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# Accuracy of root canal length determination with the impedance ratio method

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## Abstract

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**Aim** To provide insight into the principles of operation of electronic apex locators, determine optimal measuring parameters of the impedance ratio method, and to evaluate its accuracy.

**Methodology** Electrical impedance was measured *ex vivo* on 14 extracted human teeth using a QuadTech 1920 precision impedance analyzer. A file electrode was inserted into the root canal; the second electrode was placed in the saline solution surrounding the tooth. Measurements were performed in a frequency range from 20 Hz to 1 MHz, and repeated with different distances of the file tip from the major apical foramen. The measured impedances were analysed as a function of distance of the file tip to the major apical foramen. Parameters (e.g. measurement frequencies, impedance ratio value) that would result in optimal working length determination were evaluated.

**Results** The optimal determination of the major apical foramen position was obtained at frequencies of 5 kHz and 0.5 kHz, 10 kHz and 0.5 kHz, and 5 kHz and 1 kHz, for the impedance ratios 0.73 (95% CI: −0.33 to 1.74 mm), 0.66 (95% CI: −0.34 to 1.81 mm) and 0.79 (95% CI: −0.33 to 1.58 mm) respectively. The limit of ±0.5 mm was attained in 86% of all measurements. Standard deviations decreased as the average measured distance approached and extended beyond the major apical foramen.

**Conclusions** With the obtained optimal measuring parameters, the impedance ratio method determined position of the major foramen within ±0.5 mm. Accuracy varied depending on the set of frequencies used for evaluation as well as on the selected impedance ratio.

**Keywords:** apex locators, canal length, endodontics, impedance spectroscopy.

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## Introduction

Accurate root canal length determination is a crucial factor for successful root canal treatment (Cohen & Hargreaves 2006). By using measurement of electrical impedance, root canal length determination is made more accurate and predictable (Fouad & Reid 2000).

The first attempts to use the measurement of electrical resistance to determine root canal length were discussed by Custer (1918). Much later, Sunada (1962) demonstrated that when the tip of a file placed inside the root canal reached the apical foramen the electrical resistance between a file and an electrode placed on the oral mucosa dropped to about 6.5 kΩ. It was, however, difficult to obtain consistent values, largely due to the polarisation effects at the surface of the electrodes that occur with the application of direct current. This deficiency was identified and eliminated by the introduction of the Root Canal Meter (Onuki Medical Co., Tokyo, Japan) in 1969 (Kobayashi 1995). This device measured electrical impedance at a frequency of 150 Hz. This approach not only reduced the effect of interfacial polarisation, but also gave additional information about the conduction properties of the media between the measuring electrodes. The Root

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Canal Meter was later replaced by the Endodontic Meter (Onuki Medical Co., Tokyo, Japan) which increased the frequency from 150 Hz to 400 Hz. The drawback of devices operating at only one frequency is that they are vulnerable to the electrical properties of the area surrounding the tip (Sunada 1962). The impedance changes significantly depending on the presence of electrolytes in the canal, usually reducing the resistance between the tip of the file and the oral mucosa. As a result it was generally suggested that the canal should be dry between measurements, a requirement which complicated the clinical endodontic procedure.

A significant improvement as a result of a suggestion by Yamashita (1991) to use a 1 kHz rectilinear signal, extract the impedances at 1 kHz and 5 kHz, and to then use the difference between the two to determine the major apical foramen position. This approach reduced the influence of the conductive canal environment on the resistance (Frank & Torabinejad 1993) and improved the accuracy of the method (Fouad *et al.* 1993). A device called the Apit (Osada Electric Co., Tokyo, Japan) was developed using this approach. Another improvement was achieved by the Root ZX device (Morita Corp., Tokyo, Japan) using an approach suggested by Kobayashi & Suda (1994). Two frequencies of 0.4 kHz and 8 kHz were used and the ratio, instead of the difference between the impedances, was used as a measure for determination of the root canal length. When using this approach, no additional calibration or adjustments of the device were needed. Recently developed devices use the same principle but the accuracy is further improved by measuring impedance at several frequencies.

The accuracy of these devices has been evaluated mainly by studying the results of *ex vivo* or *in vivo* measurements with commercial apex locators. Studies with apex locators using two frequencies report accuracy rates within 0.5 mm of the major apical foramen from 82% (Pagavino *et al.* 1998) to 100% (Czerw *et al.* 1995) of the measurements. Results of the investigations support the overall effectiveness in determination of both the major apical foramen and also the minor foramen, although to a lesser extent in the latter case (Hoer & Attin 2004, Nekoofar *et al.* 2006). However, results and practice indicate that due to instability, not all measurements could be used for determination of the root canal length (Venturi & Breschi 2005).

