Shaping ability of ProFile and K3 rotary Ni-Ti instruments when used in a variable tip sequence in simulated curved root canals

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Abstract

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Aim To compare the shaping ability of ProFile and K3 rotary Ni-Ti instruments when used in a variable tip sequence in simulated curved root canals with different curvature and radius.

Methodology ProFile or K3 .06 taper instruments were used to prepare simulated canals of 20° curvature and 5 mm radius ($n = 10$) and 30° curvature and 3 mm radius canals ($n = 10$) in resin blocks. All canals were prepared to an apical size 40 at 0.5 mm from the canal terminus using a variable tip crown-down sequence. Pre- and postinstrumentation digital images were recorded, and an assessment of the canal shape was determined using a computer image analysis program. The material removal from the inner and outer wall of the canal was measured at 28 measuring points, beginning 0.5 mm from the end-point of the canal and the data compared using the Mann–Whitney *U*-test.

Results In 20° and 30° canals both instruments significantly removed more ($P < 0.05$) material on the outer wall than the inner wall in the apical half of the canal. For ProFile files there was no significant difference in the amount of material removed on the outer canal wall between the 20° and 30° canals. However, in the K3 groups significantly more ($P < 0.05$) outer canal wall was removed in the apical area in 20° canals. When comparing both instruments the results showed that in 20° canals K3 instruments removed more outer and inner canal wall than ProFile instruments ($P < 0.05$) but that there was no significant difference ($P > 0.05$) between the instruments in 30° canals.

Conclusion Within the limitation of this study, both rotary nickel-titanium instruments prepared a well-shaped root canal with minimal canal transportation.

Keywords: canal transportation, nickel-titanium, root canal preparation.

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Introduction

The objective of root canal preparation is to clean and shape the canal system to eliminate necrotic material, microorganisms, and canal irregularities, and to facilitate the placement of a permanent root filling (Schilder 1974). The ideal preparation for a root canal is a continuously tapered funnel shape with the smallest diameter at the apex and the widest diameter at the canal orifice (Schilder & Yee 1984). The shape can be achieved either by hand or by mechanical preparation and is readily produced in straight canals. However, cleaning and shaping of narrow and curved canals with stainless steel instruments can be difficult and may not provide the optimal shape (Weine *et al.* 1975).

Many reports have described the tendency of root canal preparation techniques to cause canal transportation and other procedural problems such as ledge

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formation, apical perforation, and mid-root strip perforation. These complications may compromise the long-term success of treatment by failing to eliminate infection of the root canal system and making obturation more difficult (Weine *et al.* 1975, El-Deeb & Boraas 1985, Al-Omari *et al.* 1992a,b). Various instrumentation techniques and endodontic instruments have been introduced in an attempt to reduce these problems aiming to provide the optimum shaped preparation.

The unique properties of nickel-titanium alloy, such as flexibility, have allowed the development of nickel-titanium endodontic instruments in order to overcome the limitations imposed by stainless steel alloy (Walia *et al.* 1988). Rotary nickel-titanium instruments have been shown to prepare the root canal rapidly, and maintain the canal shape and working length with few aberrations during root canal preparation (Thompson & Dummer 1997a,b,c,d,e,f, 1998a,b,c,d, 2000a,b, Bryant *et al.* 1998a,b). They are available in various designs that differ in tip and taper design, rake angles, helical angles, pitch, and presence of radial lands.

The K3 file (SybronEndo, West Collins, CA, USA) is a rotary instrument with a radial land relief in combination with a positive rake angle, a flattened noncutting tip, and an asymmetrical constant tapered active file design with variable helical flute and variable core diameter (Bergmans *et al.* 2003). These are features that are claimed to enhance cutting-efficiency, debris removal, and file guidance and strength.

A number of articles have reported on the shaping ability of ProFile instruments (Dentsply Maillefer, Ballaigues, Switzerland) (Bryant *et al.* 1998a,b, 1999) whilst to date there is limited published research on the use of K3 instruments. However, Schafer & Florek (2003) recently showed that K3 instruments prepared curved canals rapidly with minimal transportation towards the outer aspect of the curve. The purpose of this study was to compare the shaping ability of ProFile .06 taper and K3 .06 rotary nickel-titanium instruments in simulated root canals with different curvatures and radii when used in a crown-down variable tip sequence.

