

Is the reciprocating movement *per se* able to improve the cyclic fatigue resistance of instruments?

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Abstract

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Aim To compare cyclic fatigue resistance of two geometrically similar nickel–titanium instruments, used in conditions similar to clinical use in reciprocating and continuous rotary motion.

Methodology Four groups of eighteen instruments each, Reciproc[®] files sizes ISO 25 and 40 (R25 and R40) and Mtwo[®] files sizes ISO 25 and 40 (M25 and M40), were tested in reciprocating and continuous rotary motion, employing a novel experiment device. An artificial root canal (diameter, 1.4 mm; angle of curvature, 60 °; and curvature radius, 5 mm) was milled into a stainless steel block. To simulate clinical conditions, instead of rotating the file in static position, the set-up was designed to produce a continuous up-and-down pecking motion along the vertical axis of the instrument. Time to fracture (TTF) and push–pull cycles (PPC) were recorded, the number of cycles to fracture (NCF) was determined, and fractured instrument surfaces were examined under a scanning electron microscope (SEM).

Results Mean time to fracture was 34.44 ± 8.58 min for R25 in reciprocation motion, 35.77 ± 4.82 min for R40 in reciprocation motion, 12.15 ± 1.74 min for M25 in continuous rotary motion and 13.27 ± 2.02 min for M40 in continuous rotary motion, whereas 28.52 ± 3.27 min for R25 in continuous rotary motion, 23.87 ± 1.52 min for R40 in continuous rotary motion, 31.07 ± 1.79 min for M25 in reciprocation motion and 31.08 ± 3.26 min for M40 in reciprocation motion. There was a significant difference ($P < 0.0001$) for the cyclic fatigue resistance between the reciprocation motion and the continuous rotary motion groups. Reciproc[®] files in reciprocating movement had a significantly higher NCF than Mtwo[®] files, when used in continuous rotation. The highest resistance to failure was shown by Reciproc[®] files in reciprocation movement, followed by Mtwo[®] files in reciprocation and Reciproc[®] files in continuous motion. Mtwo[®] files in continuous rotary movement had the least resistance. SEM analysis of the fracture surface confirmed typical features of cyclic fatigue failure.

Conclusion Reciprocating movement increased the cyclic fatigue resistance of NiTi instruments.

Keywords: continuous rotary motion, cyclic fatigue, fracture resistance, nickel–titanium rotary file, reciprocating motion.

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Introduction

Nickel–titanium (NiTi) rotary instruments enable more efficient mechanical preparation of the root canal, whilst diminishing the probability of iatrogenic errors, such as transportation or perforation (Glossen *et al.* 1995). The superelastic property of NiTi alloy

makes it suitable for use in curved canals (Walia *et al.* 1988). However, in such situations, rotary NiTi instruments undergo torsional and flexural changes, potentially leading to instrument fracture. Instrument fracture can occur due to torsional load or cyclic fatigue (Sattapan *et al.* 2000a, Sattapan *et al.* 2000b, Martín *et al.* 2003). Torsional load occurs when the tip of the file is locked in the confines of the canal, whilst the shank keeps rotating. When the torque of the motor-driven handpiece exceeds the characteristic elastic limit of the NiTi alloy, fracture of the instrument is inevitable (Haïkel *et al.* 1999, Peters *et al.* 2002, Peters 2004). Fracture due to cyclic fatigue is caused by repeated tension/compression cycles generated within a rotating instrument in a curved canal (Pruett *et al.* 1997). At the flexural point in the curvature, the file is undergoing an alternate tension/compression deformation, leading to formation of microcracks that propagate, resulting in instrument fracture (Peters *et al.* 2002, Yared *et al.* 2003). The torsional load leading to fracture is also detrimentally affected by repeated use of the files (Ullmann & Peters 2005, Yared 2008).

NiTi instruments for use in reciprocating motion have been advocated to reduce the risk of fracture during instrumentation (De-Deus *et al.* 2010). Reciprocating movement is purported to always work below the elastic limit of the instruments, thus extending the cyclic fatigue life as compared to their use in conventional rotary motion (Varela-Patiño *et al.* 2010, Kim *et al.* 2012, Pedullà *et al.* 2013). The data available comparing the cyclic fatigue behaviour of NiTi instruments used both in a reciprocating and in a continuous rotary movement are limited. Most experimental designs test these files in static conditions, not accounting for the effect of the back and forth motion applied during clinical use. Recent findings support the belief that movement kinematics directly impacts on the cyclic fatigue behaviour of rotary NiTi instruments (De-Deus *et al.* 2010, Varela-Patiño *et al.* 2010, Gambarini *et al.* 2012). Moreover, it has been shown that reciprocating motion is associated with a longer lifespan of the instruments regardless of the alloy used in manufacturing (Pedullà *et al.* 2013).

