Determining working length, or how to locate the apical terminus (Part 2)

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Figs. 1a & b_Two identical EFLs sold under different brand names.

Fig. 1a

Fig. 1b

_We would like to start the second part of our article with a quotation: "Adequate radiographs, knowledge of anatomy, and tactile sense and not apex locators will help to determine apical constriction."[2] We found this statement provocative enough to give electronic locators a chance.

As is well known, apex locators actually locate the foramen and not the root apex. As the foramen is usually not on the root apex, the term *electronic foramen locators* (EFLs) is more accurate. *Electronic root-canal length measuring devices* or similar descriptive terms are also incorrect, since the root-canal length does not appear on a display, particularly not in some standardised units.

EFLs are usually classified into different generations. The following classification of EFLs based on their functional properties is useful for dentists who, besides desiring the latest and best models, would like to know how a particular device works and why it is better than another model:

1. resistance-based devices (Generation I)
2. low frequency based devices (Generation II)
3. high frequency (capacitance) based devices (Generation II)
4. capacitance and resistance based devices (Generation IV)
5. voltage gradient devices
6. two frequency (impedance difference) based devices (Generation III)
7. two frequency (impedance ratio quotient) based devices (Generation III)
8. multi frequency based devices (Generation III).

The authors of this classification give perhaps the most appropriate comment: "The use of Generation X to describe and classify these devices is unhelpful, unscientific and perhaps best suited to marketing issues."[5] Marketing firms and manufacturers often cooperate to increase turnover, which is why, in some cases, you can find two identical devices that are sold under different brand names (Figs. 1a & b).

_*In vitro* studies

A remarkable number of studies have been conducted in the last 20 to 30 years on the use of EFLs. A majority were conducted *in vitro*, with all research conditions and variables controlled and standardised. We believe it would be useful to point out a number of variables that influence the accuracy of EFLs in *in vitro* studies.

Embedding media simulate periodontal ligaments through their physical and electrical properties and thus could affect the results if those media vary from the natural tissue. Electrical properties of intracanal solution, particularly with extremes of electroconductivity and ion concentration, can significantly influence the EFLs' accuracy. The discrepancies vary amongst the different EFL models.

Fig. 2a

Fig. 2b

Figs. 2a & b_The difference between the real values and those shown on the Dentaport ZX (a) and ProPex I (b) is approximately 300 µm.

File size with respect to the diameter of the apical constriction and foramen can also affect precision. Since the measurements are repeated a number of times on the same tooth, it is wise to use smooth canal instruments (for example, small size finger spreader for lateral condensation) that cause less damage to the fine apical structures than endodontic files.

The EFL model used can also affect the results. The majority of studies conducted on this have confirmed that with newer and improved models, higher precision and more consistent results can be obtained.

Pre-flaring of the coronal third of the root canal improves determination of the apical diameter. The first file that binds at the apical constriction, stabilises and increases the precision of the readings in any type of EFL. The range of tolerance, which varies from approximately 0.1 to 0.5 mm, and sometimes 2 mm, significantly affects the EFLs' accuracy; the wider the range is, the higher the percentage of EFL precision is.

From a number of articles, we concluded that the method and the apical landmark selected to determine the real or actual length of the tooth also significantly influences the results. The apical end-points selected varied greatly, from the anatomical apex to the anatomical foramen, and in some cases to the cemento-dentinal junction. Additionally, only vague explanations for the method and obtained results were offered at times, making the results incomparable.

It is generally believed that *in vitro* studies offer valuable and useful facts and results for the clinical practice. However, most of the currently available studies are on single-rooted or single-canal teeth. Many of these studies also have too many variables, resulting in confusion rather than leaving the reader with clear and appropriate conclusions.

Owing to the apparent lack of precise and reliable information, Prof Joshua Moshonov (Hadassah University, Jerusalem) and a team of researchers from MedicNRG, which we accompanied at a later stage, tested several of the newer EFL models, namely ProPex I (DENTSPLY Maillefer), Dentaport ZX (J. Morita), Raypex 5 (VDW) and ApexPointer+ (MICRO-MEGA).

