An overview of electronic apex locators: part 2

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VERIFIABLE CPD PAPER

IN BRIEF

- Describes the different generations of electronic apex locators, how they function and their relative accuracies.
- Describes how the use of third and fourth generation electronic apex locators are recommended to help clinicians determine the apical limit of the root canal system.
- Describes clinical tips to help optimise the use of an electronic apex locator whilst carrying out orthograde root canal therapy.

PRACTICE

A number of electronic apex locators are available for use during endodontic treatment. The use of third and fourth generation electronic apex locators (EAL) are recommended to help clinicians determine the apical limit of the root canal system (RCS). The presence of different irrigating media in the RCS does not impact significantly on the performance of third/fourth generation apex locators. The devices are most accurate at determining the apical limit when the attached endodontic file contacts the periodontal ligament space and the visual analogue displays 'Apex' or '0'. Given the accuracies of modern generation EALs, the clinician should be able to consistently identify the apical limit of the tooth under treatment. Their use in conjunction with appropriate radiographs and the clinician's knowledge of average RCS lengths and anatomy will maximise the successful outcome of any orthograde endodontic treatment.

INTRODUCTION

In Part 1 of this series, readers were introduced to the micro-anatomical features of the apical terminus and the ability of a tooth to function as a capacitor. In the second part of this series, readers will be introduced to: (a) the different types of electronic apex locator (EAL); (b) their modes of action; (c) their relative accuracies and (d) methods to optimise their success in clinical practice.

RESISTANCE BASED (FIRST GENERATION) APEX LOCATORS (RBEALS)

Sunada[1] carried on earlier work by Custer[2] and Suzuki[3] and determined that the electrical resistance between an endodontic instrument at the apical foramen and an electrode attached to oral mucous membrane was approximately 6.5 kW. RBEALs (such as the Root Canal Meter (Onuki Medical Co., Tokyo) and Dentometer (Dahlin Electromedicine, Copenhagen) are based on a simple model. They apply a small direct current to the tooth under investigation of known voltage. The resistance at each level of the RCS can be calculated using these two variables using Ohm's Law. At the periodontal ligament space (PDLS), the resistance of the circuit will equal 6.5 kΩ and the RBEAL are programmed to detect this value (Fig. 1).

Although these devices were accurate under dry conditions, their accuracy decreased when electrolytes, pulp tissue, inflammatory exudate or excessive haemorrhage were associated with the RCS.[4,5] As soon as the file tip touched an electrolyte, the direct current (DC) voltage would polarise the tissue, complete the circuit and incorrectly register that the PDLS had been reached. The devices also ignored the capacitance component of the circuit. Furthermore, the use of a DC would often cause an electric shock sensation to be felt by the patient which is clearly disadvantageous.[6] The fact that these devises were less reliable than using radiographs to determine RCS length[7] led practitioners to stop using them.

IMPEDANCE BASED (FIRST GENERATION) APEX LOCATORS (IBAL)

To overcome the aforementioned problems, the next set of EALs were based on the impedance of the circuit set up within the RCS. This would in theory be more accurate than the solely resistive devices. However, the impedance (and therefore capacitance) of the RCS was dependent on many variables and would vary between different RCSs. Consequently, the biggest disadvantage for IBALs was the need for

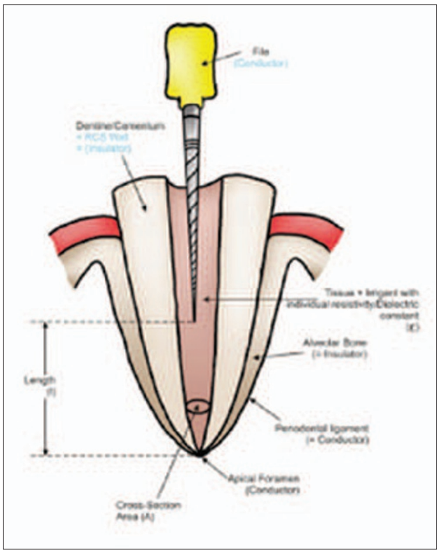

Fig. 1 Schematic representation of an endodontic instrument, the root canal system and the periodontium functioning as a capacitor. (From Nekoofar *et al.*[14]). The resistance of the system is 6.5 kW when a file touches the PDLS at the apical foramen. Different irrigants in the RCS will have different diaelectric constants (ε) (Part 1 of this series, Fig. 4) EALs need to take this feature into account to avoid generating inaccurate readings

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individual calibration between each tooth. To decrease the variable capacitance features the circuit, EALs like the Endocater (Hygenic Corp., Akron, OH, USA) were developed which incorporated an insulated file. However, the insulated sheath could not enter narrow canals and was often rubbed off.[8] Furthermore IBALs often gave inaccurate readings when used in canals containing electrolytes. Different fluids within the RCS will each have different diaelectric constants (ε) (Fig. 1). This will clearly alter the capacitance of the entire circuit (a phenomenon that the device is not accounting for) and may generate erroneous readings.