Materials and methods

Clear acrylic blocks with a simulated root canal (SybronEndo) were selected for study. One set of blocks ($n = 20$) had canals of 20° curvature and 5 mm radius whilst the other set ($n = 20$) had a canal of 30° curvature and 3 mm radius as determined according to Schneider (1971). Both canals were 17.5 mm in length with the curvature commencing at approximately 7 mm from the canal terminus. Canal dimensions were calculated as described below and the apical diameter of the canal was 0.39 ± 0.04 mm and the coronal diameter was 0.78 ± 0.09 mm. Each block had three orientation holes cut into the acrylic with a pear shape number 330 tungsten-carbide bur (Komet, Lemgo, Germany) in a high-speed handpiece, and then an image taken using a digital camera (Nikon D1X; Nikon Corporation, Japan) at a standard object–camera distance of 21 cm. The image was stored as a JPEG file in a personal computer (Compaq nx9010; Hewlett Packard, Malaysia).

Analysis of canal dimensions

Images of the 20° and 30° curve canals were analysed using Adobe Photoshop 7.0 software (Adobe Systems Inc., San Jose, CA, USA). The canal was visualized at 11× magnification and lines were superimposed over the image at 1 mm intervals starting 0.5 mm from the canal terminus for 14 mm. The centre of the canal was identified along a line and the distance at right angle from the centre to the inner and outer canal was measured to the nearest 10 μm. A mean and standard deviation was calculated for each level.

Preparation of simulated canals

In order to standardize access to the curved portion of the canal the straight coronal portion of all the canals was prepared using ProFile orifice shapers (Dentsply Maillefer) (Table 1) in a 16 : 1 reduction mini head handpiece (Dentsply) powered by high torque electric motor (Tecknica/ATR motor, Pistoia, Italy) at 250 rpm. The canals were divided into four groups of 10: Group 1 (ProFile, 20° canal), the canal was prepared with ProFile .06 taper instruments (Dentsply) using the handpiece described previously in a pecking-motion. A variable tip sequence was used from 40 to 35, 30 to 25 in a crown-down sequence until the canal was prepared to a instrument size 40 at 0.06 taper

Table 1 Crown-down sequence used to prepare the straight coronal portion of all simulated canals

ProFile orifice shaper	Depth into canal
Size 6 (0.08 taper, 40 tip size)	3.5 mm
Size 5 (0.08 taper, 40 tip size)	5.5 mm
Size 4 (0.07 taper, 30 tip size)	7.5 mm
Size 3 (0.06 taper, 25 tip size)	9.5 mm

0.5 mm from the canal terminus. Group 2 (K3, 20° canal), the canal was prepared with K3 .06 taper files (SybronEndo) in the same manner as group 1 to a file size 40 at a .06 taper 0.5 mm from the canal terminus. Group 3 (ProFile, 30° canal), the canal was prepared as described for group 1. Group 4 (K3, 30° canal), the canal was prepared as described for group 2.

Each acrylic block was masked with tape so that the canal was instrumented blindly. Copious irrigation with water was used during the preparation and a light coating of an EDTA preparation (RC-PREP; Stone Pharmaceutical, Philadelphia, PA, USA) was applied to the files as a lubricant. After instrumentation the canal was irrigated to remove debris and dried with paper points. Each acrylic block was cleaned and then imaged as described above and the image centred so as to superimpose it over the original image. The prepared canal dimensions were recorded as above and the amount of resin removed at each level calculated. The resultant data was analysed using the Mann–Whitney *U*-test (Schafer & Florek 2003).

Results

Comparison of canal shape produced by ProFile instruments or K3 instruments

Canals with 20° curvature

The results in Table 2 show that the removal of material over the length of the canal was not equal on the inner and outer curves. For both instruments significantly ($P < 0.05$) more material was removed on the outer wall than the inner wall in the apical half of the canal. There was no significant difference in the amount of material removed in the coronal half of canals prepared with ProFile instruments (Table 1, Fig. 1a) whilst in the K3 group more material was removed on the inner curve in the mid-coronal region (level 9–11) (Table 2, Fig. 1b).