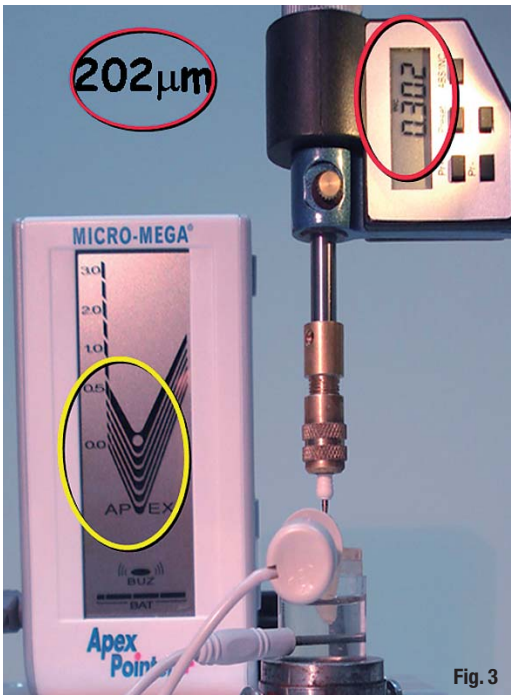


Fig. 3

Fig. 3_A difference of 200 µm between the real value and that shown on the ApexPointer+.

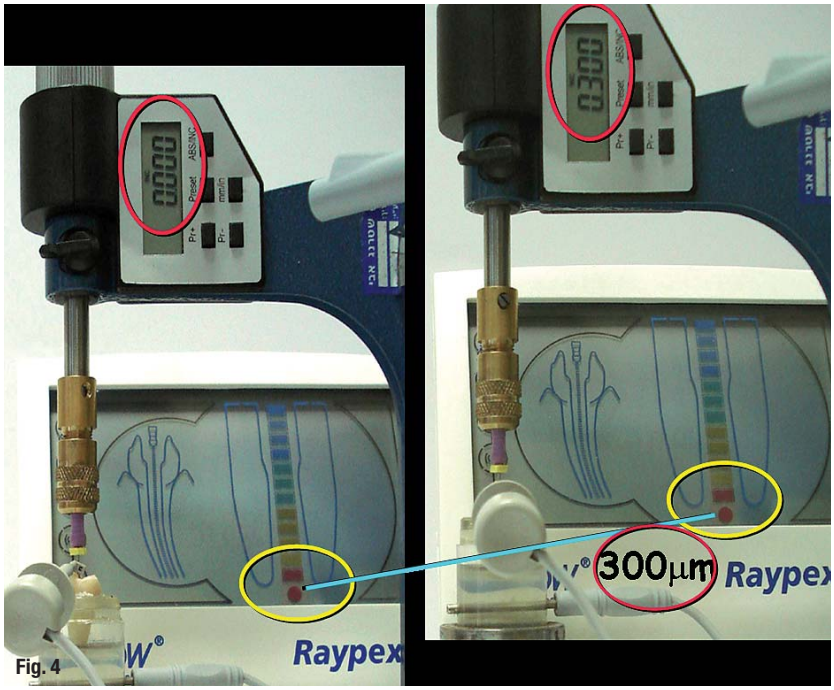


Fig. 4

Fig. 4_Tolerable difference of 300 µm between the real value and that shown on the Raypex 5.

One of the first questions the study aimed to address was: are differences between real values of distances from the file tip to the referent point and those shown on a EFL display clinically significant? Using a high-tech electronic micrometer, with measuring precision at 0.1 µm, the distances from the file tip to the reference point (anatomical foramen) were measured. We tested and gained almost identical results for all four EFLs.

The findings of this study can be summarised thus:

a) Figures or marks on the display of the EFL scales do not represent strict values in mm.
b) The difference between the real values and those on the display is smaller than 0.5 mm (Figs. 2a & b), and thus may be considered clinically insignificant, owing to our manual inability to distinguish such short movements of the canal instrument.
c) We may tolerate small differences between real values on a high-tech measuring instrument and those on the display of the EFLs because they are not even detectable by the hand of a practitioner, since they are approximately 300 µm and smaller and are therefore acceptable in clinical work (Figs. 3 & 4).

While taking measurements, we sometimes noticed a slight bouncing on the scale of the EFL, even when the file tip was not moving in the root canal. This was due to a slight mixing of electrolytes and changes in ion concentrations between the embedded media outside and solution inside the root canal at the level of the apical foramen. Therefore, in clinical use waiting for three to four seconds for a stable reading is recommended.

