*Original Article*

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# Shaping Ability of Protaper Rotary Nickel-Titanium Instruments in Simulated Root Canals

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**Abstract**

*Aim:* To assess the shaping ability of ProTaper rotary nickel-titanium instruments in simulated canals. *Methodology:* A total of 40 simulated root canals consisting of four different shapes in terms of angle and position of curvature were prepared using the 'crown down' approach recommended by the manufacturer. Pre-operative images of each canal were recorded using an image analysis package, the simulated canals were prepared and post-operative images were taken following preparation to sizes F1, F2 and F3. The pre and post-operative images were then superimposed on the original images. Development of canal aberrations and transportations as a result of preparation were assessed together with a variety of other parameters including width measurements at standard positions along the canal length. *Results:* Overall two instruments fractured (F1, F3) and 2 deformed (F3). None of the canals became blocked with debris. Five danger zones were produced, 3 after F1 and 2 after F2 and F3. Three perforations occurred (F3), 1 shoulder (F3), 3 ledges (F3) and 1 outer widening (F3). There were highly significant differences ($p<0.0001$) between canal types for total width measurements at standard positions along the canal length. There were highly significant differences ($P<0.0001$) between the canal types for the amount of resin removed from the outer aspect of the curve at the beginning of the curve, halfway to the orifice and at the orifice. There were highly significant differences ($P<0.0001$) between the canal types for the amount of resin removed from the inner aspect of the curve at the beginning of the curve and at the orifice. Following the use of F3 instrument, transportation toward the inner aspect of the canal occurred in 25 (64%) specimens at the beginning of the curve; all canals with $40^{o}$ curves transported to the inner. Overall, transportation was towards the outer aspect of the canal except at the beginning of the curve. *Conclusions:* Under the conditions of this study ProTaper instruments produced few aberrations following use of the F1 and F2 instruments. Further preparation up to the F3 instrument tends to straighten the canal and produce more aberrations.

**Keywords:** Pro-Taper; Canal Shape; Simulated Canals; Canal Aberrations; Nickel-Titanium; Rotary Instruments; Aberrations.

## Introduction

The ideal preparation shape for the root canal when obturating with gutta-percha is a funnel or conical form with the minimum width at the apex and maximum width at the orifice that maintains the original canal configuration (Schilder 1974, Schilder & Yee 1984). This shape can be achieved easily in straight canals but is challenging to achieve in curved canals. Nickel-titanium instruments have been shown to be flexible due to superelasticity, shape memory and resistance to torsional stress (Walia et al. 1988) which allow safe rotary instrumentation of narrow curved canals. Rotary nickel-titanium instruments are available in various designs but all with a constant taper along the length of the instrument unlike ProTaper (Dentsply Maillefer Instruments SA, Ballaigues, Switzerland) which has a variable taper along its length. The manufacturers state that the flute design provides the flexibility and efficiency to achieve consistent, successful cleaning and shaping, especially in tighter or more curved canals. The instruments have a convex triangular cross-section which reduces the contact area between the file and dentine. The greater cutting efficiency has been safely incorporated through balancing the pitch and helical angles. There are 3 shaping (SX, S1 and S2) and 3 finishing

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(F1, F2 and F3) instruments: The SX provides orifice enlargement, S1 is designed to prepare the coronal one-third of the canal and S2 enlarges and prepares the middle one third; both progressively enlarge the apical one third. The Finishing Files finish the apical one third and progressively expand the shape in the middle one-third of the canal. Generally, only one Finishing is required to prepare the apical one-third of a canal and the one selected is based on the canal's curvature and cross-sectional diameter. The files engage a smaller area of dentin, reducing torsional loads, file fatigue and the potential for separation (www.dentsply.co.uk)

The aim of this study was to investigate the shaping ability of the ProTaper nickel-titanium rotary instruments in simulated canals.

