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Flexibility and torsional resistance of three nickel–titanium retreatment instrument systems

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Abstract

Hussne RP, Braga LC, Berbert FLCV, Buono VTL, Bahia MGA. Flexibility and torsional resistance of three Nickel–titanium retreatment instrument systems. *International Endodontic Journal*, **44**, 731–738, 2011.

Aim To assess the dimensional characteristics, flexibility and torsional behaviour of nickel–titanium retreatment instruments.

Methodology Using image analysis software and high-resolution digital images, the instrument length, tip angle, diameter at 3 mm from the tip and the distance between the blades (pitch length) of the following eight instruments were measured ($n = 12$ for each measurement parameter): the ProTaper Universal retreatment (PTU-R) D1, D2 and D3 instruments; the R-Endo R1, R2 and R3 retreatment instruments; and the Mtwo retreatment (Mtwo-R) sizes 25 and 15 retreatment instruments. Maximum torque and the angular deflection at fracture as well as the bending moment at 45° were measured ($n = 12$) according to the International Standards Organisation (ISO) specification number 3630-1. Data were analysed using the analysis of variance ($\alpha = 0.05$).

Results The length of the active part of the instruments was found to vary according to the depth of the canal into which they were designed to reach. The pitch length also increased along the active length. The PTU-R D1 and the Mtwo-R instruments had active tips. Measurements of the bending moment at 45° revealed that the Mtwo-R 15 instrument was the most flexible, whereas the PTU-R D1 was the least flexible. The maximum torque tended to increase as the instrument diameter at 3 mm from the tip increased, whereas the angular deflection at fracture varied in the opposite direction.

Conclusions The geometrical characteristics of the retreatment instruments and their flexibility and torsion behaviour were consistent with their intended clinical application.

Keywords: endodontic retreatment instruments, flexibility, nickel–titanium, torsional resistance.

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Introduction

Nonsurgical root canal retreatment is undertaken in an attempt to re-establish healthy periapical tissue after ineffective treatment or reinfection of a filled root canal system (Schirrmeister *et al.* 2006a). The main causes of treatment failure are retained microorganisms through insufficient cleaning, root fractures, missed canals, inadequate filling and coronal or apical leakage (Siqueira 2001, Ruddle 2004, Nair 2006, Schirrmeister *et al.* 2006b). Endodontic retreatment is often indicated to eliminate or to substantially reduce the microbial load from the root canal by thoroughly removing the root filling to enable effective cleaning, shaping and refilling of the root canal system (Stabholz & Friedman 1988, Gu *et al.* 2008).

Several techniques have been recommended for the removal of root filling materials during retreatment.

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These include endodontic hand files combined with heat or chemical solvents, ultrasonic instruments, lasers and engine-driven rotary files (Vidučić *et al.* 2003, Ruddle 2004). However, previous studies that employed these techniques have reported that completely clean canal walls were never produced (Kosti *et al.* 2006, Schirrmeister *et al.* 2006a, Saad *et al.* 2007). Various nickel–titanium (NiTi) rotary instruments to enhance removal of the filling material from the root canal walls have been developed, and their efficacy, cleaning ability and safety have been studied (Schäfer *et al.* 2003, Ayar & Love 2004, Gu *et al.* 2008, Tasdemir *et al.* 2008, Fenoul *et al.* 2010).

Recently, three systems of NiTi rotary retreatment instruments have been introduced: the ProTaper Universal retreatment (PTU-R) instruments (Dentsply Maillefer, Ballaigues, Switzerland), the Mtwo retreatment (Mtwo-R) files (VDW, Munich, Germany) and the R-Endo instruments (Micro-Mega, Besançon, France). These instruments are specifically designed for use in removal gutta-percha. The PTU-R instruments, the D1, D2 and D3, are manufactured in three sizes, 30, 25 and 20, respectively, with 0.09, 0.08 and 0.07 tapers; these instruments are designed for the removal of filling materials from the coronal, middle and apical portions of root canals (Huang *et al.* 2007, Gu *et al.* 2008). The R-Endo system, which consists of three size-25 instruments, the R1, R2 and R3 with 0.08, 0.06 and 0.04 tapers, respectively, is designed to work in each root canal third (Fenoul *et al.* 2010). The Mtwo-R file sizes 15 and 25, both with 0.05 taper, were designed with two blades, a tighter pitch that increases in the distal direction and an active point for easy penetration (Somma *et al.* 2008).