Following this study, Prof Moshonov wished to address a more detailed and profound question: to what extent do the readings on a display correspond to the real values on a high-tech measuring instrument? In addressing this question, he examined two models of mini-EFLs: the MedicNRG-XFR and the MedicNRG-Blue.

The MedicNRG-XFR displayed extra fine resolution with very small values of distortion from the real measurements—only 12 to 38 µm in instances in which the EFL indicated 0.25 mm from the mark 'apex' (Fig. 5a) and 22 to 65 µm at the 0.5 mm mark from the 'apex' on a EFL display (Fig. 5b).

The MedicNRG-Blue enables users to connect to their PC via a Bluetooth connection. Prof Moshonov compared the value on the EFL itself with a scheme on the screen of a PC. He found that there was no

Figs. 5a & b_The MedicNRG-XFR displays extra fine resolution and very small values of distortion from the real measurements: from 12 µm (a) to 65 µm (b).

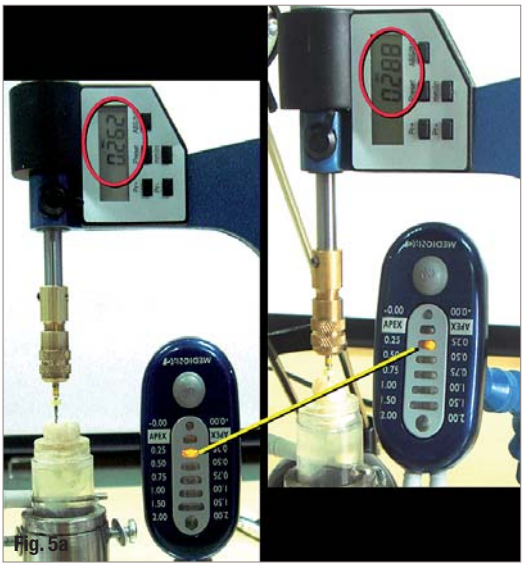


Fig. 5a

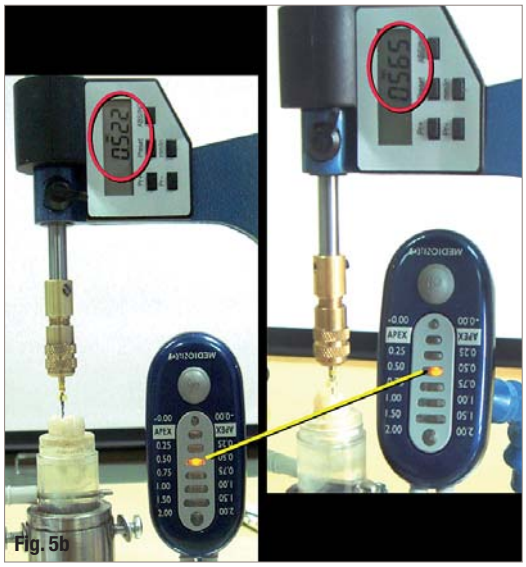
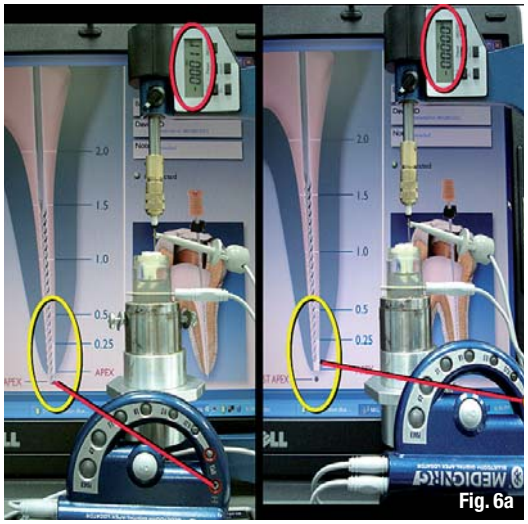
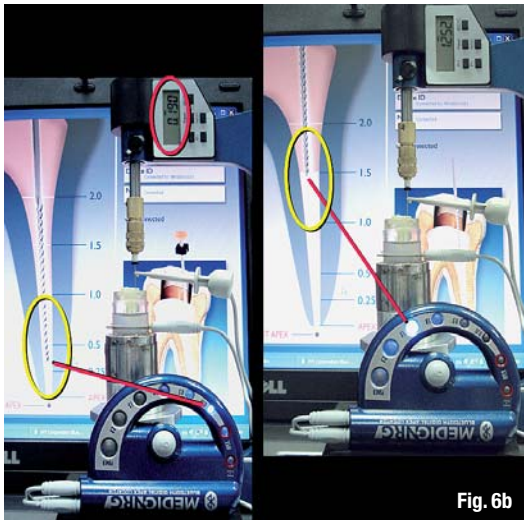


