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# Centring ability and apical transportation after overinstrumentation with ProTaper Universal and ProFile Vortex instruments

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## Abstract

**González Sánchez JA, Duran-Sindreu F, de Noé S, Mercadé M, Roig M.** Centring ability and apical transportation after overinstrumentation with ProTaper Universal and ProFile Vortex instruments. *International Endodontic Journal*.

**Aim** To evaluate morphological changes to the major foramen after overinstrumentation with ProTaper Universal and ProFile Vortex Ni–Ti rotary instruments.

**Methodology** Twenty-eight mesiobuccal canals of maxillary and mandibular first molars were divided into two groups of 14 canals each. The root canals were prepared with ProTaper Universal or ProFile Vortex instruments. ProTaper and Vortex instruments were used until the file tip protruded 1 mm beyond the working length (0.5 mm beyond the major foramen). The major foramen was photographed before and after overinstrumentation with each file of the two systems used. The images were superimposed and evaluated using Adobe Photoshop. The parameters evaluated were canal transportation, centring ability and shape of the major foramen. Transportation and centring ability were calculated in two directions: the direction of maximum curvature (MC) and a direction vertical to the maximum curvature (VC). Measurements of canal transportation and centring ability were analysed by ANOVA followed by post hoc least significance difference (LSD) multiple comparisons.

**Results** No significant differences were observed amongst the different instruments with respect to centring ability in either direction ($P > 0.05$). The F3 ProTaper Universal instrument was associated with a higher mean values for transportation in the direction of MC ($P < 0.05$) than the S1, S2 and F1 ProTaper Universal instruments and the size 15, 0.06 taper, size 20, 0.06 taper, and size 25, 0.06 taper ProFile Vortex instruments. The size 30, 0.06 taper ProFile Vortex instrument had a larger mean value for transportation in the direction of MC ($P < 0.05$) than the S1 ProTaper Universal and size 15, 0.06 taper ProFile Vortex instruments. The S1, S2, F1, F2 and F3 ProTaper Universal files and the size 15, 0.06 taper, size 20, 0.06 taper, size 25, 0.06 taper, and size 30, 0.06 taper ProFile Vortex files produced an oval foramen in 71%, 71%, 85%, 85%, 71%, 71%, 85%, 85% and 89% of the cases, respectively.

**Conclusions** In most samples, the ProTaper Universal and ProFile Vortex files produced transportation of the major foramen and created an oval-shaped major foramen after overinstrumentation.

**Keywords:** apical transportation, centring ability, overinstrumentation, ProFile Vortex, ProTaper Universal.

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## Introduction

The aims of root canal treatment are to eliminate microorganisms, to remove infected and necrotic pulpal remnants and to shape the root canal system in order to facilitate irrigation and the placement of a medicament and/or filling material (Haapasalo *et al.* 2005). At the same time, the procedure should avoid any iatrogenic events, such as fracture of the instruments, transportation of the root canal, formation of a ledge or perforation of the tooth. A number of studies on both extracted teeth and simulated canals have shown that rotary nickel–titanium (Ni–Ti) instruments allow more rapid, more centred, rounder and more conservative shaping of canals than stainless steel instruments (Glossen *et al.* 1995, Kum *et al.* 2000, Schäfer & Lohmann 2002).

The Ni–Ti rotary instruments that are on the market vary considerably in design. Studies evaluating the cutting efficiency of various tip designs suggest less apical transportation with noncutting tips than those with cutting tips (Dummer *et al.* 1998, Powell *et al.* 1998). An increasing taper is directly related to increased cross-sectional area and decreased flexibility (Javaheri & Javaheri 2007). Several other variables, such as canal curvature, root canal anatomy and diameter, might also be involved in changes to root canal morphology (Schäfer & Dammaschke 2006).

ProTaper instruments (Dentsply Maillefer, Ballaigues, Switzerland) have a convex triangular cross-sectional design with three cutting edges, a negative cutting angle and a flute design that combines progressive tapers within the shaft (Yang *et al.* 2006). A new design feature of the ProTaper Universal Ni–Ti system is that the tips of the finishing files are more rounded than those of the original ProTaper Ni–Ti system to improve working and shaping ability (Aguiar *et al.* 2009). Furthermore, the convex lateral surfaces of the F3 to F5 instruments are machined to increase flexibility (Vaudt *et al.* 2009). The ProTaper Universal instruments performed better than the original ProTaper files evaluated previously, probably because the file tip was changed from the 'modified guiding tip' to the 'rounded safe tip' (Câmara *et al.* 2009).

ProFile Vortex rotary instruments (Dentsply, Tulsa Dental Specialities, Tulsa, OK, USA) were introduced in 2009. Vortex files are manufactured from modified Ni–Ti raw alloy known as M-wire. M-wire, which was introduced in 2008, is produced by applying a series of heat treatments to Ni–Ti wire blanks. Preliminary evidence suggests that the use of M-wire improves the fatigue lifespan of rotary instruments whilst maintaining the same torsional properties as instruments that have been ground conventionally (Bardsley *et al.* 2011). ProFile size 25, 0.04 taper files that are manufactured from M-Wire Ni–Ti show nearly 400% more resistance to cyclic fatigue than size 25, .04 taper ProFile files manufactured from SE508 Ni–Ti (Johnson *et al.* 2008). The system has 0.04 and 0.06 taper instruments in sizes that range from 15 to 50. ProFile Vortex rotary files have a triangular cross section and a specific helical angle without radial lands with a noncutting safety tip (Gao *et al.* 2010).