A number of studies have assessed the clinical efficacy of the rotary NiTi retreatment systems (Huang *et al.* 2007, Giuliani *et al.* 2008, Gu *et al.* 2008, Só *et al.* 2008, Somma *et al.* 2008, Fenoul *et al.* 2010), and some found that they were effective for removing filling material (Giuliani *et al.* 2008, Gu *et al.* 2008, Somma *et al.* 2008). The amount of debris that was extruded beyond the apical foramen during removal of material was analysed by Huang *et al.* (2007), who reported that the rotary instruments produced significantly less extrusion compared to the hand files and solvent techniques.

Despite the evident advantages of rotary techniques, unexpected instrument fracture is not uncommon, especially for less-experienced operators (Mandel *et al.* 1999, Peters & Barbakow 2002, Yared 2002, Yared *et al.* 2003, Vieira *et al.* 2008). Failure because of torsional overload has been reported as the most common cause of fracture of the rotary NiTi instruments (Sattapan *et al.* 2000). Thus, knowledge of the mechanical properties of these instruments is of fundamental importance for the practicing dentist. Torsional failure occurs when the tip of the instrument is locked in the canal whilst the shaft continues to rotate. When the elastic limit of the metal is exceeded, the instrument undergoes plastic deformation, which can be followed by fracture if the load is sufficiently high (Peters & Barbakow 2002). There is a strong relationship between the torsional and bending characteristics of the instruments and their diameter (Peters & Barbakow 2002, Bahia *et al.* 2006) and cross-sectional configuration (Berutti *et al.* 2003, Melo *et al.* 2008, Câmara *et al.* 2009).

The purpose of this study was to characterize the dimensional aspects of the three types of NiTi retreatment instruments mentioned earlier and to assess their flexibility and torsional resistance using mechanical tests. The null hypothesis is that retreatment instruments with different dimensions present the same flexibility and torsional resistance.

Materials and methods

Eight instrument types were evaluated: 72 ProTaper Universal rotary retreatment (PTU-R) instruments, which included 24 each of the D1, D2 and D3 instruments; 72 R-Endo instruments, which included 24 each of the R1, R2 and R3 instruments; and 48 Mtwo-R instruments, which included 24 each of the size 15 and size 25. Prior to mechanical testing, 12 instruments of each of the eight types and sizes were randomly selected and photographed in a standardized manner using a high-resolution digital camera (Canon 20D, Tokyo, Japan) for the assessment of the tip angle and instrument diameter at 3 mm from the tip, based on ANSI/ADA specification number 101. The measurements were taken on the digital images, using ImagePro Plus 6.0 software (Media Cybernetics, Silver Spring, MD, USA). The measurements of the length of the active part of the instruments and the distance between the blades (pitch length) were also taken on the digital images.

One group comprising 12 of each of the eight instrument types (n = 12 each) was tested for bending resistance according to specification International Standards Organisation (ISO) 3630-1: PTU-R D1, D2 and D3; R-Endo R1, R2 and R3; and Mtwo-R sizes 15 and 25. The apparatus (Fig. 1) and test conditions were

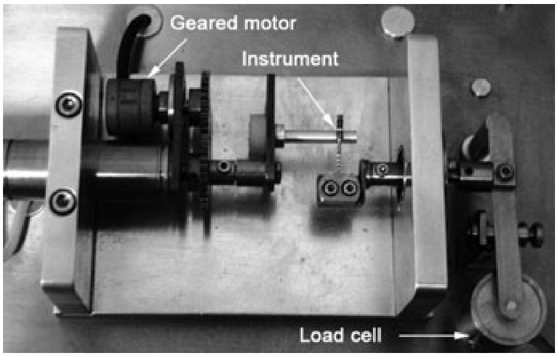

Figure 1 Apparatus for testing bending resistance.

similar to that described in the specification with the instrument secured 3 mm from the tip and then bent to a 45° angle to its long axis whilst the bending moment was automatically recorded by a load cell. The bending moment values were obtained by multiplying the registered bending force by the distance between the point at which the force was applied and the fixed tip of the instrument.