Table 3 presents the result comparing the ProFile and K3 groups and demonstrates that in the K3 group significantly ($P < 0.05$) more outer canal wall was removed than in the ProFile group at levels 4, 5, 12, 13 and 14 (Table 3, Fig. 1). K3 significantly ($P < 0.05$) removed more inner canal wall than ProFile along the whole canal length except at the level 3 and 14 (Table 3, Fig. 1).

Canals with 30° curvature

The results show a pattern of unequal canal wall removal by each instrument similar to that seen in 20° canals (Table 4, Fig. 2). Overall, the amount of canal wall material removed was not significantly different between the two instruments (Table 5).

Comparison of canal shape between 20° and 30° canal curvatures

ProFile instrument There was no significant difference in the amount of material removed on the outer curvature between the two canal curvatures (Table 6). More material was removed on the inner wall of 30° curved canals at levels 5, 6, 7, 11, 12, 13 and 14 than in the 20° canals ($P < 0.05$). There was no significant difference at any other level (Table 6).

K3 instrument On the outer wall there was significantly ($P < 0.05$) more material removed in the 20° canals at levels 4 and 5; there were no other significant differences (Table 7). For the inner wall there was no significant differences for material removed at any level between the two canals (Table 7).

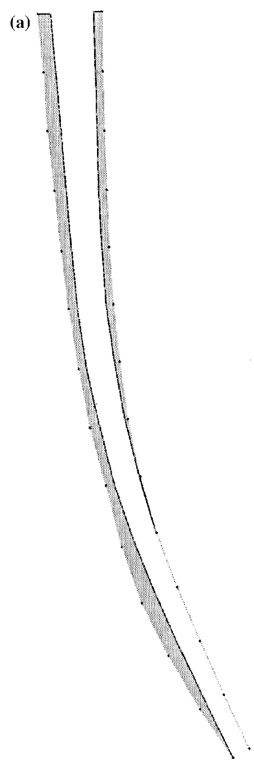

Figure 1 A plot of the mean changes (shaded area) in the canal shape of 20° curved canals as the result of instrumentation with (a) ProFile instruments and (b) K3 instruments ($n = 20$ canals in each case).

Table 2 Comparison of the amount of material removed (μm) from outer and inner canal walls for each file in 20° canals

Level	1	2	3	4	5	6	7	8	9	10	11	12	13	14
ProFile														
Outer	2.0 ± 3.4	10.2 ± 6.12	20.7 ± 9.44	23.4 ± 9.77	22.0 ± 6.15	17.8 ± 5.2	16.3 ± 3.59	14.0 ± 1.63	12.9 ± 3.9	16.6 ± 3.4	19.5 ± 4.0	19.5 ± 2.9	21.6 ± 3.3	22.0 ± 3.6
Inner	0.6 ± 1.58	0.5 ± 0.97	1.5 ± 0.51	0.6 ± 0.97	0.5 ± 0.71	2.8 ± 2.3	6.9 ± 3.45	13.3 ± 3.98	15.5 ± 5.72	16.4 ± 6.5	15.5 ± 7.2	15.2 ± 6.7	15.6 ± 5.6	18.1 ± 5.0
P-value	>0.05	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05
K3														
Outer	4.0 ± 1.38	16.5 ± 7.47	28.0 ± 9.1	33.0 ± 7.48	28.7 ± 8.0	21.5 ± 5.38	17.4 ± 4.74	14.4 ± 2.7	14.9 ± 2.4	16.5 ± 3.9	20.2 ± 4.7	24.1 ± 5.3	27.9 ± 5.0	31.8 ± 6.2
Inner	2.6 ± 2.01	3.1 ± 2.69	0.9 ± 1.2	3.0 ± 2.31	3.6 ± 2.99	6.3 ± 3.74	14.7 ± 4.45	20.6 ± 4.77	25.1 ± 4.3	27.1 ± 4.0	26.2 ± 4.7	24.5 ± 5.2	23.0 ± 6.5	22.3 ± 7.0
P-value	>0.05	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	>0.05	>0.05	**<0.05**	**<0.05**	**<0.05**	>0.05	>0.05	>0.05

Values in bold are statistically significant.