Fig. 5b





Figs. 6a & b_The MedicNRG-Blue displays extremely small differences between real values and those shown on the display: from only 1 µm (a) to 198 µm (b).

difference between real values and the PC screen values when the EFL indicated 'past apex' and 'apex' (Fig. 6a). When the MedicNRG-Blue indicated 0.3 mm to 1.4 mm from the apex (Fig. 6b), the differences ranged from 110 to 158 µm, respectively. These figures coincide with the values of the XFR model, revealing that both EFLs had high precision and a very high level of resolution. Differences are far below the acceptable 0.5 mm and therefore have no relevant influence on clinical work. Prof Moshonov's tests also confirmed that the closer the measuring file tip is to the apex, the more precise the readings are and the higher the resolution of the EFL is (Fig. 6a). When the tip of the measuring file is a bit farther from the apical foramen, the readings coincide slightly less with the real distances (Fig. 6b).

While testing the Raypex 5, we asked ourselves a question that every practitioner might ask: can we trust the values indicated on the EFL display and can we rely on the manufacturer's instructions? The measuring device clearly showed values of 0.5 mm and 0.8 mm (Fig. 7), proving that the EFL very precisely indicates the position of the file tip with respect to anatomical details, since the distance from the foramen to constriction is 0.5 to 1.0 mm. We recommend that practitioners follow what the display indicates as well as the manufacturer's instructions, but reconsider unusual or strange readings.

The last test conducted in our laboratories aimed to determine whether different EFLs display the same values for the same distance in the same root canal. The tip of the finger spreader #15 was introduced into the canal until it reached the plastic plate barrier firmly placed at the plane of the anatomical foramen (Fig. 8). The tooth was normally mounted and each of the EFLs immediately indicated that the spreader tip was beyond the foramen. Presumably, this was due to the gelatine embedding medium inside the external portion of the cemental cone of the apical foramen; thus all EFLs indicated the same: contact with artificial periodontal ligament.

For all EFLs, the measuring device was adjusted to 0.001 mm (0.1 µm) at this stage. With the micrometer screw, the canal instrument was retreated until the display of the EFL indicated that the tip was no longer beyond but exactly at the foramen: apex reading (ApexPointer+, MedicNRG-XFR, Dentaport ZX), 0.0 reading (ProPex I) and red square segment (Raypex 5; specific marks on each EFL). At this stage, we had already received a definite answer to our question: the different EFLs do not indicate the same values for the same distance in the same root canal.

After recording this value, the canal instrument was withdrawn further with the micrometer screw until the mark on the display of each EFL indicated that the tip had been moved and switched from the apical foramen to the first next mark/segment

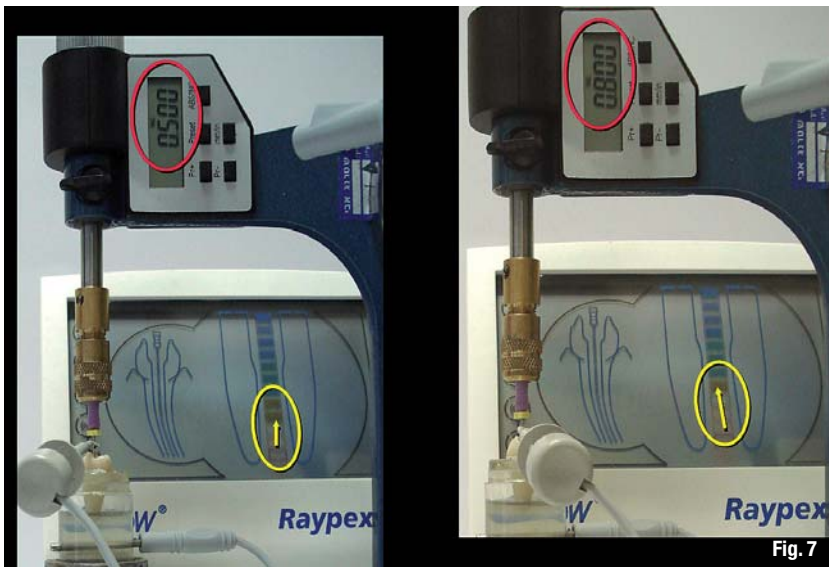


Fig. 7_The Raypex 5 very accurately indicated the position of the file tip, which is approximately 0.5 to 0.8 mm between the anatomical foramen and apical constriction.