Another group that was composed of 12 of each of the eight instrument types was tested in torsion until fracture, based on specification ISO 3630-1, using a torsion test device (AN8050; Analógica, Belo Horizonte, MG, Brazil) as shown in Fig. 2 (Bahia *et al.* 2006). The rotation speed was set at 2 rpm in a clockwise direction. The shaft of each instrument was clamped in a chuck with brass jaws to prevent sliding and was connected to the reversible geared motor of the test apparatus. Three millimetres of the instrument's tip was clamped into another chuck with brass jaws. Continuous recording of the torque and angular deflection, as well as measurements of the maximum torque and angular deflection to failure, was acquired by a specifically designed computer program.

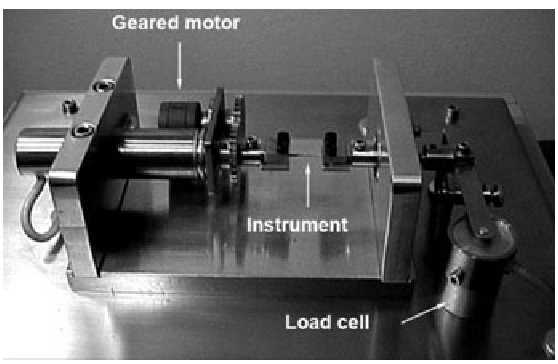

Figure 2 The torsion test device.

Data obtained in the torsion and bending tests were subjected to a one-way analysis of variance (ANOVA). Significance was determined at a 95% confidence level.

Results

The measurement of the length of the active part of the instruments, the tip angle and the diameter at 3 mm from the tip, which is the position at which the instruments were secured during the bending and torsional tests, led to the mean values (and standard deviations) shown in Table 1. The total length of the active part varied from 8.6 to 17.5 mm, and in the three systems that were analysed, this length increased as the diameter of the instrument decreased. Similarly, the mean tip angle increased as the instrument diameter decreased, except for the R-Endo instruments, in which larger tip angles were observed in the thicker instruments. The tip designs of the instruments are shown in Fig. 3; all of the instruments, except the PTU-R D1 and the Mtwo-R 25 and 15, had inactive tips. It can also be observed that the instruments had different tip designs and surface finishing. Figure 4 shows that the pitch length increased sharply along the active part of the PTU-R and Mtwo-R instruments, whereas in the R-Endo instruments, this steep increase was only observed until the third pitch, after which the pitch length increased slowly.

For the presentation of the mechanical test results, the instruments were grouped based on the similarities in their diameters at 3 mm from the tip. Flexibility was

Table 1 Mean values (and standard deviations) of the total length of the active part of the instruments, mean tip angle and diameter at 3 mm from the tip

Instruments	Length of the active part (mm)	Tip angle (degrees)	Diameter at 3 mm from the tip (mm)
ProTaper Universal retreatment			
D1	12.6 (0.1)	63.4 (4.6)	0.49 (0.01)
D2	15.6 (0.0)	65.1 (2.3)	0.42 (0.01)
D3	17.5 (0.1)	65.5 (6.1)	0.35 (0.01)
R-Endo			
R1	8.6 (0.1)	111.3 (6.6)	0.46 (0.01)
R2	12.0 (0.1)	81.8 (3.4)	0.40 (0.01)
R3	16.2 (0.1)	79.7 (4.0)	0.35 (0.01)
Mtwo retreatment			
25	14.4 (0.1)	71.7 (9.6)	0.35 (0.03)
15	17.4 (0.1)	75.5 (7.5)	0.26 (0.04)