The effectiveness of various instruments in root canal preparation has been studied after the correct working length (WL) has been determined, which does not take into account the fact that instrumentation might occur beyond the major foramen. It has been shown that the WL was overestimated in more than 50% of premolar samples and 22% of molar samples, although the radiographic WL was located 0–2 mm short of the radiographic apex (ElAyouti *et al.* 2001). Some authors have shown that electronic apex locators (EALs) provide a more accurate estimation of the WL than radiographs (Pratten & McDonald 1996, Cianconi *et al.* 2010). For this reason, the use of EALs has been proposed to obtain a more accurate length for the root canal (Pratten & McDonald 1996). However, in *in vivo* studies, Wrbas *et al.* (2007) and Stöber *et al.* (2011a) observed that the file tip passed the major foramen in 20% and 15% of the samples, respectively, when the Raypex 5 (VDW, Munich, Germany) EAL was used. In addition, Wrbas *et al.* (2007), Shabahang *et al.* (1996), Dunlap *et al.* (1998) and Stöber *et al.* (2011b) observed that, with the Root ZX (J Morita Corp, Tokyo, Japan) EAL, the file tip protruded beyond the major foramen in 40%, 30.8%, 26% and 16.7% of the samples, respectively. Furthermore, Stöber *et al.* (2011a,b) reported that, with the iPex (NSK, Tochigi, Japan) EAL, the file extended beyond the major foramen in 26.3% of the samples.

In addition, some authors have observed that EALs used with rotary Ni–Ti files cannot determine and control the apical extent of rotary instrumentation accurately. Jakobson *et al.* (2008) found that the auto-reverse function of the Root ZX II with the Low-Speed Handpiece unit could not control the apical extent of rotary instrumentation when the auto-reverse function was set to 1. Uzun *et al.* (2008) observed that, when the auto-reverse function was used, the Tri Auto ZX (J Morita Co., Kyoto, Japan) and TCM Endo V (Nouvag, Goldach, Switzerland) EALs instrumented beyond the major foramen in 60% and 95% of cases of retreatment, respectively. Siu *et al.* (2009) reported that the rotary Ni–Ti file protruded beyond the major foramen 28.6% of the time for the Root ZX II with the Low-Speed Handpiece module (J. Morita USA, Tustin, CA, USA), 28.6% of the time for the Apex NRG XFR (Medic

NRG Ltd, Tel Aviv, Israel) attached to the Brasseler handpiece (Brasseler USA, Savannah, GA, USA) and 25% of the time for the Mini Apex Locator attached to the Brasseler handpiece. On the basis of these results, some authors have proposed that, when determining the WL, the instrument should be withdrawn by approximately 0.5 mm from the position given by some EALs (Wrbas *et al.* 2007, Pascon *et al.* 2009). However, the range of values of WL obtained with EALs is broad (i.e. the standard deviation is high), and thus, the WL will be underestimated in some cases, although in others it will be overestimated. By following the recommendations of the above-mentioned authors, the WL would be underestimated more frequently; underestimation of the WL can lead to insufficient debridement of the root canal and may jeopardize the outcome of the treatment (Sjögren *et al.* 1990).

In the light of the concerns about overestimation of the WL, it is important to understand the effects of overinstrumentation on the major foramen when the WL has been overestimated. The aim of the study was to evaluate the morphological changes in the major foramen after overinstrumentation with the ProTaper Universal and ProFile Vortex rotary instruments.

The null hypothesis was that ProTaper Universal and the ProFile Vortex would demonstrate the same morphological changes to the major foramen when used to prepare the root canal with the file tip protruding 1 mm beyond the working length (0.5 mm beyond the major foramen).

## Materials and methods

### Selection of root canals

Fourteen maxillary and 14 mandibular molar teeth with complete root formation and no history of endodontic treatment were used. The teeth were extracted because of periodontal disease and comprised a total of 28 mesiobuccal root canals. For the maxillary molars, the main mesiobuccal root canal was chosen, and only mesiobuccal canals from mesial roots that had two separate orifices that terminated in two separate foramina were selected for the mandibular molars. Teeth were only selected if they allowed placement of a size 06 K-file to the major foramen and did not allow passive placement of a size 15 K-file to within 1 mm of the major foramen. The teeth were cleaned, disinfected, immersed in 0.9% saline solution and stored at room temperature. The root canals were divided equally into two instrumentation groups, such that there was an equitable distribution of canal numbers, canal curvatures and radii between the two groups. Both the ProTaper Universal group and the ProFile Vortex group contained seven mesiobuccal canals from maxillary molars and seven from mandibular molars. The angle of curvature and radius of each canal were determined from periapical radiographs, in accordance with the method of Pruett *et al.* (1997).

The means and standard deviations of the angles and radii of curvature of the root canals in the ProTaper group were 33.8 ± 10.1 degrees and 4.83 ± 1.14 mm, and in the ProFile Vortex group, 31.14 ± 8.32 degrees and 5.21 ± 1.81 mm. A *t*-test showed no statistically significant differences in these variables between the two groups.

### Preparation of the model and root canal instrumentation

All the teeth were shortened to a length of 18 mm. Each tooth was placed coronally in a customized silicone block, leaving the apical portion of the root visible. The teeth could be removed and repositioned in the block easily to allow instrumentation and irrigation. The silicone block was adjusted with precision on an acrylic base coupled to a stereomicroscope to visualize the position of the major foramen. Each root was illuminated directly and orientated until the major foramen was located in the middle of and parallel to the objective lens, which allowed the entire major foramen to be observed under the stereomicroscope. The major foramen was photographed at 20× magnification using a 35-mm digital camera coupled to the stereomicroscope (pre-instrumentation photograph, [Po0]); (Fig. 1a).

