doi:10.1111/j.1365-2591.2006.01151.x

Shaping ability of progressive versus constant taper instruments in simulated root canals

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Abstract

Yang GB, Zhou XD, Zhang H, Wu HK. Shaping ability of progressive versus constant taper instruments in simulated root canals. *International Endodontic Journal*, **39**, 791–799, 2006.

Aim To compare the shaping ability of progressive versus constant taper shaft designed instruments in simulated root canals.

Methodology Simulated L- and S-shaped resin canals were prepared by ProTaper (progressive taper) and high elasticity in rotation 642 (Hero 642) (constant taper) instruments ($n = 10$ canals in each case). The pre- and post-instrumentation images were recorded and assessment of the canal shape was completed with IMAGE PRO PLUS 5.0. The width of resin removed was measured at 9 measuring points. Incidence of canal aberrations, instrument fracture, preparation time and change of working length were recorded. In addition, the change of curvature and centring ability were also assessed. The data were analysed statistically using Student's *t*-test or Fisher's exact-test.

Results In both canal types, Hero 642 instruments prepared canals more rapidly ($P < 0.01$) and maintained working length significantly more accurately than ProTaper instruments ($P < 0.05$). In canals prepared with Hero 642 instruments, there was less change in curvature. Instrumentation with ProTaper results in transportation towards the outer aspect of the L-shaped curved canals in the apical part and the inner aspect of the S-shaped canals at the curve. Hero 642 instruments had a better centring ability in the apical part of the canal, but resulted in shapes with a poor taper.

Conclusions ProTaper and Hero 642 instruments prepared curved canals rapidly, maintained working length well and were relatively safe without creating perforations and danger zones. In both canal types, Hero 642 instruments maintained the original canal curvature better, and had a better centring ability in curved canals because of its constant taper design. The taper prepared by Hero 642 instruments in the coronal part of the canal was generally poor.

Keywords: canal transportation, Hero 642, nickel–titanium, ProTaper, rotary instruments simulated root canals.

Received 13 January 2006; accepted 31 March 2006

Introduction

Canal preparation is one of the major steps in root canal treatment and directly related to subsequent disinfection and filling (Peters *et al.* 2001). The aim of root canal shaping is to form a continuously tapered shape with the smallest diameter at the apical foramen and the largest at the orifice so as to allow effective irrigation and filling and not change the original canal curvature (Schilder 1974). However, traditional stainless steel hand instruments are time consuming and often fail to achieve the desired root canal shape, especially in narrow and curved canals, which, in turn, hinders filling (Schäfer *et al.* 1995). These instruments are stiff, thus increase the incidence of canal aberrations such as zips, elbows, ledges and perforations, particularly with increasing instrument size. In order to overcome the shortcomings of these traditional instruments, nickel–titanium (Ni–Ti) instruments have been developed. The development of new design features such as varying tapers, non-cutting safety tips and

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varying length of cutting blades in combination with the metallurgic properties of Ni–Ti alloy (Thompson & Dummer 2000a) has resulted in a new generation of instruments.

All new Ni–Ti rotary systems incorporate instruments with a taper greater than the ISO standard 0.02 taper design; indeed rotary Ni–Ti instruments are available with tapers ranging from 0.04 to 0.12 (Thompson & Dummer 1997a). These greater taper instruments have been introduced to improve the relatively low cutting efficiency of Ni–Ti instruments, to reduce the incidence of instruments failures and to enhance canal shape (Tepel *et al.* 1995).

The ProTaper (Dentsply Maillefer, Ballaigues, Switzerland) instruments have a convex triangular cross-sectional design, three cutting edges with a negative cutting angle, a noncutting modified safety tip and a flute design that combines progressive tapers within the shaft. The shaping instruments have a progressive taper sequence (increasing from tip to coronal) whereas the finishing instruments have a decreasing taper profile. It is claimed that the progressive taper sequence will enhance the flexibility of the files in the middle and at the tip region, and that the decreasing taper sequence will enhance the strength of the files whilst making them rather stiff (Bergmans *et al.* 2003).

High elasticity in rotation 642 (Hero 642, Micro-Mega, Besençon, France) (0.06, 0.04 and 0.02 tapers) rotary instruments incorporate files with 0.06, 0.04 and 0.02 tapers in ISO sizes 20, 25 and 30. The Hero 642 instruments are essentially modified Helifiles (Micro-Mega, Besençon, France) that have triple helicoidal cross-section design, three equally spaced rounded cutting blades with positive cutting angle combining constant taper and a noncutting tip.

