Evaluation of the accuracy of three electronic apex locators using glass tubules

W. Fan[1], B. Fan[1], J. L. Gutmann[2], Z. Bian[1] & M. W. Fan[1]

[1]Endodontic Center, School and Hospital of Stomatology, Wuhan University, Wuhan, China; and [2]Department of Endodontics, Baylor College of Dentistry, Texas A&M University System Health Science Center, Dallas, TX, USA

Abstract

Fan W, Fan B, Gutmann JL, Bian Z, Fan MW. Evaluation of the accuracy of three electronic apex locators using glass tubules. *International Endodontic Journal*, **39**, 127–135, 2006.

Aim To evaluate the accuracy of three different electronic apex locators (EALs) using glass tubules.

Methodology Forty-eight glass tubules with different diameters and an agar model were used to mimic root canals. A size 15 stainless steel K-file was used as the measuring electrode. The Root ZX, Propex and Neosono Ultima EZ were used to measure the tubule length with tubules dry, or filled with 0.9% NaCl, 3% H_2O_2, 2.5% NaOCl or 17% EDTA. The distance between the real length (RL) and measured length (ML) of the tubules was recorded. The range of RL ± 0.5 mm and RL ± 1 mm was used to evaluate the accuracy of the EALs. Results were subject to correlation analysis and Friedman's test.

Results In dry tubules, the accuracy of Root ZX was 75–91.7% for RL ± 0.5 mm and 100% for RL ± 1 mm, whilst the measurements of the other two EALs were all within the RL ± 0.5 mm. No influence from the increase in tubule diameter on the accuracy of all three EALs was observed in dry tubules. In tubules filled with electrolyte, the accuracy of the Root ZX decreased as tubule diameter increased ($R_d > 0$, $P < 0.05$). The RL–ML distance recorded by Propex was inversely related to the tubule diameter ($R_d < 0$, $P < 0.05$). The accuracy of Propex was 75–100% for RL ± 0.5 mm and 100% for RL ± 0.5 mm when the tubule diameter was not more than 0.80 mm, but decreased in tubules with diameter over 0.80 mm and filled with 2.5% NaOCl or 17% EDTA. Nearly, all the measurements (except for six tubules) using Neosono Ultima EZ were within 1 mm shorter than RL despite the contents in tubules and the increase of tubule diameter.

Conclusions The accuracy of the Root ZX decreased as the tubule diameter increased when tubules were filled with electrolytes. The electrolytes in the tubules decreased the accuracy of Propex when the tubule diameter was large. The electrolytes in tubules and tubule diameter had no influence on the accuracy of Neosono Ultima EZ. The Propex and Neosono Ultima EZ were more accurate than the Root ZX under various conditions in this laboratory study.

Keywords: diameter, electrolyte, electronic apex locator, root canal.

Received 26 April 2005; accepted 30 September 2005

Introduction

Accurate determination of root canal length is a crucial factor that influences the outcome of root canal treatment (Steffen *et al.* 1999, Tamarut *et al.* 2000, Kaufman *et al.* 2002). To achieve this purpose, many methods have been used including tactile sense and radiography. Tactile sense is unreliable, however, and the radiograph can provide only a 2D image for a 3D object, whilst being subject to observer interpretation (McDonald & Hovland 1990, Martinez-Lozano *et al.* 2001).

Many studies have shown that the apical foramen is not always located at the anatomical apex (Green

Correspondence: Bing Fan, Professor, Key Lab for Oral Biomedical Engineering of Ministry of Education, School & Hospital of Stomatology, Wuhan University, 65 Luoyu Road, Wuhan 430079, China (Fax: 0086 27 87873260; e-mail: bingfan8@hotmail.com).

© 2006 International Endodontic Journal

1960, Stein *et al.* 1990, Wu *et al.* 2000). The deviation between the apical foramen and root tip may be between 0 and 3 mm and occur in 50–98% roots (Gordon & Chandler 2004). The deviation can also change as the age of patient increases (Stein *et al.* 1990). These factors increase the inaccuracy and discrepancy of radiographic canal length determination. To overcome the drawbacks of radiography, the electronic apex locator (EAL) was designed and marketed to determine the terminus of the root canal objectively and accurately (Pratten & McDonald 1996, Steffen *et al.* 1999).

Sunada (1962) first realized the practical value of the relatively consistent electrical resistance between the periodontal ligament and the oral mucous membrane. Subsequently, efforts have been made to clarify the principle of this electronic method and to improve the stability and the precision of EALs under a wide array of conditions.

The electrolyte in root canals and the diameter of the apical foramen are thought to be the two main factors affecting the precision of EALs (Huang 1987, Wu *et al.* 1992). The first and second generations of EALs, which used a single direct or a single-frequency alternating current as the measuring signal, were not stable and accurate in a canal filled with a strong electrolyte (Fouad *et al.* 1990). The third generation of EALs, such as the Endex (Osada Electric Co., Los Angeles, CA, USA)/Apit (Osada Electric Co., Ltd, Tokyo, Japan) and the Root ZX (J Morita Corp., Tokyo, Japan), used two alternating currents with different frequencies. Both were able to overcome the interference of electrolyte in canals (Jenkins *et al.* 2001), especially the Root ZX. The Root ZX is designed to calculate the ratio of impedances of two different currents at a certain canal level, and express this ratio in terms of the position of the electrode (file) inside the canal (Kobayashi 1995). This ratio is near the value '1' and hardly affected by the contents in the canal when the file tip is at a distance from the apical foramen, but will be reduced to a value of 0.66 as the file approaches the apical constriction (Vajrabhaya & Tepmongkol 1997). However, the large immature or 'blunderbuss' apical foramen, which is often found in primary teeth or young permanent teeth, would still tend to give a short measurement when using the third generation EALs, including the Root ZX (Fouad *et al.* 1993, Kaufman & Katz 1993, Vajrabhaya & Tepmongkol 1997). According to Meredith & Gulabivala (1997), the impedance characteristics of a root canal are a complex electrical network comprising resistive and capacitive series and parallel elements. The large apical foramen would affect the resistance gradient inside the canal (Huang 1987). The Root ZX, as described previously, reads the largest gradient change in the impedance ratio wherever the file tip exists in the canal. The large apical foramen with very thin dentine walls would influence the total impedance between the file tip and the apical foramen, which will render a short reading (Gordon & Chandler 2004, Kim & Lee 2004).