The most important phase in root canal therapy is cleaning and shaping of the root canals (Schilder 1974, Peters 2006). Canal curvature is suspected to be the predominant risk factor for instrument failure caused by flexural stresses ( Berutti E, et al. 2009 and Plotino G, et al. 2009 ). Because of the curvature of the canals, the iatrogenic errors like ledges, zips, perforations, and root canal transportation during shaping and cleaning is most likely to happen (Weine 1975; Peter 2003).

Enlargement of the root canal space is needed to insure the flow of the irrigating agent towards the apical region (Stock et al., 2004) and for the placement of root canal filling. Root canal Ni-Ti engine-driven files were developed using NiTi alloy for its known mechanical properties like elasticity, flexibility and shape memory (Andreasen and Morrow, 1978; Bergmans et al., 2001; Buchler and Wang, 1963; Gergi et al., 2010; Yoneyama and Kobayashi, 2009); (Hulsmann et al., 2005). Using NiTi alloy for hand instruments and later for rotary instruments allow enabled a safer and easier preparation of complex canal anatomy (Hartmann et al., 2007). An instrument will fracture if its ultimate strength is exceeded, or if a crack has extended to such a degree that the remaining intact cross-section of material is unable to bear the usual operating load (Cheung, 2009), thus complicating the entire treatment or even leading to treatment failure. (Martin et al., 2003) found that the instrument fracture depends on the rotational speed and the angle of the curvature of the canal.

## Materials and methods

*Construction of simulated canals*

Four simulated root canals in clear resin blocks were constructed as described previously (Dummer et al. 1991) using size 15 silver points. Forty canals were produced, with either 20$^{o}$ or 40$^{o}$ curves and with a straight portion prior to the curve of either 8 mm or 12 mm. The radius of the arc which made up the curve was 16 mm.

*Preparation of simulated canals*

All the 40 canals were prepared by one operator using ProTaper (Dentsply Maillefer) nickel-titanium rotary instruments with a 16:1 reduction handpiece powered by a TCM 3000 (Nouvag, Goldach, Switzerland) set at a constant speed of 250 r.p.m. in a crown-down technique using the sequence S1, SX, S1, S2, F1, F2 and F3. Light pressure was used together with a gentle in and out (pecking) motion. Each instrument was used for about 7 seconds then removed and inspected. Prior to the preparation and after the use of each instrument, copious irrigation was carried out with water using disposable syringes. A sponge was used regularly to clean debris from the instruments. Each instrument was used to prepare four canals, one of each shape and then replaced unless on inspection deformation or fracture were observed when it was replaced immediately. All canals were prepared to a working distance of 16 mm with F1 (tip size = 20) in the first instance and then to size F2 (tip size = 25), and then size F3 (tip size = 30).

*Assessment of canal preparation*

Pre-operative images were taken of the canals using a camera (Panasonic F10 CCD) secured a fixed distance (32 cm) from a microscope stage together with Image-Pro Plus software (Media Cybernetics, Maryland, USA). Post-operative images were taken following the use of F1, F2 and F3. The pre- and post-operative images of each canal were combined using the software. Combination of pre- and post-operative specimens was aided through holes placed in the resin blocks.

*Preparation time*. The time taken for canal preparation was recorded in minutes and seconds and excluded file changes and irrigation.

*Instrument failure.* Instruments were examined after every use and a record kept of permanently deformed or fractured instruments.

*Loss of working distance.* The final length of each canal was determined following preparation to size F3. An F3 instrument was inserted into the canal by hand and its length within the canal measured to the nearest 0.5 mm. Change in the working distance was determined by subtracting the final length from the original length.

*Canal aberrations.* Following preparation with size F1, size F2 and size F3, an assessment of the images was made of the presence and position of several types of canal aberration (Alodeh & Dummer 1989) including zips and elbows, ledges, perforations, danger zones and outer widening (Bryant et al. 1999).

*Canal measurements.* The composite images of the pre-operative and post-operative image following the use of F3 enabled measurement of the total amount of resin removed during preparation and that removed on the inner and outer aspects of the curve. Measurements were carried out perpendicular to the axis of the original canal, at specific points along the length of the canal (the orifice, halfway to the orifice, and at the beginning of the curve). From the width measurements, the direction and degree of transportation were computed.