The WL was established with a size 06 K-file. The file was introduced into each canal until the file tip became visible through the major foramen under a stereomicroscope at 20× magnification. The file was then withdrawn until the tip was tangential to the major foramen. The silicone stop was adjusted to the nearest flat anatomical tooth landmark, which was chosen as a reference for measurement of the root canal. The distance between the file tip and the rubber stop was measured under a stereomicroscope at 4.5× magnification with a millimetre ruler. Subsequently, 0.5 mm was subtracted from this measurement, and the resulting value was considered to be the WL.

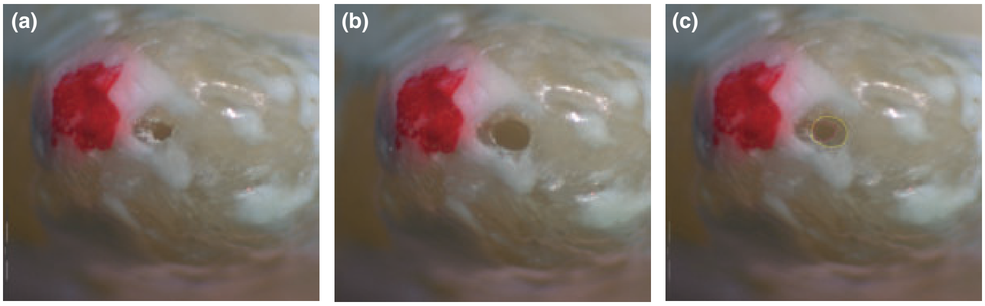


**Figure 1** (a) Pre-instrumentation photograph, [Po0]. (b) Post-instrumentation photograph [Po3], after use of the F1 ProTaper Universal. (c) F1 image [Po3] superimposed over its pre-instrumentation image [PoO].

A customized jig was designed in silicone (Optosil P Plus® HERAEUS KULZER, Hanau, Germany) and provided a reproducible position for the digital dental X-ray sensor and cone alignment. A size 15 K-file was placed in the root canal to the WL, and two digital radiographs (Kodak RVG 6100; Kodak, Rochester, NY, USA) were taken of each tooth. The first radiograph was obtained orthoradially. Then, the tooth was rotated through 90°, and a second radiograph was taken. The radiographs were transferred to AutoCad 2009 (Autodesk Inc, San Rafael, CA, USA), and the angle and radius of curvature of each root canal were measured.

Group A was assigned to preparation with ProTaper Universal instruments and group B to preparation with ProFile Vortex instruments. Both the ProTaper Universal and ProFile Vortex instruments were used with a 16 : 1 reduction handpiece (X-Smart; Dentsply Maillefer) powered by a torque-limited electric motor (X-Smart; Dentsply Maillefer). The instrumentation was carried out in accordance with the manufacturer's instructions. Vortex rotary files were used at 400 rpm and ProTaper rotary files at 300 rpm. Table 1 shows the instrument sequence for each group.

**Table 1** Instrumentation for each system

| ProTaper | | ProFile Vortex | | |
|---|---|---|---|---|
| Type | | Length | | |
| Size 10 K-File | | WL | | |
| Size 15 K-File | | WL | | |
| Size 20 K-File | | WL | | |
| Type | Length | Taper | Size | Length |
| SX | Meet resistance | 0.06 | 40 | Meet resistance |
| Size 10 K-File | WL + 1 mm | 0.06 | 35 | Meet resistance |
| S1 | WL + 1 mm | 0.06 | 30 | Meet resistance |
| S2 | WL + 1 mm | 0.06 | 25 | Meet resistance |
| F1 | WL + 1 mm | 0.06 | 20 | WL |
| F2 | WL + 1 mm | 0.02 | Size 10 K-File | WL + 1 mm |
| F3 | WL + 1 mm | 0.06 | 15 | WL + 1 mm |
| | | 0.06 | 20 | WL + 1 mm |
| | | 0.06 | 25 | WL + 1 mm |
| | | 0.06 | 30 | WL + 1 mm |

WL, working length.

## ProTaper Universal

A glide path up to a size 20 K-file was created to the WL before instrumentation. The teeth were pre-flared with an SX ProTaper file, which was applied in a brushing motion away from the furcation. Subsequently, a size 10 K-file was introduced passively into the root canal until the file tip protruded 1 mm beyond the WL (0.5 mm beyond the major foramen). The rotary files were withdrawn immediately upon reaching the WL + 1 mm. ProTaper instruments were used up to F3 until the file tip protruded 1 mm beyond the WL (Table 1).

## ProFile Vortex

In the second group, the glide path and patency were established in an identical manner to those of group A. The canals were prepared using 0.06 tapered instruments in a crown-down technique, starting with a size 40 file, followed by sizes 35, 30, 25 and 20. It should be noted that only the size 20, 0.06 taper file reached the WL. Subsequently, the root canals were instrumented with size 15, 0.06 taper, size 20, 0.06 taper, size 25, 0.06 taper, and size 30, 0.06 taper files until the file tip protruded 1 mm beyond the WL (Table 1).