The latest generation EALs are based on the new multi-frequency principle, and are thought to be able to overcome previous drawbacks; however, they remain untested. The Neosono Ultima EZ (Satalec Inc., Mérignac, France) and the Propex (Densply Maillefer, Ballaigues, Switzerland) are two newly developed locators based on the multi-frequency principle. Therefore, the main purpose of this investigation is to evaluate the accuracy of the Root ZX, the Neosono Ultima EZ and the Propex locators under different electrolyte conditions and different size of 'apical foramen' using a standardized model of glass tubules.

Materials and methods

Forty-eight flat-ended cylindrical glass tubules (customized by Xiangchun Glass Factory, Wuhan, China) with 16 different diameters (three tubules in each diameter) were selected. The 16 diameters were from 0.25 ± 0.025 mm to 1.00 ± 0.025 mm with an interval of 0.05 mm. The length of all tubules was from 10.30 to 11.84 mm. A 2% agar model with neutral electrode was prepared to simulate the periodontium based on the formula (2 g agar in 100 mL phosphate buffered saline containing 9 g of NaCl, 1.43 g of $Na_2HPO_4 \bullet 7H_2O$, 0.18 g of KH_2PO_4 and 1 L of H_2O) described by Aurelio *et al.* (1983). The glass tubules were mounted onto the agar model with one end just touching the agar surface to prevent the agar moving into the tubules resulting in erroneous measurements (Czerw *et al.* 1994) (Fig. 1). The whole agar model was kept moist and in a refrigerator before measurement, and renewed every 12 h.

The Root ZX (J Morita Corp.), Neosono Ultima EZ (Satalec Inc.) and Propex (Densply Maillefer) locators were used to measure the length of tubules under the following five measuring conditions within the glass tubule:

- Dry
- 3% hydrogen peroxide (H_2O_2)
- 0.9% sodium chloride (NaCl)
- 2.5% sodium hypochlorite (NaOCl)
- 17% EDTA

 © 2006 International Endodontic Journal

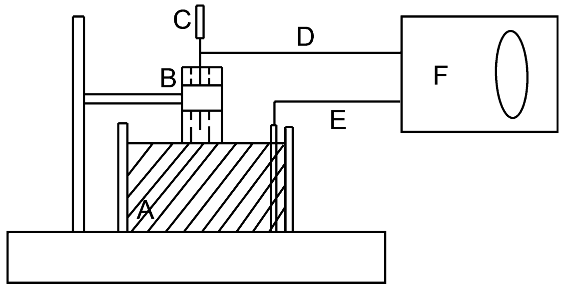

Figure 1 Illustration of the testing agar model. (A) agar; (B) glass tubule; (C) No.15 K-file; (D) measuring electrode; (E) neutral electrode; (F) electronic apex locator.

All the EALs were operated according to the manufacturer's instruction: for Root ZX, the length was recorded when the file was withdrawn to the '0.5' flashing bar on the display after going through to the 'Apex'; for Propex and Neososno Ultima EZ, the length was recorded when the '0.0' was shown. The electrolytes were injected into the tubules using a syringe with No. 27 gauge needle. A No.15 stainless steel K-file (Densply Maillefer) was used as the measuring electrode. The real length (RL) of the tubules and the measured length (ML) were obtained using a Vernier caliper with the precision of 0.02 mm under an endodontic microscope at 10× magnification. Every length was measured three times and the average was recorded. The distance between the RL and ML (RL–ML distance) was calculated, and the RL ± 0.5 mm and RL ± 1 mm (Ounsi & Naaman 1999, Kim & Lee 2004) were used to evaluate the accuracy of the three EALs. All the results were subject to correlation analysis and Friedman's test. A statistically significant difference was considered at $P < 0.05$.

Results

The accuracy of three EALs with dry tubules

The range and distribution of the RL–ML distance of different tubule diameters are shown in Table 1 and Fig. 2. The RL–ML distance of the three EALs was not influenced by the diameter of tubules ($R_d = 0.147$, $P = 0.319$). The accuracy (RL ± 1 mm & RL ± 0.5 mm) of the three EALs is shown in Table 2. The accuracy of RL ± 0.5 mm of Root ZX was slightly lower than the other two EALs ($P = 0.011$, Table 2), but there was no difference amongst the accuracy of RL ± 1 mm for all the three EALs (all were 100%, Table 2). No measurement of Root ZX was longer than RL, whilst 10 tubules (20.8%) measured by the Propex and four tubules (8.3%) by the Neosono Ultima EZ had an ML longer than RL (≤0.5 mm).

The accuracy of three EALs with tubules filled with 3% H_2O_2

The range and distribution of the RL–ML distance of different tubule diameters are shown in Table 3 and

Table 1 The RL–ML distance of three EALs with dry tubules

Tubule diameter (mm)	RL–ML distance ($\bar{x}$ ± SD mm) of three EALs		
	Root ZX	Propex	Neosono
0.25 ≤ D ≤ 0.40	0.36 ± 0.11	0.08 ± 0.16	0.067 ± 0.07
0.40 < D ≤ 0.60	0.41 ± 0.09	0.13 ± 0.11	0.11 ± 0.05
0.60 < D ≤ 0.80	0.42 ± 0.11	0.11 ± 0.11	0.11 ± 0.07
0.80 < D ≤ 1.00	0.39 ± 0.12	0.10 ± 0.13	0.11 ± 0.07
R_d	0.147	0.047	0.230
P-value	0.319	0.752	0.116

R_d, coefficient of correlation for distance of different diameter groups.