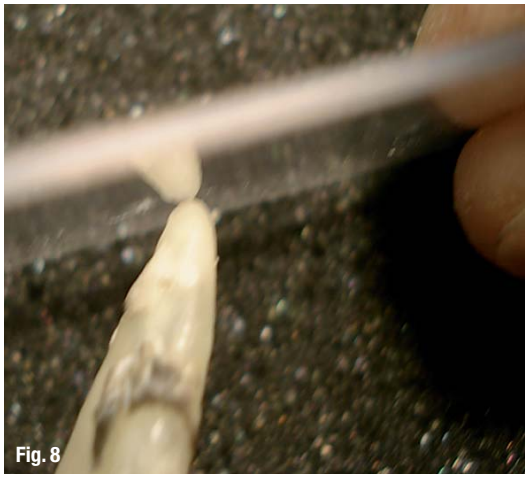


Fig. 8

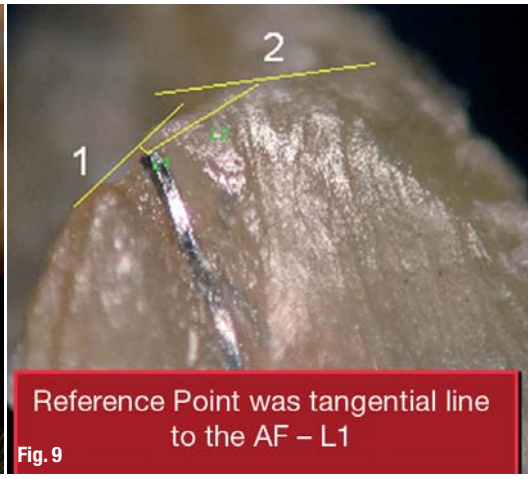


Fig. 9

Fig. 8_The tip of the finger spreader #15 was introduced into the canal until it reached the plastic plate barrier firmly placed at the plane of the anatomical foramen.
Fig. 9_Microscopic image of the distance from the file tip to the line tangent to the anatomical foramen (L1).

indicated before the foramen. The recorded values are reviewed in Table 1.

The first group of values indicates the moment at which the position of the tip of the finger spreader switched from beyond the apex to the mark apex, 0.0 or red segment (all indicating anatomical or major foramen). These variations are likely due to fine variations in the position of the tip of the finger spreader, since positioning of the plastic plate could not have been identical in each case. The second group of values indicates the moment at which the reading switched from the mark indicating the anatomical foramen to the first mark coronal to this one: 0.1 (ProPex I and ApexPointer+), 0.25 (MedicNRG-XFR), lowest green line (Dentaport ZX) and lowest yellow square (Raypex 5). The red figures in the last column indicate the EFLs' precision in measuring the same distance, in other words, the level of resolution. The blue figures are from previous tests. Together they present the EFLs' ability to make fine distinctions.

Therefore, the answer to our question is that different EFLs show different values with different levels of resolution for the same distance in the same root canal. However, and fortunately, all deviations are far below the range of clinically acceptable tolerance of approximately 0.5 mm (about 0.3 mm and less), and therefore do not significantly influence the precision and accuracy of EFLs in locating anatomical foramen.


Fig. 10

Fig. 10_Post-op radiograph of tooth #46.

_*In vivo* studies

In vivo studies are generally conducted on extracted teeth, offering much more realistic, relevant, reliable, and thus useful data for practitioners. There are several factors that can affect the readings and, consequently, the results achieved in clinical conditions. These factors are:

1. status of pulp tissue (vital, necrotic, infected, etc.);
2. pre-flaring of the coronal and/or middle third of the canal;
3. status of the diameter of the minor and major foramen (preserved in its natural dimension or deviated by pathological resorption or instrumentation);
4. size of measuring file;
5. file material;
6. canal content (empty and dry, or inflamed pulp tissue, pus, necrotic tissue and bacterial detritus, etc.);
7. electroconductive properties and ion concentration of irrigating solution used; and
8. type of tooth (anterior, posterior, single, multi-rooted, etc.).