Table 3 Comparison between the files of the amount of material removed (μm) at the different measuring points in simulated 20° curved canals

Level	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Outer canal wall														
ProFile	2.0 ± 3.4	10.2 ± 6.12	20.7 ± 9.44	23.4 ± 9.77	22.0 ± 6.15	17.8 ± 5.2	16.3 ± 3.59	14.0 ± 1.63	12.9 ± 3.9	16.6 ± 3.4	19.5 ± 4.0	19.5 ± 2.9	21.6 ± 3.3	22.0 ± 3.6
K3	4.0 ± 1.38	16.5 ± 7.47	28.0 ± 9.1	33.0 ± 7.48	28.7 ± 8.0	21.5 ± 5.38	17.4 ± 4.74	14.4 ± 2.7	14.9 ± 2.4	16.5 ± 3.9	20.2 ± 4.7	24.1 ± 5.3	27.9 ± 5.0	31.8 ± 6.2
P-value	>0.05	>0.05	>0.05	**<0.05**	**<0.05**	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	**<0.05**	**<0.05**	**<0.05**
Inner canal wall														
ProFile	0.6 ± 1.58	0.5 ± 0.97	1.5 ± 0.51	0.6 ± 0.97	0.5 ± 0.71	2.8 ± 2.3	6.9 ± 3.45	313.3 ± 3.98	15.5 ± 5.72	16.4 ± 6.5	15.5 ± 7.2	15.2 ± 6.7	15.6 ± 5.6	18.1 ± 5.0
K3	2.6 ± 2.01	3.1 ± 2.69	0.9 ± 1.2	3.0 ± 2.31	3.6 ± 2.99	6.3 ± 3.74	14.7 ± 4.45	20.6 ± 4.77	25.1 ± 4.3	27.1 ± 4.0	26.2 ± 4.7	24.5 ± 5.2	23.0 ± 6.5	22.3 ± 7.0
P-value	**<0.05**	**<0.05**	>0.05	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	>0.05

Values in bold are statistically significant.

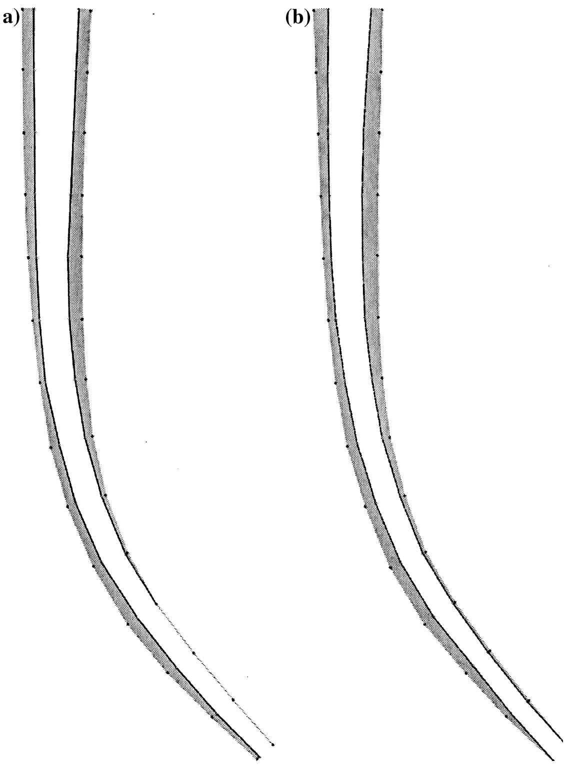

Figure 2 A plot of the mean changes (shaded area) in the canal shape of 30° curved canals as the result of instrumentation with (a) Profile instruments and (b) K3 instruments (n = 20 canals in each case).