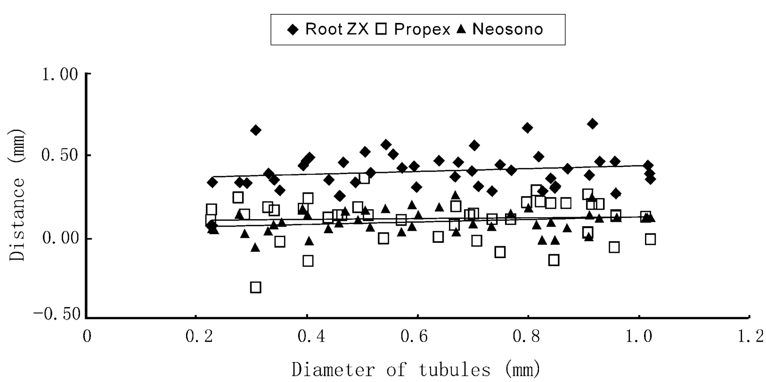

Figure 2 Distribution of RL–ML distance of three EALs with dry tubules.

Table 2 Accuracy of three EALs with dry tubules

Tubule diameter (mm)	Accuracy (%) with different tubule diameter		
	Root ZX	Propex	Neosono
$0.25 \le D \le 0.40$	91.7[a]	100.0	100.0
	100.0[b]	100.0	100.0
$0.40 < D \le 0.60$	75.0	100.0	100.0
	100.0	100.0	100.0
$0.60 < D \le 0.80$	83.3	100.0	100.0
	100.0	100.0	100.0
$0.80 < D \le 1.00$	91.7	100.0	100.0
	100.0	100.0	100.0

$M_{RL \pm 0.5} = 8.00$, $P = 0.018$; $M_{RL \pm 1} = 0$, $P = +\infty$; $M_{RL \pm 0.5/RP} = -2.56$, $P = 0.011$; $M_{RL \pm 0.5/RN} = -2.56$, $P = 0.011$.

a, accuracy of RL ± 0.5 mm; b, accuracy of RL ± 1 mm; $M_{RL \pm 0.5}$, Friedman's test for accuracy (RL ± 0.5 mm) difference amongst three EALs; $M_{RL \pm 1}$, Friedman's test for accuracy (RL ± 1 mm) difference amongst three EALs; $M_{RL \pm 0.5/RP}$, Friedman's test for accuracy (RL ± 0.5 mm) difference between Root ZX and Propex; $M_{RL \pm 0.5/RN}$, Friedman's test for accuracy (RL ± 0.5 mm) difference between Root ZX and Neosono.

Table 3 The RL–ML distance of three EALs with tubules filled with 3% H_2O_2

Tubule diameter (mm)	RL–ML distance($\bar{x}$ ± SD mm) of three EALs		
	Root ZX	Propex	Neosono
$0.25 \le D \le 0.40$	0.63 ± 0.13	−0.01 ± 0.13	0.47 ± 0.08
$0.40 < D \le 0.60$	0.85 ± 0.13	0.01 ± 0.06	0.49 ± 0.08
$0.60 < D \le 0.80$	0.84 ± 0.09	0.04 ± 0.07	0.48 ± 0.07
$0.80 < D \le 1.00$	0.98 ± 0.21	−0.04 ± 0.09	0.54 ± 0.14
R_d	0.650	−0.072	0.184
P-value	<0.001	0.626	0.211

R_d, coefficient of correlation for distance of different diameter groups.

Fig. 3. The accuracy of the Root ZX decreased as the diameter of tubules increased ($R_d = 0.65$, $P < 0.001$) (Tables 3 and 4). For the accuracy of RL ± 0.5 mm, Propex was more accurate than the other two (Table 4), but there was no significant difference amongst the accuracy of RL ± 1 mm for all the three EALs (Table 4). Considering individual values, 22 tubules (45.8%) measured by the Propex had an ML longer than RL (≤0.5 mm), whilst no measurements of the other two EALs were longer than RL.

Table 4 Accuracy of three EALs with tubules filled with 3% H_2O_2

Tubule diameter (mm)	Accuracy (%) with different tubule diameter		
	Root ZX	Propex	Neosono
$0.25 \le D \le 0.40$	25.0[a]	100.0	66.7
	100.0[b]	100.0	100.0
$0.40 < D \le 0.60$	0.0	100.0	41.7
	91.7	100.0	100.0
$0.60 < D \le 0.80$	0.0	100.0	66.7
	100.0	100.0	100.0
$0.80 < D \le 1.00$	0.0	100.0	50.0
	75.0	100.0	100.0

$M_{RL \pm 0.5} = 8.00$, $P = 0.018$; $M_{RL \pm 1} = 4.00$, $P = 0.135$; $M_{RL \pm 0.5/RP} = -2.53$, $P = 0.011$; $M_{RL \pm 0.5/RN} = -2.38$, $P = 0.017$; $M_{RL \pm 0.5/PN} = -2.47$, $P = 0.013$.

a, accuracy of RL ± 0.5 mm; b, accuracy of RL ± 1 mm; $M_{RL \pm 0.5}$, Friedman's test for accuracy (RL ± 0.5 mm) difference amongst three EALs; $M_{RL \pm 1}$, Friedman's test for accuracy (RL ± 1 mm) difference amongst three EALs. $M_{RL \pm 0.5/RP}$, Friedman's test for accuracy (RL ± 0.5 mm) difference between Root ZX and Propex; $M_{RL \pm 0.5/RN}$, Friedman's test for accuracy (RL ± 0.5 mm) difference between Root ZX and Neosono; $M_{RL \pm 0.5/PN}$, Friedman's test for accuracy (RL ± 0.5 mm) difference between Propex and Neosono.

