Determining the apical terminus of root-end resected teeth using three modern apex locators: a comparative *ex vivo* study

A. ElAyouti, I. Kimionis, A.-L. Chu & C. Löst
Department of Conservative Dentistry and Endodontology, University of Tübingen, Tübingen, Germany

Abstract

ElAyouti A, Kimionis I, Chu A.-L., Löst C. Determining the apical terminus of root-end resected teeth using three modern apex locators: a comparative *ex vivo* study. *International Endodontic Journal*, **38,** 827–833, 2005.

Aim To assess *ex vivo* the accuracy of various electronic apex locators in locating the apical terminus of root-end resected teeth.

Methodology Ninety extracted human posterior teeth (182 root canals) were prepared to a minimum size of 40 and filled with gutta-percha and sealer. After resection of the apical 3 mm of the root, the root canal filling was removed using HERO rotary instruments. The size of the root canal at the apical terminus after removal of the filling ranged from size 50 to 90. The root canal length to the apical terminus was determined using 3 apex locators (Root ZX, Raypex®4 and Apex Pointer). A new mounting model that utilized a micrometer was used to perform the measurements and to visually determine the actual position of the apical terminus. The frequency of locating the apical terminus and the corresponding 95% confidence interval (CI) were calculated. Additionally, the coefficient of repeatability of each apex locator and the limits of inter-operator agreement were determined.

Results All apex locators showed an acceptable repeatability (0.02–0.03 mm coefficient of repeatability) and narrow limits of inter-operator agreement (+0.07 and −0.07 mm). The accuracy of determining the apical terminus within 1 mm in the root canal was as follows: Root ZX 90% (164/182 root-canals) [95%CI: 86–94%], Raypex®4 74% (135/182 root-canals) [95%CI: 68–80%], and Apex Pointer 71% (129/182 root canals) [95%CI: 65–77%]. No over-instrumentation resulted when the Root ZX device was used. In contrast, using the Raypex®4 or the Apex Pointer device resulted in over-instrumentation in 8 of 182 root canals (4%).

Conclusions Under the conditions of this study all three apex locators were able to detect the apical terminus of root-end resected teeth with an acceptable range. The Root ZX device was the most accurate without over-instrumentation of the root canals.

Keywords: apicectomy, electronic apex locators, odontometry, retreatment, root canal treatment, working length.

Received 24 June 2005; accepted 1 July 2005

Introduction

Further canal preparation in root-end resected teeth is not a routine procedure. However, root-end resected teeth may require orthograde revision in case of persistent infection or after reinfection of the root canal. This is usually a result of insufficient, fractured or missing coronal restorations. Intra-radicular infection with virulent micro-organisms is often the causative factor of a persisting apical periodontitis. In such cases root-end resection alone will not result in resolution of apical periodontitis (Grung *et al.* 1990, Danin *et al.* 1999). For example, even when a root-end filling is placed, leakage can still occur as most root-end filling

Correspondence: A. ElAyouti, Department of Conservative Dentistry and Endodontology, University of Tübingen, Osianderstraße 2-8 Tübingen 72076, Germany (Tel.: 0049 7071 2983498; fax: 0049 7071 295656; e-mail: ashraf.elayouti@med.uni-tuebingen.de).

materials will leak in time (Siqueira *et al.* 2001, Tang *et al.* 2002, Mangin *et al.* 2003, De Bruyne *et al.* 2005). Healing of apical periodontitis can be initiated by reduction or elimination of intra-radicular infection (Sedgley & Wagner 2003). This could be achieved by an orthograde revision of the insufficient or infected root canal filling (Friedman 1991, Kontakiotis *et al.* 2004).

Radiographic working length determination is often difficult because the apical terminus of the root canal is difficult to locate on the radiograph (ElAyouti *et al.* 2002, Hoer & Attin 2004), especially in root-end resected teeth when the root is extremely bevelled. Apical microsurgery that utilizes an operating microscope and small ultrasonic surgical tips reduced the need for apical bevelling. Nevertheless, the apical terminus of the root canal will, in most cases, end short of the radiographic apex and overestimation of the radiographic working length is common (Kuttler 1955, Wu *et al.* 2000). The distance between the apical terminus of the root canal and the radiographic apex will vary according to the form of the apex (Olson *et al.* 1991, Stein & Corcoran 1992) and the angulations of the X-ray beam to the long axis of the tooth.