The literature pertaining to second generation EALS reports much variation in terms of their accuracy. Fouad *et al.*[8] looked at the Endo Analyser (Analytic/Endo, Orange, California, USA) and Apex Finder and noted that they were only accurate 67% of the time at being +/– 0.5 mm from the apex. The accuracy of the Sono-Explorer has been found to vary considerably between 48%[9] to 92%.[10] These reported differences in accuracy are probably due to differences in methodology. The Endocater was also of variable accuracy. McDonald and Hovland[11] noted that the EAL was 93% accurate while Keller *et al.*[12] reported a much lower figure of 68%. The Formatron IV was found to be accurate to being +/– 0.5 mm away from the apex only 65% of the time.[13] However, like most IBALs, it was found to be inaccurate in the presence of conductive irrigants (with different diaelectric constants), a shortcoming which the manufacturers were quick to point out.

THIRD GENERATION ELECTRONIC APEX LOCATORS (TGEALS) (FIG. 2)

These use multiple frequencies to determine the distance between an endodontic instrument and the end of a canal, unlike second generation EALs which only use a single AC of known frequency. Some third generation EALs work by calculating the impedance ratio of two electric currents with *different* sine wave frequencies. One sine wave will be of a high frequency (HF) while the other will have a low frequency (LF). The impedance of the system is measured at each individual frequency and the position of the file is determined from the ratio described below:[14]

Equation 1: $\text{Ratio} = \frac{HK}{LF}$

The quotient of these two sine wave frequencies is nearly 1 when the endodontic file is some distance from the apical terminus.[15] However, at the AC, the capacitive effect of the impedance variable plays a much bigger role and the ratio of Equation 1 approaches a value of 0.67.[16] It is this change in ratio at the apical constriction which some third generation EALs detect. This phenomenon is clearly related to the morphology of the AC. If it is absent or the canal has an open apex, the accuracy of these devices has been shown to diminish.[17,18]

Unlike IBALs, the accuracy of third generation EALs tends to be unaffected by the presence of electrolytes in the RCS. This is unsurprising because although different electrolytes will have different dielectric constants (Equation 2), the change in constant (between different media) will equally affect both the numerator and denominator of the frequencies in Equation 1. Given that mathematically they 'cancel each other out' because a quotient is being derived, the final ratio will be unaffected by a change in electrolyte.[15]

Equation 2: $C = \frac{\varepsilon \times A}{D}$

C = The capacitance of the tooth.
A = The surface area of the endodontic file in the RCS (conductor) and the PDLS (conductor) (Fig. 1).
D = The distance between the endodontic file and the PDLS.
ε = Diaelectric constant of the irrigant in the RCS (Fig. 1).

The Root ZX (J. Morita, Tokyo, Japan) is an example of a third generation EAL. It is based on two electric currents which have a frequency of either 8 kHz or 400 Hz. The instruction manual claims that the device measures the position of the AC, as indicated by a ratio value of 0.67 (calculated by Equation 1). The Root ZX has been studied exhaustively in the dental literature. Unsurprisingly, it produces more stable electronic readings when the RCS contains an electrolyte (such as NaOCl).[19] It is, however, less accurate when the RCS has low conductance (for example, if it is completely dry or contains alcohol). By stark contrast, second generation EALs (like the Apex Finder) are more accurate when the RCS is dry and produce less stable electronic measurements when an electrolyte is present in the RCS.[19] This is not surprising as second generation EALs do not account for the change in capacitance properties that are accompanied by a change in electrolyte.

Fig. 2 An example of a third generation EAL, the Dentaport ZX

In vitro when used on permanent teeth, the accuracy of the Root ZX varies from 84% (within 0.5 mm of the CDJ or AC depending on the reference point[20,21]) to 100%.[22] In the presence of different irrigants, the accuracy was similarly found to be very high, with reported accuracies varying from 83%[23] to 96%.[24] The presence of different irrigants did not appear to statistically affect the accuracy of the EAL to determine the position of the AC.[25-28] This was not surprising as the Root ZX EAL works on the impedance quotient highlighted in Equation 1 and will therefore function independently of the electrolyte (and its ε) within the RCS.

