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Review

Electronic Apex Locators —A Review

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The establishment of a correct working length is one of the fundamental parameters for endodontic success. Traditionally this has been determined using radiography, but electronic apex locators are increasingly being used. Electronic apex locators reduce the number of radiographs required and assist where radiographic methods create difficulty. The use of an electronic apex locator in combination with the radiograph is greater precision in the determination of root canal length. The aim of this paper is to review the electronic determination of the length of the root canal.

Key words: Electronic apex locators, endodontics, root canal length.

Abbreviations and acronyms:
AC = apical constriction, AF = apical foramen, CDJ = cemento-dentinal junction, EAL = electronic apex locator, μCT = micro computed tomography.

Introduction

The success rate of conventional root canal treatment is predictably high, as long as the basic principles of endodontic treatment are followed. Accurate determination of root canal length is particularly important to the success of root canal treatment: cleaning, adequate shaping and complete filling of the root canal system cannot be accomplished unless the correct working length is established, and if the canal length is known, damage to the periapical tissues and procedural accidents such as ledging can be avoided by confining instruments and root filling materials within the root canal system.

The radiograph is one from the traditional method for the determination of the root canal length, but it is difficult to achieve accuracy of canal length because the apical constriction (AC) cannot be identified, and variables in technique, angulations and exposure distort this image and lead to error[1-2]. Thus, in addition to radiographic measurements, electronic root canal working length determination has become increasingly important.

Electronic apex locators (EALs) have been used clinically for more than 40 years as an aid to determine the file position in the canal. These devices, when connected to a file, are able to detect the point at which the file leaves the tooth and enters the periodontium. An electronic method for root canal length determination was first investigated by Custer[3]. In 1962, Sunada[4] constructed the first EAL. Since then, different generations of EALs have been developed to measure root canal length[5]. The electronic method eliminates many of the problems associated with radiographic measurements. It is most important advantage over radiography is that it can measure the length of the root canal to the end of the apical foramen (AF), not to the radiographic apex[6]. Advances in technology have led to the development of EALs such as Root ZX (J. Morita Co., Kyoto, Japan) that determine the minor diameter position using the “ratio method”. This method allows for simultaneous measurement of impedance at two fre-

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quencies, a quotient of impedance is then calculated which is expressed as a position of file in the canal[7]. The Root ZX works in the presence of electrolytes and nonelectrolytes requires no calibration[7].

The aim of this paper is to review the electronic determination of the length of the root canal.

Determination of the working length

The cemento-dentinal junction (CDJ), where the pulp tissue changes into the apical tissue, is the most ideal physiologic apical limit of the working length. It is also is referred to as the minor diameter or the AC. However, the CDJ and AC do not always coincide, particularly in senile teeth as a result of cementum deposition, which alters the position of the minor diameter. Therefore, setting the AC as the apical limit of the working length, where it is easy to clean and shape or obturate the canals, is recommended[8,9].

The major AF is not always located at the anatomical apex of the tooth. The AF may be located to one side of the anatomical apex, sometimes at distances of up to 3.0 mm in 50-98%[10-12]. Kuttler reported that the distance between the AC and the AF is 0.659 mm in adults, whereas it is 0.524 mm in young people[10]. Figure 1 shows the anatomy of apical portion of root.

