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Effectiveness of four electronic apex locators to determine distance from the apical foramen

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Abstract

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Aim To evaluate the accuracy of four electronic apex locators (EAL) in the apical region (0–3 mm short of the foramen) and to compare the precision of the readings on the display with the real position of the file in the root canal.

Methodology Twenty single-rooted extracted teeth with round root canals were used. The canal orifices were preflared, and the length to the major foramen was determined visually under a microscope. Canals were enlarged, so that a size 15 file fitted well inside the canal. Teeth were mounted in acrylic test tubes filled with physiologic saline solution. Electronic length was determined in the region between the major foramen and 3 mm short of it in 0.5 mm steps with the Dentaport ZX, Root ZX mini, Elements Diagnostic Unit and Apex Locator and Raypex 5 using files of size 10 and size 15. The data were analysed using linear regression between true length and EAL reading, Bland–Altman plots and non-parametric tests at a significance level of alpha = 0.05.

Results The major foramen was detected by all EALs. With a measurement file positioned directly at the major foramen, meter readings were equivalent to a position 0.01–0.38 mm away. For the Dentaport ZX, a better accuracy using the size 15 file for the area 0–1.5 mm short of the apex was found. The differences in measurements between the two files were smaller for the other EALs. In linear regression, a good linearity for Dentaport ZX and Root ZX mini and moderate linearity for Elements Diagnostic Unit and Apex Locator and Raypex 5 were found. The slope of the measurement curve was too low (0.37–0.57) for the Raypex 5 and almost optimal for the Dentaport ZX (1.01–1.05). The Root ZX mini and the Elements Obturation Unit produced lower slope values and especially the Elements Obturation Unit revealed much higher SDs at the different measurement levels.

Conclusion Amongst the four EALs, the Dentaport ZX and Root ZX mini had the best agreement between true lengths and meter readings. For the Raypex 5, an interpretation of the colour-coded zones as distance to the foramen cannot be recommended and might lead to erroneous interpretations.

Keywords: apical region, electronic apex locator, meter reading display, root canal length determination.

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Introduction

The determination of working length is one of the most important steps in root canal treatment (Ingle & Bakland 2002). Failure in determining the correct working length might result in over-filling or under-filling and has the potential to increase the failure probability of root canal treatment after a 10-year observation period from around 10% to around 50% as shown in a retrospective clinical study (Stoll *et al.* 2005).

The apical constriction is the ideal and recommended end-point for instrumentation and canal filling (Ricucci 1998). It is located about 0.5–1 mm from the major foramen (Kuttler 1955). The foramen does not coincide

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with the anatomical apex; it might be located laterally and in a distance of up to 3 mm from the anatomical apex (Dummer *et al.* 1984). This makes it difficult to localize the foramen and constriction using a radiological approach (Olson *et al.* 1991).

Recently developed electronic apex locators (EAL) are based on the measurement of alternating current impedance. For that, two or more different frequencies are used and processed using different mathematical algorithms (Gordon & Chandler 2004, Kim & Lee 2004, Nekoofar *et al.* 2006). These EALs are now widely accepted by practitioners, especially because they can reduce the number of diagnostic radiographs required for working length determination (Brunton *et al.* 2002). Current EALs have a high reliability, high accuracy and high reproducibility in locating the major apical foramen regardless of the electrolyte (Jenkins *et al.* 2001).

The RootZX (J.Morita Corp., Tokyo, Japan), which has been the object of numerous *ex vivo* and *in vivo* studies (Gordon & Chandler 2004), was able to measure in an *ex vivo* study the correct working length (±0.5 mm) in 97.37% of cases (Plotino *et al.* 2006). In another study, precise readings in 50% and acceptable readings (±0.5 mm) were found in 97.5% of all measurements (Janolio de Camargo *et al.* 2009). The overall accuracy of the Root ZX was reported to range from 82% (Pagavino *et al.* 1998) to 100% (Czerw *et al.* 1995). Modified versions of the Root ZX have been developed including the Dentaport ZX and the Root ZX mini, based on the electronics of the Root ZX. Pascon *et al.* (2009) reported that the mean distance between the file tip and radiographic apex was 1.08 ± 0.73 mm for the Dentaport ZX and 1.0 ± 0.67 mm for Raypex 5, demonstrating no statistically significant differences ($P > 0.05$). A literature review revealed no studies on the Root ZX mini device.

The Raypex 5 (VDW, Munich, Germany) was able to detect the correct working length (±0.5 mm) in 80–85.59% of cases (Briseño-Marroquín *et al.* 2008) and in 80% of all cases within the same limits (Wrbas *et al.* 2007).