In vivo studies that have extracted the teeth (after investigation) have reported similar accuracies for the Root ZX ranging from 83%[29] to 100%.[30] With both the *in vivo* and *in vitro* studies, the authors correctly used the actual length of the extracted teeth to determine RCS length. However, the sample sizes under analysis were (in some instances) very small (n = 16 teeth). There was also uncertainty relating to operator blinding, which would clearly introduce bias into the study.

The Root ZX has been combined with a handpiece to determine the length of the

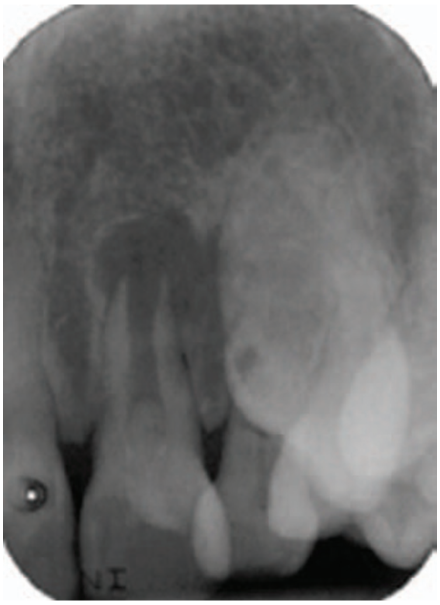

Fig. 3a UL1 with immature apex and apical infection. A third generation EAL was not able to accurately determine its position

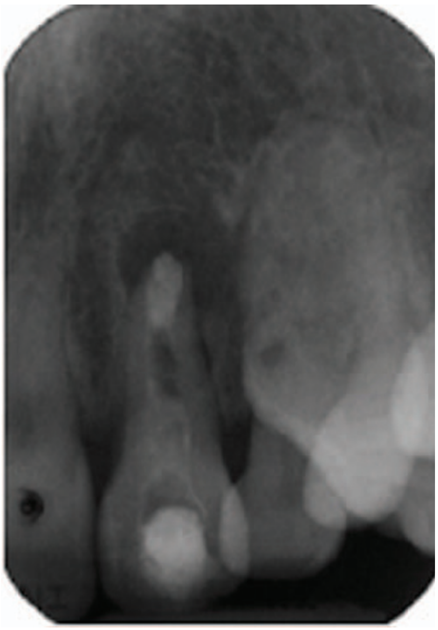

Fig. 3b The apex was determined using the paper point technique (Part 1 of this series)

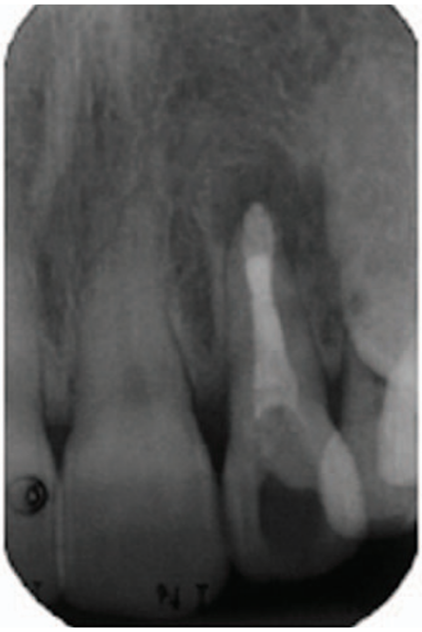

Fig. 3c The UL1 post obturation with thermoplastic gutta percha

RCS as a rotary file is being used.[31] This is sold as the Tri-Auto ZX (with an integrated handpiece) but more recently as the Dentaport ZX. The Tri-Auto ZX has been found to have a similar accuracy to the Root ZX at 95%.[32] However, Siu *et al.*[33] reported that the use of rotary endodontic instruments integrated with an EAL was not as accurate as using hand files in conjunction with a separate EAL. They noted that in 100% of cases where hand files were used, the determined RCS length was within 0.5 mm of the AC. However, when the rotary handpiece/integrated EAL was used, the electronically determined length was only within 0.5 mm of the AC in 50% (or less) of cases. The authors proposed that perhaps EALs need time to process the position of a file within the RCS. Rotary instruments are used with a continuous motion while hand files are controlled more slowly. This may account for the increased accuracy observed when using hand files in this situation.