Modern apex locators have been shown to be accurate in determining the apical constriction of the root canal (Gordon & Chandler 2004). In resected teeth the apical anatomy is altered. In most of the cases the apical constriction, which is within 3 mm from the apex (Dummer *et al.* 1984), is removed either by root-end resection or by initial root canal preparation. Factors that may influence the accuracy of apex locators are the size of the apical foramen, type and size of the measuring file, irrigation solution and electro-conductivity of the pulp (Saito & Yamashita 1990, Fouad *et al.* 1993). In root-end resected teeth, the large size of the root canal at the apical terminus may influence the accuracy of apex locators. Although few studies examined the performance of apex locators in teeth with altered apical anatomy (Huang 1987, Hulsmann & Pieper 1989), there is insufficient information concerning the performance of apex locators in root-end resected teeth.

Therefore, the aim of this *ex vivo* study was to assess the accuracy of three modern apex locators in determining the apical terminus of the root canal in root-end resected human teeth.

Material and methods

Ninety human extracted teeth (50 premolars, 40 molars) were selected after visual (×4.3 magnification) and radiographic examination. Exclusion criteria were the presence of metallic restorations and root resorption or fractures. The teeth had a total of 182 root canals. The teeth were cleaned and access cavities were performed. Patency of each root canal was checked using a size 06 K file. The root canals were prepared with a hybrid technique using Hero instruments (MicroMega, Besançon, France) for the crown-down phase and LightSpeed (LightSpeed Technology, San Antonio, TX, USA) for the preparation of the apical third. All rotary instruments were driven by an EndoStepper motor (S.E.T., Gröbenzell, Germany). All root canals were prepared to a master apical rotary larger than size 40. Seventeen per cent EDTA and 1% NaOCl were used as irrigants. Root canals were then filled with gutta-percha and AH plus sealer (Dentsply Detray, Konstanz, Germany) using the lateral condensation technique. The apical 3 mm of the roots were resected using a diamond disc. The root canal filling material was then removed using Hero rotary instruments and Hedström files. After cleaning and irrigation of the root canals with 0.9% NaCl, the size of each root canal at the apical terminus (s_{ter}) was prepared and determined using LightSpeed rotary instruments. The largest instrument fitting at the level of the apical terminus represented s_{ter}. All root canals had a minimum s_{ter} of size 50. The root canals were divided into two groups according to s_{ter}. In group 'A' the s_{ter} of root canals was 50–60 and in group 'B' the s_{ter} of root was 70–90. Teeth were stored in 0.9% NaCl solution.

Mounting model

The mounting model (Fig. 1) was presented in detail in another article (ElAyouti & Löst 2005). Briefly, it consists of an adjustable ring for tooth fixation and a micrometer to which a measuring file is connected. The reading of the micrometer indicates the position of the file/file tip. The distance travelled by the file/file tip is determined by calculating the difference between two successive readings of the micrometer. The measuring file used in this study was a stainless steel reamer size 15.

Repeatability of apex locator devices

For this study three apex locators were used:

- Root ZX (Morita, Tokyo, Japan)
- Raypex®4 (VDW, Munich, Germany) also marketed as Bingo 1020 (Gordon & Chandler 2004)
- Apex Pointer (MicroMega, Besançon, France)