*Data recording, storage and analysis.* Data was recorded directly on coding sheets and stored in Excel. Following error and range checks, the data were analysed using ANOVA in SPSS (IBM SPSS Statistics 21; SPSS Inc., Chicago, IL).

## Results

### *Preparation time*

Table 1 shows the mean, maximum and minimum preparation times taken to prepare canals following use of size F3. The mean time was 2.86 min and the one-way analysis of variance indicated that the time taken was influenced significantly by canal shape. It was obvious that 20° canals were prepared more rapidly than 40° canals.

### *Instrument failure*

Two instruments fractured (F1, F3) and two deformed (F3). Three of the instruments fractured or deformed (F3) occurred in the last stage of the procedure.

### *Change in working length*

The mean loss of working distance that occurred as a result of preparation to size F3 is shown in Table 2. There was no significant difference between the canal shapes. Twenty-one (54%) canals showed no change in working distance, 11 (28%) lost 0.5 mm, 6 lost 1 mm (15%) and 1 (2.6%) lost 1.5 mm (Table 3).

### *Canal aberrations*

*Perforations.* Three perforations were created, 2 in 20° canals and 1 in 40° canal all following the use of the F3 instrument.

*Danger zones.* Five danger zones were produced, all in 40°, 8 mm canals (12.8%). Three of them were created as a result of preparation the canal to size F1 and 2 after F2.

**Table 1:** Mean, minimum & maximum preparation time (min.) by canal shape

Canal shape

| Time | 20° 8mm | 40° 8mm | 20° 12mm | 40° 12mm | Total | P value |
|---|---|---|---|---|---|---|
| Mean | 2.64 | 2.96 | 2.70 | 3.15 | 2.86 | 0.000 |
| Min | 2.20 | 2.58 | 2.45 | 2.87 | 2.20 | |
| Max | 3.12 | 3.52 | 3.98 | 3.43 | 3.52 | |

**Table 2:** Mean, minimum & maximum finished canal preparation length (mm) by canal shape

Canal shape

| Length | 20° 8mm | 40° 8mm | 20° 12mm | 40° 12mm | P value |
|---|---|---|---|---|---|
| Mean | 15.70 | 15.78 | 15.55 | 15.65 | 0.701 |
| Min | 15.00 | 15.50 | 15.00 | 14.50 | |
| Max | 16.00 | 16.00 | 16.00 | 16.00 | |

**Table 3:** Finished canal preparation length (mm) by canal shape

Canal shape

| Length | 20° 8mm | 40° 8mm | 20° 12mm | 40° 12mm | Total | P value |
|---|---|---|---|---|---|---|
| 14.5 | - | - | - | 1 | 1 | 0.551 |
| 15.0 | 2 | - | 3 | 1 | 6 | |
| 15.5 | 2 | 4 | 3 | 2 | 11 | |
| 16.0 | 6 | 5 | 4 | 6 | 21 | |
| Total | 10 | 9 | 10 | 10 | 39 | |

*Shoulders.* One shoulder was created in 20º, 12 canals after the use of F3.

*Ledges.* Three ledges were created, 2 in 40º, 12 mm canals and 1 in 40º, 8 mm canals. all following the use of the F3 instrument.

*Zips and elbows.* No zips and elbows were created.

*Outer widening.* Only one outer widening was observed following the use of the F3 instrument.

*Total Width measurements*

Table 4 shows the mean, minimum & maximum total widths of the prepared canals at the various measurement positions along the canal length.

*Orifice.* There was a highly significant difference ($p<0.001$) between the canal types. Overall the largest mean values (1.933 mm) were found in the 40º, 8 mm canals whilst the 20º, 8 mm canals were (1.477 mm) the narrowest.

*Halfway to the orifice.* There was a highly significant difference ($p<0.001$) between the canal types. Overall the largest mean values (1.238 mm) were found in the 40º, 8 mm canals whilst the 20º, 12 mm canals were the narrowest (1.012 mm).