In both groups, after each instrument had been used and the root canal was irrigated with 2 mL of 5.25% sodium hypochlorite solution using a plastic syringe with a 27-gauge closed-end needle (Hawe Max-I-probe; Hawe Neos, Bioggio, Switzerland). In both groups, each instrument was used to enlarge three canals and was then discarded. During the study, three instruments were discarded owing to surface deformation.

Digital images of the major foramen (Fig. 1b) were taken post-instrumentation following an identical method to that used for the pre-instrumentation images. The major foramen was photographed after the use of each single instrument. The root canals and the major foramen were dried carefully before each photograph was taken.

All photographs were transferred to Adobe Photoshop (Adobe Systems, Inc, San Jose, CA, USA) to outline the perimeter of the major foramen. Photoshop was used to transform each image to 50% transparency and to superimpose each photograph separately over its pre-instrumentation image (PoO) (López *et al.* 2008). Precision was achieved by marking the apical surface with indelible dye, which allowed the post-instrumentation image to be superimposed over the pre-instrumentation images (Fig. 1c).

The superimposed images were transferred to AutoCAD (Autodesk Incorporated), which was used to calculate and pinpoint the centre of gravity (Paqué *et al.* 2005) (CG; the mean location of all the mass in a system) of each Po0 (Fig. 2).

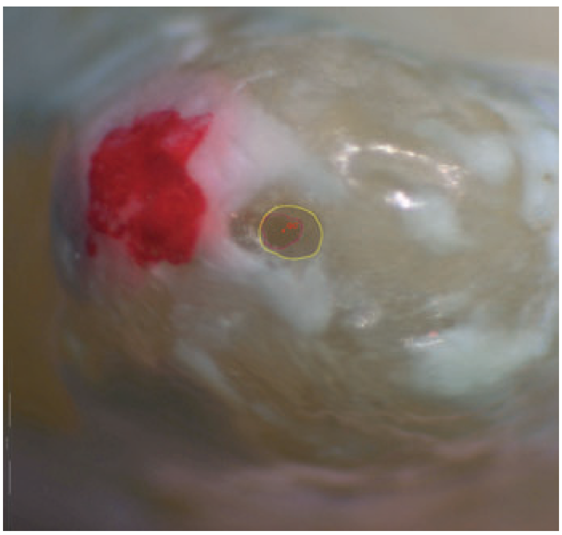

**Figure 2** The superimposed images were transferred to AutoCAD, which was used to calculate and pinpoint the centre of gravity (CG).

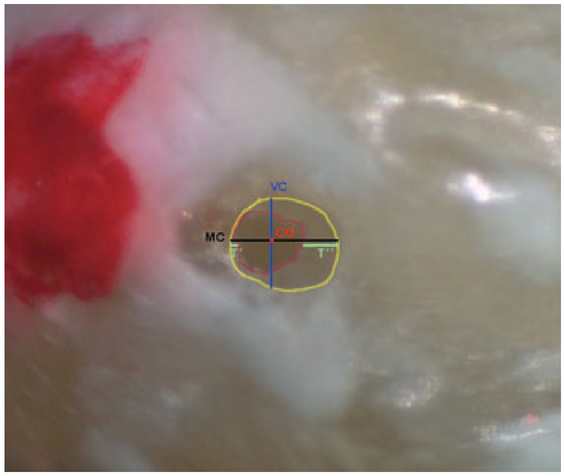


**Figure 3** Definition of transportation (T = T′ − T″) and centring ability (ratio = T′/T″ or T″/T′). Representation of the two directions of measurement: MC, direction of maximum curvature (black line); VC, direction vertical to the maximum curvature (blue line).

## Image analysis

The following parameters were used to evaluate the ability of the instruments to shape the canal:

### *Canal transportation*

Transportation of the canal after instrumentation was measured in accordance with the method described by Yang *et al.* (2007). Transportation was calculated for the major foramen in two directions (Fig. 3): the direction of maximum curvature (MC) and the direction vertical to the maximum curvature (VC).

### *Centring ability*

According to Gambill *et al.* (1996), the mean centring ratio indicates the ability of the instrument to stay centred in the canal. The centring ability of the instrument was calculated from the ratio of T′/T″ or T″/T′ in accordance with the method of Gambill *et al.* (1996). Centring ability was also calculated in two directions (Fig. 3): MC and VC. A result of ‘1’ indicates perfect centring ability.

### *Shape of the major foramen*

The shape of the major foramen after instrumentation was measured in accordance with the method described by Marroquin *et al.* (2007). Two measurements of the diameter, defined as wide and narrow, were made for each major foramen. A major foramen

**Table 2** Absolute values (mean ± SD) for transportation (μm)

| | File | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Transportation | S1 | +/– | S2 | +/– | F1 | +/– | F2 | +/– | F3 | +/– | V15 | +/– | V20 | +/– | V25 | +/– | V30 | +/– |
| Direction of maximum curvature | 27.81 | 22.88 | 36.64 | 24.15 | 42.55 | 29.83 | 56.95 | 45.15 | 88.95 | 98.48 | 27.76 | 29.90 | 36.73 | 42.45 | 48.05 | 46.68 | 73.67 | 63.46 |
| Direction vertical to the maximum curvature | 5.88 | 5.07 | 8.64 | 5.28 | 9.68 | 7.05 | 17.95 | 13.59 | 26.70 | 14.60 | 5.60 | 3.25 | 7.55 | 8.43 | 9.45 | 7.42 | 14.94 | 12.47 |

with a difference equal to or greater than 0.02 mm between the wide and narrow diameters was defined as having an oval instead of a round shape.