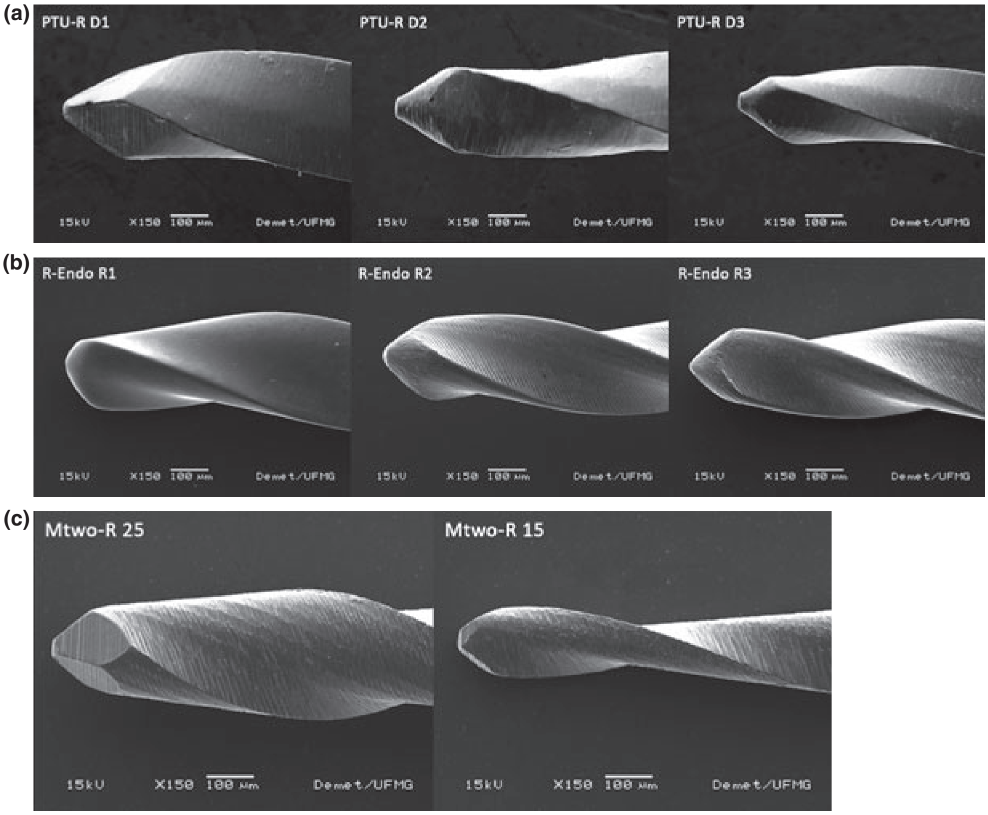

Figure 3 SEM images of the tips of (a) ProTaper Universal retreatment D1, D2 and D3, (b) R-Endo R1, R2 and R3 and (c) Mtwo retreatment sizes 25 and 15 instruments.

characterized by the mean values of the bending moment at 45° (M_B) and increased as the M_B decreased. Figure 5 shows the mean values of the bending moment for the instruments and demonstrates that the Mtwo-R 15 instrument was the most flexible, whilst the PTU-R D1 was the least flexible. The comparative statistical analysis of the bending moments showed statistically significant differences between the pairs of the analysed instruments, which is illustrated in Fig. 5.

The maximum torque until failure (M_T) measures the torsional resistance of the instruments, and the mean values obtained for this parameter and those of the angular deflection at fracture are shown in Fig. 6. The maximum torque tended to increase when the instrument diameter at 3 mm from the tip increased (Fig. 6a), and the mean values of M_T were significantly different ($P < 0.05$) when the instruments were compared to each other, except for the pairs that are indicated in the bar diagram. Figure 6b shows that the angular deflection at fracture tended to increase as the instrument diameter decreased in each system. The results of the comparative statistical analysis of this parameter between the pairs of instruments are also shown in Fig. 6b.

Discussion

Nickel–titanium rotary instruments have increased in popularity, and recently, new retreatment instrument systems based on this technology have become available. This study analysed the dimensional aspects, flexibility and torsional resistance of three NiTi retreatment instrument systems: the PTU-R, the R-Endo and the Mtwo-R. The PTU-R and R-Endo systems are each comprised of three instruments with a convex triangular and triangular cross-section, respectively; they were designed for root filling removal from the coronal, middle and apical thirds of root canals during retreatment. Based on a different concept, the Mtwo-R system consists of only two instruments with a 0.05 taper, sizes 15 and 25, with two blades and an active

