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Influence of a brushing working motion on the fatigue life of NiTi rotary instruments

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Abstract

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Aim To evaluate the cyclic fatigue resistance of M*two* NiTi rotary instruments when used with a brushing or no-brushing action in oval root canals.

Methodology Cyclic fatigue testing of instruments was performed in tapered artificial canals with a 5 mm radius of curvature and an angle of curvature of 60°. Twenty M*two* instruments for each size were selected and divided into two groups: group A = 10 instruments used with a no-brushing motion (control group); group B = 10 instruments used with a brushing-milling action. Each M*two* instrument was used for cleaning and shaping 10 oval root canals. In all 80 instruments were rotated until fracture occurred and the number of cycles to failure (NCF) recorded. Data were analysed by one-way ANOVA, Tukey HSD test and independent sample *t*-test to determine any statistical difference; the significance was determined at the 95% confidence level.

Results No statistically significant reduction of NCF between instruments used with a no-brushing motion (group A) and instruments used with a brushing motion (group B) were apparent except for size 25, 0.06 taper. M*two* size 10, 0.04 taper, size 15, 0.05 taper, size 20, 0.06 taper, size 25, 0.06 taper instruments had a decrease in life span of 1%, 0.5%, 8% and 19%, respectively.

Conclusions Fatigue life of instruments of larger size could be reduced by using them with a lateral brushing or pressing movement. However, each file was successfully operated without intracanal failure, demonstrating that M*two* rotary instruments can be used safely in a brushing action in simulated clinical conditions up to 10 times in oval canals.

Keywords: brushing action, cyclic fatigue, M*two* NiTi rotary instruments.

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Introduction

In recent years, interest in NiTi rotary endodontic instruments has grown (Thompson 2000). At the same time, the increased risk of NiTi instrument fracture, compared with stainless steel instruments, has represented a challenge for clinicians, as demonstrated by the attention that researchers have placed on studying this risk (Kazemi *et al.* 1996, 2000, Bergmans *et al.* 2001, Li *et al.* 2002, Ullmann & Peters 2005).

Ex vivo studies and reports on clinical use, show a relatively high incidence of unexpected failure of rotary nickel–titanium instruments with use (Barbakow & Lutz 1997, Zuolo & Walton 1997, Mandel *et al.* 1999, Martin *et al.* 2003). These rotary nickel–titanium endodontic instruments frequently fracture and become lodged in narrow, curved root canals, impeding optimal cleaning and shaping procedures (Friedman 2002, Suter *et al.* 2005).

The rotating movement of NiTi instruments, their super-elasticity and self-centering properties result in a nonselective cutting action along the walls of the root canal (Peters 2004). Therefore, rather than creating an anatomical enlargement the increased taper tends to create a canal that has the same shape as the

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instrument, resulting in a cone-shaped enlargement with a circular base (Wu & Wesselink 2001, Baroni Barbizam *et al.* 2002, Rödig *et al.* 2002, Weiger *et al.* 2002, Wu *et al.* 2003). This shape, however, is not the most common in root canals, which are more oval rather than circular. The area where canals tend to be more circular is the apical third, that is the last 3–4 mm before the cemento-dentinal junction (Kerekes & Tronstad 1977a,b,c, Wu *et al.* 2000, Bellucci & Perrini 2002).

In canals with oval shape, it is preferable to use an instrument that is able to maintain the original anatomy of the root canal, to preserve maximum dentine thickness and to enhance cleaning of buccal and lingual recesses (Hülsmann *et al.* 2005). Originally, NiTi rotary instruments were recommended to be used passively inside the root canals avoiding lateral movements (Ruddle 2002).

Recently, it has been suggested that NiTi rotary instruments should be used like a 'brush' to optimize efficacy of the preparation, particularly in oval canals (Clauder & Baumann 2004, Ruddle 2005). However, the use of NiTi instruments in a brushing action and the effect it has on the efficacy of the preparation has not been investigated. Furthermore, it is still not clear if active lateral movements of instruments used for circumferential filing could reduce their lifespan.