The accuracy of three EALs with tubules filled with 0.9% NaCl

The range and distribution of RL–ML distance of different tubule diameters are shown in Table 5 and Fig. 4. The accuracy of Root ZX decreased rapidly as the diameter of tubules increased ($R_d = 0.849$, $P < 0.001$) (Tables 5 and 6). For the accuracy of RL ± 0.5 mm, Propex was more accurate than the

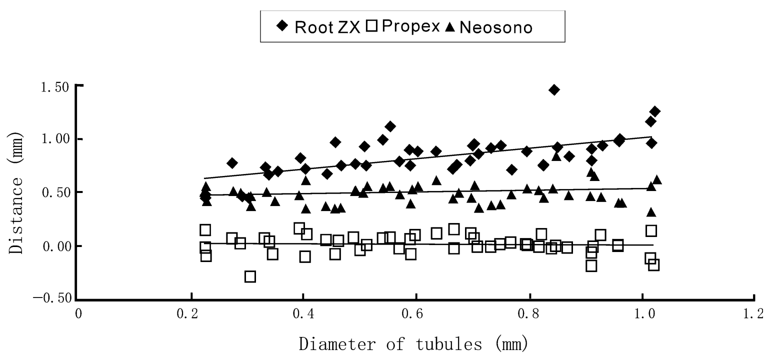

Figure 3 Distribution of RL–ML distance of three EALs with tubules filled with 3% H_2O_2.

© 2006 International Endodontic Journal

Table 5 The RL–ML distance of three EALs with tubules filled with 0.9% NaCl

Tubule diameter (mm)	RL–ML distance($\bar{x}$ ± SD mm) of three EALs		
	Root ZX	Propex	Neosono
0.25 ≤ D ≤ 0.40	0.76 ± 0.27	0.02 ± 0.12	0.45 ± 0.07
0.40 < D ≤ 0.60	1.44 ± 0.35	−0.01 ± 0.07	0.41 ± 0.08
0.60 < D ≤ 0.80	2.05 ± 0.60	0.04 ± 0.15	0.43 ± 0.11
0.80 < D ≤ 1.00	2.59 ± 0.65	−0.12 ± 0.16	0.46 ± 0.14
R_d	0.849	−0.327	0.084
P-value	<0.001	0.023	0.568

R_d, coefficient of correlation for distance of different diameter groups.

other two (Table 6). For the accuracy of RL ± 1 mm, there was no difference between the Propex and Neosono Ultima EZ (both were 100%), and the Root ZX was significantly the least accurate in all the three EALs ($P < 0.05$, Table 6). Overall, 29 tubules (60.4%) measured by the Propex had an ML longer than RL (≤0.5 mm), whilst no measurements of the other two EALs were longer than RL.

The accuracy of three EALs with tubules filled with 2.5% NaOCl

The range and distribution of RL–ML distance of different tubule diameters are shown in Table 7 and Fig. 5. The accuracy of the Root ZX decreased rapidly as the diameter of tubules increased ($R_d = 0.903$, $P < 0.001$) (Tables 7 and 8). The accuracy of Root ZX was significantly lower than the other two EALs for both RL ± 0.5 mm and RL ± 1 mm ($P < 0.05$, Table 8), and there was no statistically significant difference between the Propex and the Neosono Ultima EZ ($P > 0.05$, Table 8). For the Propex, 24 tubules (50%) had an ML longer than RL (≤0.5 mm) and four tubules (8.3%) with diameter over 0.80 mm had an ML

Table 6 Accuracy of three EALs with tubules filled with 0.9% NaCl

Tubule diameter (mm)	Accuracy (%) with different tubule diameter		
	Root ZX	Propex	Neosono
0.25 ≤ D ≤ 0.40	16.7[a]	100.0	58.3
	75.0[b]	100.0	100.0
0.40 < D ≤ 0.60	0.0	100.0	91.7
	0.0	100.0	100.0
0.60 < D ≤ 0.80	0.0	100.0	83.3
	0.0	100.0	100.0
0.80 < D ≤ 1.00	0.0	100.0	66.7
	0.0	100.0	100.0

$M_{RL \pm 0.5} = 8.00$, $P = 0.018$; $M_{RL \pm 1} = 8.00$, $P = 0.018$; $M_{RL \pm 0.5/RP} = -2.53$, $P = 0.011$; $M_{RL \pm 0.5/RN} = -2.37$, $P = 0.018$; $M_{RL \pm 0.5/PN} = -2.46$, $P = 0.014$; $M_{RL \pm 1/RP} = -2.53$, $P = 0.011$; $M_{RL \pm 1/RN} = -2.53$, $P = 0.011$.
a, accuracy of RL ± 0.5 mm; b, accuracy of RL ± 1 mm; $M_{RL \pm 0.5}$, Friedman's test for accuracy (RL ± 0.5 mm) difference amongst three EALs; $M_{RL \pm 1}$, Friedman's test for accuracy (RL ± 1 mm) difference amongst three EALs. $M_{RL \pm 0.5/RP}$, Friedman's test for accuracy (RL ± 0.5 mm) difference between Root ZX and Propex; $M_{RL \pm 0.5/RN}$, Friedman's test for accuracy (RL ± 0.5 mm) difference between Root ZX and Neosono; $M_{RL \pm 0.5/PN}$, Friedman's test for accuracy (RL ± 0.5 mm) difference between Propex and Neosono. $M_{RL \pm 1/RP}$, Friedman's test for accuracy (RL ± 1 mm) difference between Root ZX and Propex; $M_{RL \pm 1/RN}$, Friedman's test for accuracy (RL ± 1 mm) difference between Root ZX and Neosono.

