Root canal preparation with Endo-Eze AET: changes in root canal shape assessed by micro-computed tomography

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Abstract

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Aim To evaluate the relative performance of Endo-Eze Anatomic Endodontic Technology (AET) stainless steel instruments when shaping maxillary molar root canals *in vitro*.

Methodology Extracted human maxillary molars were scanned, before and after root canal shaping with Endo-Eze AET, employing micro-computed tomography (μCT) at an isotropic resolution of 34 μm. Three-dimensional root canal models were reconstructed and evaluated for volume, surface area, 'thickness' (diameter), canal transportation and prepared surface. Preparation errors such as apical zips, perforations and fractured instruments were visually determined from those models. Means were contrasted using ANOVA and Scheffé *post-hoc* tests.

Results Volume and surface area increased significantly and similarly in mesiobuccal (mb), distobuccal (db) and palatal (p) canals and gross preparation errors ($n = 17$) were found. Mean root canal diameters, 5 mm coronal to the apex, increased from 0.31 to 0.52, 0.35 to 0.50 and 0.50 to 0.70 mm for mb, db and p canals, respectively. Mean canal transportation ranged from 0.15 to 0.29, 0.15 to 0.27 and 0.21 to 0.33 mm for apical, middle and coronal root canal levels, respectively, with highest values found for mb canals ($P < 0.003$). Root canals were significantly straightened during preparation ($P < 0.002$).

Conclusions In summary, Endo-Eze AET instruments shaped root canals in maxillary molars with substantial canal transportation, particularly in mesiobuccal root canals. Preparation with this instrument removed high volumes of dentine, even though apical preparation was size 30. Based on the current results, Endo-Eze AET cannot be recommended for the preparation of teeth with curved root canals.

Keywords: canal shape, Endo-Eze AET, micro-computed tomography, transportation.

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Introduction

Cleaning and shaping the root canal is a key to success in root canal treatment. This includes the removal of organic substrate from the root canal system by chemomechanical methods, and the shaping of the root canal system into a continuously tapered preparation. This should be done while maintaining the original path of the root canal. Furthermore, shapes of the prepared canals should ensure adequate filling of the canals (Schilder 1974). These objectives are often difficult to achieve because of the highly variable root canal anatomy. Variations in canal cross-sectional shape and the presence of anatomical irregularities together with

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canal curvature lead to procedural errors such as ledge, zip, elbow formation, canal transportation and perforation (Weine *et al.* 1975, Kerekes & Tronstad 1977, Abou-Rass *et al.* 1980).

Modern preparation techniques should eliminate or at least minimize the degree and types of procedural errors that occur during shaping. During the last decade engine-driven root canal preparation particularly with rotary nickel-titanium instruments has become very popular. Numerous *in vitro* studies have shown that in fact most available rotary techniques do minimize the degree of procedural errors (Peters 2004).

However, new instruments are frequently evaluated using plastic blocks with simulated curved canals. Unfortunately, such plastic blocks do not simulate the coinciding bucco-lingual and mesio-distal curvatures often found in natural teeth (Cunningham & Senia 1992). In contrast to using plastic blocks, Bramante *et al.* (1987) described serial sectioning of natural roots in a reassembly procedure to evaluate changes in canal geometry, before and after shaping that is widely used (Portenier *et al.* 1998, Hülsmann *et al.* 1999, Deplazes *et al.* 2001). Disadvantages of such reconstructive techniques include loss of material due to serial sectioning, its labour-intensive nature and the fact that not all sections are at right angles to the main canal.

A recently introduced non-destructive method to evaluate changes of root canal geometry after endodontic preparation in more detail is the use of high-resolution computed tomography (Peters *et al.* 2000, 2001a,b, Rhodes *et al.* 2000, Bergmans *et al.* 2001, Gluskin *et al.* 2001). This analytical procedure permits three-dimensional evaluation of root canal geometry, before and after preparation. In addition, the technique yields a mass of exact metric data (Peters *et al.* 2000).