*Beginning of the curve.* There was a highly significant difference ($p<0.001$) between the canal types. Overall, the 40º canals were wider than the 20º canals.

*Inner Width measurements*

Table 5 describes the mean widths of resin removed from the inner aspect of the canal curves.

*Orifice.* There was a highly significant difference ($p<0.0001$) between the canal types. Overall, most resin removal (0.543 mm) occurred in the 20º, 12 mm canals and least (0.300 mm) in the 40º, 8 mm canals.

*Halfway to the orifice.* No significant difference was found between the canals types. Overall, most resin removal occurred in the 40° canals.

*Beginning of the curve.* There was a highly significant difference ($p<0.0001$) between the canal types. Overall, most resin removal (0.558 mm) occurred in the 40°, 8 mm canals and least (0.167 mm) in the 20º, 12 mm canals.

*Outer Width measurements*

Table 6 describes the mean widths of resin removed from the outer aspect of the canals.

*Orifice.* There was a highly significant difference between the canal types ($p<0.001$). Overall, the resin removal from the outer aspect of the curve was greatest (1.091 mm) in the 40°, 8 mm canals and least (0.401 mm) in the 20º, 12 mm canals.

*Halfway to the orifice.* There was a highly significant difference between the canal types ($p<0.001$). Overall, the resin removal from the outer aspect of the curve was greatest (0.427 mm) in the 40°, 8 mm canals and least (0.294 mm) in the 20º, 12 mm canals.

*Beginning of the curve.* There was a highly significant difference between the canal types

**Table 4:** Mean, minimum & maximum total widths (mm) of canals by canal shape

Canal shape

| Position | 20° 8mm | 40° 8mm | 20° 12mm | 40° 12mm | Total | P value |
|---|---|---|---|---|---|---|
| Orifice | | | | | | |
| Mean | 1.477 | 1.933 | 1.494 | 1.655 | 1.632 | 0.000 |
| Min | 1.418 | 1.772 | 1.351 | 1.516 | 1.351 | |
| Max | 1.592 | 2.028 | 1.557 | 1.882 | 2.028 | |
| Half-way to orifice | | | | | | |
| Mean | 1.038 | 1.238 | 1.012 | 1.066 | 1.085 | 0.000 |
| Min | 0.969 | 1.198 | 0.968 | 1.012 | 0.968 | |
| Max | 1.074 | 1.321 | 1.074 | 1.119 | 1.321 | |
| Beginning of curve | | | | | | |
| Mean | 0.814 | 1.073 | 0.755 | 0.827 | 0.862 | 0.000 |
| Min | 0.761 | 1.008 | 0.657 | 0.796 | 0.657 | |
| Max | 0.899 | 1.165 | 0.832 | 0.875 | 1.165 | |
| Danger zone | | | | | | |
| Mean | * | 1.139 | * | * | 1.139 | |
| Min | * | 1.042 | * | * | 1.042 | |
| Max | * | 1.213 | * | * | 1.213 | |
| Number of canals | 10 | 9 | 10 | 10 | 39 | |

* No data

($p$<0.001). Overall, the largest resin removal occurred in the 20° canals and the least in the 40° canals.

*Direction of Transportation*

Table 7 shows the direction of transportation at specific positions along the canal length following the final preparation of the canal (F3).

*Orifice.* Transportation was towards the outer in 22 canals (56%), most of them (n=18) were in the 40° canals. 17 canals (44%) were transported to the inner aspect, where most of them (n=16) were among the 20° canals. There was a highly significant difference ($p$<0.0001) between the canal types.

*Halfway to the orifice.* Transportation was towards the outer in 25 canals (64%). Only 5 canals remained centred and 9 were transported to the inner aspect. There were no significant differences between canal types.