A number of studies have confirmed that some factors facilitate more consistent, straight forward, faster and precise readings. These beneficial factors are:

1. pre-flaring of the coronal and middle portion of the root canal;
2. removing of the pulp tissue and debris from the canal;
3. foramen not enlarged by instrumentation or periapical pathosis;
4. size of the measuring file coincides with the lumen of the apical portion of the canal; and
5. application of moderately conductive irrigating solutions such as 2 % NaOCl, chlorhexidine, or EDTA solution.

The type of the tooth and file material have been proven not to affect the readings and accuracy of EFLs.

Contradictory and controversial results and statements about certain factors that influence the accuracy of EFLs when tested in vivo (both with statistical and/or clinical significance) still exist, particularly with regard to vital and necrotic cases. Reports vary from higher precision in teeth with vital pulp to higher precision in cases with necrotic/infected pulp or even no difference at all. Whether EFLs demonstrate better results in moist or dry canals is yet another controversial issue. Here, the type of EFL used is most often the determining factor. The same can be concluded for the type of irrigant used, considering its conductivity and ion concentration.

The following factors adversely affect the accuracy of all tested EFLs:

1. presence of peri-apical lesions associated with periodontal ligament and bone destruction that have destroyed both the anatomical foramen and apical constriction;
2. wide-open apical foramen in immature teeth; and
3. extremes in conductive properties of the irrigating solution in the canal, such as saline versus distilled water.

According to the literature, the precision of EFLs tested in clinical conditions varies between 15 and 100%. Evidently, additional factors or variables that influence clinical results must exist. In general, measurements of an extracted tooth with a revealed apical segment of the root canal taken using a microscope and software programmes are more precise compared to measurements taken using radiographs of a tooth under clinical conditions. Furthermore, the range of tolerance or targeted interval from approximately 0.5 to 1.0 and 1.5 mm significantly affects accuracy: the higher the value of tolerance is, the higher the percentage of precision is.

The display mark selected to be the apical terminus for measuring the electronic working length may influence clinical results of the accuracy of EFLs. In reality, each operator will select his/her preferred display mark and therefore select his/her personal apical terminus.

The anatomical landmark selected to measure the distance from the file tip also varies and can significantly affect the results. The cemento-dentinal junction and the apical constriction are not reliable reference points. However, the apical anatomical foramen and, even more so, the anatomical apex are well defined and easy to distinguish, even without magnification.

The type of EFL used also influences the results. Generally, the more sophisticated and newer the model is, the more accurate the measurements will be. Manufacturers constantly strive to improve their models in order to make our work easier and more precise. However, all instruments are handled and results interpreted by practitioners, which leaves room for random and unforeseeable errors.

In the early 1980s, we conducted a number of studies at the Department of Restorative Odontology and Endodontics in the School of Dentistry at Belgrade University using two EFLs—DIAPEX (DiaDent) and Odontometer (Goof). The results achieved with Odontometer demonstrated 77% precision in locating the apical constriction, checked by the same radiographic criteria as explained before. Significantly less overestimation was found than with the tactile sense and the radiographic method. Similar results were achieved with the Foramatron (Parkell, Inc.) several years later, with measurement deviations of up to -1.0 mm.

Traditionally, the accuracy of EFLs has been corroborated with radiographs, but any correction of the file position according to radiographic projections would invariably lead to overextension. Comparing

electronic foramen locator	from – to (in µm)	range (in µm; resolution/subtlety)
Raypex 5	0 – 508 – 701	193 (300)
ProPex I	0 – 354 – 705 0.0 0.1	351 (340)
MedicNRG-XFR	0 – 305 – 380 -0.0 Apex 0.25	75 (48)
Dentaport ZX	0 – 367 – 674 Apex	307 (350)
ApexPointer+	0 – 143 – 312 AP EX 0.0 0.1	169 (202)

Table 1

electronic foramen locator	mean (+/- SD)	beyond AF
MedicNRG-XFR	0.148 (0.079)	Ø
Dentaport ZX	165 (0.222)	2; +0.076 +0.131
ProPex I	0.169 (0.149)	9; +0.226 (0.102)
Raypex 5	0.187 (0.142)	3; +0.119 +0.208 +0.075
ApexPointer+	0.189 (0.168)	1; +0.129