Recently, Endo-Eze Anatomic Endodontic Technology (AET) was introduced as a minimally invasive endodontic preparation system (Ultradent Products Inc., South Jordan, UT, USA). The patient kits used in this study included seven instruments, all instruments are made of stainless steel: three shaping files with tip diameters of 0.10–0.13 mm and tapers of 2.5, 4.5 and 6.5%, respectively, as well as four apical files with tip diameters of 0.15–0.30 mm and tapers 2.0% (sizes 15, 20 and 25) and 2.5% (size 30), respectively. Endo-Eze AET shaping files are used in a special reciprocating/oscillating handpiece for instrumentation of the coronal part of the root canal about 3 mm short of the apex. The apical files are hand files with shortened cutting flutes to cut only in the apical region of the canal and are used in a clockwise turn and pull motion. The manufacturer claims that Endo-Eze AET prepares irregular shaped canals less aggressively in comparison with nickel-titanium rotary motion systems.

Little is known about the impact of this new root canal preparation system on canal shaping ability, and consequently, the aim of the present study was to assess the shaping potential of Endo-Eze instruments. The main parameters to be investigated included (i) changes in canal dimensions, (ii) percentage of shaped canal walls and (iii) degree of canal transportation. The same methodology was used as in previous studies (Peters *et al.* 2001a,b, 2003, Hübscher *et al.* 2003) to allow comparisons among different root canal preparation systems.

Materials and methods

Preparation of specimens

Twelve three-rooted maxillary molars of similar root shape, i.e. slightly to moderately curved buccal roots, were selected from a pool of extracted teeth for this study and stored in 0.1% thymol until used. The specimens were mounted on SEM stubs (014001-T; Balzers Union AG, Balzers, Liechtenstein) and scanned using micro-computed tomography (μCT) (see below) without probing the canals for patency to avoid modifying the canals' apical anatomy. Severity of canal curvatures were assessed and root canals were statistically similar to earlier batches (Peters *et al.* 2001a,b, 2003, Hübscher *et al.* 2003).

All endodontic procedures were carried out by an experienced dentist, who was familiar with the preparation system. Root canal preparation was performed as specified in the manufacturer's guidelines. Teeth were hand-held during preparation to allow easy access. Preoperative digital radiographs were taken in both bucco-lingual and mesio-distal projection (Digora; Soredent, Helsinki, Finland). After gaining access, pulp chambers were irrigated with 5 mL of 2.5% NaOCl and root canal orifices explored using hand instruments. If a second mesiobuccal root canal was obvious while examining the pulp chamber, an attempt was made to shape it to full working length. Data regarding second mesiobuccal root canals were not evaluated due to the limited number of comparable canals.

The coronal two-thirds of the mb, db and p root canals were prepared using Endo-Eze shaping files numbers 1, 2 and 3 sequentially in the reciprocating handpiece. After determining working length with a K-file size 10 apical root canal preparation was performed using Endo-Eze apical files size 15 through to size 30. In detail, the instruments used were:

- 1 shaping file in the coronal two-thirds
- 2 shaping file in the coronal two-thirds
- 3 shaping file in the coronal two-thirds
- size 15 apical file to full working length
- size 20 apical file to full working length
- size 25 apical file to full working length
- size 30 apical file to full working length

Instruments were used to shape the root canals of one specimen (three or four canals) before being discarded. After each instrument the root canal was irrigated with 5 mL 2.5% sodium hypochlorite. FileEze (Ultradent Products Inc.) was used as lubricating agent for each instrument to facilitate preparation. The operator was not allowed to see CT images before treatment in order to maintain clinical conditions.

Micro-computed tomography measurements and evaluations

Scanning and evaluation procedures have been described elsewhere in more detail (Peters *et al.* 2000, 2001b, 2003). Briefly, specimens were scanned at an isotropic resolution of 34 μm using a micro-computed tomography system (μCT-20; Scanco Medical, Bassersdorf, Switzerland) and three-dimensional images of the root canals were constructed after filtering and thresholding. The canals were again scanned, as above, after shaping so that each canal served as its own control (Fig. 1).

Root canal models were used to detect gross preparation errors such as straightening apical zips, perforations and retained fractured instruments. These errors were tabulated and canals that did not meet minimal clinical standards were subsequently excluded from the evaluation because it was not possible to extract meaningful measurements from these canal models.