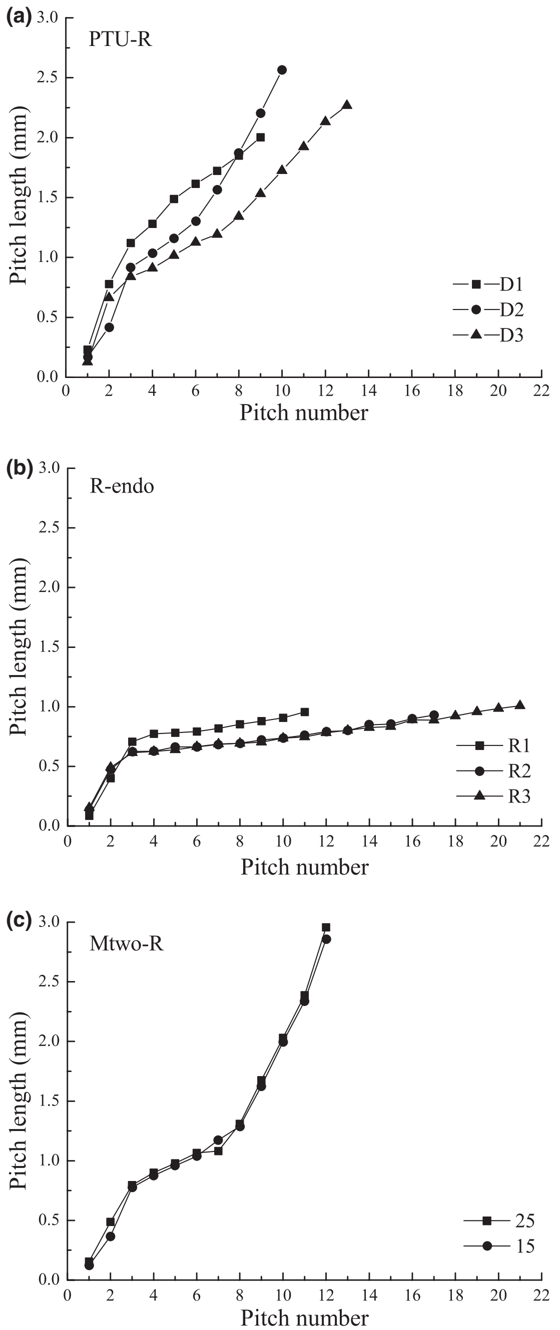

Figure 4 Mean values of the pitch length for (a) ProTaper Universal retreatment, (b) R-Endo and (c) Mtwo retreatment instruments.

point that is claimed provides easy penetration into the gutta-percha.

Although some studies investigated the clinical performance of these retreatment instrument systems (Huang *et al.* 2007, Giuliani *et al.* 2008, Gu *et al.*

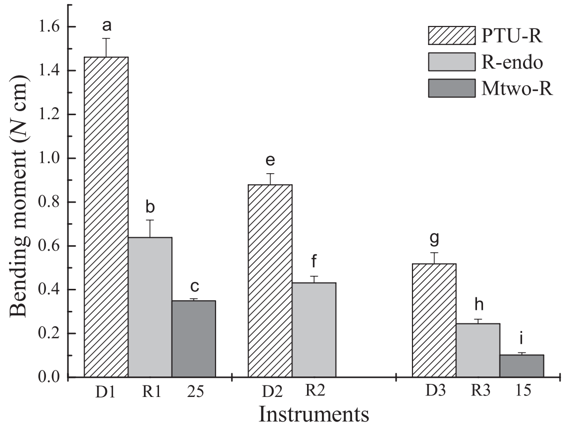

Figure 5 Mean values of the bending moment at 45° (M_B) of the retreatment instruments.