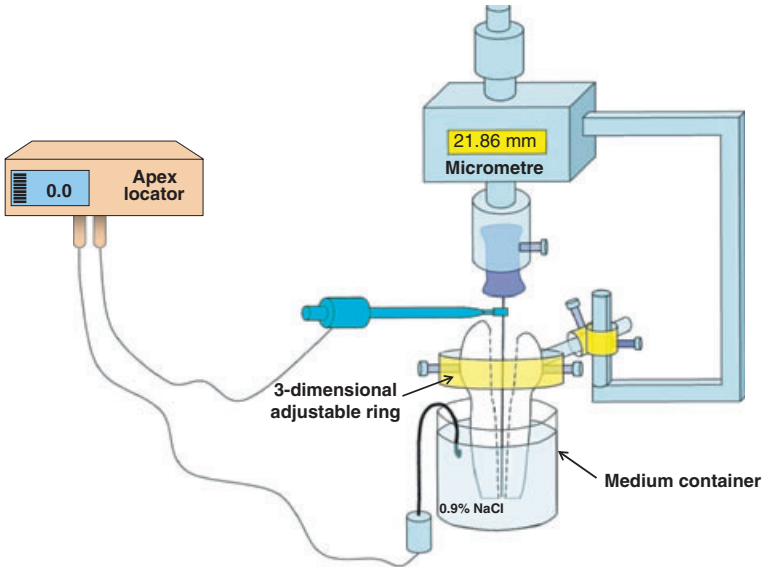

Figure 1 Components of the mounting model and study set-up.

For each apex locator device 24 root canals were randomly selected from the 182 root canals assigned for this study. Using the mounting model each root canal measurement at the display level '0.0' of the apex locators was performed twice. This resulted in 24 repeated measurements for each apex locator. All repeated measurements were performed by the same operator. The detailed procedure for performing the measurements is described later.

Inter-operator agreement

Using the mounting model, measurements of ninety root canals (30 for each apex locator) were performed. The root canals used for the inter-operator agreement evaluation were randomly selected from the 182 root canals assigned for this study. Two operators performed the measurements. Each root canal was measured once by each of the operators. This resulted in 90 paired measurements. The sequence of using the three apex locator devices was randomly assigned using block randomization. The detailed procedure for performing the measurements is described later.

Distance to apical terminus (d_{ter})

This is the distance between the actual position of the apical terminus and the position determined as apical terminus by the apex locators (apex locator display level '0.0') (Fig. 2).

This was calculated by subtracting the reading of the mounting model at apex locator display level '0.0' from the reading of the mounting model at the actual position of the apical terminus. The detailed procedure for performing the measurements was as follows.

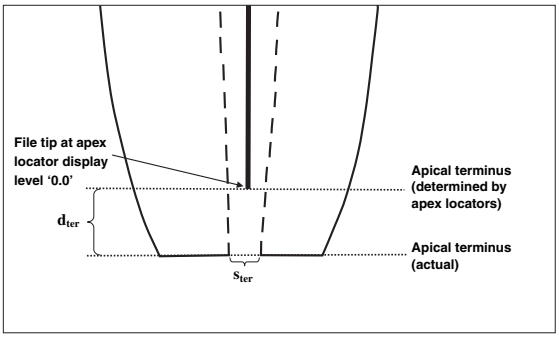

Figure 2 Schematic presentation of the distance to apical terminus (d_{ter}) and the size of root canal at the apical terminus (s_{ter}).

Mounting model reading at the actual position of the apical terminus (r_{ter})

The measuring file connected to the micrometer (Fig. 1) was advanced apically until the file tip was flush with the apical terminus. This was performed under ×4.3 magnification. The reading of the micrometer was recorded. To exclude any inaccuracy resulting from movement of the teeth within the adjustable ring, the reading of the micrometer at the apical terminus was recorded twice (at the beginning

and at the end of the measuring procedure). A difference of more than 0.1 mm between the two readings indicated inconsistency and the measuring procedure was repeated after checking the fixation of the tooth and file to the mounting model. This was the case in seven root canals. In most of the canals the difference between the two readings (at the beginning and at the end of the measurement procedure) was 0.03 mm. r_{ter} was determined by taking the average of the two readings.