Subsequently, canals were superimposed with a precision better than one voxel and matched root canals were evaluated for changes in volume and surface area. The same models were also used to determine the Structure Model Index (SMI) of the root canals. This index characterizes the structure of an object as having an ideal ribbon-like shape, corresponding to an SMI score of 0 or cylindrical shape, corresponding to an SMI of 3. Furthermore, 'thicknesses' of the canals were determined using recently described distance transformation techniques (Peters *et al.* 2000) and related to canal length in order to construct canal diameter profiles (Fig. 2). Then, 'centres of gravity' of the canals, calculated for each slice,

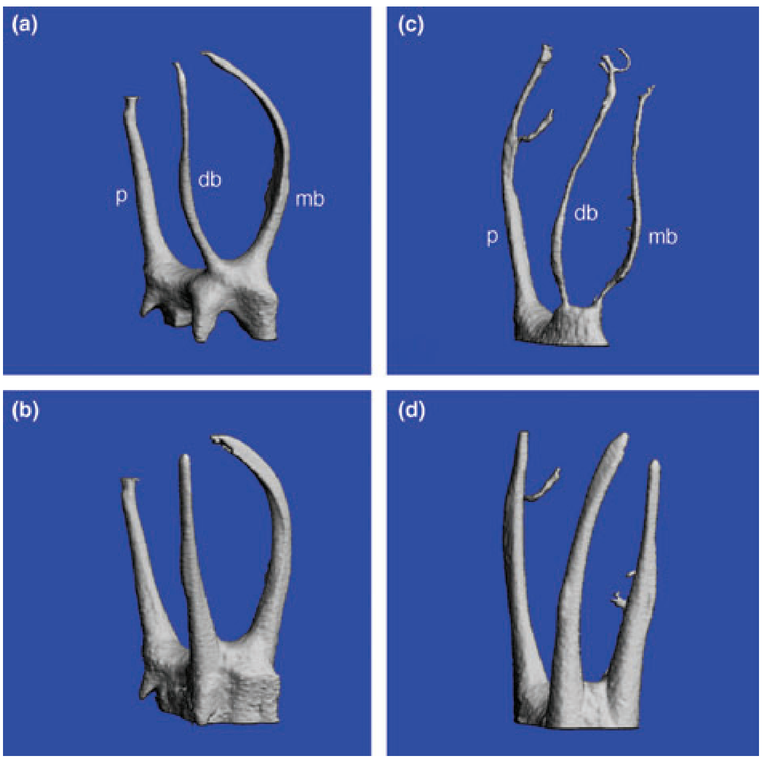

Figure 1 Images of unshaped (a, c) and prepared (b, d) root canal systems reconstructed from μCT data.

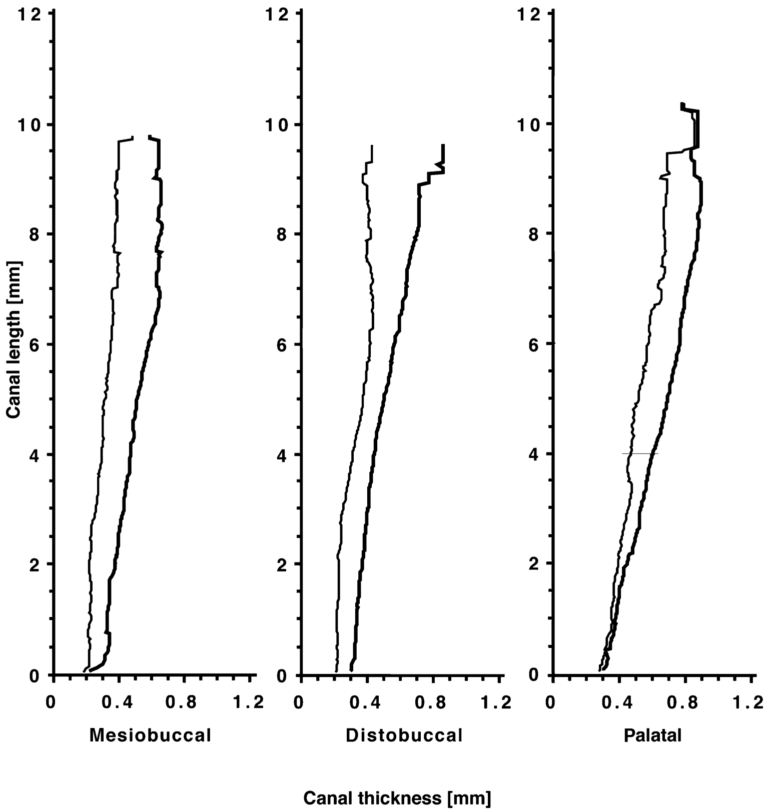

Figure 2 Canal 'thickness' profiles detailing clinical diameters along canal length (mean scores from 10 mesiobuccal, 12 distobuccal and 12 palatal canals).

were connected along the z-axis by a fitted line. Canal transportations (CM shifts expressed in mm, Fig. 3), were calculated by comparing the centres of gravity before and after treatment for the apical, mid and coronal thirds of the canals. From a polynomic equation, describing a fitted line for each canal, curvatures were calculated as second derivatives.