The Elements Diagnostic Unit and Apex Locator (Sybron Endo, Sybron Dental, Anaheim, CA, USA) was able to determine the correct working length (±0.5 mm) in 94.28% (Plotino *et al.* 2006) or 82.19–85.62% (Briseño-Marroquín *et al.* 2008) of cases. This device has a numeric meter reading that shows the distance of the file tip to the apex during measurements in the apical region.

The Root ZX, like many other similar devices, has numbers on the display that do not reflect the distance readings in millimetres. The Raypex 5 has a meter scale with colour-coded segments for different zones in the apical region.

Although modern EALs can locate the apical foramen and the apical constriction with high precision, it is unclear how accurate these devices are as they approach the apical region and how precise the meter readings correlate with the file position. A study by Higa *et al.* (2009) demonstrated that there were differences between EALs depending on the distance of the measurement file to the apical foramen.

The precision of measurement might also depend on the file size and the dimensions of root canal and foramen. Herrera *et al.* (2007) reported that the Root ZX apex locator precision varied as a function of apical constriction diameter. It was reported that with increasing diameter of the root canal, the electronically measured length became shorter with small files, depending on the fluid inside the canal (Ebrahim *et al.* 2006, 2007). Normally, small-diameter files of size 10 are used to determine the initial working length. Small files are likely to leave space within the canal exposing more metallic surface to the surrounding electrolyte, whereas files of large diameter will fit more tightly, a smaller surface exposed to electrolytes and hence different electrochemical properties.

The aim of this study is to evaluate the accuracy of four EALs in the apical region (0–3 mm short of the foramen) and to compare precision of the readings on the display with the real file position in the root canal.

Materials and methods

Twenty single-rooted extracted teeth were used. All teeth had narrow round canals, no severe curvatures and closed apices. The teeth were stored in saline not longer than 3 weeks after extraction. Calculus and soft tissue debris were removed before the teeth were sectioned at the cemento-enamel junction at right angles to the root axis using a diamond disc (Fig. 911HK; Komet Brasseler, Lemgo, Germany), producing a level surface to serve as a stable reference for length measurement. The preparation was made by one operator. The canal orifices were preflared with a rotary file (PreRace size 35, .08 taper, FKG Dentaire, La Chaux-de-Fonds, Switzerland). Patency was checked with a size 06 K-File (VDW, Munich, Germany). Pulp tissue was partially removed with a size 10 Hedström File (VDW). Canals were cleansed of debris with at least 5 mL of 3% sodium hypochlorite. A size 10 silver point was inserted until the tip became visible at the foramen.

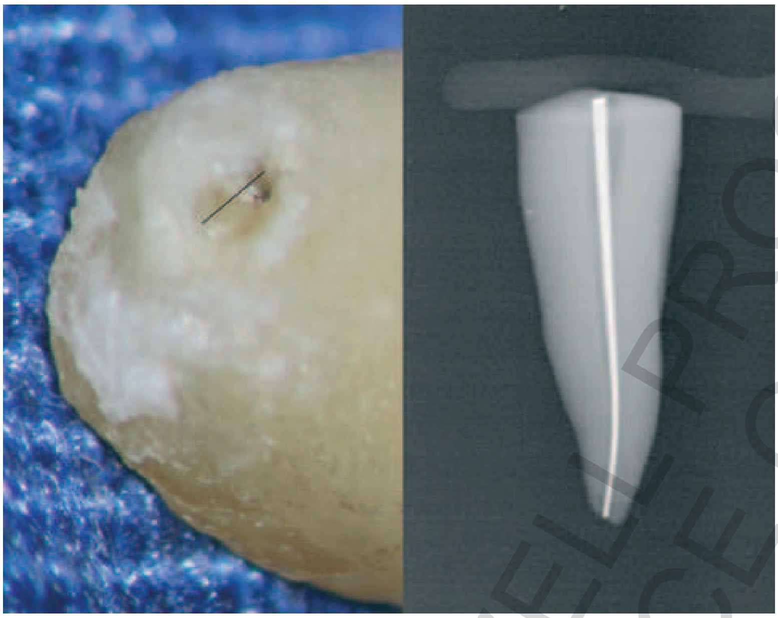

Figure 1 Placement of the silver point in funnel shaped foramina (microscope and radiograph). The tip of the silver point is placed at a line tangential to the root surface.

In funnel-shaped foramina, the tip of the point was placed tangential to the major foramen (Fig. 1). These steps were conducted by an experienced endodontic specialist using a surgical operation microscope (ProErgo; Carl Zeiss Meditec, Jena, Germany) with a magnification of 18.2×. The silver points were cut at the reference point. Radiographs in mesio-distal and bucco-lingual planes were taken to allow proper selection of teeth. The silver points were removed and measured using an endodontic millimetre ruler (VDW) with a measurement accuracy of 0.5 mm. The measured length was noted as the true L_0 for that root. After that, the canal was enlarged to a size 15 K-file. Patency was achieved with a size 06 K-File. All roots were immersed in saline for at least 1 day.