Discussion

The objective during instrumentation of a root canal is to maintain the original canal curvature in order to produce a continuously tapering and conical form with the smallest diameter at the end-point of the preparation (Schilder & Yee 1984). The problem of straightening of the canal during instrumentation occurs mostly in curved canals at the outer wall of the apical portion of the canal (Weine *et al.* 1975) and the inner aspect of the mid-root of the canal (Abou-Rass *et al.* 1980). Rotary nickel-titanium instruments have been shown to prepare the root canal rapidly, and maintain the canal shape and working length with fewer aberrations compared with hand instrumentation (Thompson & Dummer 1997a,b,c,d,e,f, 1998a,b,c,d, 2000a,b, Bryant *et al.* 1998a,b). This is due to the combination of the crown-down instrumentation technique, and file design characteristics such as flexibility, flute design, and noncutting tip. The aim of the present study was to compare the shaping ability of Profile .06 taper

Table 4 Comparison of the amount of material removed (μm) from outer and inner canal walls for each file in 30° canals

Level	1	2	3	4	5	6	7	8	9	10	11	12	13	14
ProFile														
Outer	6.2 ± 7.18	12.7 ± 9.67	18.0 ± 8.6	20.8 ± 5.75	18.4 ± 5.6	17.3 ± 5.9	17.6 ± 6.67	14.8 ± 7.9	15.3 ± 5.72	17.5 ± 4.7	19.9 ± 6.1	21.7 ± 7.4	23.4 ± 7.8	23.1 ± 8.2
Inner	1.6 ± 3.69	2.1 ± 4.12	1.9 ± 3.87	4.6 ± 6.19	6.9 ± 8.28	11 ± 7.66	15.3 ± 7.2	17.7 ± 7.13	20.7 ± 6.7	20.4 ± 6.5	20.6 ± 6.4	20.4 ± 5.8	20.9 ± 6.8	22.5 ± 6.0
P-value	>0.05	**<0.05**	**<0.05**	**<0.05**	**<0.05**	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05
K3														
Outer	1.9 ± 3.54	6.5 ± 3.21	13.6 ± 4.67	18.6 ± 3.92	13.6 ± 4.67	20.4 ± 2.55	18.8 ± 2.82	14.7 ± 2.06	12.8 ± 2.3	14.0 ± 2.2	17.1 ± 4.0	20.0 ± 5.9	23.8 ± 6.2	27.3 ± 4.8
Inner	0.4 ± 0.97	1.6 ± 1.71	1.5 ± 1.43	1.2 ± 1.4	2.7 ± 2.54	5.3 ± 3.47	11.7 ± 5.54	17.0 ± 4.42	22.9 ± 3.6	23.9 ± 3.7	23.0 ± 4.2	22.7 ± 4.7	20.5 ± 3.8	18.8 ± 3.5
P-value	>0.05	**<0.05**	**<0.05**	**<0.05**	**<0.05**	**<0.05**	>0.05	>0.05	**<0.05**	**<0.05**	**<0.05**	>0.05	>0.05	**<0.05**

Values in bold are statistically significant.

Table 5 Comparison between the files of the amount of material removed (μm) at the different measuring points in simulated 30° curved canals

Level	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Outer canal wall														
ProFile	6.2 ± 7.18	12.7 ± 9.67	18.0 ± 8.6	20.8 ± 5.75	18.4 ± 5.6	17.3 ± 5.9	17.6 ± 6.67	14.8 ± 7.9	15.3 ± 5.72	17.5 ± 4.7	19.9 ± 6.1	21.7 ± 7.4	23.4 ± 7.8	23.1 ± 8.2
K3	1.9 ± 3.54	6.5 ± 3.21	13.6 ± 4.67	18.6 ± 3.92	13.6 ± 4.67	20.4 ± 2.55	18.8 ± 2.82	14.7 ± 2.06	12.8 ± 2.3	14.0 ± 2.2	17.1 ± 4.0	20.0 ± 5.9	23.8 ± 6.2	27.3 ± 4.8
P-value	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	**<0.05**	>0.05	>0.05	>0.05	>0.05
Inner canal wall														
ProFile	1.6 ± 3.69	2.1 ± 4.12	1.9 ± 3.87	4.6 ± 6.19	6.9 ± 8.28	11.0 ± 7.66	15.3 ± 7.2	17.7 ± 7.13	20.7 ± 6.7	20.4 ± 6.5	20.6 ± 6.4	20.4 ± 5.8	20.9 ± 6.8	22.5 ± 6.0
K3	0.4 ± 0.97	1.6 ± 1.71	1.5 ± 1.43	1.2 ± 1.4	2.7 ± 2.54	5.3 ± 3.47	11.7 ± 5.54	17.0 ± 4.42	22.9 ± 3.6	23.9 ± 3.7	23.0 ± 4.2	22.7 ± 4.7	20.5 ± 3.8	18.8 ± 3.5
P-value	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05

Values in bold are statistically significant.