Table 2

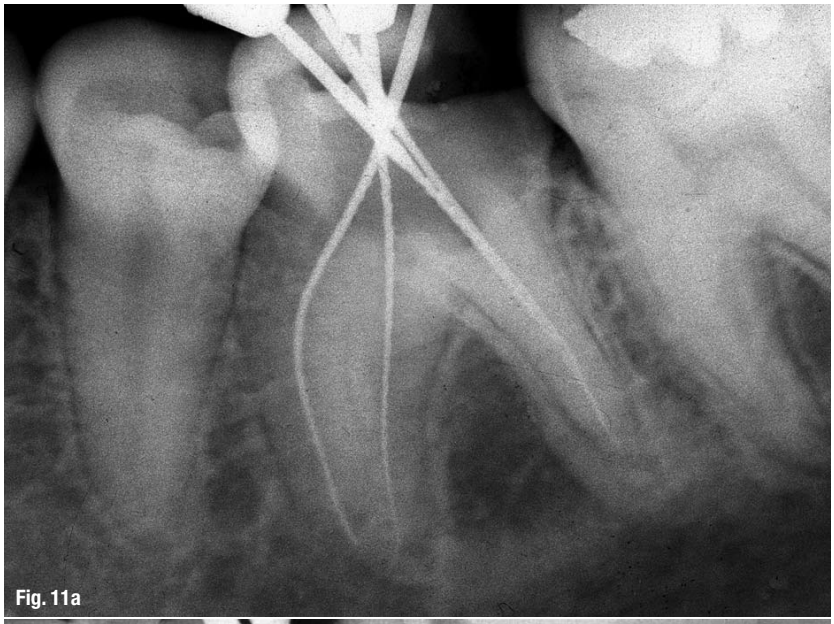


Fig. 11a

Fig. 11b

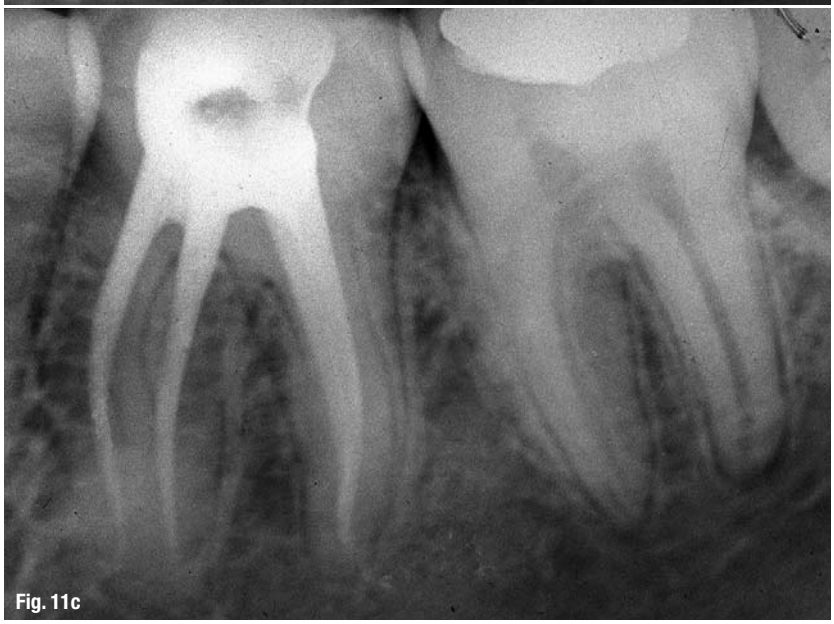


Fig. 11c

the precision of EFLs with radiographs will not lead to accurate results, as the radiographic method is unreliable in determining both the apical constriction and apical foramen.

In 2006, our team conducted the *Belgrade in vivo studies*—which later became an *in vitro* study—in molars and multi-rooted premolars using a strict protocol that was reviewed by Dr Julian Webber, Prof Moshonov and Prof Paul Dummer. The above-mentioned EFL models were tested once again.