Each root was firmly fixed with acrylic resin in a plastic tube (Arthur Krüger KG, Barsbüttel, Germany) with a height of 30 mm and an inner diameter of 9 mm. A copper wire was fixed on the wall of the plastic tube to serve as the ground electrode for the EALs.

For the electric length measurement, the test tubes were filled with 0.9% physiologic saline solution (B.Braun, Melsungen, Germany) as an electrolyte (Hör *et al.* 2005) such that the apical third of the roots was immersed into the liquid.

For the combination of each root and each EAL (Dentaport ZX, Root ZX mini, Elements Diagnostic Unit and Apex Locator and Raypex 5), meter readings for the file positions 0, 0.5, 1, 1.5, 2, 2.5 and 3 mm short of the apex were recorded. Additionally, the measurement file was placed so that the meter reading of the EAL displayed the positions 0, 0.5, 1, 1.5, 2, 2.5 and 3. Here, the file length was recorded. All measurements were conducted with a K-file size 10 and a K-file size 15. Unstable or out-of-scale measurements were counted, but not considered for statistical evaluation. As the meter scale of Raypex 5 has colour-coded areas for different apical regions, a conversion table was set up (Table 1) based on the interpretation of the different zones in the user manual (VDW 2005).

Results were analysed using linear regression between true length and EAL reading, Bland–Altman plots and nonparametric tests at a significance level of alpha = 0.05. All statistical procedures were computed with SPSS 15.0 (SPSS Inc., Chicago, IL, USA).

Table 1 Measurement scheme for Raypex 5 (VDW, Munich, Germany)

Meter reading	Interpretation	Length interpretation
Red Bar	Apical Foramen	0.0 mm
Middle of the yellow area	Region adjacent to the apical foramen	0.5 mm
Middle of the green area	Apical constriction	1.0 mm
Middle of the blue area	Beginning of the apical region	≥2.0 mm

Table 2 Number of valid and missing measurements. Number of unstable or out-of-range measurements in different groups depending on the real file position. Unstable and out-of-range measurements have been recorded and statistically processed as missing data

		Valid	Missing (unstable or out of range)				
File	Electronic apex locators	All (%)	All (%)	0–1 mm	>1–2 mm	>2–3 mm	>3 mm
#10	Dentaport ZX	243 (86.8)	37 (13.2)	2	1	15	19
	Root ZX mini	227 (81.1)	53 (18.9)	0	7	27	19
	Elements Diagnostic Unit and Apex Locator	184 (65.7)	96 (34.3)	8	29	39	20
	Raypex 5	210 (75.0)	70 (25.0)	0	15	36	19
#15	Dentaport-ZX	253 (90.4)	27 (9.6)	0	1	8	18
	Root-ZX mini	253 (90.4)	27 (9.6)	0	1	11	15
	Elements Diagnostic Unit and Apex Locator	218 (77.9)	62 (22.1)	0	20	29	13
	Raypex 5	230 (82.1)	50 (17.9)	0	4	27	19

Results

Table 2 shows the number of valid measurements for all groups and the distribution of unstable or out-of-range measurements. Unstable or out-of-range measurements were recorded and processed statistically as missing data.

A normal distribution was not found inside the test groups using a one-sample Kolmogorov–Smirnov goodness of fit test ($P < 0.05$), and no equality of variances was found using a Levene test ($P < 0.05$).

Table 3 shows the results of the linear regression analysis. Table 4 shows the meter readings of all devices with the measurement file positioned at the major foramen. Additionally, the percentage of file positions between −0.5 and 0.5 relative to the major foramen with a meter reading of 0 was calculated.

Figures 2–5 show the mean of EAL readings with error bars (±SD) at the different true lengths. Additional Bland–Altman plots were created for all groups. Tables 5 and 6 show the result of the statistical comparisons for file size and EAL device.

Table 3 Results of linear regression analysis. b0 gives the intercept point of the regression line with the y-axis, b1 is the slope of the regression line, and r^2 is the correlation coefficient

File	Electronic apex locators	b0 (y intercept)	b1 (slope)	r^2
#10	Dentaport-ZX	0.474	1.045	0.629
	Root-ZX mini	0.569	0.823	0.531
	Elements Diagnostic Unit and Apex Locator	0.346	0.795	0.419
	Raypex 5	0.254	0.568	0.316
#15	Dentaport-ZX	0.171	1.010	0.747
	Root-ZX mini	0.328	0.836	0.659
	Elements Diagnostic Unit and Apex Locator	0.410	0.669	0.434
	Raypex 5	0.403	0.366	0.364