The hypothesis tested in the present study was that there are no differences in fatigue fracture resistance between reciprocal and conventional rotary movements. To verify this hypothesis, NiTi instruments of the same apical size and similar geometric parameters – Reciproc[®] and Mtwo[®] (VDW, Munich,

Germany) – were subjected to dynamic fatigue life tests. The instrument surface fracture morphology and the helical shaft of the instruments were evaluated using a scanning electron microscope to check for fracture patterns.

Materials and methods

A sample of 144 Mtwo[®] and Reciproc[®] instruments were used. All instruments had nominal sizes of 0.25 mm and 0.40 mm at D0. For standardization and reliability of the experiment, the instruments tested were examined for defects or deformities under a stereomicroscope.

During mechanical testing, various movement kinematics were used, which resulted in 8 experimental groups ($n = 18$), as follows:

- G1) Reciproc[®] R25 in reciprocation movement;
- G2) Reciproc[®] R40 in reciprocation movement;
- G3) Reciproc[®] R25 in rotary movement;
- G4) Reciproc[®] R40 in rotary movement;
- G5) Mtwo[®] M25 in reciprocation movement;
- G6) Mtwo[®] M40 in reciprocation movement;
- G7) Mtwo[®] M25 in rotary movement;
- G8) Mtwo[®] M40 in rotary movement;

The files were used with an endodontic motor (VDW.SILVER[®]; VDW, Munich, Germany) and a 6 : 1 reduction hand piece (Sirona, Bensheim, Germany) at 300 rpm, according to manufacturer's specifications.

To maximize reproducibility in practice, a custom-made testing device was designed. The jig had a fixed and a mobile part. The fixed part consisted of a steel plate into which the artificial root canal was milled and covered with a transparent plexiglas plate, held in place with four screws. The dimensions of the simulated root canal were as follows: 1.4 mm diameter, angle of curvature 60 ° and a curvature radius of 5.0 mm. The centre of the curvature was located 5 mm from the end of the root canal. The mobile part consisted of a stainless steel platform equipped with a custom-made holder for the endodontic handpiece. The entire frame allowed the movement in linear direction along the longitudinal axis of the root canal to simulate the progressive pecking movement of the file towards the root canal apex, as it would in a clinical situation (Fig. 1).

The artificial canal was filled with glycerine to serve as a lubricant to avoid frictional heat.

Each file was tested in the simulated root canal until instrument fracture occurred. The time to



Figure 1 Cyclic fatigue dynamic testing device with mobile platform for simulation of the clinical use of the instruments.

fracture in seconds was multiplied by the numbers of rotation cycles per second (rpm/60) to obtain the number of cycles to failure (NCF) for each instrument. According to the manufacturer, three reciprocating cycles describe a complete instrument rotation. The reciprocating movement cycle is characterized by a CCW (counterclockwise) rotation of 150 degrees followed by a CW (clockwise) rotation of 30 degrees. The reciprocation movement pattern had a frequency of 10 cycles per second – the equivalent of rotation movement with 300 rpm. The time to fracture was recorded with a digital chronometer. The parameter push–pull cycles (PPC) denotes the number of cycles in vertical push–pull direction (pecking movement) and was recorded by an electronic counting device attached to the apparatus. The endodontic motor was recalibrated after each instrument use to avoid measure errors due to motor mechanics.

The fractured fragment surfaces were examined with a scanning electron microscope (FEI-ESEM-XL30-FEG, Environmental Scanning Electron Microscope XL30 Field Emission Gun, Philips, Netherlands), for characterization of the fracture pattern of the instrument and confirmation of hypothesis that fracture occurred due to cyclic fatigue rather than due to excessive torsional load.

A statistical analysis using the Student's *t*-test ($P = 0.001$) for the significance of the difference between the means of the NCF of the pairwise two independent instrument samples (R25/M25 and R40/M40 in the acknowledged movement pattern) was computed from the recorded data. Supplementary, the comparison between the data offered by the behaviour of both types of instruments in reciprocating movement pattern and traditional continuous rotary

motion pattern was analysed. The degrees of freedom were estimated using the Welch–Satterthwaite approximation and the one-sided test at the 5% significance level.