Table 7 The RL–ML distance of three EALs with tubules filled with 2.5% NaOCl

Tubule diameter (mm)	RL–ML distance($\bar{x}$ ± SD mm) of three EALs		
	Root ZX	Propex	Neosono
0.25 ≤ D ≤ 0.40	1.06 ± 0.39	0.07 ± 0.08	0.41 ± 0.07
0.40 < D ≤ 0.60	2.31 ± 0.65	−0.06 ± 0.07	0.43 ± 0.11
0.60 < D ≤ 0.80	3.35 ± 0.51	−0.22 ± 0.10	0.48 ± 0.12
0.80 < D ≤ 1.00	5.65 ± 1.84	−0.83 ± 0.36	0.40 ± 0.13
R_d	0.903	−0.835	0.077
P-value	<0.001	<0.001	0.603

R_d, coefficient of correlation for distance of different diameter groups.

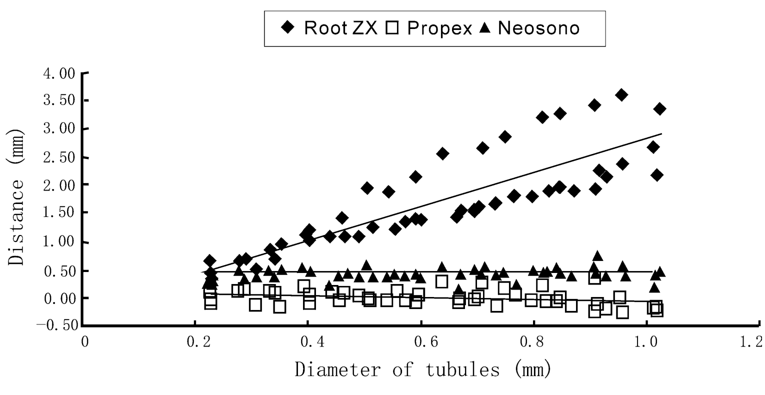

Figure 4 Distribution of RL–ML distance of three EALs with tubules filled with 0.9% NaCl.

© 2006 International Endodontic Journal

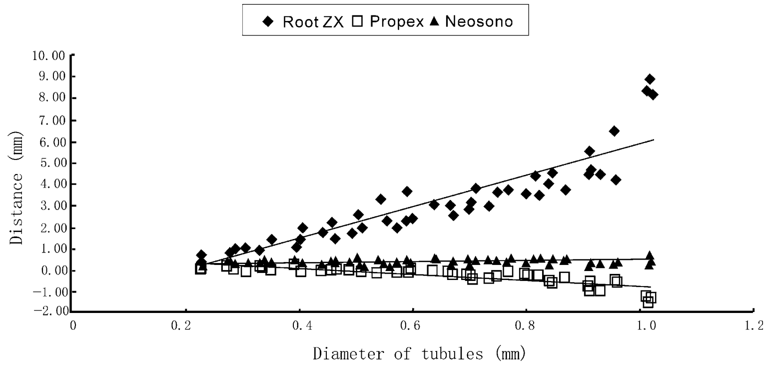

Figure 5 Distribution of RL–ML distance of three EALs with tubules filled with 2.5% NaOCl.

Table 8 Accuracy of three EALs with tubules filled with 2.5% NaOCl

Tubule diameter (mm)	Accuracy (%) with different tubule diameter		
	Root ZX	Propex	Neosono
0.25 ≤ D ≤ 0.40	0.0[a]	100.0	91.7
	58.3[b]	100.0	100.0
0.40 < D ≤ 0.60	0.0	100.0	83.3
	0.0	100.0	100.0
0.60 < D ≤ 0.80	0.0	100.0	58.3
	0.0	100.0	100.0
0.80 < D ≤ 1.00	0.0	16.7	75.0
	0.0	66.7	100.0

$M_{RL \pm 0.5} = 6.50$, $P = 0.039$; $M_{RL \pm 1} = 7.538$, $P = 0.023$; $M_{RL \pm 0.5/RP} = -2.53$, $P = 0.011$; $M_{RL \pm 0.5/RN} = -2.46$, $P = 0.014$; $M_{RL \pm 0.5/PN} = -1.183$, $P = 0.237$; $M_{RL \pm 1/RP} = -2.43$, $P = 0.015$; $M_{RL \pm 1/RN} = -2.53$, $P = 0.011$; $M_{RL \pm 1/PN} = -1.00$, $P = 0.317$.
a, accuracy of RL ± 0.5 mm; b, accuracy of RL ± 1 mm; $M_{RL \pm 0.5}$, Friedman's test for accuracy (RL ± 0.5 mm) difference amongst three EALs; $M_{RL \pm 1}$, Friedman's test for accuracy (RL ± 1 mm) difference amongst three EALs. $M_{RL \pm 0.5/RP}$, Friedman's test for accuracy (RL ± 0.5 mm) difference between Root ZX and Propex; $M_{RL \pm 0.5/RN}$, Friedman's test for accuracy (RL ± 0.5 mm) difference between Root ZX and Neosono; $M_{RL \pm 0.5/PN}$, Friedman's test for accuracy (RL ± 0.5 mm) difference between Propex and Neosono. $M_{RL \pm 1/RP}$, Friedman's test for accuracy (RL ± 1 mm) difference between Root ZX and Propex; $M_{RL \pm 1/RN}$, Friedman's test for accuracy (RL ± 1 mm) difference between Root ZX and Neosono; $M_{RL \pm 1/PN}$, Friedman's test for accuracy (RL ± 1 mm) difference between Propex and Neosono.

longer than RL (>1 mm). No measurements of the other two EALs were longer than RL.