Table 4 Meter readings (mean and SD) with measurement file positioned at the apical foramen. Accuracy was given in per cent of file positions between −0.5 and 0.5 mm with a meter reading of 0

File	Electronic apex locators	Mean	Sddev	Accuracy (±0.5 mm) (%)
#10	Dentaport-ZX	0.20	0.31	97.4
	Root-ZX mini	0.21	0.39	95.0
	Elements Diagnostic Unit and Apex Locator	0.08	0.51	86.2
	Raypex 5	0.05	0.16	82.4
#15	Dentaport-ZX	0.01	0.34	97.6
	Root-ZX mini	0.13	0.28	93.4
	Elements Diagnostic Unit and Apex Locator	0.38	0.42	84.8
	Raypex 5	0.06	0.17	87.2

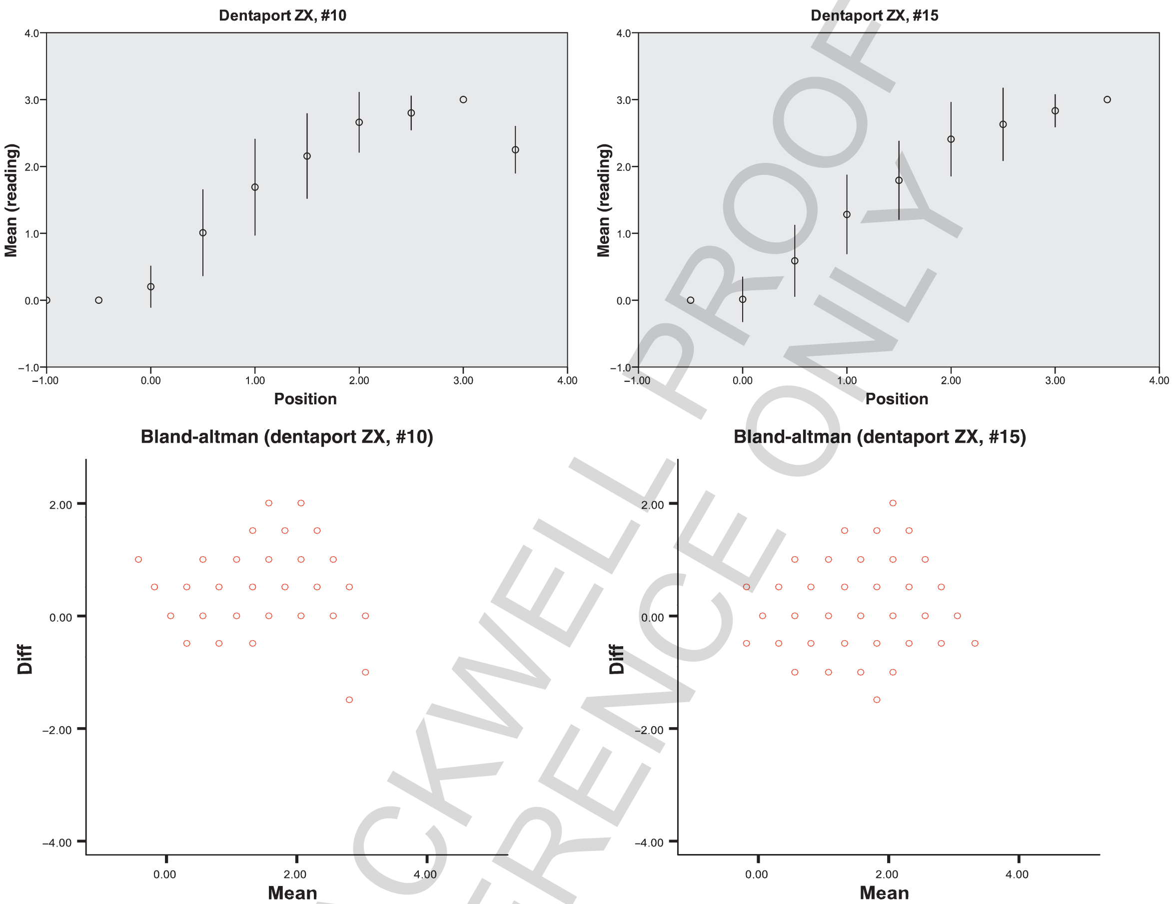

Figure 2 Meter reading versus true file length for Dentaport ZX (J.Morita Corp., Tokyo, Japan). Mean and SD error bars (upper diagrams) and Bland–Altman plot (lower diagrams). Bland–Altman plots show a scatter plot of the difference between two measurement methods versus the mean of both methods. The horizontal lines represent the mean of differences and ±2 × SD, so 95% of all measurements are expected to be between these lines.