Even though the fundamental electronic operating principles of the commercially available electronic apex locators are often unknown (Nekoofar *et al.* 2006), most previous studies have been made with them (Gordon & Chandler 2004, Kim & Lee 2004). There are only a few studies that have investigated impedance changes with noncommercial devices, aiming to evaluate factors that influence the measurement or to improve the method itself (Pilot & Pitts 1997, Nam *et al.* 2002, Križaj *et al.* 2004).

The aim of this study was, therefore, to provide insight into the principles of operation of electronic apex locators. In contrast to most previous studies which evaluated accuracies of electronic apex locators the study also aimed to determine the best range of measurement frequencies and optimal impedance ratio value for root canal length determination with the impedance ratio method.

## Materials and methods

A total of 14 extracted human teeth (10 incisors, two canines, two pre-molars) from adults (mean age 57 years, range 45–75 years), preserved in Thymol solution and kept refrigerated, were used. The teeth had mature root apices and a single root canal configuration. They did not have restorations, fractures, nor had they been root filled previously. Standard endodontic access cavities were prepared on all teeth. A flat reference point was prepared on the incisal edge or occlusal surface of the teeth to allow for precise positioning of the test K-file (Dentsply Maillefer, Ballaigues, Switzerland). The contents of each canal were not removed. The actual canal length was determined by introducing a size 10 K-file into the canal until the tip of the file became visible at the major apical foramen under a light microscope. The file that was inserted into the root canal served as one electrode; the second electrode was placed in a 0.9% NaCl solution surrounding the extracted tooth, which was fixed with light-cured composite resin.

Electrical impedance was measured between the size 10 K-file inserted into the root canal and the outer metal electrode placed in the saline solution surrounding the tooth. A QuadTech 1920 precision impedance analyzer (LCR meter) (QuadTech; Maynard, MA, USA) in a frequency range from 20 Hz to 1 MHz was used for impedance measurements. Only the impedances measured at frequencies 0.5 kHz, 1 kHz, 5 kHz, 10 kHz and 50 kHz were used in this investigation. The measurements were repeated with different distances of the file tip from the major apical foramen: from 8, 6, 4, 3, 2, 1.5, 1, 0.5, 0 mm inside the canal to 0.5, 1 and 2 mm beyond the major foramen. The distance

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between the file tip and the rubber stop, corresponding to each distance to the major apical foramen, was determined using a caliper to 0.1 mm accuracy. The rubber stop was adjusted in contact with the flat, horizontal reference surface of the tooth. The instrument was connected to a PC. Dedicated software was developed that controlled the instrument and collected the measurement data. The measured impedances were analysed as a function of distance of the file tip to the major apical foramen. Parameters evaluated were measurement frequencies as well as impedance ratio values that would result in optimal determination of the position of the major foramen.

For determination of an optimal impedance ratio value at the 10 selected frequency pairs (Fig. 3) a criterion was chosen that required maximal accuracy in a range 0.5 mm before to 0.5 mm through the major apical foramen. An impedance ratio was determined where the distance from the major apical foramen would be within ±0.5 mm for as many samples as possible: criterion = max(number of samples with $X_i$ within ±0.5 mm distance).

Box plots were used to illustrate the impact of selected pairs of frequencies on distances of the file tip to the major apical foramen. Average distances and their standard deviations were also calculated. An analysis of variance was conducted to explore the impact of selected pairs of frequencies with different impedance ratios on distances from major apical foramen. The level of statistical significance was set to 5%. The *XY* plot was used to assess the correlation between standard deviations and average distances to the major apical foramen.

## Results

Figure 1 presents the measured absolute values of impedances for 14 teeth at a selected frequency of 50 kHz, with different distances of the file tip from the major apical foramen. For most measurements the impedance value was almost constant up to approximately 2 mm from the major apical foramen and then decreased as the file tip advanced apically. When the tip of the file reached the major apical foramen an additional decrease of the impedance occurred. However, this decrease was not large and appeared at different values of the impedance (from 1 kΩ to 10 kΩ).