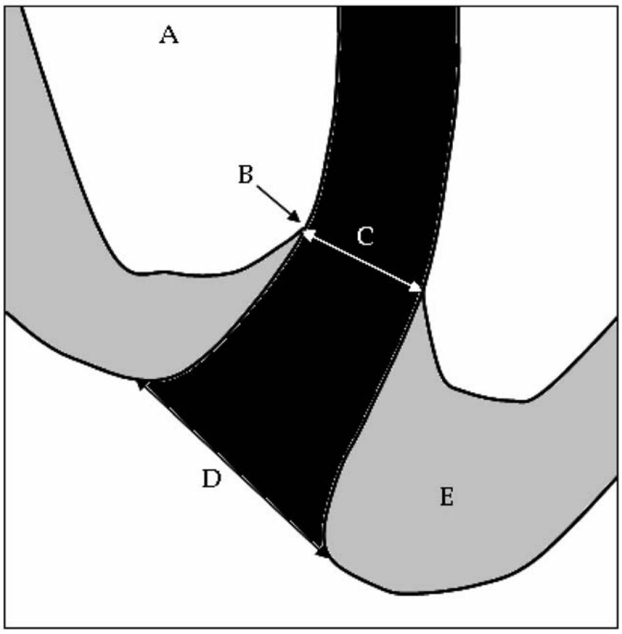

Fig. 1. Anatomy of the root apex (A) dentin, (B) cemento-dentinal junction (CDJ), (C) minor foramen (AC), (D) major foramen (AF) and (E) cementum

Many methods are used to assess the working length in root canal treatment, including:

1. Moisture in the paper point.
2. Reliance on tactile sensation to “feel” the AC.
3. Knowledge of the average length of a tooth as a guide.
4. A variety of imaging techniques.

Before any root canal treatment is commenced, a high-quality radiograph should be taken by the paralleling technique. This will reveal the number of roots and canals present, their shapes and curvatures, all factors relevant to canal length determination. It will also indicate the approximate length of the root canal.

Determination of the working length using radiography

The working length is most commonly determined using radiography. The practitioner places an endodontic instrument into the root canal to the depth corresponding roughly to the AC, and then a radiograph is taken. The working length is considered to be between 0.5 and 1.0 mm from a radiographic profile of the apex. A radiograph for root canal length determination has been reported to be accurate in only 80% of cases[13].

Currently, direct digital radiography has not been shown to exceed conventional radiograph in quality, even with enhancement and measuring features, but is useful for it is speed and lower doses of radiation[14].

Recently, micro computed tomography (μCT) was introduced in endodontic to evaluate cross-sections and three-dimensional shapes of canals at resolutions as high as 36 μm[15,16]. This innovation was achieved because new hardware and software was available to evaluate the metrical data created by μCT, thus allowing geometrical changed in prepared canals to be determined in more detail[15].

Determination of the working length using electronic apex locators

・ **History of Electronic Apex Locators**

Although the term “apex locator” is commonly used and has become accepted terminology[17], it is a misnomer[18]. Some authors have used other terms to be more precise such as electronic root canal length measuring instruments[19] or electronic canal length measuring devices[20-23]. These devices all attempt to

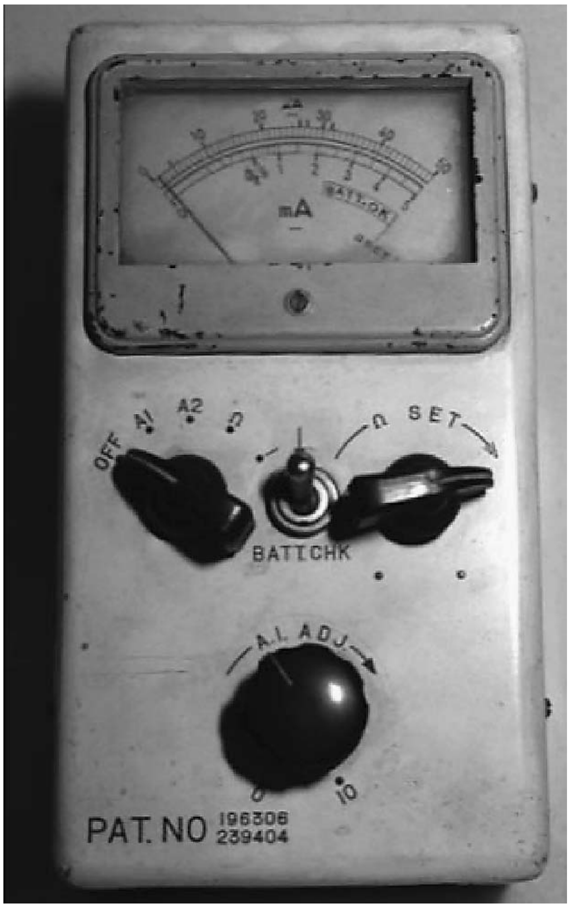

Fig. 2. Simple d.c. ohmmeter for measuring the length of the root canal using direct electric current

locate the AC, CDJ, or the AF. They are not capable of routinely locating the radiographic apex.