The M*two* endodontic instruments (Sweden & Martina, Padova, Italy) have been recently introduced. The transverse section of the M*two* is an italic 'S' with two blade-cutting surfaces (Plotino *et al.* in press). A few studies have been reported on these instruments. Foschi *et al.* (2004) compared the cleaning efficacy of M*two* and ProTaper NiTi rotary instruments and reported clean and debris-free dentine surface in the coronal and middle thirds; both instruments were unable to produce a dentine surface free from smear layer and debris in the apical third. Veltri *et al.* (2005) reported that M*two* instruments were effective in shaping curved canals *ex vivo*, respecting the original canal anatomy with no aberrations or failures. Schäfer *et al.* (2006a,b) reported that M*two* instruments maintained the original canal curvature significantly better than K3 and RaCe instruments and remained better centered. Furthermore, M*two* instruments created good cleaning with significantly less debris compared with the two other systems, were significantly faster without substantial change in working length and were safe to use with no fractures during preparation. Grande *et al.* (in press a) showed that M*two* NiTi rotary instruments performed better than ProTaper in terms of cyclic fatigue fracture resistance, whereas Plotino *et al.* (in press) reported that M*two* instruments had low instrument fatigue when discarded after controlled clinical use.

Tha aim of this study was to evaluate the cyclic fatigue resistance of M*two* NiTi rotary instruments after simulated clinical use when manipulated with a brushing and no-brushing action in oval root canals.

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) were selected and divided into two groups: group A consisting of 10 instruments of each size used with a no-brushing motion (control group); group B consisting of 10 instruments of each size used with a brushing-milling action. Each M*two* instrument was used to shape 10 root canals.

Canal preparation

A total of 210 distal root canals of human mandibular molars were chosen for this study. Roots with resorption, fractures, open apices or radiographically invisible canals were excluded. Two preliminary radiographs were exposed in a bucco-lingual and mesio-distal direction; the exposure time and processing were standardized. Radiographs were evaluated in normal room lighting, using a view box and 3.5X loupes. Only roots with a single oval root canal were included in the study. According to the criteria used in the study of Wu & Wesselink (2001) only teeth with a bucco-lingual distance at least 2X as great as the mesio-distal distance (internal long- to short-diameter ratio) were defined as oval. If radiographs determined that at the cervical and mid-root level the bucco-lingual to mesio-distal dimension had a ratio of at least 2 : 1, the roots were included in the experiment. The corresponding roots had mature apices and demonstrated moderate curvatures (<10°, Schneider 1971). Roots with abrupt apical curvatures (with a radius of curvature ≤2 mm in the last 3 mm) were also excluded. Canals were categorized according to the curvature and to the long : short diameter ratio, then randomly divided into two experimental groups, such that all ranges of curvatures and diameter ratios were equally represented in each group.

The teeth were stored in formalin solution (10%) and placed into 5.25% sodium hypochlorite solution for 2 h to remove the periodontal ligament. All remaining organic residue were removed from external root surfaces with a scaler. After rinsing in tap water the teeth were transferred again to formalin solution.

The clinical protocols were standardized. 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. The size 25, 0.07 taper, size 30, 0.05 taper, size 35, 0.04 taper, size 40, 0.04 taper instruments were not tested because their specific clinical use was not appropriate in this study.

The cusps of all teeth were flattened with a tapered diamond bur using a high-speed handpiece under water irrigation to establish a level surface to serve as a stable reference. Access openings were prepared, the canal orifices located and the cavities irrigated with 5.25% NaOCl. The canals were initially scouted with sizes 8 and 10 hand MMC K-type files (MicroMega, Besançon, France) using the lubricant RC Prep (Premiere, Stone Pharmaceuticals, Philadelphia, PA, USA). Patency of the root canal was established with a size 10 K-file to discard any teeth with canal obstructions. The working length of the canal was determined by observing the tip of the file tangential to the apical foramen and subtracting 0.5 mm from the recorded length. Radiographs were made in a bucco-lingual and mesio-distal direction. Working length and reference points were recorded for each root canal. One operator using 2.5X magnification performed all instrumentation.