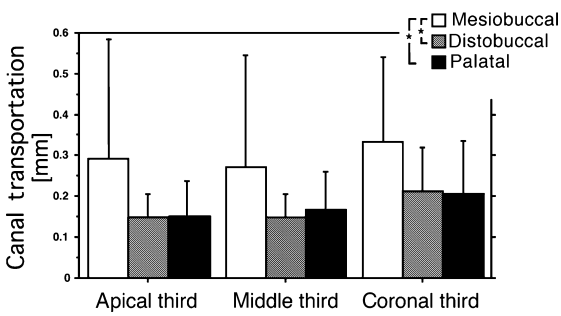

Figure 3 Canal transportation (CM shift) in mesiobuccal ($n = 10$), distobuccal ($n = 12$) and palatal ($n = 12$) canals, split by canal third (mean ± SD). *Significant differences between canal types ($P < 0.01$, two-way ANOVA). No differences between canal levels.

Finally, matched images of the surface area voxels of the canals, before and after preparation were examined to evaluate the amount of un-instrumented surface (Fig. 4), using volume-rendering software (VGStudio-Max; VolumeGraphics, Heidelberg, Germany). This parameter was calculated by subtracting the number of static surface voxels from the total number of surface voxels. Scores expressed as mean ± SD, were compared using one- and two-way ANOVAs with Scheffé tests for *post-hoc* comparisons. When appropriate, repeated-measures ANOVAs were constructed. A level of $P < 0.05$ was considered significant.

Results

Scanning of unprepared (Fig. 1a,c) and instrumented canals (Fig. 1b,d) yielded detailed three-dimensional canal images. Volume rendering was used to illustrate the relationship between root canals and outer root contour (Fig. 4a,d). Procedural errors such as apical zips or ledges were detected in 17/36 canals after canal preparation with Endo-Eze. In particular, one mesiobuccal root canal was ledged and perforated in the apical third and another mesiobuccal root canal was straight-