The accuracy of three EALs with tubules filled with 17% EDTA

The range and distribution of RL–ML distances with different tubule diameters are shown in Table 9 and Fig. 6. The accuracy of the Root ZX decreased rapidly as the diameter of tubules increased ($R_d = 0.967$, $P < 0.001$) (Tables 9 and 10). The accuracy of Root ZX was significantly the lowest in all the three EALs for both RL ± 0.5 mm and RL ± 1 mm ($P < 0.05$, Table 10), and there was no statistically significant difference between the Propex and the Neosono Ultima EZ ($P > 0.05$, Table 10). Overall, 18 tubules (37.5%) measured by the Propex had an ML longer than RL (≤0.5 mm) and six tubules (12.5%) with diameter over 0.80 mm had an ML longer than RL (>1 mm). Two tubules (4.2%) measured by the Neosono Ultima EZ had an ML longer than RL (≤0.5 mm). All measurements of Root ZX were shorter than RL.

Table 9 The RL–ML distance of three EALs with tubules filled with 17% EDTA

Tubule diameter (mm)	RL–ML distance($\bar{x}$ ± SD mm) of three EALs		
	Root ZX	Propex	Neosono
0.25 ≤ D ≤ 0.40	1.16 ± 0.33	0.11 ± 0.16	0.34 ± 0.08
0.40 < D ≤ 0.60	2.11 ± 0.44	0.04 ± 0.21	0.31 ± 0.16
0.60 < D ≤ 0.80	3.08 ± 0.48	−0.25 ± 0.37	0.26 ± 0.15
0.80 < D ≤ 1.00	4.02 ± 0.38	−1.09 ± 0.58	0.14 ± 0.17
R_d	0.967	−0.837	−0.509
P-value	<0.001	<0.001	<0.001

R_d, coefficient of correlation for distance of different diameter groups.

Discussion

The apical constriction (minor foramen) represents the boundary between the pulp and the periodontal tissue. The root canal preparation should ideally be performed to the cementodentinal junction or the apical constriction (Ricucci 1998, Gordon & Chandler 2004). Studies on the anatomy of root apices found that the distance between the apical major foramen and the minor foramen varied from 0.5 to 1 mm for the teeth of different ages (Green 1960, Stein *et al.* 1990, Wu *et al.* 2000). Furthermore, root canals do not always terminate with a well-delineated apical constriction (Wu

© 2006 International Endodontic Journal

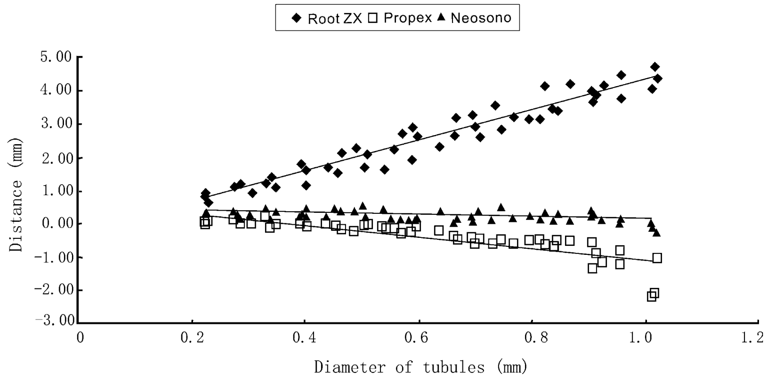

Figure 6 Distribution of RL–ML distance of three EALs with tubules filled with 17% EDTA.

Table 10 The RL–ML distance of three EALs with tubules filled with 17% EDTA

Tubule diameter (mm)	Accuracy (%) with different tubule diameter		
	Root ZX	Propex	Neosono
0.25 ≤ D ≤ 0.40	0.0[a]	100.0	100.0
	33.3[b]	100.0	100.0
0.40 < D ≤ 0.60	0.0	100.0	91.7
	0.0	100.0	100.0
0.60 < D ≤ 0.80	0.0	75.0	91.7
	0.0	100.0	100.0
0.80 < D ≤ 1.00	0.0	0.0	100.0
	0.0	50.0	100.0

$M_{RL\pm0.5} = 6.53$, $P = 0.038$; $M_{RL\pm1} = 7.538$, $P = 0.023$; $M_{RL\pm0.5/RP} = -2.00$, $P = 0.046$; $M_{RL\pm0.5/RN} = -2.49$, $P = 0.013$; $M_{RL\pm0.5/PN} = -0.619$, $P = 0.536$; $M_{RL\pm1/RP} = -2.43$, $P = 0.015$; $M_{RL\pm1/RN} = -2.53$, $P = 0.011$; $M_{RL\pm1/PN} = -1.00$, $P = 0.317$.

a, accuracy of RL ± 0.5 mm; b, accuracy of RL ± 1 mm; $M_{RL\pm0.5}$, Friedman's test for accuracy (RL ± 0.5 mm) difference amongst three EALs; $M_{RL\pm1}$, Friedman's test for accuracy (RL ± 1 mm) difference amongst three EALs. $M_{RL\pm0.5/RP}$, Friedman's test for accuracy (RL ± 0.5 mm) difference between Root ZX and Propex; $M_{RL\pm0.5/RN}$, Friedman's test for accuracy (RL ± 0.5 mm) difference between Root ZX and Neosono; $M_{RL\pm0.5/PN}$, Friedman's test for accuracy (RL ± 0.5 mm) difference between Propex and Neosono. $M_{RL\pm1/RP}$, Friedman's test for accuracy (RL ± 1 mm) difference between Root ZX and Propex; $M_{RL\pm1/RN}$, Friedman's test for accuracy (RL ± 1 mm) difference between Root ZX and Neosono; $M_{RL\pm1/PN}$, Friedman's test for accuracy (RL ± 1 mm) difference between Propex and Neosono.

et al. 2000, Nekoofar *et al.* 2002). For these reasons, the tolerance ±1 mm from the major foramen for EALs has been deemed clinically acceptable although the tolerance ±0.5 mm was thought the strictest acceptable range by others (Ounsi & Naaman 1999, Kim & Lee 2004). In this experiment, both RL ± 0.5 and RL ± 1 mm were used to evaluate the accuracy of three EALs.