In Fig. 2 a ratio of impedances $Z(f_2)/Z(f_1)$ for a pair of frequencies $f_2$ = 50 kHz and $f_1$ = 0.5 kHz is shown. In all the teeth examined a significant reduction of the impedance ratio value appeared when the tip of the file approached the major apical foramen. This drop was observed when the file tip was less than 1 mm away from the major apical foramen. The major apical foramen (zero length) could be determined at a certain range of ratios, from about 0.6 to 0.4. The thicker line in Fig. 2 represents an average for all 14 teeth with added standard deviations. On average, a ratio value around 0.5 would appear to be the optimal choice.

A closer examination of impedance ratios was performed for data from five selected frequencies (0.5 kHz, 1 kHz, 5 kHz, 10 kHz and 50 kHz). Impedance ratios for

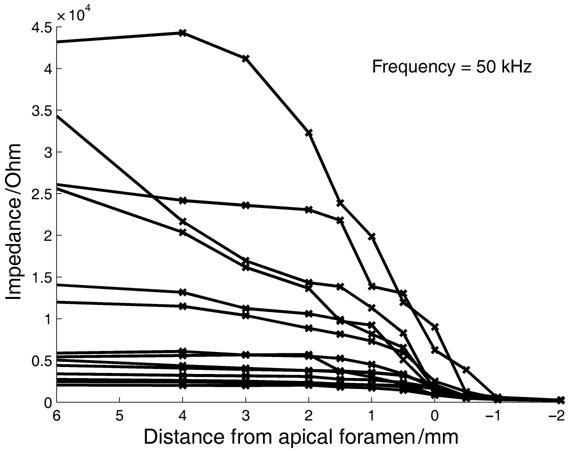


**Figure 1** Absolute impedance measured at frequency 50 kHz as a function of distance of the file tip to the major apical foramen for 14 teeth. The value 0 shows the major apical foramen. Negative values are located beyond the foramen.

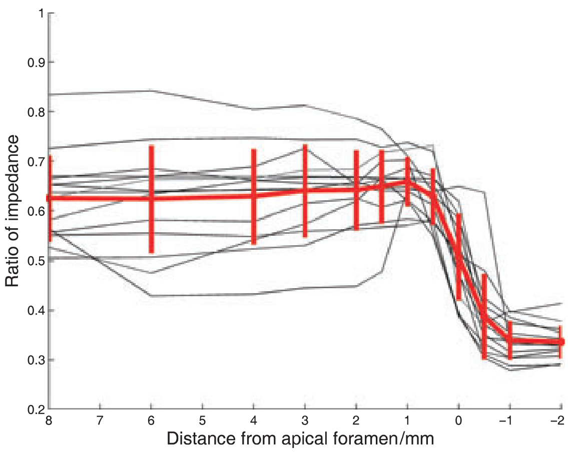


**Figure 2** Ratio of impedances for a selected pair of frequencies (50 kHz and 0.5 kHz) as a function of distance of the file tip to the major apical foramen for 14 teeth. The thicker red curve represents an average of all curves with added standard deviations.

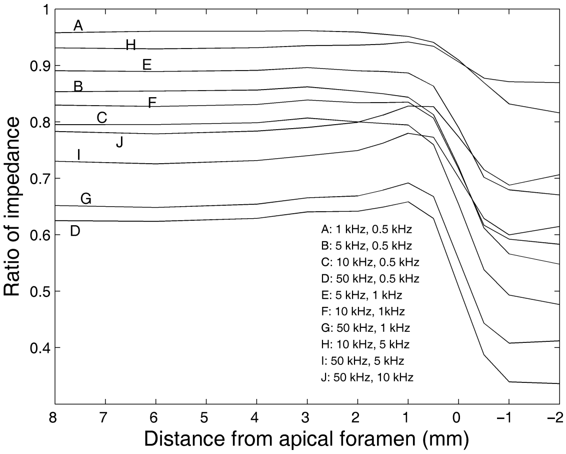


**Figure 3** Average ratios of impedances for 10 selected pairs of frequencies as a function of distance of the file tip to the major apical foramen.

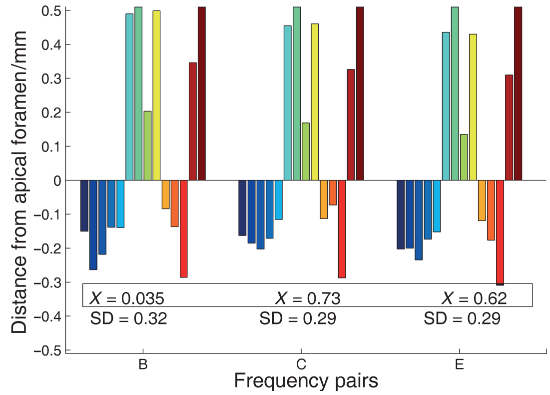


**Figure 5** Distances (*X*, SD) of the file tip to the major apical foramen for the three pairs of frequencies, denoted with letters B, C and E (see the legend in Fig. 3), at optimal impedance ratio values, for 14 individual teeth.