The purpose of the present study was to compare the relative shaping ability of two representative rotary Ni–Ti instruments: ProTaper (progressive taper) and Hero 642 (constant taper) during the shaping of simulated-curved root canals in resin blocks.

Materials and methods

Simulated canals

Simulated canals made of clear polyester resin (Endo Training-Bloc, 0.02 Taper; Dentsply Maillefer, Ballaigues, Switzerland) were used to assess instrumentation. Two types of canals were used in this investigation: L- and S-shaped canals. The diameter and the taper of all simulated canals were equivalent to an ISO standard size 15. The L-shaped canals were 17-mm long, and had a 40° curvature according to the Schneider method (Schneider 1971) with a radius of 6 mm according to the method of Pruett (Pruett *et al.* 1997). The straight part was 12-mm long and the curved part was 5-mm long. The S-shaped canals were 18-mm long, and had two 36° curves. The coronal curvature was 4 mm to apical point and the apical curvature was 2 mm to apical point. The radius was 6 mm for the coronal curvature and 3 mm for the apical curvature.

Preparation of simulated canals

The simulated canals were prepared with either ProTaper or Hero 642 rotary Ni–Ti instruments. The clear resin canal blocks were covered with adhesive tape during the preparation phase. Each instrument was used to enlarge five canals only and then discarded. Before being used, each instrument was coated with EDTA cream (Meta Biomed, Choon Chong Buk-Do, Korea) to act as a lubricant. After the use of each instrument, the root canal was flushed with 5 mL of 2.5% NaOCl solution using a plastic syringe with a 27-gauge irrigating tip (Endo-tips, Ultradent Products Inc., South Jordan, UT, USA). All canals were prepared by one operator experienced in preparation with both ProTaper and Hero 642 instruments. Measurement of the canals was carried out by a second examiner who was unaware of the experimental groups.

Both ProTaper and Hero 642 instruments were set into permanent rotation (300 r.p.m.) with a 16 : 1 reduction handpiece (ATR Tecnika vision; Dentsply Maillefer) powered by a torque-limited electric motor (ATR Tecnika vision; Dentsply Maillefer). Preparation was completed in a crown-down manner according to each manufacturer's instructions using a gentle in-and-out motion. The final apical preparation was set to a size 30 for L-shaped canals and size 25 for S-shaped canals. The instruments sequence is described in Table 1. Once the instrument had negotiated working length and rotated freely, it was withdrawn and changed for the next one. In each of these two test groups, 10 L-shaped canals and 10 S-shaped canals were prepared. Thus, a total of 40 canals were prepared.

Assessment of canal preparation

During the preparation procedure, the following parameters were recorded:

Table 1 The instruments sequence for each system

ProTaper			Hero 642			
	Working length (mm)				Working length (mm)	
Type	L-shaped	S-shaped	Taper	Size	L -shaped	S-shaped
S1	12	14	0.06	20	12	14
SX	11	13	0.04	20	15	16
S1	17	18	0.02	20	17	18
S2	17	18	0.06	25	12	14
F1	17	18	0.04	25	15	16
F2	17	18	0.02	25	17	18
F3	17	–	0.02	30	17	–

1. Instrument fracture: instruments that fractured during preparation were noted.
2. Preparation time: the time for canal preparation was recorded in minutes and seconds and included file changes within the instrumentation sequence as well as irrigation.
3. Canal blockage: canals that became blocked with resin debris during preparation.
4. Change of working length: the final length of each canal was determined following the preparation. An F3 ProTaper instrument or a 0.02T size 30 Hero 642 instrument was inserted into the prepared L-shaped canals, and an F2 ProTaper instrument or a 0.02T size 25 Hero 642 instrument for S-shaped canals. Change of working length was determined by subtracting the final length from the original length with an accuracy level of 0.02 mm.

