambarini (2001a,b) reported a statistically significant reduction of rotation time to breakage between new and used ProFile rotary instruments in all sizes. Furthermore, Gambarini (2001b) showed that the use of an endodontic motor with lower torque values reduced cyclic fatigue of Ni–Ti rotary instruments. Fife *et al.* (2004) demonstrated a progressive decrease in the number of rotations until fracture between new, used and extensively used ProTaper instruments.

In the present study, a significant reduction in the resistance to cyclic fatigue was noted between new and used instruments. This result was expected, as endodontic instruments are subjected to stress fatigue during intracanal use, especially in the presence of curvature. Zuolo & Walton (1997) noticed that after prolonged experimental use most files were considered to be unusable. Therefore, the number of rotations to breakage would be expected to decrease. The results are consistent with those findings reported previously (Gambarini 2001a,b, Fife *et al.* 2004).

The results of the present study indicate that all the instruments had low instrument fatigue when discarded after controlled clinical use (10 canals of molar teeth). This demonstrates that rotary instruments can be used safely in clinical practice up to 10 times with a reduced potential for breakage under cyclic fatigue stress.

The absence of instrument fracture during clinical use could be explained because instruments were operated by an experienced endodontic specialist. Nevertheless, eight instruments had visible signs of plastic deformation in their apical portion and were immediately discarded. Instruments showed elongation of flutes probably because they were used in more complex cases and subjected to high levels of torque. If torque is higher than the elastic limit of the instrument, plastic deformation can occur readily.

Analysis of the data regarding the length of the fractured segment revealed no statistically significant difference in the mean size between new and used groups for all of the instrument sizes except for size 25, 0.06 taper. Data demonstrated a progressive increase in the mean length of the fragments, thus, as the instrument size increased the length of the fragments became greater in both groups, except for the size 40, 0.04 taper instrument in group A and the size 30, 0.05 taper and size 35, 0.04 taper instruments in group B (Table 2).

Despite the statistically significant differences in the mean length of the fractured segments, the maximum overall difference was <1 mm (Table 2). This confirms that instruments subjected to cyclic fatigue fractured at the centre of the curvature or just below this point, confirming previous findings (Pruett *et al.* 1997, Fife *et al.* 2004).

Conclusions

Clinical use significantly reduced cyclic fatigue resistance of Ni–Ti rotary instruments when compared with the control group of the same instrument size. However, each instrument was successfully operated without any intracanal failure, demonstrating that M*two* rotary instruments can be used safely in clinical conditions up to 10 times in curved molar teeth (one canal for each use) when used by an endodontic specialist.

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