In previous studies on teeth, the accuracy of the Root ZX varied greatly, from 50% to 100% (RL ± 0.5 mm was considered) and 64% to 100% (RL ± 1 mm was considered) despite the canal contents (Ounsi & Naaman 1999, Kielbassa *et al.* 2003, Gordon & Chandler 2004). For example, Vajrabhaya & Tepmongkol (1997), using extracted single-rooted teeth, reported that the accuracy of the Root ZX was 100% (RL ± 0.5 mm) with normal saline in canals, which was higher than those found in the present study (16.7% for RL ± 0.5 mm and 75% for RL ± 1 mm in tubules with diameter between 0.25 mm and 0.40 mm, respectively). In a laboratory study performed by Goldberg *et al.* (2002) on single-rooted teeth with simulated apical root resorption that were inserted into a sponge soaked with normal saline solution, the accuracy of the Root ZX was 62.7% (RL ± 0.5 mm) and 94% (RL ± 1 mm). Kaufman *et al.* (2002) showed on permanent teeth that all the measurements of Root ZX in canals dry or filled with 3% NaOCl, normal saline and 17% EDTA were within 1 mm shorter than RL, whilst in the present study the accuracy within the 1 mm short of the RL was 33% (17% EDTA in tubules), 58.3% (2.5% NaOCl in tubules), 75% (normal saline in tubules) and 100% (dry tubules) in tubules with diameter between 0.25 and 0.40 mm as showed in Tables 2, 8 and 10. In the study of Weiger *et al.* (1999) on permanent single-rooted teeth, the RL ± 1 mm accuracy of Root ZX was 93.5%, 95.7% and 97.8% for canals filled with 0.9% NaCl, 1% NaOCl and 3% H_2O_2, respectively, compared with the 75%, 58.3% and 100% in tubules with diameter between 0.25 and 0.40 mm in this study. Ounsi & Naaman (1999), using extracted single-rooted teeth with closed apices that were filled with 5.25% NaOCl, found that the RL ± 0.5 mm accuracy of the Root ZX was only 50% and the accuracy of the RL ± 1 mm was nearly 70%. It is noteworthy that in the laboratory study of Kielbassa *et al.* (2003) on primary teeth, the canals were irrigated alternately with 3% H_2O_2 and 1% NaOCl, the RL ± 1 mm accuracy of Root ZX was 64%, which was comparable with that of the glass tubules in the present study (0.25 mm ≤ Diameter ≤0.40 mm) filled with 2.5% NaOCl (58.3%) or 0.9% NaCl (75%).

The main reasons that may account for the differences between previous studies and the present one are as follows: the glass tubules were parallel without taper or constriction, which is unlike the natural anatomy of mature permanent teeth but more like that of primary or young permanent teeth; the tubule wall had the same thickness over its length; the electrical features of glass were different from that of dentine; and the tubule diameter in this study began with 0.25 ± 0.025 mm and increased gradually.

Although there are some differences between glass tubules and root canals, using glass tubules to mimic root canals could help avoid bias resulting from canal curvature, canal taper and the latent lateral canals in electronic length determination in root canals. Furthermore, the diameter of tubules is easier to customize and measure precisely than the anatomical foramen of teeth, thus the influence of apical foramen size on the EALs could be studied more clearly. The agar model developed by Aurelio *et al.* (1983) has also proved suitable for evaluating the accuracy of EALs (Nekoofar *et al.* 2002). It is also worth noting, however, that agar is dissimilar to the periodontium. Based on these concerns, the results of the present study would only be considered as references to clinical situations.

In this experiment, when the tubules were dry, the accuracy of the Root ZX was very high (75–91.7% for RL ± 0.5 mm and 100% for RL ± 1 mm) with the tubule diameter having no bearing on the outcome. Even when the canals were filled with the less conductive electrolyte 3% H_2O_2 solution, the accuracy of RL ± 1 mm was 75–100% despite the increase of tubule diameter. For strong electrolytes such as 0.9% NaCl, 2.5% NaOCl and 17% EDTA, the accuracy of the Root ZX decreased as the tubule diameter increased. Based on these findings, the use of the Root ZX in canals with large diameter and filled with electrolytes may need to be re-evaluated.

Similar studies are lacking for the Propex apex locator. In the present study, when the tubules were dry or filled with the less conductive electrolyte 3% H_2O_2 solution, the measurements were all within the RL ± 0.5 mm without being influenced by an increase in tubule diameter. When the tubules were filled with strong electrolytes, the RL–ML distance recorded by Propex was inversely related to tubule diameter and the ML became gradually longer than the RL. All the measurements were still within RL ± 0.5 mm except for the tubules with diameter over 0.8 mm and filled with 2.5% NaOCl and 17% EDTA. This laboratory study suggests that the measurements of the Propex locator should be reduced by 0.5 mm and in canals with large diameter (≥0.80 mm) and filled with either with NaOCl or EDTA, the measurement achieved with the Propex may not be reliable.