In 1918, Custer[3] was the first to report the use of electric current to determine working length. In 1962, Sunada[4] reported that there is a constant value ($6.5\ k\Omega$) of the electrical resistance between the mucous membrane and the periodontium, and he stated that it is possible to use this value of resistance in the estimation of the root length. Additionally, he showed that if an endodontic instrument that is connected to an ohmmeter is introduced into the canal and advanced until the ohmmeter shows the value of 40 μA, the tip of the instrument has reached the periodontal ligament at the AF (Fig 2). The device by Sunada in his research became the basis for most EALs[4].

・ How to measure the root canal by using EAL?

All EALs function by using the human body to complete an electrical circuit. One side of the apex locator's circuitry subsequently is connected to the oral mucosa through a lip clip and the other side to a file. When the file is placed into the root canal and advanced apically until it is tip touches periodontal tissue at the apex, the electrical circuit is completed (Fig 3). The electrical resistance of the EAL and the resistance between the file and oral mucosa are now equal, which results in the device indicating that the apex has been reached.

There is evidence that electronic devices measure mainly the impedance of the probing electrode (contact

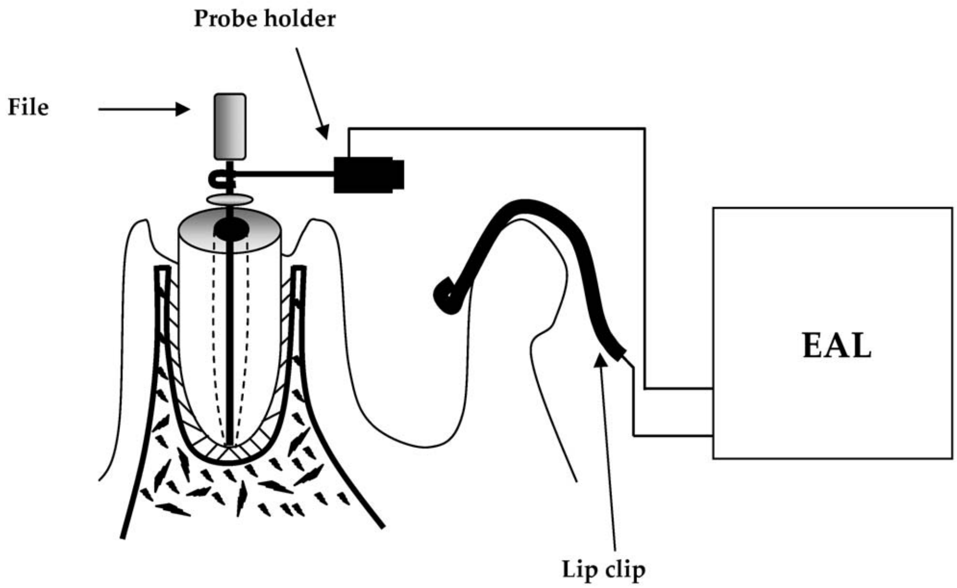

Fig. 3. Typical circuit for electronic determination of working length

impedance with the same fluid) rather than tissue impedance itself. In 1987, Huang[24] reported that the principle of electronic root canal measurement could be explained by physical principles of electricity alone. On the other hand, Ushiyama and colleagues presented the "voltage gradient method" that could accurately measure working length in root canals filled with electrolyte[25-27]. A major disadvantage with this method was that it used a special bipolar electrode that was too large to pass into narrow root canals.

Experimental design and parameters of accuracy studies

In vitro studies use electroconductive materials to simulate the clinical situation. Researchers have found alginate, gelatine, agar or saline to be media that give predictable results with EALs when compared with tooth length[22,28-32]. Some of these media can leak through the AF and cause premature readings[22]. It appears that some *in vitro* experimental models give greater accuracy than can be achieved clinically[23].