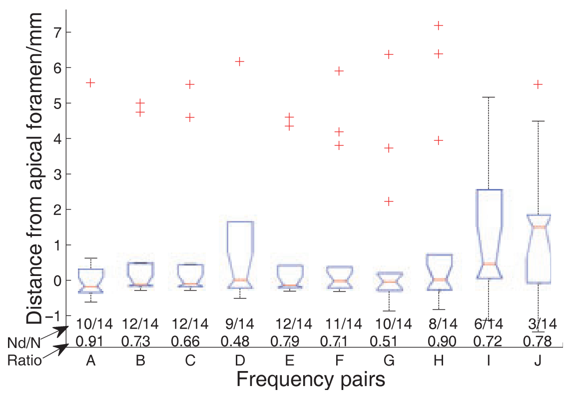


**Figure 4** Box plot of the measured distances of the file tip to the major apical foramen for the 10 pairs of frequencies, denoted with letters A though J (see the legend in Fig. 3), at optimal impedance ratio values determined using the selected criterion. Each box has lines at lower quartile, median and upper quartile values, and below, the number of teeth where root canal length could be determined according to the criteria (Nd/N), and impedance ratio value (Ratio).

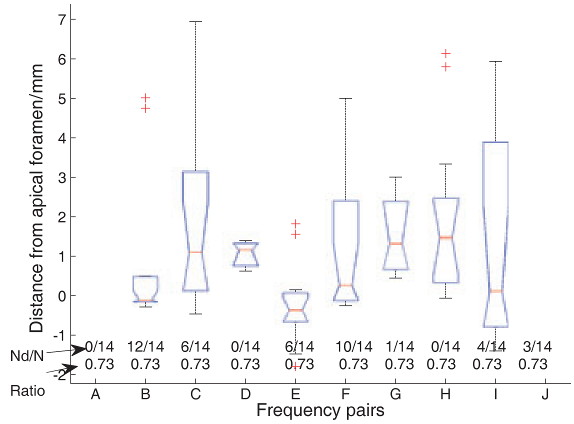


**Figure 6** Box plot of the measured distances of the file tip to the major apical foramen for the 10 pairs of frequencies, denoted with letters A though J (see the legend in Fig. 3), at an impedance ratio value of 0.73. Below is the number of teeth where root canal length could be determined according to the criteria (Nd/N), and impedance ratio value (Ratio).

a set of 10 pairs of frequencies were investigated as shown in Fig. 3. They are denoted with letters A through J. Each curve in Fig. 3 represents an average ratio of impedances for 14 teeth at a selected frequency pair. For example, curve D represents an average impedance ratio measured at frequencies of 50 kHz and 0.5 kHz. This curve is the same as the thicker curve in Fig. 2. Curves differ for different pairs of frequencies; however, in all cases a considerable decrease of the ratio occurred when the tip of the file approached the major apical foramen. The decrease of the ratio started before the major apical foramen, around the area where the position of the minor foramen would be expected.

An optimal impedance ratio was determined as a ratio of absolute values of frequencies at which the maximal number of measurements was found within ±0.5 mm from the major apical foramen. Figure 4 presents statistical evaluation of average distances to the major apical foramen at optimal impedance ratio values for 10 selected frequency pairs according to the selected criterion. Twelve samples were found at most from a possible 14 within the set accuracy, i.e. 86% of all evaluated teeth. Optimal results were obtained for sets B, C and E at impedance ratios 0.73 (95% CI: −0.33 to 1.74 mm),

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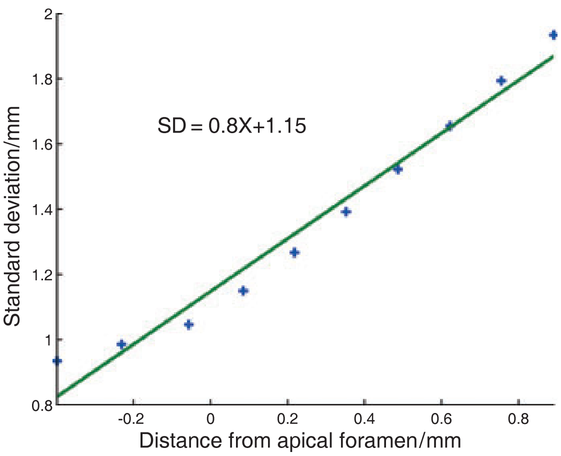


**Figure 7** Average distances of the file tip to the major apical foramen (*X*) and standard deviations (SD) for various impedance ratios for set E, with the measuring signals 5 kHz and 1 kHz.