Discussion

Several studies have been conducted *in vitro* and *in vivo* to determine the precision of EAL (Gordon & Chandler 2004). Most of them demonstrate a high-degree accuracy in measurement of the working length (Plotino *et al.* 2006, Guise *et al.* 2009). Usually extracted teeth are placed in a conductive environment made of agar-agar (Briseño-Marroquín *et al.* 2008), alginate (Herrera *et al.* 2007), gelatin (Guise *et al.* 2009), or saline (Goldberg *et al.* 2008) for laboratory studies. The use of a saline solution has shown to produce reliable measurement data (Hör *et al.* 2005, Venturi & Breschi 2007).

Preflaring of root canals before measurement with EALs can increase the precision of working length determination (Ibarrola *et al.* 1999, Janolio de Camargo *et al.* 2009). Thus, the canals were preflared in the current study before measurement.

Usually the major foramen (Guise *et al.* 2009) or the apical constriction (Ibarrola *et al.* 1999) is used as an apical reference point for laboratory studies. With the Root ZX, a difference of 0.3 mm has been recorded *in vivo* between actual file length and working length as obtained with the EAL (Haffner *et al.* 2005). Nevertheless, the apical constriction was located in only 45% (Haffner *et al.* 2005) to 90.7% (Welk *et al.* 2003) of all evaluated cases. So the major foramen might be a more reproducible reference point for laboratory studies (Venturi & Breschi 2007).

Venturi & Breschi (2007) reported a significant number of unstable and inaccurate measurements.

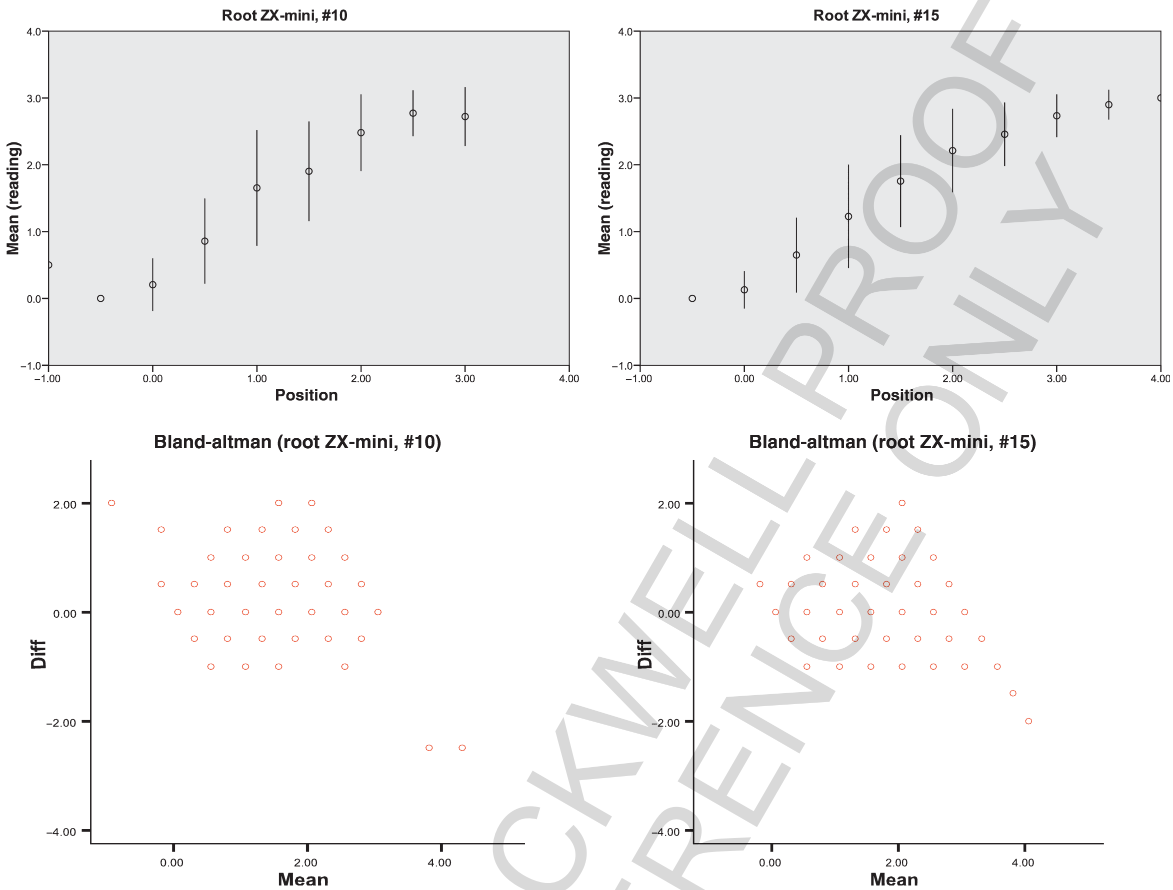

Figure 3 Meter reading versus true file length for Root ZX mini (J.Morita Corp., Tokyo, Japan). Mean and SD error bars (upper diagrams) and Bland–Altman plot (lower diagrams). Bland–Altman plots show a scatter plot of the difference between two measurement methods versus the mean of both methods. The horizontal lines represent the mean of differences and ±2 × SD, so 95% of all measurements are expected to be between these lines.