The M*two* NiTi 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 (Plotino *et al.* in press) without any early coronal enlargement. Each instruments was taken to working length with light apical pressure and only allowed to rotate at length for a few seconds.

In group A, rotary instruments were used passively within the root canal with a continuous axial motion, allowing them to travel apically until they reached the apex. In group B, the instruments were used in a brushing action with a lateral pressing movement. As soon as the clinician reached the apex, the instrument was withdrawn 1–2 mm so that it could be worked in a brushing action to obtain a circumferential cut.

The patency of the apical foramen was checked by passing the tip of a size 8 file through the foramen after each instrument of the M*two* sequence until completion of the root canal shaping. Preparation was considered complete when a size 25, 0.06 taper reached the working length, as this was the largest file tested in this study.

During shaping, each canal was irrigated between each successive instrument with 2.5 mL of 5.25% NaOCl using an endodontic syringe (Navy Tip, 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. 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 10X magnification (Global G6, St Louis, MO, USA) between uses for signs of plastic deformation or fracture. The instruments with any sign of failure were excluded from the study and replaced 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 (CNC) machining bench (Bridgeport VMC 760XP3; Hardinge Machine Tools Ltd, Leicester, UK) was used. The copper duplicates were constructed according to the curvature parameters that were chosen for the study. With these negative moulds the artificial canals were made using a die-sinking EDM (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, 80 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).

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 (RPM) 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 HSD test. To determine any statistical significance between the values of instruments of the same size used in brushing action or not, data obtained were subjected to an independent sample *t*-test. Significance was determined at the 95% confidence level.

Results

No instrument underwent intracanal failure during simulated clinical use in the real root canals, whilst three size 10, 0.04 taper (2 in group A, 1 in group B), one 15, 0.05 taper (group B) and one size 20, 0.06 taper (group A) instruments demonstrated visible signs of plastic deformation and were discarded and replaced. Deformations occurred in the apical 4 mm of the instruments. Data did not show a statistically significant reduction of NCF between instruments used with the no-brushing motion (group A) and instruments used with a brushing motion (group B) except for size 25, 0.06 taper (Table 1).

No statistically significant difference ($P > 0.05$) was noted between instruments of groups A and B in all sizes, with the exception of size 25, 0.06 taper, showing that the use of M*two* NiTi engine-driven instruments with a lateral pressing movement did not statistically reduce the resistance to cyclic fatigue of the smallest sizes. A reduction of the life span was registered for M*two* size 20, 0.06 taper (8%) and size 25, 0.06 taper (19%) instruments demonstrating a direct correlation with the instrument size (Table 1). M*two* size 10, 0.04 taper (1%) and size 15, 0.05 taper (0.5%) instruments had no decrease in life span (Table 1).

No statistically significant difference ($P > 0.05$) in the mean length of the fractured fragments was evident with the brushing or no-brushing motion for all of the instruments (Table 2). The multiple comparison Tukey HSD test demonstrated a statistically significant difference in the mean length of the fragments between the size 25, 0.06 taper and the sizes 10, 0.04 taper and 15, 0.05 taper both in group A and B ($P < 0.05$).

Table 1 Mean ± SD expressed in number of cycles to failure (NCF) registered during the cyclic fatigue testing of each instrument, reduction of lifespan between instruments used with a brushing or no-brushing motion and their *P*-values

M*two*	10/0.04	15/0.05	20/0.06	25/0.06*
Group A (no-brushing)	677 ± 124	613 ± 77	485 ± 104	431 ± 55
Group B (brushing)	671 ± 123	609 ± 118	444 ± 48	347 ± 51
Lifespan reduction (%)	1	0.5	8	19
P-value	0.915	0.929	0.273	0.002

*Statistically significant difference between the values of instruments used with brushing or no-brushing motion of the same file size ($P < 0.05$ indipendent sample *t*-test).