In vivo accuracy studies more closely reflect the reality of conditions in clinical practice[23]. The best studies are those that use an EAL to determine the working length of a canal followed by "locking" the measuring instrument at the electronic length[33]. The tooth is extracted, and the exact relationship between the electronic length and the AC is determined. Unfortunately, this design is not a viable alternative in most studies. Even when the design is used, the studies might be improved by prior shaping and cleaning of the canal followed by multiple electronic working length determination.

Another important point in accuracy studies is the error tolerance that is accepted in the experimental design. It would be useful clinically to use the AC as the ideal apical reference point in the canal rather than the AF[34]. Consideration should also be given to using −0.5 mm to 0.0 mm as the most clinically ideal error tolerance.

Classification and Accuracy of Electronic Apex Locators

1. First Generation Electronic Apex Locators (1GEALs)

First-generation EAL devices, also known as resistance apex locators[35], measure opposition to the flow of direct current or resistance. When the tip of the file reached the apex in the canal, the resistance value is 6.5 kΩ (current 40 μA)[4]. The disadvantage of 1GEAL devices is the pain was often felt due to high electric currents. Today, most 1GEAL devices are off the market.

2. Second Generation Electronic Apex Locators (2GEALs)

Second-generation EALs, also known as impedance apex locator[35], measure opposition to the flow of alternating current or impedance. In 1972, Inoue developed Sono-Explorer (Hayashi Dental Supply, Tokyo, Japan)[36], one of the earliest of the 2GEALs.

The major disadvantage of 2GEALs is that the root canal has to be reasonably free of electroconductive materials to obtain accurate readings. The presence of tissue and electroconductive irrigants in the canal changes the electrical characteristics and leads to inaccurate, usually shorter measurements[37].

・ **There are several 2GEALs. These include:**

1. Root Canal Meter (Onuki Medical Co., Tokyo, Japan).
2. Endodontic Meter S II (Onuki Medical Co., Tokyo, Japan).
3. Sono-Explorer Mark II (Hayashi Dental Supply, Tokyo, Japan).
4. Sono-Explorer Mark II Junior (Hayashi Dental Supply, Tokyo, Japan), in United States it is know as Sono-Explorer Mark III (Figure 4). In 1990, Fouad et al. found that the Sono-Explorer Mark III to be accurate to ±0.5 mm from the AF 75% of the time[19].
5. Endocator (Yamaura Seisakusyo, Tokyo, Japan) (Figure 5). In 1990, Fouad et al. found that the Endocator to be accurate to ±0.5 mm from the AF 75% of the time[19]. In 1994, Pallarés & Faus found that 89.6% and 88.7% of the Endocator readings for dry and nondry canals, respectively, occurred within 0.5 mm intervals closest to the AC[38].
6. Apex Finder (Analytic/Endo, Orange, California, USA). In 1990, Fouad et al. found that the Apex Finder to be accurate to ±0.5 mm from the AF 67% of the time[19].
7. Foramatron IV (Parkell Dental, Formingdale, New York, USA). In 1993, Himel & Cain found that the Foramatron IV to be accurate to ±0.5 mm from the radiograph apex 65% of the time and within 1.0 mm 83% of the time[39].
8. Digipex I, II, III (Mada Equipment Co., Carlstadt,

New Jersey, USA). In 1994, Czerw et al. found the Digipex II to be as reliable as the Root ZX in an *in vitro* study[22].

9. Exact-A-Pex (Ellman International, Hewlett, New York, USA). In 1990, Fouad et al. found that the Exact-A-Pex to be to $\pm$0.5 mm from the radiograph apex 55% of the time[19].
10. Dentometer (Dahlin Electromedicine, Copenhagen, Denmark).
11. Endo Radar (Elettronica Liarre, Imola, Italy). In 1985, Tidmarsh et al. found that the Dentometer and Endo Radar to be unreliable when compared with radiograph[40], with many of the readings being significantly longer or shorter than accepted working length.