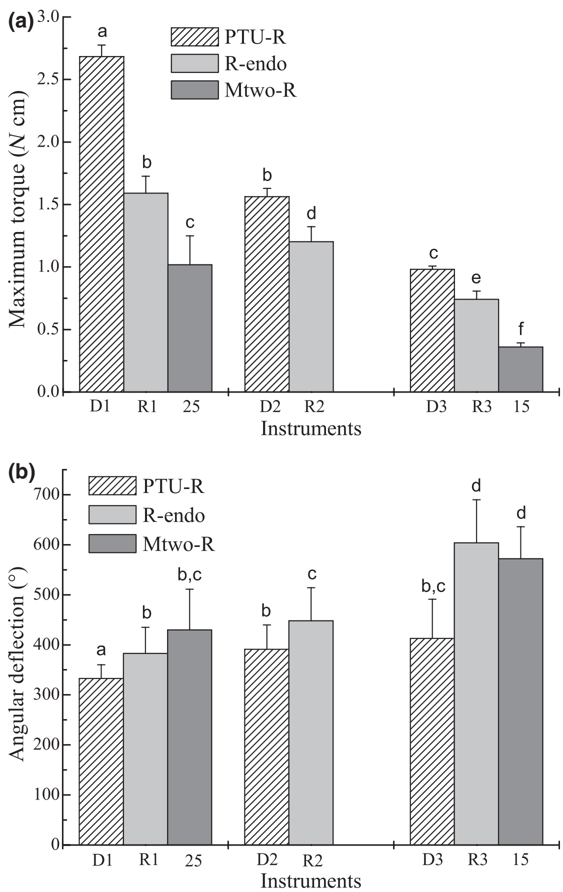

Figure 6 (a) Mean values of the maximum torque (torsional moment, M_T) and (b) the angular deflection at fracture of the retreatment instruments.

2008), their mechanical behaviour has not been thoroughly evaluated. The mechanical properties of endodontic instruments are affected by a variety of factors, such as size, taper, design, alloy composition and thermomechanical processes used during manufacturing (Kuhn & Jordan 2002, Miyai *et al.* 2006). Furthermore, the geometrical shape and the dimensions of the NiTi instruments might play a crucial role in their flexibility and torsional resistance characteristics (Camps & Pertot 1995, Melo *et al.* 2008).

In terms of the shape and dimensions of the instruments, the results of the analysis confirmed that the length of the active part of the instruments, which was consistent with the depth of the canal they were designed to reach, increased as the instrument diameter decreased. In the PTU-R and Mtwo-R instruments, the pitch length increased sharply along the active length, whereas for the R-Endo instruments, this increase in pitch length was less pronounced after the third pitch. In general, a smaller pitch distance tends to provide greater torsional resistance to the instrument and reduced cutting efficiency, whereas a longer pitch length tends to permit higher cutting efficiency and a more efficient removal of debris, in addition to preventing the screw-in effect (Mounce 2003, Diemer & Calas 2004). Therefore, the longer pitch lengths of the PTU-R D1, the R-Endo R1 and the Mtwo-R 25 instruments, which are used for larger volumes of the filling material and the shorter pitch lengths of the other instruments, which are used in the apical third and therefore do not require a substantial cutting efficacy, are clinically justified features.

The tip angle was smaller in the three PTU-R system instruments compared to the two other systems. Consistent with descriptions in the literature (Huang *et al.* 2007, Giuliani *et al.* 2008, Somma *et al.* 2008, Fenoul *et al.* 2010), only the PTU-R D1 and Mtwo-R instruments have active tips (Fig. 3). Because it facilitates the initial penetration into the filling material, this type of tip is appropriate for PTU-R D1 instruments, but is not necessary for the Mtwo-R 15 instruments because these latter instruments can access the apical third, with the potential to increase the risk of the occurrence of ledge, perforation and stripping during use.

Similar to conventional NiTi rotary instruments, there should be a chance of fracture with the retreatment instruments, especially because of torsional overload, which was reported as the most common cause of fracture of rotary NiTi instruments (Sattapan *et al.* 2000). There is a strong relationship between the torsional and bending behaviour of an instrument and its diameter (Peters & Barbakow 2002, Bahia *et al.* 2006) and cross-sectional configuration (Turpin *et al.* 2000, Berutti *et al.* 2003, Melo *et al.* 2008, Câmara *et al.* 2009). Torque is the product of the tangent force on the instrument surface and the distance to its central axis. The results obtained in the present study, which show that the mean values of the maximum torque increased as the instrument diameter at 3 mm from the tip increased, are consistent with other reports in the literature (Peters & Barbakow 2002, Bahia *et al.* 2006, Melo *et al.* 2008, Câmara *et al.* 2009). Thus, the Mtwo-R instruments, which have the smallest diameters at 3 mm, also showed lower torsional resistance compared to the PTU-R and R-Endo instruments. Previous studies indicated that there was no correlation between the instrument diameter and the angular deflection (Gambarini 2000, Bahia *et al.* 2006). Nevertheless, in the present study, the angular deflection at fracture tended to increase as the instrument diameter decreased in all of the evaluated instruments.

Conclusions

Instruments that work specifically in the middle and coronary thirds of the root canal were less flexible, whereas the instruments that are used in on the apical third were found to be less resistant to torsion, but more flexible, which reduces the potential risk of canal transportation.

Acknowledgements

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