The accuracy of the Root ZX may be unaffected by whether the tooth under investigation is necrotic or not. Dunlap *et al.*[34] noted that the mean distance from the AC was 0.21 in vital teeth and 0.49 in necrotic teeth. There was no statistically significant difference between these two values. Indeed the findings of this paper are surprising. A non-vital tooth with an apical area may have significant amounts of apical resorption occurring. This may destroy the AC and increase the width of the major foramen[17] and therefore its resistance properties. If this does occur histologically, the resistance of a resorbed apex would be higher than that of a non-resorbed apex. Therefore the impedance change as the foramen is reached would be less for a necrotic tooth than a vital tooth, suggesting that EALs should work less effectively in non-vital teeth. Indeed EALs have been shown to be less accurate when the width of the major foramen is greater than 0.2 mm. Stein *et al.*[35] found that as the width increased, the distance between an endodontic file and the foramen also increased. Taking this property to an extreme, the same phenomenon has also been observed in teeth with open apices. Electronically determined RCS lengths were often short when used on immature teeth with blunderbuss apices due to the instruments not touching the canal walls.[18,36] Again this is not surprising as the impedance change at the apex would be far less abrupt in an immature tooth than a tooth with a fully formed apex (Fig. 3). Perhaps the degree of resorption affecting the non-vital teeth in Dunlap's study[34] was not sufficient to alter the resistance of the apical terminus.

The Apex Finder, Model 7005 (Analytic Endodontics, Orange, California) is multi-frequency based EAL that uses five different frequencies (0.5, 1, 2, 4 and 8 kHz) to measure the length of a RCS. Pommer *at al.*[37] reported that it correctly identified the position of the AC in 94% of vital canals,

Fig. 4 An example of a fourth generation EAL, the Ray-Pex 4

but only 77% of the time in necrotic canals. Their statistical analyses suggested that these two values were significantly different from one another. Unlike Dunlap *et al.*'s study,[34] the findings of Pommer *et al.*[37] suggest that third generation EAL work better in vital canals than necrotic canals. This makes sense from an impedance change (at the AC) point of view. However, their methodology was flawed in that the authors used the radiographic apex as their reference point to determine the position of the AC. This can lead to error as there may be considerable difference between the actual AC and the radiographic apex.[38]

FOURTH GENERATION APEX LOCATORS (FGEAL) (FIG. 4)

The Ray-Pex 4 and 5 (Forum Engineering Technologies, Rishon Lezion, Israel) are examples of fourth generation EALs. Although it uses two frequencies of 400 Hz and 8 KHz to determine RCS length, the device only uses one frequency at a time (unlike third generation EALs which use both simultaneously). The manufacturers claim that using each frequency separately and by calculating the standard deviation of the differences between the two frequencies increases the accuracy of the device.[39] This seems logical as the use of a single, separate frequency signal would eliminate the need for a filter (which would clearly be necessary if two signals were being measured simultaneously). The electrical 'noise' inherent in these filters may decrease the accuracy of the third generation EAL. The manufacturers claim is based on the fact that the Ray-Pex 4 does not incorporate a filter and therefore may be more accurate than a third generation EAL.

Whether or not this is actually the case is unclear. El Ayouti *et al.*[40] reported that the Root ZX was more accurate at determining the apical terminus (within 1 mm) compared to the Ray-Pex 4. Wrbas *et al.*,[41] Pascon[42] and Stoll[43] found no difference in accuracy between the Dentaport ZX and the Ray Apex EAL. Kaufman *et al.*[44] similarly noted that there was no difference between the two EALs in the presence of different irrigating media.

Although it is not known whether fourth generation EALs are any more accurate than third generation EALs, it is wise to remove any excess fluid form the pulp chamber to prevent the system from short-circuiting.[45] For similar reasons, it is also wise to remove any metallic restorations from the access cavity to prevent any electrical shunting.[6]

The Elements Diagnostic Unit and Apex Locator (Sybron Endo, Anaheim, California, USA) is another type of FGEAL. It assimilates resistance and capacitance measurements and compares them to an internal database to determine the distance between an endodontic file and the apical terminus.[39] The device uses two frequencies: 0.5 kHz and 4 kHz. The signals are converted to an analogue signal, which is subsequently amplified before being passed on to some form of resistor/capacitor based parallel circuit. The resultant waveforms are then processed to reduce noise, which will reduce error and produce consistently more accurate readings regarding the position of the apical terminus.[39]