For Root ZX, these occurred especially under low conductive conditions. Indeed, in a laboratory study, 4.2% of measurements were unstable (Venturi & Breschi 2007), whereas *in vivo*, 20.9% were unstable (Venturi & Breschi 2005). In this study, 9.6–13.2% unstable or out-of-range measurements for the Dentaport ZX were found, depending on the file size. With a file size 15, the least number of unstable measurements was observed. Briseño-Marroquín *et al.* (2008) reported a nonsignificant higher number of unstable measurements with size 15 instruments (Briseño-Marroquín *et al.* 2008). As it was not possible to determine whether an unassessable measurement was caused by an open or weak electric circuit or by a measurement out of range of the display, these findings were treated as missing data. The largest number of these unassessable data was observed in a distance more than 2 mm short of the apical foramen (Table 2).

The size of the measurement file appears to have no impact on the accuracy of measurements (Briseño-Marroquín *et al.* 2008), even when files were smaller than the diameter of the enlarged canal (Nguyen *et al.* 1996). Contrary to that, Ebrahim *et al.* (2006, 2007) reported that with increasing diameter of the root canal, the electronically measured length with small files became shorter, depending on the fluid inside the canal. In this study, significant differences for the Dentaport ZX between the size 10 and the size 15 file for the area 0–1.5 mm short of the apex ($P < 0.05$) were found, which when taking into account Fig. 2 might be interpreted as a higher accuracy of the size 15 file and slightly shorter measurements for the smaller file size 10. For the other