### Analysis of data

The values for canal transportation and centring ability were analysed using ANOVA followed by post hoc least significance difference (LSD) multiple comparisons. When the ANOVA test indicated a significant difference, the LSD multiple range test procedure was used to ascertain which means differed from the others. Significance was considered at $P < 0.05$.

## Results

### Transportation

Table 2 shows the mean values for transportation after instrumentation for each file. The F3 ProTaper Universal instrument had a higher mean value for transportation in the direction of MC ($P < 0.05$) than the S1, S2 and F1 ProTaper Universal instruments and the size 15, 0.06 taper, size 20, 0.06 taper, and size 25, 0.06 taper ProFile Vortex instruments. The F2 and F3 ProTaper Universal instruments had a higher mean value for transportation in the direction of VC ($P < 0.05$) than the S1, S2 and F1 ProTaper Universal instruments and the size 15, 0.06 taper, size 20, 0.06 taper, and size 25, 0.06 taper ProFile Vortex instruments. The F3 ProTaper Universal instrument had a larger mean value for transportation in the direction of VC ($P < 0.05$) than the F2 ProTaper Universal instrument. The ProFile Vortex size 30, 0.06 taper instrument had a larger mean value for transportation in the directions of MC and VC ($P < 0.05$) than the S1 ProTaper Universal instrument and the size 15, 0.06 taper ProFile Vortex instrument. No significant differences were observed amongst the other instruments.

### Centring ability

The centring ability (as expressed by the centring ratio) for each instrument in the two directions is detailed in Table 3. There were no significant differences amongst the different instruments with respect to centring ability in either direction ($P > 0.05$).

### Shape of the major foramen

The S1, S2, F1, F2 and F3 ProTaper Universal files and the size 15, 0.06 taper, size 20, 0.06 taper, size 25, 0.06 taper and size 30, 0.06 taper ProFile Vortex files produced an oval foramen in 71% (10/14), 71%

**Table 3** Absolute values (mean ± SD) for centring ability (ratio)

| | File | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Centring ability | S1 | +/– | S2 | +/– | F1 | +/– | F2 | +/– | F3 | +/– | V15 | +/– | V20 | +/– | V25 | +/– | V30 | +/– |
| Direction of maximum curvature | 0.341 | 0.26 | 0.278 | 0.26 | 0.299 | 0.15 | 0.307 | 0.22 | 0.344 | 0.25 | 0.353 | 0.29 | 0.307 | 0.28 | 0.259 | 0.19 | 0.240 | 0.16 |
| Direction vertical to the maximum curvature | 0.542 | 0.32 | 0.563 | 0.19 | 0.658 | 0.19 | 0.623 | 0.28 | 0.546 | 0.25 | 0.537 | 0.26 | 0.691 | 0.16 | 0.724 | 0.15 | 0.525 | 0.28 |

 

(10/14), 85% (12/14), 85% (12/14), 71% (10/14), 71% (10/14), 85% (12/14), 85% (12/14) and 89% (8/9) of the cases. In five of the samples, the size 30, 0.06 taper ProFile Vortex file could not pass the major foramen.

## Discussion

The purpose of this study was to evaluate the morphological changes in the major foramen after overinstrumentation with ProTaper Universal and ProFile Vortex rotary instruments. In general, two experimental models are used to evaluate the preparation of root canals with different instruments: (i) simulated root canals in clear resin blocks and (ii) root canals in extracted human teeth.

In simulated root canals in resin, the diameter, length and angle of curvature of the root canals are standardized. However, the resin might not represent clinical conditions owing to differences in the surface texture, hardness and cross sectioning of dentine (Bertrand *et al.* 2001). Moreover, the heat generated by rotary instruments through friction may cause the resin to melt (Rhodes *et al.* 1999). Extracted teeth provide conditions that are close to the clinical situation (Schäfer & Vlassis 2004). Despite variations in the morphology of natural teeth, efforts were made in this study to ensure comparability of the experimental groups. On the basis of the initial radiographs, the two groups were balanced with respect to the angles and radii of curvature of the canals. The use of an operator-driven instrument rather than a standardized computer-driven instrument has the drawback of introducing operator bias but the advantage of simulating clinical conditions wherein an operator can compensate for the shortcomings of the instrument by modifying digital pressure (Ounsi *et al.* 2011). It is important to highlight that the present study investigated two types of Ni–Ti rotary instruments. Thus, the results obtained cannot be directly extrapolated to other instruments with different designs (Ounsi *et al.* 2011).

Radiographic evaluation allows only a two-dimensional evaluation of the root canal (Sydney *et al.* 1991). In this study, as in others, pre- and postoperative photographs of the cross section of the root canal were evaluated, which enabled the most important parameters of root canal preparation, i.e. transportation, centring ability, cross-sectional area and the shape of the major foramen, to be assessed (Hülsmann *et al.* 2003).

Fourteen canals in each group were used in this study. Six instruments were used for the ProTaper group for each canal and four instruments for the Vortex group. Having used each instrument, the major foramen was measured twice to obtain the direction of maximum deformation and the direction vertical to maximum deformation. Next transportation and centring ability were analysed. Thus, 1164 measurements were obtained for the two groups, and the statistical analysis showed significant differences. For this reason, the sample was not increased.