Several previous studies have shown the Neosono Ultima EZ to be accurate under various conditions. In the study of De Moor *et al.* (1999) on 20 extracted incisors and canines, sugar-free gelatin and a sponge soaked in 1% sodium hypochlorite solution were used to simulate periodontium. Under different testing conditions (canal dry or irrigated with distilled water or with 2.5% sodium hypochlorite), the accuracy of the Neosono Ultima EZ was found to be 100% in the range of RL ± 0.5 mm (Gordon & Chandler 2004). Nekoofar *et al.* (2002) tested the accuracy of the Neosono Ultima EZ on extracted teeth using a similar agar model to that used in this study, and found the accuracy to be 94.4% and 91.6% in the range of RL ± 0.5 mm for files of different alloys. In the present laboratory study performed on glass tubules, nearly all measurements (except for six tubules) were within 1 mm short of the RL irrespective of the contents in tubules and the increase of tubule diameter. Based on the features of Neosono Ultima EZ shown in this experiment, its accuracy was not affected by either the electrolytes in the tubules or tubule diameter. However, the results from this laboratory study must be interpreted with caution.

Conclusions

In this simulated laboratory study, the accuracy of the Root ZX decreased as glass tubule diameter increased when tubules were filled with electrolytes. The electrolytes in the tubules decreased the accuracy of Propex when the tubule diameter was large. The electrolytes in tubules and tubule diameter had no influence on the accuracy of Neosono Ultima EZ in this model. The Propex and Neosono Ultima EZ were more accurate than the Root ZX under various conditions in this laboratory study.

Acknowledgement

This research was supported by the Key Technologies R&D Programme of the Tenth Five-Year Plan of the Hubei Province, China (Grant No. 2000P1404).

© 2006 International Endodontic Journal

References

Aurelio JA, Nahmias Y, Gerstein H (1983) A model for demonstrating an electronic canal-length measuring device. *Journal of Endodontics* **9**, 568–9.

Czerw R, Fulkerson MS, Donnelly JC (1994) An in vitro test of a simplified model to demonstrate the operation of electronic root canal measuring devices. *Journal of Endodontics* **20**, 605–6.

De Moor RGJ, Hommez GMG, Martens LC, De Boever JG (1999) Accuracy of four electronic apex locators: an in vitro evaluation. *Endodontics and Dental Traumatology* **15**, 77–82.

Fouad AF, Krell KV, McKendry DJ, Koorbusch GF, Olson RA (1990) A clinical evaluation of five electronic root canal length measuring instruments. *Journal of Endodontics* **16**, 446–9.

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.

Goldberg F, De Silvio AC, Manfré S, Nastri N (2002) In vitro measurement accuracy of an electronic apex locator in teeth with simulated apical root resorption. *Journal of Endodontics* **28**, 461–3.

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

Green D (1960) Stereomicroscopic study of 700 root apices of maxillary and mandibular posterior teeth. *Oral Surgery, Oral Medicine, Oral Pathology* **13**, 728–33.

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

Jenkins JA, Walker WA, Schindler W, Flores CM (2001) An in vitro evaluation of the accuracy of the Root ZX in the presence of various irrigants. *Journal of Endodontics* **27**, 209–11.

Kaufman AV, Katz A (1993) Reliability of Root ZX apex locator tested by an in vitro model. *Journal of Endodontics* **19**, 201 (abstract).

Kaufman AY, Keila S, Yoshpe M (2002) Accuracy of a new apex locator: an in vitro study. *International Endodontic Journal* **35**, 186–92.

Kielbassa AM, Muller U, Munz I, Monting JS (2003) Clinical evaluation of measuring accuracy of Root ZX in primary teeth. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **95**, 94–100.

Kim E, Lee SJ (2004) Electronic apex locator. *Dental Clinics of North America* **48**, 35–54.

Kobayashi C (1995) Electronic canal length measurement. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **79**, 226–31.

Martinez-Lozano MA, Forner-Navarro L, Sánchez-Cortés JL, Llena-Puy C (2001) Methodological considerations in the determination of working length. *International Endodontic Journal* **34**, 371–6.

McDonald NJ, Hovland EJ (1990) An evaluation of the apex locator Endocator. *Journal of Endodontics* **16**, 5–8.

Meredith N, Gulabivala K (1997) Electrical impedance measurements of root canal length. *Endodontics and Dental Taumatology* **13**, 126–31.

Nekoofar MH, Sadeghi K, Akha ES, Namazikhah MS (2002) The accuracy of the Neosono Ultima EZ apex locator using files of different alloys: an in vitro study. *Journal of the California Dental Association* **30**, 681–4.

Ounsi HF, Naaman A (1999) In vitro evaluation of the reliability of the Root ZX electronic apex locator. *International Endodontic Journal* **32**, 120–3.

Pratten DH, McDonald NJ (1996) Comparison of radiographic and electronic working lengths. *Journal of Endodontics* **22**, 173–6.

Ricucci D (1998) Apical limit of root canal instrumentation and obturation, part 1. Literature review. *International Endodontic Journal* **31**, 384–93.

Steffen H, Splieth CH, Behr K (1999) Comparison of measurements obtained with hand files or the Canal Leader attached to electronic apex locators: an in vitro study. *International Endodontic Journal* **32**, 103–7.

Stein TJ, Corcoran JF, Park A, Arbor A (1990) Anatomy of the root apex and its histological changes with age. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **69**, 238–41.

Sunada I (1962) New method for measuring the length of the root canal. *Journal of Dental Research* **41**, 375–87.

Tamarut T, Kovačević M, Uhač I (2000) Detection of a transitional ion concentration zone during electronic measurement of root canal length: a study in vitro. *International Endodontic Journal* **33**, 374–80.

Vajrabhaya L, Tepmongkol P (1997) Accuracy of apex locator. *Endodontics and Dental Taumatology* **13**, 180–2.

Weiger R, John C, Geigle H, Löst C (1999) An in vitro comparison of two modern apex locators. *Journal of Endodontics* **25**, 765–8.

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

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

© 2006 International Endodontic Journal

This document is a scanned copy of a printed document. No warranty is given about the accuracy of the copy. Users should refer to the original published version of the material.