Table 6 Comparison between 20° and 30° canals of the material removed (μm) from the canal walls by ProFile files

Level	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Outer canal wall														
20°	2.0 ± 3.4	10.2 ± 6.12	20.7 ± 9.44	23.4 ± 9.77	22.0 ± 6.15	17.8 ± 5.2	16.3 ± 3.59	14.0 ± 1.63	12.9 ± 3.9	16.6 ± 3.4	19.5 ± 4.0	19.5 ± 2.9	21.6 ± 3.3	22.0 ± 3.6
30°	6.2 ± 7.18	12.7 ± 9.67	18.0 ± 8.6	20.8 ± 5.75	18.4 ± 5.6	17.3 ± 5.9	17.6 ± 6.67	14.8 ± 7.9	15.3 ± 5.72	17.5 ± 4.7	19.9 ± 6.1	21.7 ± 7.4	23.4 ± 7.8	23.1 ± 8.2
P-value	**<0.05**	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05
Inner canal wall														
20°	0.6 ± 1.58	0.5 ± 0.97	1.5 ± 0.51	0.6 ± 0.97	0.5 ± 0.71	2.8 ± 2.3	6.9 ± 3.45	13.3 ± 3.98	15.5 ± 5.72	16.4 ± 6.5	15.5 ± 7.2	15.2 ± 6.7	15.6 ± 5.6	18.1 ± 5.0
30°	1.6 ± 3.69	2.1 ± 4.12	1.9 ± 3.87	4.6 ± 6.19	6.9 ± 8.28	11.0 ± 7.66	15.3 ± 7.2	17.7 ± 7.13	20.7 ± 6.7	20.4 ± 6.5	20.6 ± 6.4	20.4 ± 5.8	20.9 ± 6.8	22.5 ± 6.0
P-value	>0.05	>0.05	>0.05	>0.05	**<0.05**	**<0.05**	**<0.05**	>0.05	>0.05	>0.05	**<0.05**	**<0.05**	**<0.05**	**<0.05**

Values in bold are statistically significant.

Table 7 Comparison between 20° and 30° canals of the material removed (µm) from the canal walls by K3 files

Level	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Outer canal wall														
20°	4.0 ± 1.38	16.5 ± 7.47	28.0 ± 9.1	33.0 ± 7.48	28.7 ± 8.0	21.5 ± 5.38	17.4 ± 4.74	14.4 ± 2.7	14.9 ± 2.4	16.5 ± 3.9	20.2 ± 4.7	24.1 ± 5.3	27.9 ± 5	31.8 ± 6.2
30°	1.9 ± 3.54	6.5 ± 3.21	13.6 ± 4.67	18.6 ± 3.92	13.6 ± 4.67	20.4 ± 2.55	18.8 ± 2.82	14.7 ± 2.06	12.8 ± 2.3	14.0 ± 2.2	17.1 ± 4.0	20.0 ± 5.9	23.8 ± 6.2	27.3 ± 4.8
P-value	>0.05	>0.05	>0.05	**<0.05**	**<0.05**	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05
Inner canal wall														
20°	2.6 ± 2.01	3.1 ± 2.69	0.9 ± 1.2	3.0 ± 2.31	3.6 ± 2.99	6.3 ± 3.74	14.7 ± 4.45	20.6 ± 4.77	25.1 ± 4.3	27.1 ± 4.0	26.2 ± 4.7	24.5 ± 5.2	23.0 ± 6.5	22.3 ± 7.0
30°	0.4 ± 0.97	1.6 ± 1.71	1.5 ± 1.43	1.2 ± 1.4	2.7 ± 2.54	5.3 ± 3.47	11.7 ± 5.54	17.0 ± 4.42	22.9 ± 3.6	23.9 ± 3.7	23.0 ± 4.2	22.7 ± 4.7	20.5 ± 3.8	18.8 ± 3.5
P-value	**<0.05**	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05

Values in bold are statistically significant.