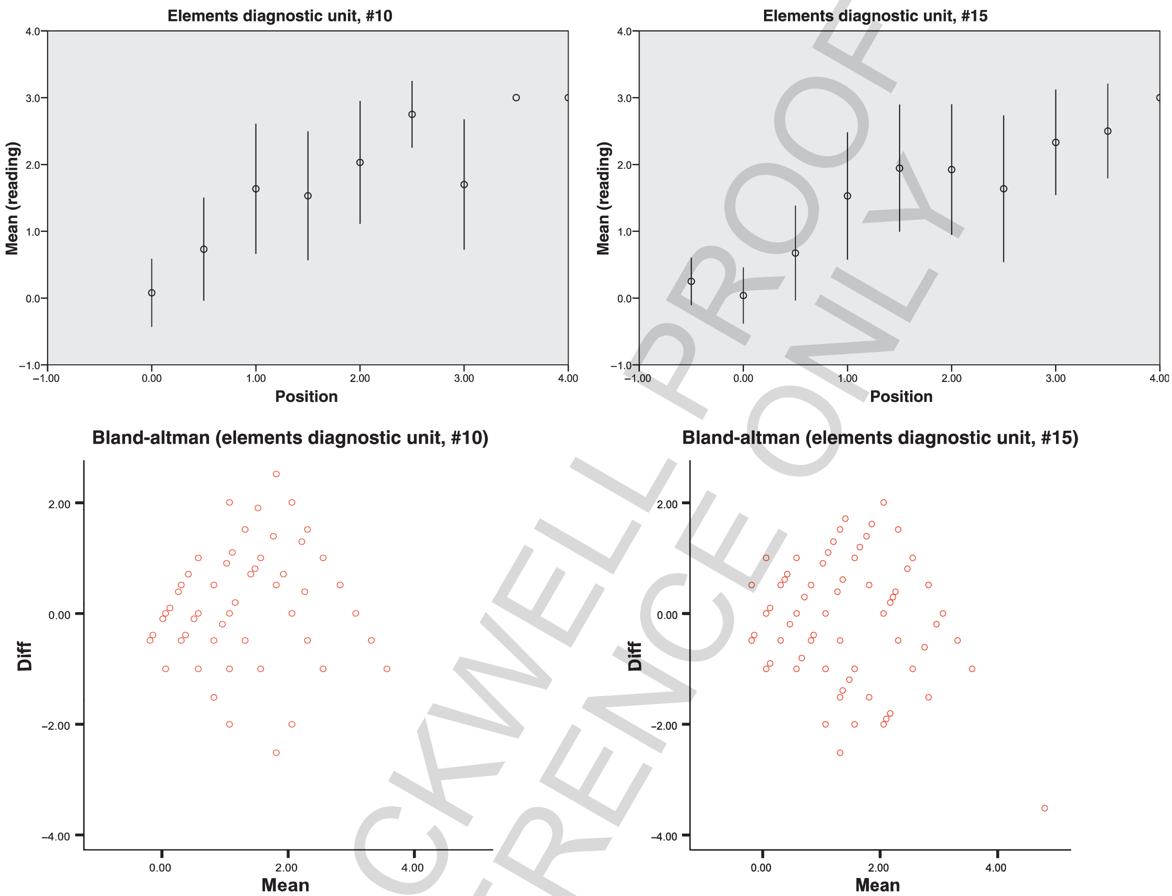

Figure 4 Meter reading versus true file length for Elements Diagnostic Unit and Apex Locator (Sybron Endo, Sybron Dental, Anaheim, CA, USA). Mean and SD error bars (upper diagrams) and Bland–Altman plot (lower diagrams). Bland–Altman plots show a scatter plot of the difference between two measurement methods versus the mean of both methods. The horizontal lines represent the mean of differences and ±2 × SD, so 95% of all measurements are expected to be between these lines.

EALs, the differences were not significant. However, this cannot be interpreted as a similar accuracy for both files; in fact, Figs 3–5 show differences in measurements, albeit less pronounced, for both files.

The accuracy of determining the major foramen can be characterized by mean and error of the measurement curves at the apical reference point (Table 4). For this point, measurement results between 0.01 mm (SD 0.34) and 0.38 mm (SD 0.42) have been found, so the major foramen can be detected with accuracy below the normal measurement accuracy of hand rulers by all EALs. The position of the major foramen can be located with all tested EALs with an accuracy (±0.5 mm) ranging from 82.4% (Raypex 5, size 10) to 97.6% (Root ZX, size 15).

The accuracy of EALs might depend on the type of display (Hör *et al.* 2005) and the distance of the measurement file to the major foramen (Venturi & Breschi 2007, Higa *et al.* 2009). For multifrequency EALs, the plots of ratio might not be linear and thus the distance from the tip of file to the apical foramen might be difficult to predict (Venturi & Breschi 2007). This study shows that the linearity of the measurement curve depends on the device. The r^2 that was calculated in this study as a measure for goodness of fit in linear regression revealed a good linearity for the Dentaport ZX (0.6–0.75) and Root ZX mini (0.53–0.66) and moderate linearity for the Elements Diagnostic Unit and Apex Locator (0.42–0.43) and Raypex 5 (0.32–0.36). As linear regression might be a misleading method for assessing agreement between two clinical measurement methods (Bland & Altman 1968), additional Bland–Altman plots were created for all groups.