Mounting model reading at apex locator display level '0.0' ($r_{\cdot 0.0 \cdot}$)

The measuring file connected to the micrometer (Fig. 1) was positioned at the coronal third of the canal or even more coronally. The apex locator was then connected as in Fig. 1 and switched on. The reading of the mounting model at apex locator display level '0.0' was determined by taking the average of the apical and coronal '0.0' readings, this was performed in three steps:

1. The measuring file was advanced apically until the display level '0.0' was surpassed. The following indicators were seen on the display of the apex locator: Root ZX 'Apex', Raypex®4 red light, Apex pointer 'AP'. This was done by clockwise rotation of the micrometer.

The measuring file was moved coronally by rotating the micrometer anticlockwise till the display level '0.0' of the apex locator was reached and the reading of the micrometer at this level was recorded. This represented the apical '0.0' reading.

2. The measuring file was moved more coronally until the display level '0.0' disappeared (Root ZX and Raypex®4: the bar corresponding to '0.0' disappeared, Apex pointer: level '0.1' was displayed). The reading of the micrometer just before disappearing of the display level '0.0' was recorded. This represented the coronal '0.0' reading.

3. $r_{\cdot 0.0 \cdot}$ was determined by taking the average of the two noted readings (apical '0.0' and coronal '0.0' readings). This represented the reading of the micrometer at the midpoint of display level '0.0'.

The operator performing the measuring procedure was unaware of the reading of the micrometer which was recorded by another operator.

In each root canal the measuring procedure described above was performed using the three apex locator devices in sequence. In each root canal the value of r_{ter} was determined once for all three apex locators because the tooth was fixed in the mounting model and the position of r_{ter} did not change. The sequence of using the apex locators was randomized using block randomization.

The distance to the apical terminus (d_{ter}) at the display level '0.0' was calculated by subtracting the reading of the mounting model at the apex locator display level '0.0' from the reading of the mounting model at the actual position of the apical terminus (r_{ter}–$r_{\cdot 0.0 \cdot}$). A positive value of d_{ter} indicated that the tip of the measuring file was short of the apical terminus and a negative value of d_{ter} indicated that the measuring file had passed beyond the apical terminus of the root canal (over-instrumentation).

Data analysis

Repeatability

In the repeated measurements (24 for each apex locator) the mean and the difference between repeated measurements in each root canal were calculated and plotted for each apex locator device (Fig. 3). The repeatability of apex locators was determined by calculating the coefficient of repeatability for each apex

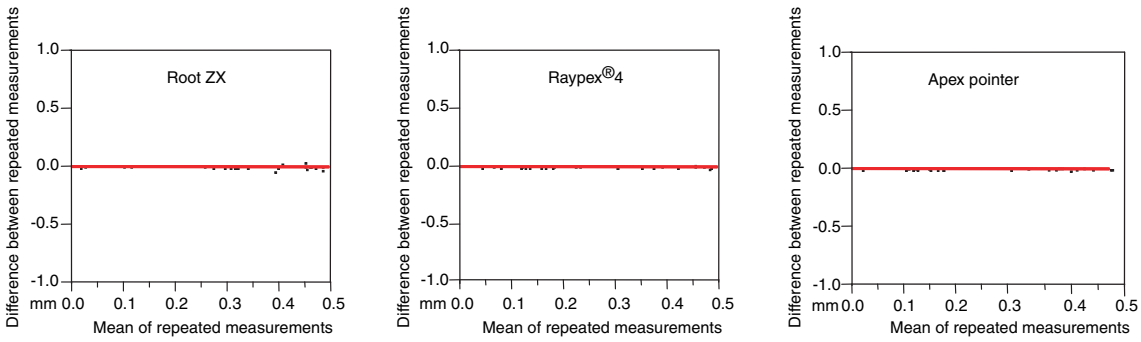

Figure 3 Plots of the repeated measurements for each apex locator.

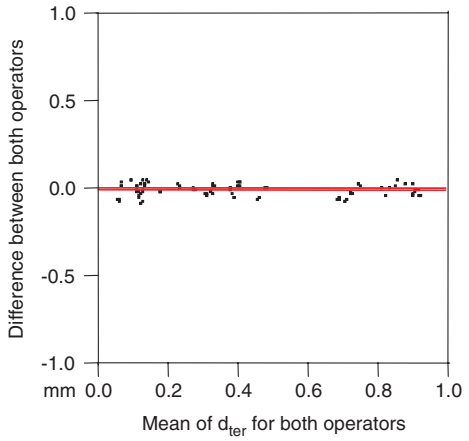

Figure 4 Plot of the paired analysis of the inter-operator agreement.

locator device (Bland & Altman 1986). This corresponds to 2 standard deviations of the differences between the first and second measurement.