(Dentsply) and K3 .06 (SybronEndo) rotary nickel-titanium instruments in simulated root canals having different curvatures and radii using a variable tip sequence.

Although rotary nickel-titanium instruments can maintain the canal shape better than other techniques the results of this study are in agreement with others (Thompson & Dummer 1997d, 1998a, 2000b) that show that canal transportation occurs in curved canals particularly at the outer curve of the apical portion of the canal (Tables 1 and 3, Figs 1 and 2). This is mainly due to the restoring forces of the metal were the forces in a straight file in a curved canal attempt to straighten the file toward the outer curvature thereby preferentially removing material in this area. Although transportation occurred it can be seen in Figs 1 and 2 that the final shape of the prepared canal was sufficiently tapered with a shape conducive to obturation with no gross preparation problems such as ledges or instrument fracture noted in any prepared canal. This pattern of canal wall removal towards the outer curve in the apical portion by both instruments was at the expense of canal preparation along the inner wall with the amount of inner canal wall removal being small or nil (Tables 2 and 3). This is in agreement with Peters *et al.* (2001) who reported that the nickel-titanium instrumentation technique left approximately 35% or more of the canal's surface area unchanged. Although not tested in the present study, this would confirm that the debridement of an infected root canal and radicular dentine on the inner wall may not be adequately accomplished by instrumentation alone.

It is generally accepted that canal transportation is more likely to occur and be more severe as the angle of the canal increases and radius decreases (Thompson & Dummer 1997c,f, 1998a,b, 2000a, Bryant *et al.* 1998a,b, 1999). However, this study showed that with ProFile instruments there was no statistical difference (Table 6) in the amount of material removed along the outer canal wall between the 20° and 30° angled simulated canals. This suggests that the instrumentation technique and instrument design characteristics of the ProFile instruments are able to prepare outer canal walls with different angulation and radius similarly within the range of canal shapes concerned. In contrast more inner wall material was removed in the 30° angle group than the 20° angle by ProFile instruments at various points on the canal (Table 6, Figs 1a and 2a). The reason for this is not clear but may reflect a combination of canal curvature, depth of the instrument penetration, and flute design that facilitated more canal wall removal. Although this may allow better cleaning of a canal, the area of inner wall removal was within the danger zone (Abou-Rass *et al.* 1980) and this may need to be taken into account when preparing sharply curved canals.

Preparation of 20° and 30° canals by K3 instruments revealed no difference in the amount of inner canal wall removed from any region, but more canal wall was removed from the outer curve of the apical portion in 20° canals (Table 7, Figs 1b and 2b). The reason for this is not obvious but may be explained by a combination of the depth of penetration, and rigidity and cutting efficiency of the instruments with each file penetrating further in the 20° canals. Presumably in the 30° canal instrument rigidity limited penetration within the greater curved and smaller radius canal, since less canal wall would be removed it is possible the instrument would tend to remain more centred. The fact that these instruments produced a better canal shape in the more severely curved canal may suggest that they are suited to this configuration.

K3 is reported to have a slightly positive rake angle in combination with a radial land relief (Bergmans *et al.* 2001). A positive rake angle tends to increase the cutting efficiency of the file (Wildey *et al.* 1992, Bergmans *et al.* 2001), whilst ProFile instruments have a neutral rake angle that the manufacturer reports results in a scraping or planing action rather than cutting into the root canal walls. When comparing the canal preparation produced by the different instruments in 20° curved canals the results showed that K3 removed more inner canal wall material along the length of the canal and more outer wall in the apical portion (Table 3, Fig. 1).

The use of a simulated canal in a resin block allows standardization of the root canal preparation and is an ideal experimental model to allow direct comparison of the shaping ability of different instruments (Schafer *et al.* 1995). However there are limitations with the model, such as the different hardness between resin and dentine, and care should be exercised in the extrapolation of the present results to the use of these instruments in the clinical situation.

Conclusions

Within the limitation of this study both rotary nickel-titanium instruments prepared a well-shaped root canal with minimal canal transportation.

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