The assessment of preparation shape was carried out with the computer program IMAGE PRO PLUS 5.0 (Media Cybernetics, Silver Spring, MD, USA). The pre- and post-preparation canal images were recorded under a stereomicroscope (Nikon SMZ1000, Tokyo, Japan) connected to a charged-coupled device camera (Nikon digital sight DS-U1, Tokyo, Japan) at a fixed position and magnification. To improve the outlines, root canals were filled with India ink. A composite image was produced by superimposing the pre- and post-preparation images of each canal at magnification of 40 times. Superimposition was aided by vertical and horizontal lines placed on the surface of the resin blocks. The position and amount of resin removed as a result of preparation was detailed on the composite image. The curvature and radius of root canal after preparation and the amount of resin removed from both the inner and outer sides of the canal in 1-mm steps were measured one dimensionally using the IMAGE PRO PLUS 5.0 program with an accuracy level of 0.01 mm. The first measuring point was 1 mm from the apical point of the canal, and the last measuring point was 9 mm from the apical point, resulting in 9 measuring points at the outer and 9-points at the inner side of the canal, for a total of 18 measuring points (Fig. 1). All measurements were made at the right angles to the surface of the canal (Schäfer & Lohmann 2002). The degree of canal straightening was deter-

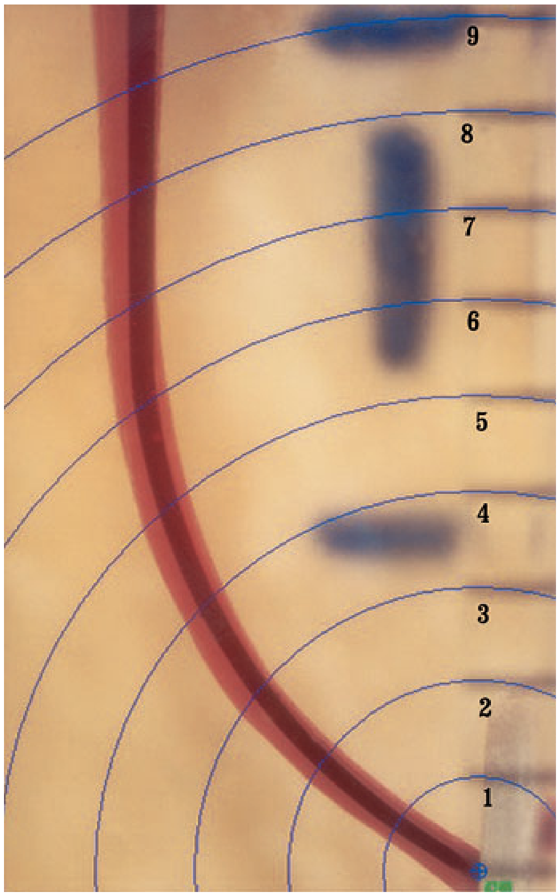

Figure 1 The positions of measurement are outlined by the nine concentric circles.

mined by the change of curvature and radius of pre- and post-instrumentation images. Centring ability was assessed by subtracting the amount of resin removed at the inner wall from that removed at the outer wall. Total amount of resin removed was assessed by adding the amount of resin removed at the inner wall and that removed at the outer wall.

Furthermore, based on the superimposition of pre- and post-preparation images, assessments were made according to the presence of different types of canal aberrations, such as apical zip associated with elbow, ledge, perforation and danger zone. These canal aberrations were defined according to Thompson & Dummer (2000b).

Analysis of data

All data were recorded and stored in a PC. Following the error and range check, incidences of canal aberration and instrument fracture were analysed with Fisher's exact-test and other data were analysed with Student's *t*-test at a significant level of 0.05 ($\alpha = 0.05$) using SPSS 11.0 (SPSS Inc., Chicago, IL, USA).

Results

Instrument fracture

In L-shaped canals, one ProTaper instrument (F3) and none of the Hero 642 instruments fractured. In the S-shaped canals, two ProTaper instruments (both F2) and one Hero 642 instrument (0.04 taper, size 25) fractured. All fractures occurred at the tip region of the instruments. There was no statistically significant difference between the two instruments in terms of the number of fractures.

Preparation time

The mean time taken with ProTaper and Hero 642 in L-shaped canals was 7.12 and 5.37 min and in S-shaped canals was 10.28 and 8.14 min, respectively. In both L- and S-shaped canals, Hero 642 was significantly faster than ProTaper ($P < 0.01$). For both instruments, preparation of L-shaped canals was significantly quicker than preparation of S-shaped canals ($P < 0.01$).

Canal blockage

None of the canals became blocked with resin debris during preparation.