Inter-operator agreement

For the inter-operator agreement (90 paired measurements) the mean and the difference between both operator measurements in each root canal were calculated and plotted against each other (Fig. 4). The inter-operator agreement was determined by calculating the upper and lower limits of agreement (Bland & Altman 1986, 1996). This corresponds to the mean of the differences between the two operators plus 2 standard deviations (upper limit) and minus 2 standard deviations (lower limit).

Distance to apical terminus (d_{ter})

The mean and the corresponding 95% confidence interval (CI) of d_{ter} were calculated for each group (A and B) and each apex locator.

Results

Repeatability

Using the mounting model, all three apex locator devices showed an acceptable repeatability. The coefficients of repeatability were: Root ZX, 0.03 mm; Raypex®4, 0.02 mm; Apex Pointer, 0.02 mm. There was no relation between the mean and difference of the repeated measurements (Fig. 3).

Inter-operator agreement

The inter-operator agreement was acceptable; this was demonstrated by the narrow limits of agreement between the two operators (upper limit +0.07 mm and lower limit −0.07 mm). There was no relation between the amplitude of the measurements and the differences between the two operators (Fig. 4).

Distance to the apical terminus (d_{ter})

The Root ZX apex locator was the most accurate in determining the apical terminus of the root canal within 1 mm (Tables 1 and 2). Moreover, using the Root ZX resulted in no overestimation of the root canal length and d_{ter} had a positive value for all root canals (Tables 1 and 2).

Table 1 Distribution of root canals according to distance to apical terminus (d_{ter}) determined by the three apex locators

	Root ZX		Raypex®4		Apex Pointer	
Distance to apical terminus	*n*	%	*n*	%	*n*	%
>1 to 2 mm	18	10	39	21	45	25
0 to 1 mm	164	90	135	74	129	71
<0 to −1 mm (over-instrumentation)	0	0	8	4	8	4
Total	182	100	182	100	182	100

Table 2 Distribution of root canals according to the distance to the apical terminus and the apical size of the root canal

	Root ZX				Raypex®4				Apex Pointer			
	Group A		Group B		Group A		Group B		Group A		Group B	
Distance to apical terminus	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
>1 to 2 mm	2	2	16	18	4	4	35	39	4	4	41	46
0 to 1 mm	90	98	74	82	85	93	50	56	83	91	46	51
<0 to −1 mm (over-instrumentation)	0	0	0	0	3	3	5	5	5	5	3	3
Total	92	100	90	100	92	100	90	100	92	100	90	100

Group A: root canals with apical sizes 50–60. Group B: root canals with apical sizes 70–90.

Table 3 Distribution of mean and the corresponding 95% confidence intervals (CI) of the distance to the apical terminus

	Group A		Group B	
Apex locator device	Mean (mm)	95% CI (mm)	Mean (mm)	95% CI (mm)
Root ZX	0.51	0.46–0.57	0.78	0.69–0.87
Raypex®4	0.46	0.41–0.51	0.82	0.73–0.91
Apex Pointer	0.47	0.42–0.53	0.85	0.76–0.94

Group A: root canals with apical sizes 50–60. Group B: root canals with apical sizes 70–90.

There was a statistically significant difference between the means of d_{ter} of the two groups of root canal apical sizes (groups A and B). The mean of d_{ter} and the corresponding 95% CI for each group and each apex locator are presented in Table 3. Further, box and whisker plots of the cumulative frequency of d_{ter} are presented in Fig. 5. There was no statistical difference between the means of d_{ter} of the three apex locators within each group (Table 3).