0.66 (95% CI: −0.34 to 1.81 mm) and 0.79 (95% CI: −0.33 to 1.58 mm) respectively. Average distances and their standard deviations are presented in Fig. 5.

The impact of selected pairs of frequencies with different impedance ratio values on distances of the file tip to the major apical foramen was also explored. The box plot of the distances of the file tip to the major apical foramen for the selected 10 pairs of frequencies, at the impedance ratio value of 0.73, is shown in Fig. 6. With a fixed impedance ratio value of 0.73, that might have seemed nearly optimal with the selected criterion, 86% of all evaluated teeth attained the limit of ±0.5 mm for set B, 71% for set F, but for eight other sets that percentage was below 50%. The observed differences in the distances to the major apical foramen were statistically significant ($P \leq 0.005$).

Figure 7 illustrates an evaluation of average distances to the major apical foramen and standard deviations for set E in the *XY* plot where the *X*-axis represents the average distance, and the *Y*-axis represents the standard deviation. A strong correlation between standard deviation and average distance of the file tip to the major apical foramen was observed. Comparable results (data not shown) were obtained for other sets of frequency pairs.

## Discussion

Root canal length determination using measurements of electrical impedance between the file inserted into a root canal and an outside electrode applied to the oral mucosa is becoming a standard method in endodontic practice (Kaufman *et al.* 2002). In order to elucidate the operating principles of electronic apex locators as well as to further improve the measurement techniques of the impedance ratio method, the impedance between the file inserted into a root canal and the surrounding saline was analysed in an *ex vivo* model by using impedance spectroscopy. The data were manipulated in a manner similar to commercial devices.

The study revealed that determination of the position of the major apical foramen directly from the measured absolute impedance values could be inaccurate. The decrease in impedance value when the file tip reached the major apical foramen was small, and further, for different teeth it appeared at different impedance values (Fig. 1). For some of the teeth studied the measured absolute impedance changes occurring when the foramen was approached and passed were minimal. The cause may be that the canal contents were not removed prior to measurement, and/or electroconductive saline in the *ex vivo* model that could have leaked through the major apical foramen, thereby complicating electrical determination of the foramen (Pilot & Pitts 1997). This finding is in accordance with the results of Venturi & Breschi (2005), wherein only under dry canal conditions did the single frequency apex locator Apex Finder provide accurate readings.

Currently, the most frequently used approach for root canal length determination is to measure the impedances of at least two different frequencies and use the impedance ratio as a measure of the canal length. In all the teeth examined, a considerable decrease of the impedance ratio value appeared when the tip of the file approached the major apical foramen (Figs 2 and 3). This confirms that the sensitivity of the method could be increased by replacing the measurements at a single frequency to the multiple frequency method. However, for a fixed impedance ratio, several different root canal lengths could be obtained. Thus this technique could not be expected to be absolutely accurate.

In order to determine the optimal impedance ratio value with the optimal set of frequency pairs, the measured root canal lengths at different selected frequency pairs were evaluated. The criterion evaluated was based on determination of optimal measuring parameters that would result in distances from the major apical foramen within the limit of ±0.5 mm. At best, 12 from 14 samples (86%) could be found within the pre-selected range (Fig. 4), and that was achieved only for sets of frequency pairs B, C and E, for each set at different impedance ratios. For those sets, it could be expected with 95% confidence to determine the major

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apical foramen position between 0.34 mm beyond the foramen to 1.81 mm inside the canal, and the average measured distance from major apical foramen ranged from 0.03 for set B to 0.73 for set C (Fig. 5). The two remaining samples from the set of 14, (those not found within the limit ±0.5 mm) had values found more than 4 mm inside the canal. No explanation for this discrepancy could be found. For other sets of frequency pairs, the proportion of measurements within ±0.5 mm distance was lower. When the impact of a fixed impedance ratio value of 0.73 on distances of the file tip to the major apical foramen was explored (Fig. 6), the results were less satisfactory. Only for one set of 10 frequency pairs was the limit of ±0.5 mm attained in 86%; for other sets the percentage was lower, for six of them even below 30%. For some samples no measurement values could be obtained at all. As seen from the results, an optimal set of frequency pairs depended on the impedance ratio value.