Changes of working length

The mean change of working length that occurred with ProTaper and Hero 642 in L-shaped canals was 0.39 and 0.23 mm and in S-shaped canals it was 0.57 and 0.31 mm, respectively. In both L- and S-shaped canals, ProTaper instruments created a significantly greater loss of working length than Hero 642 instruments ($P < 0.05$). For ProTaper, the mean change of working length was significantly greater in S-shaped canals than in L-shaped canals ($P < 0.05$). And for Hero 642 instruments, there was no significant difference between the mean changes of working length in L- and S-shaped canals.

Straightening

The degree of straightening (changes of curvature and radius) after preparation with the two instruments systems is shown in Table 2. In L-shaped canals, there was no significant difference between the two systems in terms of the mean changes of curvature degree. However, ProTaper had a tendency to increase canal radius ($P < 0.05$). In both coronal and apical curved sections of S-shaped canals, there were significant differences between two instrument systems, with ProTaper instruments showing a greater changes in curvature ($P < 0.01$) and radius ($P < 0.05$).

Table 2 Mean degree of straightening [changes of curvature (°) and radius (mm)] and SD

	L-shaped				S-shaped							
			Coronal part				Apical part					
	Curvature	Radius	Curvature		Radius		Curvature		Radius			
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
ProTaper	3.34	0.42	1.13	0.09	5.94	0.72	2.44	0.48	19.73	1.80	2.06	0.76
Hero 642	2.53	0.61	0.36	0.08	1.48	0.79	0.66	0.15	15.60	2.67	1.15	0.29

Table 3 Incidence of canal aberrations

	L-shaped		S-shaped	
Aberration type	ProTaper	Hero 642	ProTaper	Hero 642
Zip/elbow	2	1	4	2
Ledge	2	1	2	1
Perforation	0	0	0	0
Danger zone	0	0	0	0

Table 4 Mean width of material removed (mm) and SD at different measuring points after preparation of simulated L-shaped canals

	Measuring point (mm from the apex)																	
	Inner canal wall									Outer canal wall								
	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
ProTaper																		
Mean	0.07	0.09	0.10	0.22	0.30	0.36	0.27	0.20	0.16	0.22	0.26	0.32	0.35	0.40	0.42	0.52	0.57	0.66
SD	0.03	0.02	0.03	0.06	0.09	0.10	0.10	0.10	0.05	0.07	0.05	0.08	0.05	0.01	0.03	0.04	0.02	0.01
Hero 642																		
Mean	0.11	0.12	0.14	0.16	0.17	0.18	0.14	0.10	0.12	0.13	0.15	0.16	0.17	0.16	0.16	0.20	0.26	0.35
SD	0.02	0.02	0.03	0.04	0.05	0.04	0.02	0.04	0.03	0.02	0.03	0.03	0.02	0.04	0.04	0.05	0.06	0.02
P-value	**	**	**	**	***	***	***	*	0.057	**	**	**	***	***	***	***	***	***

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Table 5 Mean width of material removed (mm) and SD at different measuring points after preparation of simulated S-shaped canals

	Measuring point (mm from the apex)																	
	Inner canal wall									Outer canal wall								
	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
ProTaper																		
Mean	0.17	0.25	0.21	0.24	0.29	0.30	0.25	0.20	0.21	0.08	0.07	0.13	0.08	0.09	0.10	0.14	0.30	0.32
SD	0.04	0.03	0.03	0.04	0.03	0.06	0.04	0.05	0.06	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.05	0.03
Hero 642																		
Mean	0.12	0.17	0.13	0.10	0.15	0.13	0.11	0.12	0.13	0.14	0.10	0.09	0.12	0.11	0.12	0.15	0.20	0.23
SD	0.03	0.02	0.02	0.04	0.03	0.05	0.05	0.04	0.04	0.03	0.02	0.01	0.03	0.01	0.02	0.02	0.04	0.04
P-value	*	**	**	***	***	***	**	**	**	**	**	**	**	*	*	0.156	***	***

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Canal aberration

The results of canal aberrations are summarized in Table 3. In both L- and S-shaped canals, there were no significant differences between the two instruments types.

Amount of resin removed

The amount of resin removed at both the inner and outer canal walls is detailed in Tables 4 and 5. In L-shaped canals, ProTaper instruments removed more resin at the outer wall and only a limited amount of resin at the inner wall in the apical section of the canal. Virtually no resin was removed at 1–2 mm from the apex along the inner wall (Fig. 2a), which resulted in transportation towards the outer aspect of the curve. Hero 642 instruments removed resin more evenly at the outer as well as at the inner walls of the curved part. In general, Hero 642 instruments had a more centred enlargement compared with ProTaper instruments (Fig. 2b).