Discussion

All apex locators tested in this study detected the apical terminus within an acceptable range. The Root ZX device showed the least variation of measurements (Fig. 5) and consequently resulted in no overestimation of the working length (Tables 1 and 2). Clinically, a higher variation of measurements is expected because in contrast to *in vitro* studies favourable circumstances for precise measurements are not available.

Working length determination was influenced by the size of the canal at the apical terminus. This was in accordance with the literature (Saito & Yamashita 1990, Wu *et al.* 1992, Fouad *et al.* 1993). A root canal with a large apical size resulted in underestimation of the root canal length and consequently in short working lengths. All other known factors that influence the accuracy of apex locators were kept constant in this study. Nevertheless, not all measurement variation could be explained by the different apical sizes, showing that other factors may have a determining role, such as the electro-conductivity of the dentine walls or the presence of apical ramifications. The largest apical size of the root canals used in this study was 90; no attempt was made to further enlarge the root canals because large root canals facilitate easy access to the apex, and working length determination is simplified by various methods such as direct visualization of the apical region using magnification or probing the dentinal wall using a small file that is bent at the tip.

The mounting model allowed consistent and stable measurements. This was demonstrated by the good repeatability of all apex locators (Fig. 3) and the narrow limits of inter-operator agreement (Fig. 4). Therefore, measurements were only performed once and by one operator. Moreover, using the mounting model eliminated measurement error that may result from stopper adjustment or length determination of the measuring file, which could account to ±0.7 mm variation in the measurement (ElAyouti & Löst 2005).

In most cases the apical constriction is present within the apical 3 mm of the root canal (Dummer *et al.* 1984). In the present study the apical constriction was assumed to be removed during resection or preparation of the root canal. Therefore, only the measurements performed at the display level '0.0' of the apex locators are presented.

Measurements were performed by displacement of the measuring file in a coronal direction; this was carried out to avoid inaccurate measurements resulting from bending of the measuring file. This is often the case when a small file is advanced apically through a narrow root canal or against root canal wall irregularities.

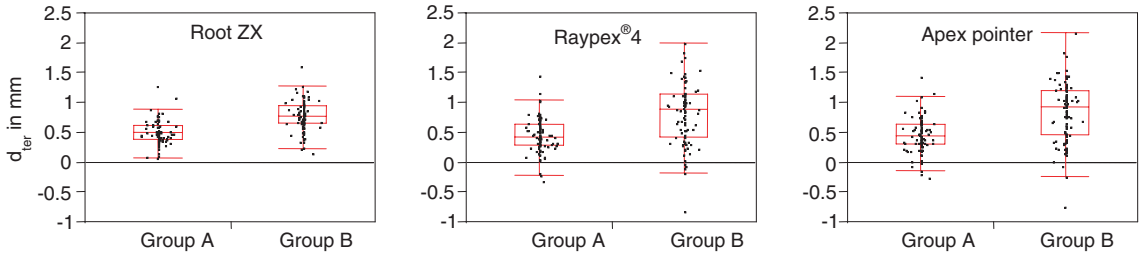

Figure 5 Box and whisker plots presenting the cumulative frequency of the distance to the apical terminus (d_{ter}). Group A: root canals with apical sizes 50–60; group B: root canals with apical sizes 70–90.

Conclusions

- All three apex locators could be used for the working length determination of root-end resected teeth.
- All three apex locators had an acceptable repeatability.
- In comparison with Raypex®4 and Apex Pointer the Root ZX device was most accurate and resulted in no overestimation of the root canal length.

Acknowledgement

We would like to thank Mr Axmann, Prosthodontic Department, School of Dental Medicine, University of Tübingen, Germany, for the statistical advice and for providing the literature of the statistical methods used in this study.

References

Bland JM, Altman DG (1986) Statistical methods for assessing agreement between two methods of clinical measurement. *The Lancet* **1**, 307–10.

Bland JM, Altman DG (1996) Measurement error and correlation coefficients. *British Medical Journal* **313**, 41–2.

Danin J, Linder LE, Lundqvist G, Ohlsson L, Ramsköld LO, Strömberg T (1999) Outcomes of periradicular surgery on cases with apical pathosis and untreated canals. *Oral Surgery, Oral Medicine and Oral Pathology* **87**, 227–32.