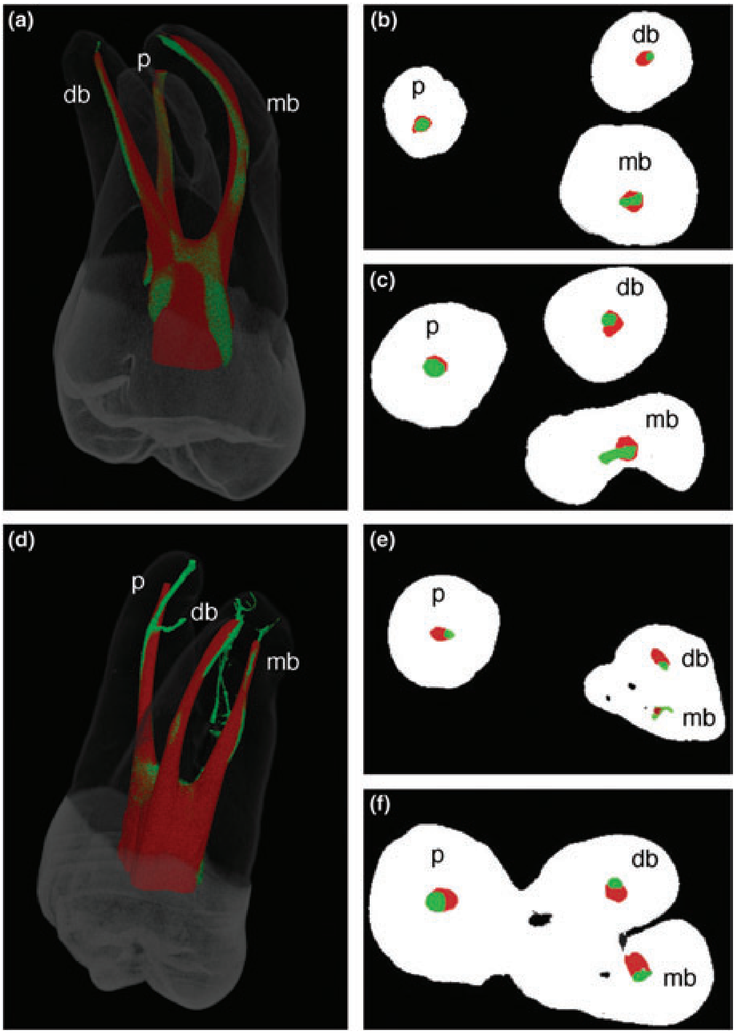

Figure 4 Two examples for matched and superimposed root canal systems. Some preparations were acceptable (a), while in other teeth excessive root canal transportations were observed (d), rendering them not acceptable for evaluation. Unprepared canals shown in green, prepared areas in red. Panels (b, c) and (e, f) show corresponding matched and superimposed two-dimensional views of root canals 2.5 and 5.0 mm from the apex, respectively. Note canal transportation in mesiobuccal canals in (c) and (f) resulting in excessive dentine removal.

Table 1 Morphometric data determined for untreated maxillary root canals (mean ± SD)

	Mesiobuccal (n = 10)	Distobuccal (n = 12)	Palatal (n = 12)
Volume (mm^3)	1.95 ± 0.82[a]	1.19 ± 0.65[b]	3.44 ± 1.17[a,b]
Area (mm^2)	21.61 ± 8.28[c]	11.49 ± 3.95[c,d]	20.46 ± 4.72[d]
SMI	2.36 ± 0.56[e]	3.17 ± 0.30[e]	2.60 ± 0.78

SMI, Structure Model Index (ranging from 0 to 4). Significant differences between canal types ($P < 0.01$, one-way ANOVA) indicated by superscript alphabets.

Table 2 Increase* in morphometric scores after preparation of maxillary root canals (means ± SD)

	Mesiobuccal (n = 10)	Distobuccal (n = 12)	Palatal (n = 12)
Volume (mm^3)	2.15 ± 1.05	1.55 ± 0.58	1.42 ± 0.93
Area (mm^2)	7.16 ± 3.51[a]	6.01 ± 2.43[b]	2.60 ± 1.94[a,b]
SMI	0.38 ± 0.37	0.08 ± 0.31[c]	0.73 ± 0.78[c]

SMI, Structure Model Index. Significant differences between canal types ($P < 0.05$, Scheffé test) indicated by superscript alphabets.
*Significant, $P < 0.005$, repeated-measures ANOVA.

ened with a considerable loss of working length. The data of these two canals were excluded from evaluation.

Overall, median initial canal volume and surface area were 1.94 mm^3 and 18.49 mm^2, respectively. Table 1 details preoperative mean scores, indicating that mb canals were significantly ($P < 0.05$) more ribbon-shaped than db canals, as shown by respective SMI scores. Repeated-measures ANOVA revealed that preparation significantly increased canal volumes, surface areas and SMI scores (Table 2). At the same time, SMI increase was highest in p canals and ANOVA indicated significant differences between canal types in this respect ($P < 0.05$, Table 2).

Figure 2 illustrates diameters of canals, evaluated as 'thickness', by plotting means against canal lengths and yielding canal dimension estimates, before and after preparation. Overall, 'thickness' increased significantly while canals were prepared. In p canals the apical 2 mm were barely enlarged (Fig. 2). Canal diameters at the 5 mm level increased from 0.31 to 0.52, 0.35 to 0.50 and 0.50 to 0.70 mm for mb and db and p canals, respectively.

Using superimposed canal models, mean Centre of Mass shift (CM shift) scores were calculated for the coronal, middle and apical thirds and scores ranged from 0.15 to 0.33 mm. Figure 3 details mean scores for mb, db and p canals. Two-way ANOVA indicated differences between both the mb and db root canals and mb and p canals, with almost identical CM shifts in db and p canals for all root canal thirds. Furthermore, no significant differences were found with respect to canal level (Fig. 3).