Table 2 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*
Group A (no-brushing)	4.9 ± 0.6	4.9 ± 0.4	5.3 ± 0.2	5.6 ± 0.4
Group B (brushing)	5 ± 0.5	5 ± 0.4	5.4 ± 0.4	5.7 ± 0.3

*No statistically significant difference between the values of instruments used with brushing or no-brushing motion of the same file size ($P > 0.05$ indipendent sample *t*-test).

Discussion

Anatomical variability of the teeth is often a complicating factor in root canal treatment. The buccal and lingual extensions of the irregular oval root canals represent difficult areas for instrumentation and filling (Wu *et al.* 2001, Wu & Wesselink 2001). It seems questionable whether flexible NiTi instruments allow controlled and complete preparation of such extensions (Hülsmann *et al.* 2005). In fact, in comparative studies of preparation of oval root canals, the middle and coronal cross-sections frequently showed circular bulges, whereas the buccal and lingual extensions of the oval root canals often remained unprepared (Wu & Wesselink 2001, Rödig *et al.* 2002, Wu *et al.* 2003, Grande *et al.* in press b). To obtain circumferential cleaning and shaping of these recesses specific instrumentation motions such as brushing have been recommended for use (Hülsmann *et al.* 2005). No information on preparation of oval root canals using NiTi rotary instruments with this specific motion are available. Furthermore, no evidence has been presented that proves that lateral movements are safe when using NiTi rotary instruments.

In the present study, no significant reduction in the resistance to cyclic fatigue was noted between rotary instruments used passively within the root canal and instruments used with a brushing action that included lateral pressing movements to obtain a circumferential preparation, with the exception of size 25, 0.06 taper. This demonstrates that M*two* NiTi rotary instruments used in a brushing motion were not subjected to more stress fatigue during intracanal use when compared with passive use. At the same time, the results demonstrated that fatigue life of instruments of larger size could be reduced by using them with a lateral pressing movement. In fact, a reduction in life span was registered for M*two* size 20, 0.06 taper and size 25, 0.06 taper instruments with a direct correlation with instrument size. This phenomenon could be explained by the fact that when using these instruments with a no-brushing action they were removed from the root canal immediately after they reached the apex, while when used with a brushing motion against the canal wall, once they reached the apex they were used for longer. The size of the instruments (meaning more rigid instruments) could have also influenced these results, thus explaining why smaller instruments did not have any reduction in cyclic fatigue.

A comparison of these results with those of a recent study investigating new and used M*two* rotary nickel–titanium instruments under identical conditions (Plotino *et al.* in press) confirm the results of the present study were in the same range as in the previous ones. All instruments had low instrument fatigue after simulated clinical use (10 distal oval canals of mandibular molar teeth), even when used in a brushing action with a lateral pressing movement. This demonstrates that rotary instruments can be used safely in clinical practice with lateral brushing movements, showing slightly more potential for breakage under cyclic fatigue stress than instruments used with no-brushing action for the larger instruments only.

Differences were found for instruments with respect to the effect of size on fatigue failure. Results showed that larger instruments underwent fracture in less time under cyclic stress than a smaller ones, confirming that the diameter of the instrument at the point of maximum curvature influenced fatigue life both on instruments tested after simulated clinical use in a brushing motion and passively. That is, NCF decreased as the diameter of the instrument increased (Serene *et al.* 1995, Pruett *et al.* 1997, Haikel *et al.* 1999, Gambarini 2001, Melo *et al.* 2002, Peters & Barbakow 2002).

The analysis of the fractured segments revealed no statistically significant difference in the mean length between the instruments used with a brushing or no-brushing motion in all sizes ($P > 0.05$). However, the data demonstrated a progressive increase in the mean length of the fragments, with increasing instrument size in both groups (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

Simulated clinical use in a brushing motion did not significantly reduced cyclic fatigue resistance of M*two*

NiTi rotary instruments when compared with the control group of the same instrument size used in no-brushing motion, with the exception of size 25, 0.06 taper. Each instrument was operated successfully without any intracanal failure, demonstrating that M*two* rotary instruments can be used safely in a brushing action with a lateral cutting movements in clinical conditions up to 10 times in oval canals.