*Beginning of the curve.* Transportation was towards the inner in 25 (64%) canals, most of them (n=19) were in the 40° canals. Twelve canals (31%) transported towards the outer aspect; all of them occurred in 20° canals. Only 2 canals, 20°,

**Table 5:** Mean, minimum & maximum inner widths (mm) of canals by canal shape

| Position | 20° 8mm | 40° 8mm | 20° 12mm | 40° 12mm | Total | P value |
|---|---|---|---|---|---|---|
| Orifice | | | | | | |
| Mean | 0.526 | 0.300 | 0.543 | 0.409 | 0.448 | 0.000 |
| Min | 0.415 | 0.151 | 0.484 | 0.352 | 0.151 | |
| Max | 0.727 | 0.393 | 0.618 | 0.520 | 0.727 | |
| Half-way to orifice | | | | | | |
| Mean | 0.269 | 0.323 | 0.256 | 0.287 | 0.283 | 0.094 |
| Min | 0.242 | 0.217 | 0.207 | 0.207 | 0.207 | |
| Max | 0.346 | 0.539 | 0.344 | 0.352 | 0.539 | |
| Beginning of curve | | | | | | |
| Mean | 0.197 | 0.558 | 0.167 | 0.289 | 0.296 | 0.000 |
| Min | 0.138 | 0.488 | 0.138 | 0.242 | 0.138 | |
| Max | 0.242 | 0.636 | 0.207 | 0.352 | 0.636 | |
| Danger zone | | | | | | |
| Mean | * | 0.527 | * | * | 0.523 | |
| Min | * | 0.262 | * | * | 0.262 | |
| Max | * | 0.658 | * | * | 0.658 | |
| Number of canals | 10 | 9 | 10 | 10 | 39 | |

* No data

**Table 6:** Mean, minimum & maximum outer widths (mm) of canals by canal shape

| Position | 20° 8mm | 40° 8mm | 20° 12mm | 40° 12mm | Total | P value |
|---|---|---|---|---|---|---|
| Orifice | | | | | | |
| Mean | 0.445 | 1.091 | 0.401 | 0.719 | 0.653 | 0.000 |
| Min | 0.331 | 0.943 | 0.311 | 0.519 | 0.311 | |
| Max | 0.553 | 1.239 | 0.484 | 0.977 | 1.239 | |
| Half-way to orifice | | | | | | |
| Mean | 0.311 | 0.427 | 0.294 | 0.299 | 0.330 | 0.000 |
| Min | 0.276 | 0.315 | 0.242 | 0.210 | 0.210 | |
| Max | 0.380 | 0.535 | 0.347 | 0.347 | 0.535 | |
| Beginning of curve | | | | | | |
| Mean | 0.211 | 0.040 | 0.201 | 0.108 | 0.142 | 0.000 |
| Min | 0.138 | 0.000 | 0.142 | 0.069 | 0.000 | |
| Max | 0.311 | 0.104 | 0.243 | 0.173 | 0.311 | |
| Danger zone | | | | | | |
| Mean | * | 0.036 | * | * | 0.036 | |
| Min | * | 0.000 | * | * | 0.000 | |
| Max | * | 0.076 | * | * | 0.076 | |
| Number of canals | 10 | 9 | 10 | 10 | 39 | |

* No data

**Table 7:** Number of canals transported towards the inner and outer aspect of the curve by canal shape

| Position | 20° 8mm | 40° 8mm | 20° 12mm | 40° 12mm | Total | P value |
|---|---|---|---|---|---|---|
| Orifice | | | | | | |
| Outer | 4 | 9 | - | 9 | 22 | 0.000 |
| None | - | - | - | - | - | |
| Inner | 6 | - | 10 | 1 | 17 | |
| Half-way to orifice | | | | | | |
| Outer | 7 | 6 | 8 | 4 | 25 | 0.626 |
| None | 1 | 1 | 1 | 2 | 5 | |
| Inner | 2 | 2 | 1 | 4 | 9 | |
| Beginning of curve | | | | | | |
| Outer | 5 | - | 7 | - | 12 | 0.000 |
| None | - | - | 2 | - | 2 | |
| Inner | 5 | 9 | 1 | 10 | 25 | |