In S-shaped canals, ProTaper instruments created a significantly greater widening of canals than Hero 642 instruments at the inner aspects of both curved regions (at the measuring points 1–2 and 4–6 mm from the

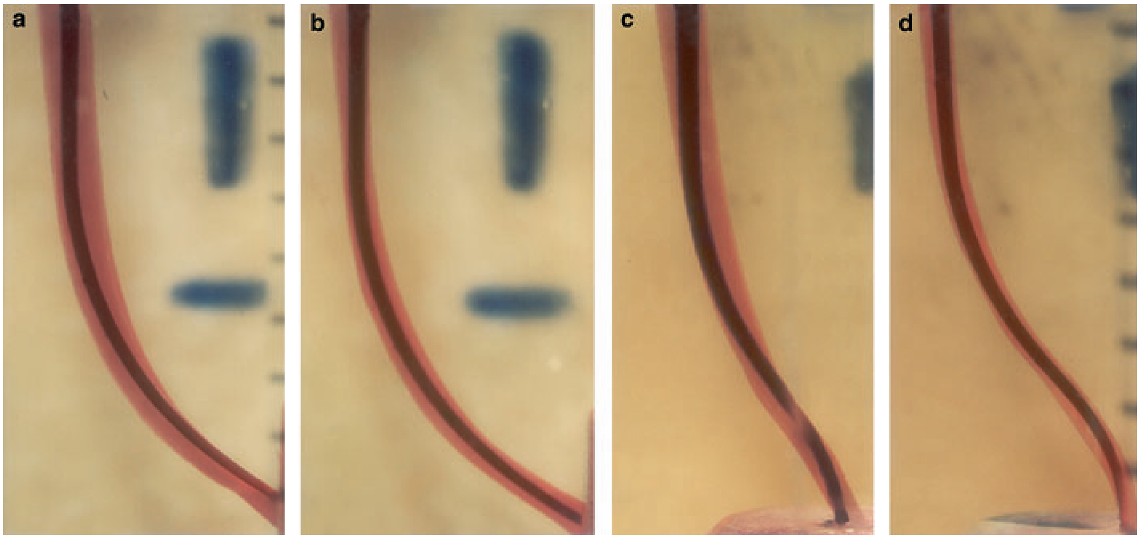

Figure 2 Superimposed images of the two canal type. The black region defines the canal before preparation and the red region defines the canal after preparation. (a: L-shaped canal with ProTaper; b: L-shaped canal with Hero 642; c: S-shaped canal with ProTaper; d: S-shaped canal with Hero 642).

apex). Along the outer aspects of both curved regions, only a limited amount of resin or no resin was removed (Fig. 2c), indicating a tendency for inner transportation at those positions. Hero 642 instruments removed resin more evenly along the outer and the inner walls of the curved regions that suggested a more centred enlargement (Fig. 2d).

Centring ability

The centring ability of the two instruments systems is shown in Fig. 3. Hero 642 instruments resulted in a better centring ability than ProTaper in the apical part of the canal.

Total amount of resin removed

The total amount of resin removed by the two instruments systems is presented in Fig. 4, which shows that ProTaper instruments removed more resin and created a better taper in the coronal part of the canal than Hero 642 instruments.

Discussion

The purpose of this study was to compare the shaping ability of a progressive (ProTaper) versus a constant taper (Hero 642) instrument. The shaping ability of these two instruments systems was compared under precisely controlled laboratory conditions. For evaluating root canal preparation by different instruments, then two experimental models most often used are simulated root canals in clear resin blocks or root canals in extracted human teeth. Simulated root canals provide standardization of root canal diameter, length and curvature in terms of angle and radius. Although use of simulated canals in resin blocks does not reflect the results of the instruments in root canals of real teeth because the hardness and abrasion behaviour of acrylic resin and root dentine may not be identical (Hülsmann *et al.* 2003), resin blocks allow the observation of the preparation in three dimensions along the whole canal length (Tasdemir *et al.* 2005) and a direct comparison of the shaping ability of different instruments (Schäfer *et al.* 1995). A major drawback of using rotary instruments in resin blocks is the heat generated, which may soften the resin material (Kum *et al.* 2000) and lead to binding of cutting blades and separation of the instruments (Baumann & Roth 1999). Thus, because of the difference on the nature of the materials, care should be exercised in the extrapolation of the present results to the use of these instruments in real root canals, where dentine is involved (Thompson & Dummer 1997b).