References

Barbakow F, Lutz F (1997) The Lightspeed preparation technique evaluated by Swiss clinicians after attending continuing education courses. *International Endodontic Journal* **30**, 46–50.

Baroni Barbizam JV, Fariniuk LF, Marchesan MA, Pecora JD, Sousa Neto MD (2002) Effectiveness of manual and rotary instrumentation techniques for cleaning flattened root canals. *Journal of Endodontics* **28**, 365–6.

Bellucci C, Perrini N (2002) A study on the thickness of radicular dentin and cementum in anterior and premolar teeth. *International Endodontic Journal* **35**, 594–606.

Bergmans L, Van Cleynenbreugel J, Wevers M, Lambrechts P (2001) Mechanical root canal preparation with NiTi rotary instruments: rationale, performance and safety. Status report for the American Journal of Dentistry. *American Journal of Dentistry* **14**, 324–33.

Clauder T, Baumann MA (2004) ProTaper NT system. *Dental Clinics of North America* **48**, 87–111.

Fife D, Gambarini G, Britto LR (2004) Cyclic fatigue testing of ProTaper NiTi rotary instruments after clinical use. *Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontics* **97**, 251–6.

Foschi F, Nucci C, Montebugnoli L et al. (2004) SEM evaluation of canal wall dentine following use of M*two* and ProTaper NiTi rotary instruments. *International Endodontic Journal* **37**, 832–9.

Friedman S (2002) Prognosis of initial endodontic therapy. *Endodontic Topics* **2**, 59–88.

Gambarini G (2001) Cyclic fatigue of Profile rotary instruments after prolonged clinical use. *International Endodontic Journal* **34**, 386–9.

Grande NM, Plotino G, Falanga A, Somma F (2005) A new device for cyclic fatigue testing of NiTi rotary endodontic instruments (Abstract R60). *International Endodontic Journal* **38**, 936–7.

Grande NM, Plotino G, Pecci R, Bedini R, Malagnino VA, Somma F (in press a) Cyclic fatigue resistance and three-dimensional analysis of instruments from two NiTi rotary systems. *International Endodontic Journal*. doi: 10.1111/j.1365-2591.2006.01143.x

Grande NM, Plotino G, Butti A, Messina F, Pameijer CH, Somma F (in press b) Cross-sectional analysis of root canals prepared with NiTi rotary instruments and stainless steel reciprocating files. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*. doi: 10.1016/j.tripelo.2005.12.022

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.

Hülsmann M, Peters OA, Dummer PMH (2005) Mechanical preparation of root canals: shaping goals, techniques and means. *Endodontic Topics* **10**, 30–76.

Kazemi RB, Stenman E, Spangberg LS (1996) Machining efficiency and wear resistance of nickel-titanium endodontic files. *Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontology* **81**, 596–602.

Kazemi RB, Stenman E, Spangberg LS (2000) A comparison of stainless steel and nickel-titanium H-type instruments of identical design: torsional and bending tests. *Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontology* **90**, 500–6.

Kerekes K, Tronstad L (1977a) Morphometric observations on root canals of human anterior teeth. *Journal of Endodontics* **3**, 24–9.

Kerekes K, Tronstad L (1977b) Morphometric observations on root canals of human premolars. *Journal of Endodontics* **3**, 74–9.

Kerekes K, Tronstad L (1977c) Morphometric observations on root canals of human molars. *Journal of Endodontics* **3**, 114–8.

Li UM, Lee BS, Shih CT, Lan WH, Lin CP (2002) Cyclic fatigue of endodontic nickel titanium rotary instruments: static and dynamic tests. *Journal of Endodontics* **28**, 448–51.

Mandel E, Adib-Yazdi M, Benhamou L-M, Lachkar T, Mesgouez C, Sobel M (1999) Rotary Ni–Ti profile systems for preparing curved canals in resin blocks: influence of operator on instrument breakage. *International Endodontic Journal* **32**, 436–43.

Martin B, Zelada G, Varela P et al. (2003) Factors influencing the fracture of nickel–titanium rotary instruments. *International Endodontic Journal* **36**, 262–6.