It is important to note that the standard deviations were often quite close to the mean values themselves. This variation indicates that even with the same experienced operator, the outcome is subject to considerable differences. This finding agrees with that observed by Ounsi *et al.* (2011), who used standardized simulated canals. Thus, having carried out a linear regression on a possible link between the angle and radius of curvature and the transportation of the major foramen (data not shown), no relationship was observed between these variables and transportation. However, it is important to note that all the canals in this study had curvatures ranging from moderate (4/28) to severe (24/28), in accordance with Di Fiore *et al.* (2006). The results might have varied if straight root canals had been used.

Gonzalez Sanchez *et al.* (2010) observed no transportation in the majority of samples when size 08 stainless steel K-Flex files and size 10 stainless steel reamers were used as patency files. Siqueira *et al.* (2002) reported that using a patency file had no influence on the incidence of flare-ups, even when the file was used by inexperienced practitioners. Torabinejad *et al.* (1988) noted that accidental overextension of small files during determination of the WL had no significant effect on the frequency of post-endodontic pain. These studies suggest that overextension of small files does not necessarily cause post-endodontic pain (Torabinejad *et al.* 1988, Siqueira *et al.* 2002, Arias *et al.* 2009). It appears that the patency file is not as harmful to periapical tissues as some think (Arias *et al.* 2009).

However, although direct evidence of the potentially negative consequences of overinstrumentation is lacking, it can be speculated that overinstrumentation, with the possible exception of the use of the smallest hand files of size 06–10 for apical patency, should be avoided for the following reasons (Haapasalo *et al.* 2003). First, large instruments that are passed through the major foramen can result in direct trauma to periapical tissues (Haapasalo *et al.* 2003), and this could increase the incidence of postoperative pain (Siqueira 2005). Second, overinstrumentation usually precedes overfilling because overinstrumentation can destroy the apical stop (Siqueira 2001, 2005). Overextended filling materials can induce pain through mechanical compression of the periradicular tissues (Siqueira 2005). However, most of the materials that are used to fill root canals are either biocompatible or exhibit cytotoxicity only before setting (Siqueira 2001). Therefore, it is highly improbable that most modern-day endodontic materials would be able to sustain periradicular inflammation in the absence of a concomitant endodontic infection (Siqueira 2001, 2005). Third, extrusion of necrotic debris and microorganisms from the root canal into the periapical area might result in persistent infection, such as periapical actinomycosis, and this poses a potential threat to the long-term outcome of the treatment (Siqueira 2001, 2005, Haapasalo *et al.* 2003). Fourth, creation of an oval foramen instead of a round one might result in a poorer apical seal with a round Gutta-percha master point (complete compensation with a sealer is theoretical) (Haapasalo *et al.* 2003). In the present study, the rotary Ni–Ti instruments did not maintain the original position of the major foramen in general and thus produced oval preparations. In the authors' opinion, it is not a problem of deformation per se, but deformation that normally causes an oval-shaped major foramen, which could hinder root canal filling. The F1, F2 and F3 ProTaper Universal files and the size 20, 0.06 taper, size 25, 0.06 taper, and size 30, 0.06 taper Vortex files created an oval major foramen in 85%, 85%, 71%, 85%, 85% and 89% of cases, respectively. The warm Gutta-percha techniques could fill these oval-shaped major foramina because these procedures can fill other irregularities in the root canal (Bowman & Baumgartner 2002). However, there is no evidence to corroborate that these techniques can fill oval-shaped major foramens correctly after overinstrumentation. In the case of a poor apical seal, percolation of tissue fluids rich in glycoproteins into the root canal system can supply substrate to surviving microorganisms, which can multiply and reach sufficient numbers to induce or sustain a periradicular lesion (Siqueira 2001, 2005). Fifth, in cases of apical transportation, an increase in the size of the major foramen makes it possible for bacteria to receive nutrients from an inflammatory exudate in the periapical area (Haapasalo *et al.* 2003).

In the present study, the ProTaper Universal instruments had a tendency to cause transportation of the major foramen. The findings of this study concur with those of Yang *et al.* (2007), Kunert *et al.* (2010) and Javaheri & Javaheri (2007). However, the results of the present study cannot be compared directly with those of the above-mentioned studies, owing to the different area of the root canal under study. Previous studies examined the entire length of the canal (apical third to furcation), whereas the current research focused exclusively on the major foramen. The Glossary of Endodontic Terms of the American Association of Endodontists (2003) defines transportation as 'the removal of canal wall structure on the outside curve in the apical half of the canal due to the tendency of files to restore themselves to their original linear shape during canal preparation'. Apical transportation may promote the harbouring of debris and residual microorganisms as a result of insufficient cleaning of the root canals.

According to McSpadden (2007), less canal transportation occurs when the file that is used has greater flexibility, an asymmetrical cross-sectional design and/or a radial land. Transportation of the major foramen after preparation with either the ProTaper or Vortex files was evident. This might be explained by the tapers of the instruments used in this study, in conjunction with the sharp cutting edges of these instruments (neither of the systems has a radial land), and the fact that neither of the systems has an asymmetrical cross-sectional design (McSpadden 2007). Radial lands are especially effective in supporting the edge of the cutting angle and reducing canal transportation because they help to distribute the pressure of the blades more uniformly around the circumference of a curved canal. This is in contrast to files that lack radial lands, which concentrate all the pressure of the cutting edges on the canal wall and tend to straighten the curvature (McSpadden 2007). The size of the taper is one of the main factors involved in apical root transportation because an increase in the taper reduces instrument flexibility (Schäfer *et al.* 2003, McSpadden 2007). Schäfer *et al.* (2003) concluded from their research on the relationship between taper size and flexibility that Ni–Ti files with tapers greater than 0.04 should not be used for apical enlargement of curved canals.