When comparing the shaping ability of different root canal instruments, it is important to have similar apical preparation diameters (Bergmans *et al.* 2003). In the present study, the diameter of the final apical

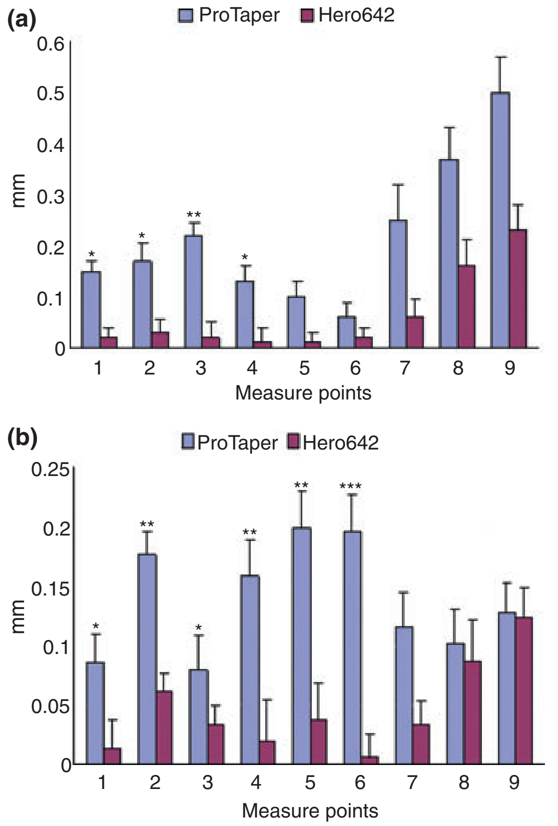

Figure 3 Centring ability of two instrument systems at 9 measuring points in L-shaped canals (a) and in S-shaped canals (b). Lower values correspond to better centring ability (*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$).

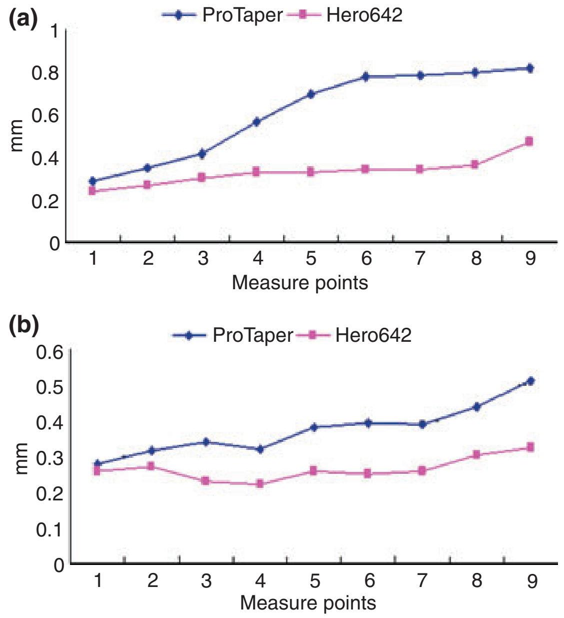

Figure 4 Total amount of resin removed in L-shaped canals (a) and in S-shaped canals (b). Steeper line corresponds to better taper.

preparation in the L-shaped canals was size 30 and in the severer S-shaped canals was size 25.

The average time for canal preparation was recorded. It included instrument changes as well as the time for irrigation. For both instruments, preparation of L-shaped canals was significantly quicker than preparation of S-shaped canals (Table 2), even though more instruments were used when preparing L-shaped canals. Thus, preparing S-shaped canals is more time consuming presumably because of their more complicated geometry.

Significant differences were found between ProTaper and Hero 642 instruments in terms of the change of working length. These changes may probably be due to minor canal straightening during canal enlargement or lack of length control by the operator (Thompson 2000). From a clinical point of view, it seems questionable whether these comparably small changes of the working length have any clinical significance.