Melo MCC, Bahia MGA, Buono VTL (2002) Fatigue resistance of engine-driven rotary nickel-titanium endodontic instruments. *Journal of Endodontics* **28**, 765–9.

Peters OA (2004) Current challenges and concepts in the preparation of root canal systems: a review. *Journal of Endodontics* **30**, 559–65.

Peters OA, Barbakow F (2002) Dynamic torque and apical forces of ProFile.04 rotary instruments during preparation of curved canals. *International Endodontic Journal* **35**, 379–89.

Plotino G, Grande NM, Sorci E, Malagnino VA, Somma F (in press) A comparison of cyclic fatigue between used and new M*two* NiTi rotary instruments. *International Endodontic Journal*. doi: 10.1111/j.1365-2591.2006.01142.x.

Pruett JP, Clement DJ, Carnes DL (1997) Cyclic fatigue of nickel-titanium endodontic systems. *Journal of Endodontics* **23**, 77–85.

Rödig T, Hülsmann M, Muhge M, Schafers F (2002) Quality of preparation of oval distal root canals in mandibular molars using nickel-titanium instruments. *International Endodontic Journal* **35**, 919–28.

Ruddle CJ (2002) Cleaning and shaping root canal systems. In: Cohen S, Burns RC, eds. *Pathways of the Pulp*, 8th edn. St Louis: Mosby, p. 274.

Ruddle CJ (2005) The ProTaper technique. *Endodontic Topics* **10**, 187–90.

Schäfer E, Erler M, Dammaschke T (2006a) Comparative study on the shaping ability and cleaning efficiency of rotary Mtwo instruments. Part 1. Shaping ability in simulated curved canals. *International Endodontic Journal* **39**, 196–202.

Schäfer E, Erler M, Dammaschke T (2006b) Comparative study on the shaping ability and cleaning efficiency of rotary Mtwo instruments. Part 2. Cleaning effectiveness and shaping ability in severely curved root canals of extracted teeth. *International Endodontic Journal* **39**, 203–12.

Schneider SW (1971) A comparison of canal preparations in straight and curved root canals. *Oral Surgery Oral Medicine and Oral Pathology* **32**, 271–5.

Serene TP, Adams JD, Saxena A (1995) *Nickel–Titanium Instruments: Applications in Endodontics*. St Louis, MO: Ishiyaku EuroAmerica.

Suter B, Lussi A, Sequeira P (2005) Probability of removing fractured instruments from root canals. *International Endodontic Journal* **38**, 112–23.

Thompson SA (2000) An overview of nickel–titanium alloys used in dentistry. *International Endodontic Journal* **33**, 297–310.

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.

Veltri M, Mollo A, Mantovani L, Pini P, Balleri P, Grandini S (2005) A comparative study of Endoflare-Hero Shaper and Mtwo NiTi instruments in the preparation of curved root canals. *International Endodontic Journal* **38**, 610–6.

Weiger R, ElAyouti A, Löst C (2002) Efficiency of hand and rotary instruments in shaping oval root canals. *Journal of Endodontics* **28**, 580–3.

Wu MK, Wesselink PR (2001) A primary observation on the preparation and obturation of oval canals. *International Endodontic Journal* **34**, 137–41.

Wu M, R'oris A, Barkis D, Wesselink PR (2000) Prevalence and extent of long oval canals in the apical third. *Oral Surgery, Oral Medicine and Oral Pathology* **89**, 739–43.

Wu MK, Kastakova A, Wesselink PR (2001) Quality of cold and warm gutta-percha fillings in oval canals in mandibular premolars. *International Endodontic Journal* **34**, 485–491.

Wu MK, van der Sluis LWM, Wesselink PR (2003) The capability of two hand instrumentation techniques to remove the inner layer of dentine in oval canals. *International Endodontic Journal* **36**, 218–24.

Zuolo ML, Walton RE (1997) Instrument deterioration with usage: nickel–titanium versus stainless steel. *Quintessence International* **28**, 397–402.