Results

The time to fracture (TTF) was determined for each instrument, and the mean values and standard deviations were calculated. The highest resistance to failure (measured in TTF) was observed with Reciproc[®] files in reciprocal movement, followed by Mtwo[®] files in reciprocal movement and Reciproc[®] files in continuous rotary motion. Mtwo[®] files used in continuous rotary movement had the least resistance. There was a statistically significant difference between R25 and M25, and R40 and M40, respectively ($P < 0.001$) (Fig. 2).

The SEM microphotographs of the fractured instruments displayed similar overload areas and fracture initiation zones, consistent with cyclic fatigue, on both reciprocating and rotary instruments. SEM analysis of the fracture surface confirmed typical features of cyclic fatigue failure. Voids (a) and cracks (b) can be identified on all fracture surfaces (Fig. 3).

The time to fracture, number of reciprocating/rotary cycles to failure (NCF) and the number of push–pull cycles until fracture occurrence (PPC) were determined for each instrument, and mean value and standard deviation were calculated. A statistical analysis using the Student's *t*-test for the significance of the difference between the means of the pairwise two independent instrument samples (R25/M25 and R40/M40 in acknowledged movement pattern) was computed from the recorded data. Supplementary, the comparison between the data offered by the behaviour of both types of instruments in reciprocating movement pattern and traditional continuous rotary motion pattern was analysed. The degrees of freedom were estimated using the Welch–Satterthwaite approximation and the one-sided test at the 5% significance level. There was a statistically significant difference for all parameters, TTF, NCF and PPC, between R25 and M25, and R40 and M40, respectively ($P < 0.001$) (Tables 1 and 2).

Discussion

The fracture of rotary NiTi files can occur due to either torsional failure or cyclic fatigue and is characterized by the development of microcracks along the point of maximal flexure of the instrument.