We selected a mark on a EFL to be the apical foramen (0.0, apex or red segment). The reference point for measuring the distance from the file tip under the stereomicroscope was the point of crossing the tangential line to the anatomical foramen and extended line of the canal instrument (L1; Fig. 9). The results are presented in Table 2.

None of the mean distances exceeded 0.2 mm. Therefore, it may be concluded that the new generation EFLs were precise in locating the apical foramen within values far below the recognised clinical tolerance of approximately 0.5 mm.

Standard deviations for Dentaport ZX, ApexPointer+, ProPex I and Raypex 5 indicated high dispersion of values (standard deviation above 30%). Standard deviation for the NRG XFR was very low (far below 30%), indicating consistent measurements and a high level of resolution.

Furthermore, NRG XFR never gave overestimations compared to the other EFLs. ApexPointer+, Dentaport ZX and Raypex 5 showed only 1, 2 and 3 overestimations, respectively. ProPex I showed more overestimations than the other four devices (about 1/3 of all measurements).

However, those values were only 0.2 mm and less and thus clinically acceptable. It could be recommended, that after establishing the location of the apical foramen as the most reliable landmark with EFLs, the instrument be withdrawn to either the shorter reading or the mark that specifically indicates the physiological foramen or the apical constriction according to the manufacturer's instructions. Also, practitioners may retreat just 0.5 mm, or even 1.0 mm, short of the apical foramen mark. In short: "When the apical foramen is located, the position of the apical constriction—if it exists—can be estimated."[3]

From our findings, we recommend that the practitioner, above everything, always have a preoperative radiograph handy and stay within the confines of the root canal. Practitioners should trust in EFL but not blindly.

_Case studies

In conclusion, we would like to present three clinical cases. The case shown in Figure 10 presented with necrotic pulp with no peri-apical pathosis and was treated based on the information gained from a single diagnostic film. Working length was determined only by using an EFL. The post-operative radiograph with all four canals obturated demonstrates the successful treatment outcome.

The case presented in Figures 11a to c was completed in accordance with regular endodontic procedure. The result brought us to the following conclusion: the combination and comparison of several methods to locate the apical terminus and determine working length always gives the practitioner more confidence, accuracy and success than using only one or none.

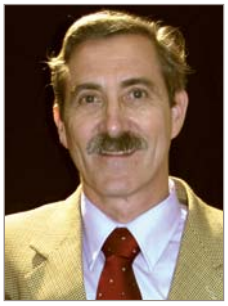
Predictable, reliable and successful endodontics were performed in teeth #36 and 46 of the same patient (Fig. 12). We are pleased to present this case here but are aware that many practitioners devoted to endodontics could achieve similar, if not better, results. Our goal is to motivate others to achieve even better results and to seek to give patients the best of treatment._

Editorial note: Figure 3b was erroneously included in Part I of this article, published in roots *4/2009. The corrected PDF version of the article, as well as a complete list of references, can be obtained from the publisher.*

Figs. 11a–c_Tooth #46 with necrotic pulp. Radiograph with ISO standard files (a); Radiograph with ProTaper files after EFL measurement (b); Obturated canals after final working length with paper points (c).
Fig. 12_Endodontic treatment in two different first mandibular molars of the same patient.

_about the author

roots



Prof Vladimir Ivanovic graduated from the Faculty of Dentistry at the University of Belgrade in 1976. He obtained a M.Dent.Sc and Ph.D. with specialisation in Oral and Dental Pathology and Endodontology. He was appointed Professor in Restorative Odontology and Endodontics in 1998 at the Faculty of Dental Medicine and served as a Vice-Dean for postgraduate and undergraduate studies. He has also chaired the School Board for Dental Pathology.

Prof Ivanovic conducts research at the University of Belgrade and Edinburgh Dental Institute. His main interests are maintaining vital pulp, resin-based composites and adhesive systems, and endodontology. He has attended numerous international endodontic seminars and courses to further his knowledge and skills. He has delivered over 100 lectures both nationally and internationally, published over sixty articles in national and international journals, and chapters in four dental textbooks.

He is founder and President of the Serbian Endodontic Society and has been a member of the ESE since 1989. He is also country representative for the ESE General Assembly, member of the International Association for Dental Research/Continental European Division and school representative for the Association for Dental Education in Europe. He has organised over a dozen endodontic meetings in Belgrade with internationally recognised speakers. Prof Ivanovic can be contacted at vladaivanovic@hotmail.com.