TIPS FOR CLINICAL SUCCESS

1. **Radiographs:** A pre-operative radiograph is essential to obtain information about the RCS's shape/anatomy, before accessing the pulp chamber and using an EAL to determine the estimated WL.
2. **The access cavity:** Any metallic restorations should be removed from the access cavity to prevent electrical shunting.[6] There should be no fluid in the pulp chamber. A gentle drying with the three in one air-jet should suffice. Generally speaking, modern apex locators work best in a 'moist' environment. This can be achieved by incomplete drying with the paper point.
3. **The irrigating media:** The presence of different irrigating media in the RCS does not impact significantly on the performance of third/fourth generation apex locators.[26] One simply must ensure that the irrigant has not flooded the pulp chamber.
4. **The endodontic file:** An endodontic file that will contact the walls of the RCS should be attached to the EAL. The metal which the file is made of does not affect the accuracy of the EAL.[46]
5. **The 'Apex (or 0)' reading:** Advance the file until the visual analogue displays 'Apex' or '0'. EALs are most accurate when the file contacts the PDL and the display shows an 'Apex' or '0' reading.[20] The '0.5' or '1' readings on the visual display do not indicate mm distances from the AC or AF. Therefore it may be wise to advance an instrument to the 'Apex' or '0' reading, and then manually subtract 0.5 mm from the measured WL. This will ensure that the file is within the RCS but still close to the PDL[14] (Fig. 4).
6. **Re-checking the WL:** The working length should be re-checked with an EAL, after the coronal two thirds of the RCS has been shaped. Shaping the coronal portion of the RCS will decrease the effective curvature of the canal. This may reduce the initial WL of the tooth. Therefore its length needs to be re-measured before shaping the apical terminus.
7. **The battery:** Low voltages cause electronic errors.[47] Therefore ensure that the EAL's batteries are well charged before using them, to prevent erroneous readings from being generated.
8. **Perforations:** If a periodontal perforation is suspected, an EAL can be used to check whether the integrity of the RCS has been breached. A small file should be attached to the device (to minimise any further trauma to the PDL space) and applied to the suspected perforation site. Any contact with exposed PDL will complete the circuit and register as an 'Apex (or zero)' reading.[48] This will alert the operator that a perforation is present and that local measures need to be taken to restore the integrity of the RCS.
9. **Unstable readings:** The 'Apex reading' should only be accepted as being accurate if the scale bar of the EAL visual analogue is (a) stable and (b) moves in symphony with the movements of the file in the RCS.[49] If the visual scale bar of the EAL (a) flashes intermittently, (b) moves erratically from one position to another or (c) displays no bars at all, the 'Apex reading' should not be accepted as being accurate. Obliterated RCSs can increase the incidence of inconsistent/unstable readings.[49] The operator should check that the batteries are fully charged and the pulp chamber contains no fluidic or metallic based substances. If the device still does not work, the operator may not be able to use the EAL for that visit and use other methods to determine the WL. Excessive inflammatory exudate in the RCS may cause the electrical circuits to shunt within the EAL and produce erroneous readings. The operator may have to dress the RCS with an appropriate intracanal medicament to induce apical healing. The EAL should then be used to check the WL at a subsequent visit.

DISCUSSION

This two-part series of papers on EALs has updated readers on the different means of determining the WL of a tooth, the different types of EAL and ways of optimising their use in clinical practice. Although numerous devices are available on the market, the clinician ultimately has to use the EAL which he or she feels most confident and comfortable working with. This can only be ascertained with time and practice, and may involve the clinician having to use multiple EALs before identifying one that is optimal for use.

Modern EALs are reasonably priced. They have a proven track record for correctly identifying the apical limit of the RCS. If practitioners wish to purchase an EAL, they are strongly advised to invest in either a third or fourth generation device as they appear to be the most accurate and consistent. Their use (supplemented with adjunctive radiographs and the clinician's knowledge of a RCS's average length) should help to correctly identify the apical limit of the RCS. Given that only a 2 mm margin of error exists for correctly identifying the limit of a RCS,[50] the adjunctive use of an EAL during RCT cannot be overstated. They can be used to confirm the presence of a perforation,[48] and can help accelerate the time it takes to complete a given RCT. Brunton *et al.*[51] noted that fewer diagnostic radiographs were needed to confirm the apical limit of an RCS when images were supplemented with an EAL. This would not only accelerate the time taken to complete a RCT, but would also reduce the patient's exposure to radiation. Given the accuracies of modern generation EALs, the clinician should be able to consistently identify the apical limit of the RCS under treatment. Their use in conjunction with appropriate radiographs and the clinician's knowledge of average RCS lengths and anatomy will maximise the successful outcome of any orthograde endodontic treatment.

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