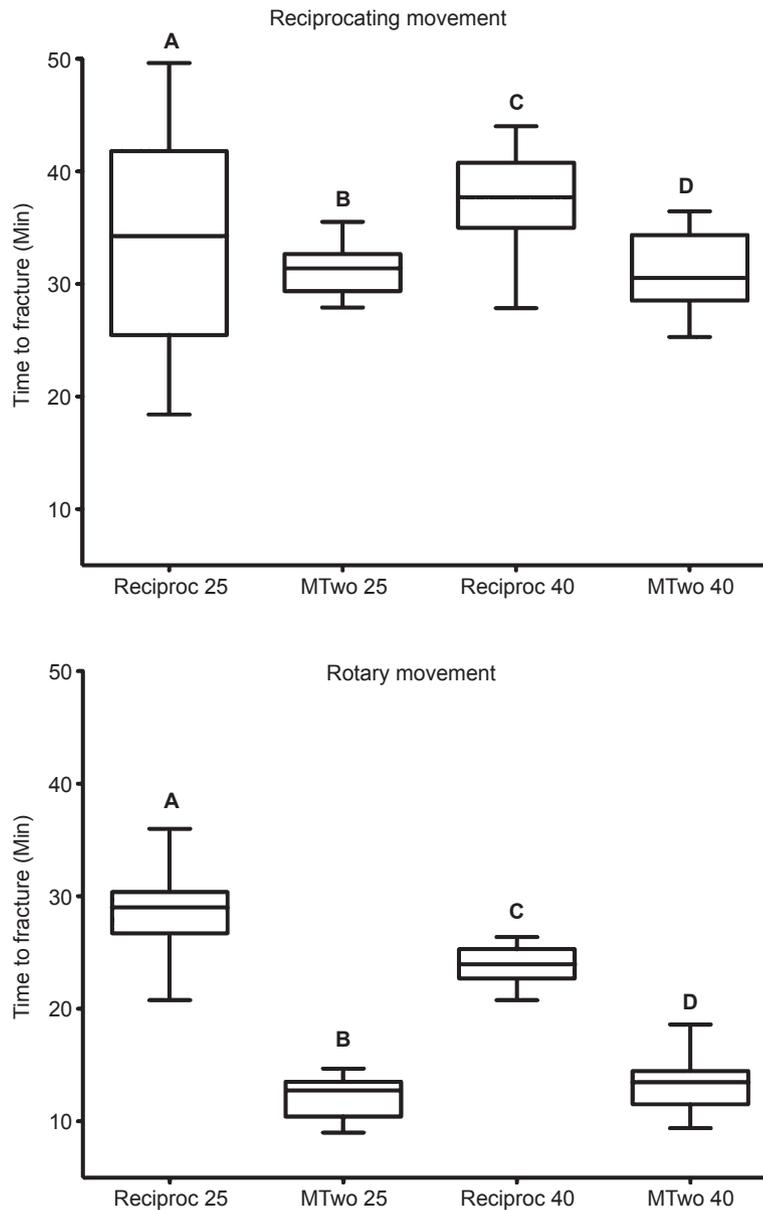


Figure 2 Measured mean values (\pm SD) of time to fracture (TTF) for each experimental group.

Recently introduced reciprocating NiTi files claim to have an increased cyclic fatigue resistance.

This study revealed significant differences in cyclic fatigue resistance between Reciproc[®] and Mtwo[®] instruments used in both reciprocating and continuous rotary motion in clinically simulated conditions. The time to fracture was three times higher for Reciproc[®] instruments in reciprocating movement compared with Mtwo[®] instruments, which have the same instrument tip size, when used in continuous rotary motion.

The diameter of the artificial root canal in this experiment was 1.4 mm, to minimize canal wall contact and to avoid friction on the lateral aspect of the root canal instrument. This could explain the higher number of cycles to fracture rate for the Reciproc[®] files used in reciprocating movement in this study compared with similar experiments.

Cyclic fatigue of rotary instruments is influenced by several factors, such as rotational speed, angle of curvature of the root canal (Yared *et al.* 2001), torque and operator's proficiency (Craveiro *et al.* 2002). The

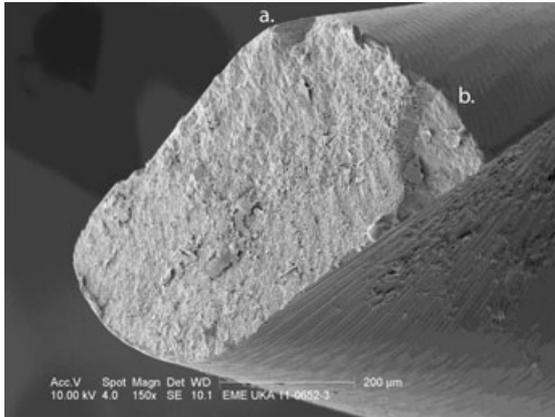


Figure 3 SEM micrograph of the fracture surface of a Reciproc[®] instrument with visible initiation point of the instrument fracture (a – void; b – crack surface).

influence of design on cyclic fatigue is controversial – some studies report the fact that cyclic fatigue behaviour is not essentially determined by design or shape of the instruments (Plotino *et al.* 2006, Cheung *et al.* 2007), whilst others suggest that differences in the

cross-sectional design have a great impact on the life-span and fracture resistance of an instrument (Pruett *et al.* 1997, Pedullà *et al.* 2013). Another questionable aspect that could influence the fracture resistance of the root canal instruments is the alloy type. The Reciproc[®] files are made from M-wire NiTi alloy, whereas the Mtwo[®] files are made of traditional NiTi alloy. Data from recently published literature are controversial: instruments made from M-wire were not found to be more resistant to fatigue than instruments produced with the traditional NiTi grinding process (Figuereido *et al.* 2009) or – on the contrary – there seems to be enough data to support the influence of manufacturing processes in favour of twisted M-wire NiTi (Rodrigues *et al.* 2011). Other studies have also demonstrated that instruments used in a reciprocating movement achieved better results with regard to cyclic fatigue resistance than instruments used in continuous rotary motion (Varela-Patiño *et al.* 2010, Kim *et al.* 2012).

It is important to observe that the current results can be interpreted as being influenced by the

Table 1 Mean values for Reciproc[®] instruments in reciprocating motion and Mtwo[®] instruments in continuous rotation motion

	Mean R25 reciprocating	Mean M25 rotary	SDev R25	SDev M25	P(type I error)
PPC	448	158	11.54	23.27	<0.001
TTF (min)	34.33	12.22	8.88	1.76	<0.001
NCF	10 332	3400	2648.6	501.1	<0.001
	Mean R40 reciprocating	Mean M40 rotary	SDev R40	SDev M40	P(type I error)
PPC	474.5	173	55.58	26.98	<0.001
TTF (min)	37	13	4.21	2.26	<0.001
NCF	10 950	3716.6	1282.6	580.9	<0.001

PPC, push–pull cycles; TTF, time to fracture; NCF, number of cycles to fracture.