**Table 8:** Mean, minimum & maximum distance (mm) of absolute transportation by canal shape

| Position | 20° 8mm | 40° 8mm | 20° 12mm | 40° 12mm | Total | P value |
|---|---|---|---|---|---|---|
| Orifice | | | | | | |
| Mean | 0.064 | 0.395 | 0.071 | 0.155 | 0.165 | 0.000 |
| Min | 0.001 | 0.332 | 0.018 | 0.001 | 0.001 | |
| Max | 0.191 | 0.544 | 0.122 | 0.278 | 0.544 | |
| Half-way to orifice | | | | | | |
| Mean | 0.031 | 0.076 | 0.029 | 0.032 | 0.041 | 0.006 |
| Min | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | |
| Max | 0.069 | 0.159 | 0.052 | 0.071 | 0.071 | |
| Beginning of curve | | | | | | |
| Mean | 0.027 | 0.259 | 0.020 | 0.091 | 0.095 | 0.000 |
| Min | 0.016 | 0.206 | 0.000 | 0.035 | 0.000 | |
| Max | 0.087 | 0.298 | 0.049 | 0.142 | 0.298 | |

12 mm were centred There was a highly significant difference ($p<0.0001$) between the canal types.

*The absolute amount of transportation*

The degree of absolute transportation irrespective of direction is detailed in Table 8.

*Orifice.* The magnitude of absolute transportation was highly significantly different between the canal shapes ($p<0.0001$) with the largest value (0.395 mm) in the 40°, 8mm canals and least (0.064 mm) in the 20°, 8 mm canals.

*Halfway to the orifice.* The magnitude of absolute transportation was significantly different between the canal shapes ($p<0.05$) with the largest value (0.076 mm) occurred in the 40°, 8 mm canals and least (0.029 mm) in the 20°, 12 mm canals.

*Beginning of the curve.* The magnitude of absolute transportation was greatest (0.259 mm) in the 40°, 8 mm specimens. There was a highly significant difference between the canal shapes ($P<0.0001$).

## Discussion

The objective during instrumentation of root canals is to maintain the original path of the canal in order to produce a continuously tapering and conical form with the smallest diameter at the end-point of the preparation (Schilder & Yee 1984).

To assess the instrumentation of different NiTi rotary systems many methods has been used like histologic sections, plastic models, serial sectioning, scanning electron microscopy, radiographic comparisons, silicone impressions of instrumented canals, and micro-computed tomography. Resin blocks was used in most of them (Berutti E et al., 2009; Berutti E et al., 2012; Burklein S et al., 2014; Gambarini G et al., 2015; Sevinc, et al.,2014).

The resin blocks do not represent the anatomic variability of a human root canal system, simulated resin canals have been used to point out differences in performance of instruments under standardized experimental conditions (Berutti E, et al., 2012). Use of resin blocks for the endodontic experiment provide a standardization of shape, size, taper and curvature of the canal. In another hand, there is a difference in hardness between resin and dentine. Also when using resin blocks, the heat generated during preparation can soften the resin which can interfere with the preparation (Kwak SW et al., 2014). Other studies have used the extracted teeth. (Yammine S, 2018; Neerja Sharma et al., 2017; Alves VDO et al., 2012; Dhingra A et al., 2014; Zanette F, 2014; Pasqualini D, 2012) but different canal anatomies were used; therefore, it was likely to affect their assessment negatively. (Nazarimoghadam K, et al. 2014). Different curvatures, initial canal diameter, and dentin hardness of the natural teeth make it difficult to standardized although they are the best specimens to evaluate the shaping effects of instrumentation. In this study the resin blocks were used.

The aim of this study was to assess the shaping ability of the newly introduced nickel-titanium rotary endodontic instruments which called ProTaper (Dentsply Maillefer Instruments SA, Ballaigues, Switzerland). Clearly, because of the nature of the experimental model, the interpretation of the data and the extrapolation of the results to the clinical situation should be exercised in a reasonable degree of caution. However, the study highlights a number of interesting phenomena.