Fig. 4. Sono-Explorer II

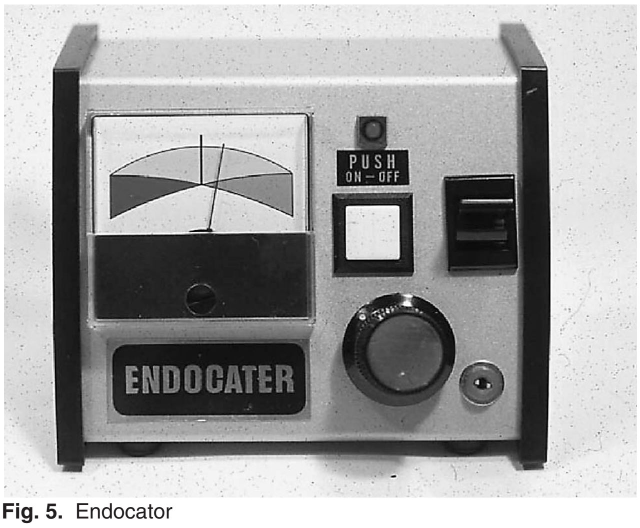

Fig. 5. Endocator

3. Third Generation Electronic Apex Locators (3GEALs)

Third-generation EALs are similar to the 2GEALs except that they use multiple frequencies to determine the distance from the end of the canal. These units have more powerful microprocessors and are able to process the mathematical quotient and algorithm calculations required to give accurate readings.

・ **The Endex/Apit**

Endex (Osada Electric Co., Tokyo, Japan) (Figure 6). In Europe and Asia, this device is available as the Apit.

The device operates most accurately when the

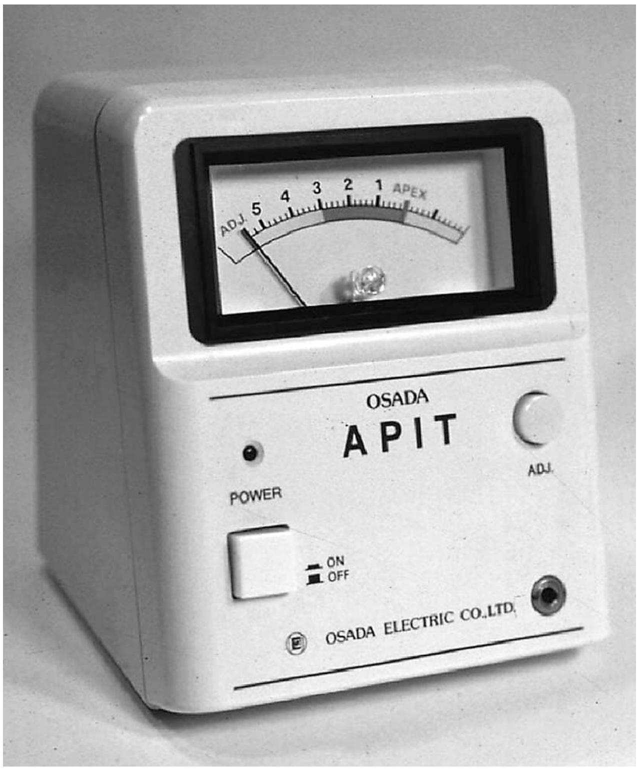

Fig. 6. Apit

canal is filled with electrolyte such as saline or sodium hypochlorite. The disadvantage of this device needs "reset" or "calibrated" for each canal. The Endex has been the subject of several studies[18,41-47]. Felippe & Soares[44] reported that the accuracy of the Apit to be 96.5% (−0.5 to 0.0 mm from the AF). Another study reported an accuracy of 85% (±0.5 mm from the AF)[46].

・ **The Root ZX**

The Root ZX (J. Morita Co., Kyoto, Japan), a 3GEALs that uses dual-frequency and comparative impedance principles, was described by Kobayashi & Suda[7]. The electronic method employed was the "ratio method." The Root ZX simultaneously measures two impedances at two frequencies (8 and 0.4 kHz) inside the canal. A microprocessor in the device calculates the ratio of the two impedances. The quotient of the impedances is displayed on a liquid crystal display meter panel and represents the position of the instrument tip inside the canal. The quotient was hardly influenced by the electrical conditions of the canal but changed considerably near the AF[7].