The main parameters used to evaluate an instrument are shaping and cleaning the root canal wall whilst protecting the curvature of the canal (Tasdemir *et al.* 2005). In this study, canal curvature was assessed using two parameters: angle of curvature and radius of curvature. Using two parameters to describe a curve could have a better value than using only one parameter (angle of curvature). The radius of curvature represents how abruptly or severely a specific angle of curvature occurs as the canal deviates from a straight line; the smaller the radius of a curvature, the more abruptly the canal deviates. The angle of curvature and radius of curvature are independent parameters (Pruett *et al.* 1997). The radius of the curvature in two types of canals and the angle of the curvature in S-shaped canals was measured according to the method of Pruett *et al.* (1997), but the angle of the curvature in L-shaped canals was measured according to the Schneider method (Schneider 1971). In comparison with the ProTaper instruments, the canals prepared with Hero 642 instruments maintained original curvature better with less straightening, especially in S-shaped canals. These observations are in accordance with recently published studies (Hülsmann *et al.* 2001, Peters *et al.* 2003, Schäfer & Vlassis 2004), which demonstrated that varying degrees of canal straightening and transportation towards the outer aspect of the curvature were evident when L-shaped curved canals were enlarged with ProTaper instruments. The fact that some canal transportation towards the outer aspect of the canal was evident with ProTaper instruments may be because of the progressive tapers along the cutting surface of these instruments, in combination with the sharp cutting edges because of their cross-sectional design (Schäfer & Vlassis 2004). The decreasing taper sequence of the finishing files enhances the strength of the files, but it increases the stiffness of their tip, especially with F3 (Schäfer & Vlassis 2004). In the present study, most of the transportations of ProTaper instruments were produced mainly by F3. The taper at the tip of F3 is 0.09 whereas the taper of F1 is only 0.07. Therefore, the apical use of larger and greater taper instrument in moderately to severely curved canals should be considered carefully (Kum *et al.* 2000). Considering the difference in the tapers of the tip region, it is questionable whether there is an absolute necessity to enlarge curved canals up to size 30 with ProTaper instruments because the larger instruments are stiffer and may cause higher lateral force in curved canals (Bergmans *et al.* 2001). In the present study, the S-shaped canals were prepared up to size 25 in an attempt to reduce transportation. The restoring forces attempt to return the file to its original shape and act on the outer side on the canal wall during preparation, especially with progressive taper instruments. As the result of such transportation, a portion of the canal wall remains uninstrumented (Bergmans *et al.* 2001). In fact, it was proved in the present study that in several cases no resin was removed at the inner side of the curvature in the apical part of the L-shaped canals (Fig. 2a) and at the outer sides of the curvatures in S-shaped canals (Fig. 2c), when ProTaper instruments were used.

Hero 642 instruments provided a more centred apical preparation and maintained the original shape of the curved canals better in apical region. This finding is in agreement with previous reports (Thompson & Dummer 2000b, Hülsmann *et al.* 2001, Hülsmann *et al.* 2003). However, the taper prepared by the Hero 642 instruments in the coronal part of the canal was generally poor compared with ProTaper. The latter instrument has a progressive taper design, which creates a better shape at the coronal part of canal. Therefore, in the coronal part of canal preparation, progressively larger taper instruments such as ProTaper can efficiently flare the canal orifice and form a better taper, but in the apical part of the canal, constant smaller taper instruments such as Hero 642 may be better in order to maintain the original canal curvature.

Conclusions

Within the limitations of this study, ProTaper and Hero 642 instruments prepared curved canals rapidly, maintained working length well and were relatively safe without creating perforations and danger zones. In both canal types, Hero 642 instruments maintained the original canal curvature better and had a better centring ability than ProTaper. ProTaper instruments tended to transport towards the outer aspect of the L-shaped curved canals in the apical part and the inner aspects of the S-shaped canals in curved parts, which resulted in straightening of the curved canals because of the progressive taper shaft design. Compared with ProTaper, the taper prepared by Hero 642 in the coronal part of the canal was generally poor.

Acknowledgements

The authors state that they have no commercial interest associated with the Dentsply Maillefer and Micro-Mega companies. The only purpose of this study is to obtain data for clinical research. This research was supported in part by the National Key Technologies R&D Programme of the Tenth Five-Year Plan of the Ministry of Science and Technology, China (Grant No. 2004BA720A23). The authors wish to acknowledge Dr. Fengming Wang for providing IMAGE PRO PLUS 5.0. In addition, the authors are extremely grateful to Dentsply Maillefer and Micro-Mega for their technical support and donation of instruments.

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