When the superimposed canals images were assessed at the initial apical preparation by size F1 (tip size = 20) and then by size F2 (tip size = 25), very limited number of aberrations were produced. The ProTaper instruments produced well-shaped canals when the canal was prepared to F2.

Using simulated canals, Yun & Kim 2003 studied canal instrumentation with ProTaper (Dentsply Mailleffer), they found no fractures but 6 deformations all F3 instruments. Using teeth, Martin et al. 2003 studied the factors influencing the fracture of ProTaper. They noted the fracture of 12 files in the canals whose curvature was greater than 30º; no instruments fractured in straight or less curve canals. Berutti et al. 2003 compared the mechanical behaviour of Pro Taper and Pro File by applying the finite element analysis method and found that ProTaper instruments are stronger and less elastic than ProFile instruments. ProTaper instruments are progressively tapered and engage only a small area of canal wall (West 2001) which may allow more control of the instruments and prevent them from preparing the canals beyond the working distance.

Aberrations (zips, elbows, perforations, outer widenings and ledges) of the root canal, can occur, with rotary instruments but to a lesser degree than hand instruments (Kum et al. 2000) especially in curved canals. In a similar study, Yun & Kim 2003 prepared simulated canals without any aberrations, but they used the finishing files F1, F2, and F3 sequentially to the working length, with only one pecking motion for each instrument and removed them as soon as possible. Peters et al. 2003 prepared canals of extracted maxillary molars with Pro Taper files with some apical canal transportation.

Comparing total width measurements with previous studies (Thompson & Dummer 1997b, Bryant et al. 1998b, Bryant et al. 1998) the greatest preparation at the beginning of the curve and halfway to the orifice occurred in 40°, 8mm specimens in all four studies. Least resin removal occurred in 20°, 12 mm specimens at the beginning of the curve and halfway to the orifice in all papers. Also in the present study, the measurements at the beginning of the curve and at halfway to the orifice measurements are wider by approximately 0.2 mm and the measurements at half way to the orifice and at orifice measurements are wider by approximately 0.5 mm which is to be expected due to the increased taper of the Pro Taper instruments which found to be 0.02 to 0.19% (West 2001) which resulted in greater material removed at all levels of the canal (Yun & Kim 2003) than the Quantec files, GT Rotary files and Pro Files.

Comparing outer width measurements with previous studies (Thompson & Dummer 1997b, Bryant et al. 1998b, Bryant et al. 1998), the greatest preparation at the halfway to the orifice occurred in 20°, 8 mm specimens in all four studies. Least resin removal occurred mostly in 20° specimens at all points measured. Most resin removal on the outer aspect of the curve occurred at the orifice in the 40°, 8 mm specimens. Least resin removal occurred on the outer aspect at the beginning of the curve for all canal types.

Comparing inner width measurements with previous studies (Thompson & Dummer 1997b, Bryant et al. 1998b, Bryant et al. 1998), the greatest preparation at the beginning of the curve and halfway to the orifice occurred in mainly in 40° 8 mm specimens in all four studies. Least resin removal occurred mostly in 20°12 mm specimens at all points measured.

At all points, no transportation occurred in a mean of 7 specimens. Most inner transportations occurred at the beginning of the curve indicating a tendency towards danger zones, a finding which is in line with several studies (Thompson & Dummer 1997b, Bryant et al. 1998b, Bryant et al. 1998, Yun & Kim 2003). The majority of blocks were transported towards the outer aspect.

The greatest absolute transportation occurred in 40° specimens at all points. Very high values were found at the beginning of the curve in 40° 8 mm specimens denoting a tendency towards zips and danger zones production.

**Conclusions**

Under the conditions of the study, ProTaper rotary nickel-titanium instruments created few aberrations following the use of F1 and F2 instruments. Further preparation up to size F3 instrument tends to straighten the canal. These aberrations possible occurred as a result of the increased stiffness of the F3 instruments. Also, ProTaper caused minimal change in working length, maintained canal patency and few instruments deform or fracture. Further work is required to determine whether this effect will occur in real teeth.

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