Most canals used in this study were slightly to moderately curved; curvature being metrically described as the second derivative of a fitted line through successive canal centres. However, canal preparation led to various degrees of straightening (Table 3). This effect was most pronounced in those canals, which had higher initial degrees of curvature. Overall, straightening was highly significant during preparation ($P < 0.002$). Mesiobuccal and distobuccal canals showed a higher degree of canal straightening, compared to palatal ones. However, this difference was not statistically significant.

Superimposed images, with colour-coded static voxels, designated untreated areas (Fig. 4a,d). These areas tended to be mid-root at the convex side and apically at the concave side of the curvature. The summation further allowed detecting areas that were only visible in the preoperative scan and not in the postoperative image (green areas in Fig. 4a,d). These represent uninstrumented parts of the root canal system. In many cases, root canal transportation led to considerable untreated areas (Fig. 4d).

Table 3 Relative degree of canal straightening* (mean ± SD)

	Mesiobuccal ($n = 10$)	Distobuccal ($n = 12$)	Palatal ($n = 12$)
Straightening (%)	26.46 ± 24.26	21.45 ± 33.03	4.24 ± 23.26

No significant differences between canal types but highly significant straightening during preparation ($P < 0.002$, repeated measures ANOVA).
*Expressed as decrease in second derivative scores, calculated from a polynomic equation fitted through the respective canal centre of mass.

Table 4 Percentages of static voxels recorded by superimposing matched images, before and after preparation (means ± SD)

	Mesiobuccal ($n = 10$)	Distobuccal ($n = 12$)	Palatal ($n = 12$)
Voxels* (%)	30.23 ± 12.19	24.99 ± 14.67	29.34 ± 17.07

No differences between canal types (ANOVA).
*Relative findings are expressed as percentages calculated in relation to surface areas after preparation.

Finally, amounts of static surface voxels, or untreated areas were calculated (Table 4) to range between 25 and 30%. Distobuccal canals had the lowest numbers of untreated voxels when compared with mb and p canals. This difference was not statistically significant (ANOVA).

Discussion

Endo-Eze instruments were recently introduced to prepare root canals less aggressively than previous endodontic instrumentation systems, while allowing for more complete shapes of oval cross-sections. In this system, all instruments are made of stainless steel. The instruments for cleaning and shaping the coronal part of the root canal are used in a special handpiece. The Endo-Eze handpiece uses a reciprocal quarter turn motion (oscillating angle of 30°). According to the manufacturer, the use of stainless steel instruments in combination with an oscillating motion should allow the preparation of anatomical irregularities in oval shaped root canals.

No previous reports have evaluated the shaping ability of Endo-Eze instruments using μCT. Recently μCT has evolved into an exciting tool for experimental endodontology (Rhodes *et al.* 1999). μCT is emerging in several endodontic research facilities as a non-destructive and accurate method to analyse root canal geometry and the relative effects of shaping techniques (Rhodes *et al.* 2000, Bergmans *et al.* 2001, Gluskin *et al.* 2001, Peters *et al.* 2001a,b, 2003, Hübscher *et al.* 2003). Accuracy and reproducibility of the system used in this study has been verified previously (Peters *et al.* 2000) and it is accepted as an important scientific tool.

In the present study, Endo-Eze instruments were used in maxillary molars to allow comparisons to the data of previous studies performed under the same technical conditions with NiTi instruments (Peters *et al.* 2001a,b, 2003, Hübscher *et al.* 2003).

The ultimate goal of root canal preparation is canal debridement to promote apical healing (Byström *et al.* 1987) and, in vital cases, to retain apical health. In this regard, apical root canal enlargement by mechanical canal shaping has an antimicrobial effect via root canal debridement (Byström & Sundqvist 1981). However, irrigation with antimicrobial solutions is required to lower bacterial counts to clinically acceptable levels (Shuping *et al.* 2000). Preparation of oval root canals with rotary NiTi instruments resulted in remaining unprepared areas (Rödig *et al.* 2002). This finding seems to be of great value as the prevalence of long oval canals in apical thirds was identified in 25% of teeth of all groups (Wu *et al.* 2000). After using balanced force technique and lateral condensation, oval recesses in 40% of oval canals were neither instrumented nor completely obturated (Wu & Wesselink 2001). According to the manufacturer of Endo-Eze, these instruments in combination with the reciprocating handpiece should allow instrumentation of all walls in such canals to clean the whole anatomical space without weakening the root. The present study addressed this question and furthermore evaluated the effect of canal anatomy on preparation outcome.