## Conclusions

In most samples, the ProTaper Universal and ProFile Vortex files resulted in transportation of the major foramen and created an oval major foramen after overinstrumentation of the major foramen.

## Disclosure

There are no disclosures with possible commercial associations.

## References

Aguiar CM, de Andrade Mendes D, Câmara AC, de Figueiredo JA (2009) Evaluation of the centreing ability of the ProTaper Universal rotary system in curved roots in comparison to Nitiflex files. *Australian Endodontic Journal* **35**, 174–9.

Arias A, Azabal M, Hidalgo JJ, de la Macorra JC (2009) Relationship between postendodontic pain, tooth diagnostic factors, and apical patency. *Journal of Endodontics* **35**, 189–92.

Bardsley S, Peters CI, Peters OA (2011) The effect of three rotational speed settings on torque and apical force with vortex rotary instruments *in vitro*. *Journal of Endodontics* **37**, 860–4.

Bertrand MF, Lupi-Pégurier L, Médioni E, Muller M, Bolla M (2001) Curved molar root canal preparations using Hero 642 rotary nickel–titanium instruments. *International Endodontic Journal* **34**, 631–6.

Bowman CJ, Baumgartner JC (2002) Gutta-percha obturation of lateral grooves and depressions. *Journal of Endodontics* **28**, 220–3.

Câmara AS, de Castro Martins R, Viana ACD, de Toledo LR, Buono VTL, de Azevedo Bahia MG (2009) Flexibility and torsional strength of Protaper and Protaper universal rotary instruments assessed by mechanical tests. *Journal of Endodontics* **35**, 113–6.

Cianconi L, Angotti V, Felici R, Conte G, Mancini M (2010) Accuracy of three electronic apex locators compared with digital radiography: an ex vivo study. *Journal of Endodontics* **36**, 2003–7.

Di Fiore PM, Genov KA, Komaroff E, Li Y, Li L (2006) Nickel–titanium rotary instrument fracture: a clinical practice assessment. *International Endodontic Journal* **39**, 700–8.

Dummer PMH, Al Omari MAO, Bryant S (1998) Comparison of the performance of four files with rounded tips during shaping of simulated root canals. *Journal of Endodontics* **24**, 364–71.

Dunlap CA, Remeikis NA, Begole EA, Rauschenberger CR (1998) An *in vivo* evaluation of an electronic apex locator that uses the ratio method in vital and necrotic canals. *Journal of Endodontics* **24**, 48–50.

ElAyouti A, Weiger R, Löst C (2001) Frequency of overinstrumentation with an acceptable radiographic working length. *Journal of Endodontics* **27**, 49–52.

Gambill JM, Alder M, del Rio CE (1996) Comparison of nickel-titanium and stainless steel hand file instrumentation using computed tomography. *Journal of Endodontics* **22**, 369–75.

Gao Y, Shotton V, Wilkinson K, Phillips G, Johnson WB (2010) Effects of raw material and rotational speed on the cycling fatigue of ProFile Vortex rotary instruments. *Journal of Endodontics* **36**, 1205–9.

*Glossary of Endodontic Terms* (2003), 7th edn. American Association of Endodontists.

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.

Gonzalez Sanchez JA, Duran-Sindreu F, Albuquerque Matos M *et al.* (2010) Apical transportation created using three different patency instruments. *International Endodontic Journal* **43**, 560–4.

Haapasalo M, Udnaes T, Endal U (2003) Persistent, recurrent, and acquired infection of the root canal system post-treatment. *Endodontic Topics* **6**, 29–56.

Haapasalo M, Endal U, Zandi H, Coil JM (2005) Eradication of endodontic infection by instrumentation and irrigation solutions. *Endodontic Topics* **10**, 77–102.

Hülsmann M, Gressmann G, Schäfers F (2003) A comparative study of root canal preparation using FlexMaster and HERO 642 rotary Ni-Ti instruments. *International Endodontic Journal* **36**, 358–66.

Jakobson SJ, Westpalhen VPD, da Silva Neto UX, Fariniuk LF, Picoli F, Carneiro E (2008) The accuracy in the control of the apical extent of rotary canal instrumentation using Root ZX and ProTaper instruments: an *in vivo* study. *Journal of Endodontics* **34**, 1342–5.

Javaheri HH, Javaheri GH (2007) A comparison of three Ni-Ti rotary instruments in apical transportation. *Journal of Endodontics* **33**, 284–6.

Johnson E, Lloyd A, Kuttler S, Namerow K (2008) Comparison between a novel nickel titanium alloy and 508 Nitinol on the cyclic fatigue life of ProFile 25/.04 rotary instruments. *Journal of Endodontics* **34**, 1406–9.

Kum KY, Spängberg L, Cha BY, Il-Young J, Seung-Jong L, Chan-Young L (2000) Shaping ability of three ProFile rotary instrumentation techniques in simulated resin root canals. *Journal of Endodontics* **26**, 719–23.

Kunert GG, Camargo Fontanella VR, de Moura AA, Barletta FB (2010) Analysis of apical root transportation associated with ProTaper Universal F3 and F4 instruments by using digital subtraction radiography. *Journal of Endodontics* **36**, 1052–5.

López FU, Fachin EV, Camargo Fontanella VR, Barletta FB, Só MV, Grecca FS (2008) Apical transportation: a comparative evaluation of three root canal instrumentation techniques with three different apical diameters. *Journal of Endodontics* **34**, 1545–8.