The Root ZX mainly detects the change in electrical capacitance that occurs near the AC[7]. Some of the advantages of the Root ZX are that it requires no adjustment or calibration and can be used when the canal is filled with strong electrolyte or when the canal is "empty" and moist.

A number of *in vitro* and *in vivo* studies on the accuracy and reliability of the Root ZX have been reported.[28-34,48-70]. Some reported accuracy studies for the Root ZX apex locator are detailed in Table 1.

There are several other 3GEALs in use worldwide. These include:

1. Justwo or Justy II (Yoshida Co., Tokyo, Japan).
2. Mark V Plus (Moyco/Union Broach, Bethpage, New York, USA).
3. Endox (Co. Lysis, Milan, Italy).
4. Endy (Loser, Leverkusen, Germany). Haffner et al. evaluated *in vivo* the accuracy of four EALs: Root ZX, Endy, Just II and Endox, to determine the working length[71]. They reported that the limit ±0.5 mm from the AC was attained by the Root ZX in 78%, by the Endy in 67%, by the Justy II in 80% and by Endox in 31% of all measurements.
5. Apex Finder AFA Model 7005 (EIE Analytic Endodontics, Orange, California, USA). Tinaz et

Table 1. Accuracy for the Root ZX apex locator.

Reference	Study type	Sample (N)	Accuracy
Czerw et al.(1995)	*in vitro*	30	100% (±0.5mm)–AF
Katz et al.(1996)	*in vitro*	20	100% (±0.5mm)–AF
Shabahang et al.(1996)	*in vivo*	26	96.2% (±0.5mm)–AF
White et al.(1996)	*in vitro*	51	84% (±0.5mm)–AC
Vajrabhaya & Tepmongko (1997)	*in vivo*	20	100% (±0.5mm)–AF
Pagavino et al.(1998)	*in vivo*	29	83% (±0.5mm)–AC, 100%(±1.0mm)–AF
Dunlap et al.(1998)	*in vivo*	34	82.3% (±0.5mm)–AC
Ibarrola et al.(1999)	*in vitro*	16	87.5% (±0.5mm)–AC
Ounsi & Naaman (1999)	*in vitro*	39	85% (±0.5mm)–AF
Weiger et al.(1999)	*in vitro*	41	85% (±0.5mm)–AC
Mears & Steiman (2002)	*in vitro*	40	83% (±0.5mm)–AF
Welk et al.(2003)	*in vivo*	32	91% (±0.5mm)–AC
Goldberg et al.(2005)	*in vitro*	20	95% (±0.5mm)–AC, 100% (±1.0mm)–AF
Tselnik et al.(2005)	*in vivo*	27	75% (±0.5mm)–AC
Plotino et al.(2006)	*in vitro*	37	97.4%(±0.5mm)–AF

*N=number of samples
±0.5mm or ±1.0mm from AF
±0.5mm or ±1.0mm from AC

al. evaluated *in vitro* the effects of the operator's experience level and pre-flaring on the accuracy of the results of three EALs: Root ZX, Apex Finder AFA Model 7005 and Bingo 1020[72]. They found that all of the EALs had a clinically acceptable result at the tolerance of ±0.5 mm.