Deviation from the canal's natural path during instrumentation is a common procedural error and may present as zipping, canal straightening, ledging or elbow formation. Several obvious procedural errors and significant canal straightening were detected in this study and the data of two mesiobuccal roots were omitted due to gross preparation errors.

These results are in contrast to findings of earlier studies with the same method, in which six NiTi preparation systems were evaluated in maxillary molars using μCT (Peters *et al.* 2001b, 2003, Hübscher *et al.* 2003). In those studies no obvious preparation errors were detected after preparation with various NiTi instruments. In fact, when transportation was expressed as CM shifts, greater degrees of root canal straightening were recorded using Endo-Eze in comparable investigations using NiTi instrumentation (Peters *et al.* 2001b, 2003, Hübscher *et al.* 2003). Concerning root canal transportation, a 'displacement of centre of gravity' of up to 0.1 mm can be regarded as acceptable (Peters 2004). In mesiobuccal root canals mean transportation was three times higher than the acceptable value (0.3 mm) with a maximum of more than 1 mm. This lead to limited amounts of remaining root dentine (data not shown).

Overall canal anatomy, as described by volume, surface area and SMI was statistically similar in the present study compared to root canals evaluated earlier using the same analytical methods (Peters *et al.* 2001b, 2003, Hübscher *et al.* 2003). Overall, preparation with Endo-Eze removed dentine volumes varying from 1.42 to 2.15 mm^3 compared to preoperative canal volumes 1.19–3.44 mm^3. These values are higher than those previously described (Peters *et al.* 2001b, 2003, Hübscher *et al.* 2003). These findings together with the incidence of obvious procedural errors may be correlated with the use of oscillating shaping files. It may be speculated that a clinician may be unable to perform a controlled preparation with oscillating shaping files, particularly when using them in curved root canals. In earlier studies a handpiece working with similar reciprocal quarter turn motions (Endolift M4; Kerr, Karlsruhe, Germany) and safety Hedström files were used to prepare curved canals (Rooney *et al.* 1996, Lloyd *et al.* 1997). The authors reported frequent canal aberrations, ledge formation, irregular root canal shaping and canal straightening when using latter instruments.

In the present study, canal diameters were described as 'thickness', which was calculated by fitting spheres into reconstructed canals, as described previously (Peters *et al.* 2000). Specifically, maximum local sphere diameter relates to a specific file tip size, which a clinician would select to gauge the apical region (Ruddle 2002).

Endo-Eze instruments used in the sequence suggested by the manufacturer at that time adequately opened most canals 5 mm from their apices with sizes varying from 0.5 to 0.7 mm. However, spreaders and pluggers with size 0.5 mm tips might not be able to reach the 5 mm level in some of the smaller canals in the present sample. Deep instrument penetration is considered critical for both lateral (Allison *et al.* 1979) and vertical (Ruddle 2002) compaction. Presently, Endo-Eze apical files are available up to ISO 50 and a step-back preparation should be recommended to perform a more tapered preparation in the apical third. Canal 'thickness' is also an important parameter when considering how far into a canal irrigation needles can be safely inserted to for optimized irrigation delivery.

When assessing the amount of un-instrumented canal areas after preparation the results were surprisingly better than in previous studies using NiTi instruments (Peters *et al.* 2001b, 2003, Hübscher *et al.* 2003). The amount of 'prepared canal walls' as expressed in Table 4 achieved 70–75% of the total areas while other techniques thus far yielded results varying from 55 to 65%. This result may be explained by the more aggressive removal of root dentine (Fig. 4). However, the high amount of root canal dentine removed due to the oscillating preparation system led to significant straightening and resulted in preparation errors, negating any positive effects. In summary, the present study does not support the notion that Endo-Eze AET instrument are conducive to a minimal invasive root canal preparation.

Conclusions

Under the conditions of this study Endo-Eze AET instruments shaped root canals in maxillary molars with obvious shaping errors. High degrees of canal transportation were evident, particularly in mesiobuccal root canals. This was probably due to limited instrument control during preparation with oscillating instruments. Preparation with Endo-Eze AET removed high volumes of dentine, even though preparation was limited to a size 30. Based on the current results, Endo-Eze AET cannot be recommended for the preparation of teeth with curved root canals.

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