A trade-off needs to be made between standard deviation, average distance, range, percentage of measurements in the clinically tolerable range of ±0.5 mm (Shabahang *et al.* 1996), and the percentage of cases that could be measured. To present only one of these parameters when describing accuracy might be misleading, as was already observed by Lee *et al.* (2002). They suggested that not only the strictest clinically acceptable range of ±0.5 mm tolerance (Kim & Lee 2004) be used for accuracy assessment, but also standard deviation that showed how the measurements could be reproduced consistently.

Results of this study revealed less measurement accuracy and consistency compared to most previous studies with commercially available dual-frequency apex locators. Few of the earlier studies reported more than one accuracy measure. In an *ex vivo* study the accuracy of the Apit, based on the gradient impedance principles, was found to be 96.5% at a ±0.5 mm clinical tolerance (Felippe & Soares 1994). In clinical studies the accuracy was lower, from 71.7% (Arora & Gulabivala 1995) to 93% (Lauper *et al.* 1996), with the average distance (SD) of −0.14 mm (±0.27), and measurement range from −0.85 to 0.65 mm.

The Root ZX accuracy was evaluated in *ex vivo* studies where the average distance from major apical foramen (SD) ranged from 0.32 mm (±0.04) (Kaufman *et al.* 2002) to 0.12 mm (±0.41) (Wrbas *et al.* 2007). A recent study (Venturi & Breschi 2007) revealed results where the average measured value with the file tip at the major apical foramen was 0.12 mm beyond the major foramen, with a relatively high standard deviation of ±1.22 mm. In clinical evaluations, where more errors may have occurred (Czerw *et al.* 1995), it was found that the Root ZX accuracy with a ±0.5 mm tolerance was higher than was achieved in this laboratory study, from 96.2% (Shabahang *et al.* 1996) to 94% (Lee *et al.* 2002), with the average distance from 0.03 mm (±0.39) (Venturi & Breschi 2005) to 0.13 mm, with 81% of the measurements within one SD (Lee *et al.* 2002).

Less accurate readings after canal enlargement were observed (Ebrahim *et al.* 2006, Venturi & Breschi 2007). The teeth chosen for this study all had closed apices with no inflammatory resorption, and the measurements were performed with the first 10 K-file inserted, so apical foramen diameter should not be responsible for the reduced accuracy observed.

In contrast to most previous studies, one of the reasons for the lower accuracies observed in this study could be the inclusion of unstable measurements. Venturi & Breschi (2005) claimed 20% of their measurements were unstable and were not taken into account in their statistical evaluation. However, in the present investigation all the measurements were registered with a precision LCR meter and were included in the final evaluation. It is worth noting that simultaneous measurements with the Root ZX (data not shown) also showed unstable readings, most frequently when the file tip approached the apical foramen.

In this study optimal measuring parameters were obtained for determining root canal length. It is generally accepted that root canal treatment procedures should be confined within the root canal system in order to prevent irritation of the periapical tissues and possible overextension of the root filling (Ingle *et al.* 1994). In Fig. 7, a correlation between standard deviation and average distance of the file tip to the major apical foramen is presented. Standard deviation decreased as the average distance from the major apical foramen decreased (was closer to the major apical foramen) and decreased even more as the average distance became more negative (was further beyond the major apical foramen). The finding that the standard deviation decreases as the average measured distance is approached and extends beyond the major apical foramen confirms results from previous studies that the average distance decreased as the file tip approached the major foramen (Venturi & Breschi 2007) and that major foramen could be determined more accurately and consistently than the minor apical foramen (apical constriction) (Lee *et al.* 2002, Hoer & Attin 2004). Some authors even suggested that taking the instrument

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slightly long and then retracting it may increase the reading accuracy (Dunlap *et al.* 1998, Lee *et al.* 2002).

In this study, not all measurement variation could be explained, showing that other factors may have influenced the electrical properties of the root canal walls and current conduction mechanisms (Križaj *et al.* 2004). Further studies are needed for their elucidation.

## Conclusions

Using a precision impedance meter provided insight into the operating principles of commercial electronic apex locators and led to conclusions that could drive further advancements of the measurement technique. The results indicate that the accuracy of the ratio method for root canal length determination varied depending on the set of frequencies used for evaluation as well as on the selected impedance ratio. With the obtained optimal measuring parameters, the impedance ratio method can be used to determine the average measured distance from the major apical foramen with a level of accuracy of ±0.5 mm.

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