Table 2 Mean values for Reciproc[®] instruments in continuous rotary motion and Mtwo[®] instruments in reciprocating motion

	Mean R25 rotary	Mean M25 reciprocating	SDev R25	SDev M25	P(type I error)
PPC	372	405	11.54	23.27	<0.001
TTF (min)	28.52	31.07	3.27	1.79	<0.001
NCF	8550	9316	981.50	537.88	<0.001
	Mean R40 rotary	Mean M40 reciprocating	SDev R40	SDev M40	P(type I error)
PPC	311	406	55.58	26.98	<0.001
TTF (min)	23.87	31.08	1.52	3.26	<0.001
NCF	7157	9317	456.81	977.67	<0.001

PPC, push–pull cycles; TTF, time to fracture; NCF, number of cycles to fracture.

interplay between two known variables: (i) the M-Wire alloy and (ii) the different taper between Reciproc and Mtwo. It is clear that the alloy as an experimental variable was not possible to control within this experimental design. As a consequence of data collection in this study, it is possible to infer that the alloy just played a minor role on the cyclic fatigue resistance of the tested instruments, as used under rotary movement, the differences between Reciproc and Mtwo instruments were even bigger. The second uncontrolled variable is the taper difference in Reciproc (0.08) and Mtwo (0.07), and it is important to acknowledge that the better performance of Reciproc instruments may have been due to their greater taper.

In the present study, as both instruments (Reciproc[®] and Mtwo[®]) have a similar S-shaped cross section with two cutting blades (Gambarini *et al.* 2008), the variables of instrument design and cross section are reduced. The primary variable is the kinematic employed (reciprocating or rotary motion). The different motion patterns of the geometrically similar instruments could account for the difference between the recorded values of the number of cycles to fracture for the Reciproc[®] and Mtwo[®] instruments.

The influence of the instrument alloy is a factor worth further consideration. As recently stated (Pedullà *et al.* 2013), different patterns of reciprocal motion (designed by different manufacturers) significantly increase cyclic fatigue resistance independently of the alloy. The current study also analysed the statistical outcome for data when using both instrument types in traditional rotary and reciprocating motion, respectively, for each of the study groups. The data reflect the fact that instrument alloy (M-wire or traditional NiTi alloy) had little impact on the number of cycles to failure or on the time to fracture. With the CI = 95%, the probability of assigning a better resistance to fatigue to instruments made of M-wire merely registered a value of 0.05%. Even at a greater confidence interval (assuming CI = 99%), rarely considered in studies similar to the present one, the minimal difference registered would attract attention to a minimal tendency of the material to influence resistance to fracture. In a recent study, there was no statistical difference between the cyclic fatigue resistance of R25 compared with Mtwo ($P > 0.05$) (Pedullà *et al.* 2013). When comparing the instruments with larger size (R40 and M40), results from the present study show no difference. Mainly, the type of motion employed, reciprocating versus continuous rotary, determined

better outcomes for both types of instruments used in the present study. In the dynamic model employed, the data revealed a higher cyclic fatigue resistance for Reciproc instruments in reciprocating motion than Mtwo in continuous rotation ($P < 0.001$).

Conclusions

Reciprocating movement did increase the cyclic fatigue resistance of instruments. The synergic effect between M-Wire and reciprocating motion was demonstrated by a significant improvement in cyclic fatigue life.