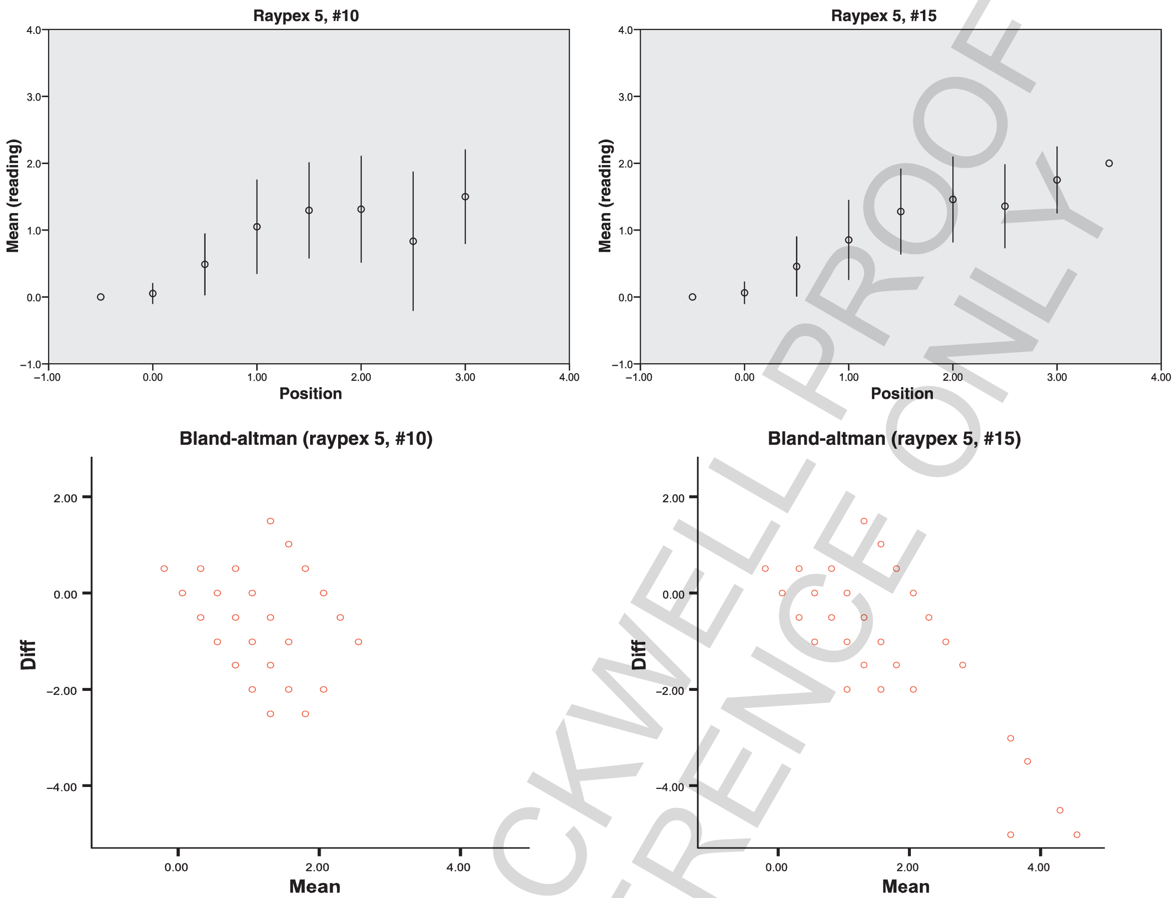

Figure 5 Meter reading versus true file length for Raypex 5 (VDW, Munich, Germany). Mean and SD error bars (upper diagrams) and Bland–Altman plot (lower diagrams). Bland–Altman plots show a scatter plot of the difference between two measurement methods versus the mean of both methods. The horizontal lines represent the mean of differences and $\pm 2 \times$ SD, so 95% of all measurements are expected to be between these lines.

Most EALs either show no distance scale in millimetres or they only give numbers that are arbitrary units. For the Raypex 5, only colour-coded zones are present on the meter scale for the apex zoom scale. A distance value for these zones was assigned according to the description in the manual (Table 1). The results from the linear regression show that the slope of the measurement curve (Table 2) is too low (0.37–0.57), so the interpretation of meter readings as distances to the apex is misleading for Raypex 5. The measurement curve of the Dentaport ZX has an almost optimal value for the slope (1.01–1.05) with small SDs on the different measurement levels (Fig. 2). Hence, the meter readings of Dentaport ZX can be interpreted as millimetre values in the distance range from 0 (apex) to 3 mm, keeping in mind that the accuracy of measurement is optimal at the major foramen.

The Root ZX mini and the Elements Obturation Unit had lower slope values and especially the Elements Obturation Unit had much higher SDs at the different measurement levels as demonstrated in the Bland–Altman plots (Fig. 4).

Conclusion

All EALs included were able to detect the major foramen with reasonable accuracy. In the apical region (0–3 mm short of the major foramen), the linearity of the measurement curve depended on the device. The Dentaport ZX had the highest linearity and agreement between meter reading and true file position, whereas the Root ZX mini and Elements Obturation Unit had less linearity and a larger variation in the measurement data. For Dentaport ZX and Root ZX mini, the meter

Table 5 Comparison (*P*-values) of different devices depending on measurement level and file size with a Kruskal–Wallis test using a significance level of alpha = 0.05. Values below 0.05 show that there is a significant difference between the tested devices at that point of the measurement curve

Position	File #10	File #15
0	0.038	0.465
0.5	0.000	0.436
1	0.001	0.003
1.5	0.000	0.016
2	0.000	0.000
2.5	0.026	0.000
3	0.020	0.008

Table 6 Comparison (*P*-values) for file size using different electronic apex locators and different measurement levels. Mann–Whitney test using a significance level of alpha = 0.05. Values below 0.05 indicate that there is a significant difference between the measurement files at that point of the measurement curve

Position	Dentaport ZX	Root ZX mini	Elements Diagnostic Unit and Apex Locator	Raypex 5
0	0.012	0.489	1.000	0.794
0.5	0.001	0.113	0.913	0.722
1	0.004	0.017	0.699	0.274
1.5	0.014	0.365	0.329	0.847
2	0.056	0.086	0.807	0.685
2.5	0.674	0.071	0.104	0.383
3	0.769	0.861	0.208	0.730

readings can be interpreted as distance in millimetres, keeping in mind that the accuracy of measurement is the highest at the major foramen. For Raypex 5, an interpretation of the colour-coded zones as distance to the foramen is not recommended.

For the Dentaport ZX, a higher accuracy using the size 15 file for the area 0–1.5 mm short of the apex was observed, whilst for the other devices, the file diameter had little influence on the measurement accuracy.

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