De Bruyne MA, De Bruyne RJ, Rosiers L, De Moor RJ (2005) Longitudinal study on microleakage of three root-end filling materials by the fluid transport method and by capillary flow porometry. *International Endodontic Journal* **38**, 129–36.

Dummer PM, McGinn JH, Rees DG (1984) The position and topography of the apical canal constriction and apical foramen. *International Endodontic Journal* **17**, 192–8.

ElAyouti A, Löst C (2005) A simple mounting model for consistent determination of the accuracy and repeatability of apex locators. *International Endodontic Journal* (in press).

ElAyouti A, Weiger R, Löst C (2002) The ability of root ZX apex locator to reduce the frequency of overestimated radiographic working length. *Journal of Endodontics* **28**, 116–9.

Fouad AF, Rivera EM, Krell KV (1993) Accuracy of the Endex with variations in canal irrigants and foramen size. *Journal of Endodontics* **19**, 63–7.

Friedman S (1991) Retrograde approaches in endodontic therapy. *Endodontic and Dental Traumatology* **7**, 97–107.

Gordon MP, Chandler NP (2004) Electronic apex locators. *International Endodontic Journal* **37**, 425–37.

Grung B, Molven O, Halse A (1990) Periapical surgery in a Norwegian country hospital: follow-up findings of 477 teeth. *Journal of Endodontics* **16**, 411–7.

Hoer D, Attin T (2004) The accuracy of electronic working length determination. *International Endodontic Journal* **37**, 125–31.

Huang L (1987) An experimental study of the principle of electronic root canal measurement. *Journal of Endodontics* **13**, 60–4.

Hulsmann M, Pieper K (1989) Use of an electronic apex locator in the treatment of teeth with incomplete root formation. *Endodontic and Dental Traumatology* **5**, 238–41.

Kontakiotis EG, Lagoudakos TA, Georgopoulou MK (2004) The influence of root-end resection and root-end cavity preparation on microleakage of root filled teeth in vitro. *International Endodontic Journal* **37**, 403–7.

Kuttler Y (1955) Microscopic investigation of root apexes. *Journal of the American Dental Association* **50**, 544–52.

Mangin C, Yesilsoy C, Nissan R, Stevens R (2003) The comparative sealing ability of hydroxyapatite cement, mineral trioxide aggregate, and super ethoxybenzoic acid as root-end filling materials. *Journal of Endodontics* **29**, 261–4.

Olson AK, Goerig AC, Cavataio RE, Luciano J (1991) The ability of the radiograph to determine the location of the apical foramen. *International Endodontic Journal* **24**, 28–35.

Saito T, Yamashita Y (1990) Electronic determination of root canal length by newly developed measuring device. Influences of the diameter of apical foramen, the size of K-file and the root canal irrigants. *Dentistry in Japan (Tokyo)* **27**, 65–72.

Sedgley CM, Wagner R (2003) Orthograde retreatment and apexification after unsuccessful endodontic treatment, retreatment and apicectomy. *International Endodontic Journal* **36**, 780–6.

Siqueira JF Jr, Rocas IN, Abad EC, Castro AJ, Gahyva SM, Favieri A (2001) Ability of three root-end filling materials to prevent bacterial leakage. *Journal of Endodontics* **27**, 673–5.

Stein TJ, Corcoran JF (1992) Radiographic 'working length' revisited. *Oral Surgery, Oral Medicine, and Oral Pathology* **74**, 796–800.

Tang HM, Torabinejad M, Kettering JD (2002) Leakage evaluation of root end filling materials using endotoxin. *Journal of Endodontics* **28**, 5–7.

Wu YN, Shi JN, Huang LZ, Xu YY (1992) Variables affecting electronic root canal measurement. *International Endodontic Journal* **25**, 88–92.

Wu MK, Wesselink PR, Walton RE (2000) Apical terminus location of root canal treatment procedures. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, & Endodontics* **89**, 99–103.