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References

- Cheung GSP, Shen Y, Darvell BW (2007) Effect of environment on low-cycle fatigue of a nickel-titanium instrument. *Journal of Endodontics* **33**, 1433–7.
- Craveiro C, De Melo M, de Azevedo BMG, Lopes Buono VT (2002) Fatigue resistance of engine-driven rotary nickel-titanium endodontic instruments. *Journal of Endodontics* **28**, 765–9.
- De-Deus G, Moreira EJJ, Lopes HP, Elias CN (2010) Extended cyclic fatigue life of F2 ProTaper instruments used in reciprocating movement. *International Endodontic Journal* **43**, 1063–8.
- Figueredo AM, Modenesi P, Buono V (2009) Low-cycle fatigue life of superelastic NiTi wires. *International Journal of Fatigue* **31**, 751–8.
- Gambarini G, Grande NM, Plotino G *et al.* (2008) Fatigue resistance of engine-driven rotary nickel-titanium instruments produced by new manufacturing methods. *Journal of Endodontics* **34**, 1003–5.
- Gambarini G, Gergi R, Naaman A, Osta N, Al Sudani D (2012) Cyclic fatigue analysis of twisted file rotary NiTi instruments used in reciprocating motion. *International Endodontic Journal* **45**, 802–6.
- Glossen CR, Haller RH, Dove SB, del Rio CE (1995) A comparison of root canal preparations using Ni-Ti hand, Ni-Ti engine-driven, and K-Flex endodontic instruments. *Journal of Endodontics* **21**, 146–51.
- Haikel Y, Serfaty R, Bateman G, Senger B, Allemann C (1999) Dynamic and cyclic fatigue of engine-driven rotary

- nickel-titanium endodontic instruments. *Journal of Endodontics* **25**, 434–40.
- Kim H-C, Kwak S-W, Cheung GS-P, Ko D-H, Chung S-M, Lee W (2012) Cyclic fatigue and torsional resistance of two new nickel-titanium instruments used in reciprocation motion: Reciproc Versus WaveOne. *Journal of Endodontics* **38**, 541–4.
- Martín B, Zelada G, Varela P *et al.* (2003) Factors influencing the fracture of nickel-titanium rotary instruments. *International Endodontic Journal* **36**, 262–6.
- Pedullà E, Grande NM, Plotino G, Gambarini G, Rapisarda E (2013) Influence of continuous or reciprocating motion on cyclic fatigue resistance of 4 different nickel-titanium rotary instruments. *Journal of Endodontics* **39**, 258–61.
- Peters OA (2004) Current challenges and concepts in the preparation of root canal systems: a review. *Journal of Endodontics* **30**, 559–67.
- Peters OA, Kappeler S, Bucher W, Barbakow F (2002) Engine-driven preparation of curved root canals: measuring cyclic fatigue and other physical parameters. *Australian Endodontic Journal* **28**, 11–7.
- Plotino G, Grande NM, Sorci E, Malagnino VA, Somma F (2006) A comparison of cyclic fatigue between used and new Mtwo Ni-Ti rotary instruments. *International Endodontic Journal* **39**, 716–23.
- Pruett JP, Clement DJ, Carnes DL Jr (1997) Cyclic fatigue testing of nickel-titanium endodontic instruments. *Journal of Endodontics* **23**, 77–85.
- Rodrigues RCV, Lopes HP, Elias CN *et al.* (2011) Influence of different manufacturing methods on the cyclic fatigue of rotary nickel-titanium endodontic instruments. *Journal of Endodontics* **37**, 1553–7.
- Sattapan B, Nervo GJ, Palamara JE, Messer HH (2000a) Defects in rotary nickel-titanium files after clinical use. *Journal of Endodontics* **26**, 161–5.
- Sattapan B, Palamara JE, Messer HH (2000b) Torque during canal instrumentation using rotary nickel-titanium files. *Journal of Endodontics* **26**, 156–60.
- Ullmann CJ, Peters OA (2005) Effect of cyclic fatigue on static fracture loads in ProTaper nickel-titanium rotary instruments. *Journal of Endodontics* **31**, 183–6.
- Varela-Patiño P, Ibañez-Párraga A, Rivas-Mundiña B, Cantatore G, Otero XL, Martín-Biedma B (2010) Alternating versus continuous rotation: a comparative study of the effect on instrument life. *Journal of Endodontics* **36**, 157–9.
- Walia HM, Brantley WA, Gerstein H (1988) An initial investigation of the bending and torsional properties of Nitinol root canal files. *Journal of Endodontics* **14**, 346–51.
- Yared G (2008) Canal preparation using only one Ni-Ti rotary instrument: preliminary observations. *International Endodontic Journal* **41**, 339–44.
- Yared GM, Bou DF, Machtou P (2001) Influence of rotational speed, torque and operator's proficiency on ProFile failures. *International Endodontic Journal* **34b**, 47–53.
- Yared G, Kulkarni GK, Ghossayn F (2003) An in vitro study of the torsional properties of new and used K3 instruments. *International Endodontic Journal* **36**, 764–9.