Marroquin BB, El-Sayed MA, Willershausen-Zönnchen B (2007) Morphology of the physiological foramen: I. Maxillary and mandibular molars. *Journal of Endodontics* **30**, 321–8.

McSpadden JT (2007) *Mastering Endodontic Instrumentation*. Chattanooga, TN, USA: Cloudland Institute.

Ounsi HF, Franciosi G, Paragliola KAH *et al.* (2011) Comparison of two techniques for assessing the shaping efficacy of repeatedly used Nickel-Titanium rotary instruments. *Journal of Endodontics* **37**, 847–50.

Paqué F, Barbakow F, Peters OA (2005) Root canal preparation with Endo-Eze AET: changes in root canal shape assessed by micro-computed tomography. *International Endodontic Journal* **38**, 456–64.

Pascon EA, Marrelli M, Congi O, Ciancio R, Miceli F, Versiani MA (2009) An ex vivo comparison of working length determination by 3 electronic apex locators. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, Endodontics* **108**, e147–e51.

Powell SE, Wong PD, Simon JHS (1998) A comparison of the effect of modified and non-modified instrument tips on apical canal configuration. Part II. *Journal of Endodontics* **14**, 224–8.

Pratten DH, McDonald NJ (1996) Comparison of radiographic and electronic working lengths. *Journal of Endodontics* **22**, 173–6.

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

Rhodes JS, Pitt Ford TR, Lynch JA, Liepins PJ, Curtis RV (1999) Micro-computed tomography: a new tool for experimental endodontology. *International Endodontic Journal* **32**, 165–70.

Schäfer E, Dammaschke T (2006) Development and sequelae of canal transportation. *Endodontic Topics*, **15**, 75–90.

Schäfer E, Lohmann D (2002) Efficiency of rotary nickel-titanium FlexMaster instruments compared with stainless steel hand K-Flexofile-Part 1. Shaping ability in simulated curved canals. *International Endodontic Journal* **35**, 505–13.

Schäfer E, Vlassis M (2004) Comparative investigation of two rotary nickel-titanium instruments: ProTaper versus RaCe. Part 1. Shaping ability in simulated curved canals. *International Endodontic Journal* **37**, 229–38.

Schäfer E, Dzepina A, Danesh G (2003) Bending properties of rotary nickel-titanium instruments. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, Endodontics* **96**, 757–63.

Shabahang S, Goon WW, Gluskin AH (1996) An *in vivo* evaluation of Root ZX electronic apex locator. *Journal of Endodontics* **22**, 616–8.

Siqueira JF (2001) Aetiology of root canal treatment failure: why well-treated teeth can fail. *International Endodontic Journal* **34**, 1–10.

Siqueira JF (2005) Reaction of periradicular tissues to root canal treatment: benefits and drawbacks. *Endodontic Topics* **10**, 123–147.

Siqueira JF, Rocas IN, Favieri A *et al.* (2002) Incidence of postoperative pain after intracanal procedures based on antimicrobial strategy. *Journal of Endodontics* **28**, 457–60.

Siu C, Marshall JG, Baumgartner JC, Marshall JG (2009) An *in vivo* comparison of the Root ZX II, the Apex NRG XFR, and Mini Apex Locator by using rotary nickel-titanium files. *Journal of Endodontics* **35**, 962–5.

Sjögren U, Hägglund B, Sündqvist G, Wing K (1990) Factors affecting the long-term results of endodontic treatment. *Journal of Endodontics* **16**, 498–504.

Stöber EK, de Ribot J, Mercadé M *et al.* (2011a) Evaluation of the Raypex 5 and the Mini Apex locator: an *in vivo* study. *Journal of Endodontics* **37**, 1349–52.

Stöber EK, Duran-Sindreu F, Mercadé M, Vera J, Bueno R, Roig M (2011b) An evaluation of Root Zx and iPex apex locators: an *in vivo* study. *Journal of Endodontics* **37**, 608–10.

Sydney GB, Batista A, De Mello LL (1991) The radiographic platform: a new method to evaluate root canal preparation *in vitro*. *Journal of Endodontics* **17**, 570–2.

Torabinejad M, Kettering JD, McGraw JC, Cummings RR, Dwayer TG, Tobias TS (1988) Factors associated with endodontic interappointment emergencies of teeth with necrotic pulps. *Journal of Endodontics* **14**, 261–6.

Uzun O, Topuz O, Tinaz C, Nekoofar MH, Dummer PMH (2008) Accuracy of two root canal length measurement devices integrated into rotary endodontic motors when removing gutta-percha from root-filled teeth. *International Endodontic Journal* **41**, 725–32.

Vaudt J, Bitter K, Neumann K, Kielbassa AM (2009) Ex vivo study on root canal instrumentation of two rotary nickel–titanium systems in comparison to stainless steel hand instruments. *International Endodontic Journal* **42**, 22–33.

Wrbas KT, Ziegler AA, Altenburger MJ, Schirrmeister JF (2007) *In vivo* comparison of working length determination with two electronic apex locators. *International Endodontic Journal* **40**, 133–8.

Yang GB, Zhou XD, Zhang H, Wu HK (2006) Shaping ability of progressive versus constant taper instruments in simulated root canals. *International Endodontic Journal* **39**, 791–9.

Yang GB, Zhou XD, Zheng YL, Zhang H, Shu Y, Wu HK (2007) Shaping ability of progressive versus constant taper instruments in curved root canals of extracted teeth. *International Endodontic Journal* **40**, 707–14.

 