6. Apex Finder (Endo Analyzer 8001; Analytic Technology, Redmond, WA, USA). Venturi & Breschi compared the Apex Finder and the Root ZX in canals with and without irrigant and different foramen diameters[66]. They reported that the accuracy of the Apex Finder was negatively influenced by high conductive conditions, whilst the Root ZX provided inaccurate and unstable measurements mostly in low conductive conditions.
7. Neosono-D (Amadent Medical and Dental, Co., Cherry Hill, New Jersey, USA).
8. Neosono Ultima EZ (Satelec Inc., Mount Laurel, New Jersey, USA) is also known as the DatApex (Dentsply Maillefer, Ballaigues, Switzerland). Lucena-Martin et al. evaluated *in vitro* the accuracy of three EALs: Justy II, Root ZX and Neosono Ultima EZ[63]. They reported that EAL reliability in detecting the apex to very from 80% to 85% and 85% to 90% for the Justy II and Neosono systems, respectively, whereas reliability was found to be 85% for the Root ZX device.
9. Foramatron D10 (Parkell Electronic Division, Farmingdale, New York, USA).
10. Apex NRG (Kibbutz Afikim, Israel).
11. Apit 7 (Osada, Tokyo, Japan).
12. Neosono MC (Amadent Medical and Dental, Co., Cherry Hill, New Jersey, USA).
13. NovApex (Forum Technologies, Rishon Le-Zion, Israel). Goldberg et al. evaluated *in vitro* the accuracy of three EALs: ProPex, NovApex and Root ZX, in determining the working length during the retreatment process[58]. They reported that the ProPex, NovApex and Root ZX were accurate within 0.5 mm 80%, 85%, and 95% of the time, and within 1.0 mm 95%, 95% and 100%, respectively.
14. ProPex (Dentsply-Maillefer, Ballaigues, Switzerland). Fan et al. evaluated the accuracy of the Root ZX, the Neosono Ultima EZ and the ProPex EALs under different electrolyte conditions and different size of AF using a standardized model of glass tubules[69]. They stated that the ProPex and Neosono Ultima EZ were more accurate than the Root ZX under various conditions in this laboratory study.
15. Bingo 1020 (Forum Engineering Technologies, Rishon Lezion, Israel). Kaufman et al. tested in an *in vitro* model the accuracy of a Bingo 1020, to compare the results to those of a well known EAL, Root ZX, as well as to those of the radiographic method of tooth length determination[59]. They reported that the measurements obtained using the Bingo 1020 were consistently closer to the actual length (0.08 mm) than those obtained using the Root ZX.
16. Elements-Diagnostic (Sybron Endo, Sybron Dental, Orange, California, USA). Tslenik et al. compared the accuracy of the Root ZX and the Elements-Diagnostic EALs in detecting the minor constriction *in vivo* under clinical conditions[65]. They found that the Root ZX was accurate 75% of the time to ±0.5 mm, 83.3% ±0.75 mm, and 88.9% to ±1.0 mm. The Elements-Diagnostic was accurate 75% of the time to ±0.5 mm, 88.9% to ±0.75 mm, and 91.7% to ±1.0 mm.
17. Raypex® 5, VDW, Munich, Germany). Wrbas et al. compared the accuracy of two EALs: Root ZX and Raypex® 5, under clinical conditions, in detecting the minor diameter in the same tooth[73]. They reported that the minor diameter was located within the limits of ±0.5 mm in 75% of the cases with the Root ZX and 80% of the cases with Raypex® 5.

Combination of Apex Locator with Endodontic Handpiece

The Root ZX has been combined with a handpiece to measure canal length when a rotary file is used[74]. This is marked as the Tri Auto ZX (J. Morita Co., Kyoto, Japan). The handpiece uses nickel-titanium rotary instruments that rotate at 240 to 280 rpm[74]. Kobayashi et al. suggested that "to get the best results, it may be necessary to use some hand instrumentation" in combination with the Tri Auto ZX, depending on the difficulty and morphology of the root canal being treated[74]. The Tri Auto ZX has a reported accuracy similar to the Root ZX of 95%[75]. Alves et al. evaluated *in vitro* the capacity of the Tri Auto ZX to locate the AF following removal of root filling material during root canal treatment[76]. They found that the Tri Auto ZX was accurate to ±0.5 mm in more than 80% of teeth when used following removal of root filling.

Recently, the Dentaport ZX (J. Morita Co., Kyoto, Japan and J. Morita Mfg. Co., Irvine, California, USA)

Fig. 7. Dentaport ZX

was introduced to the Japanese and United States markets (Figure 7). The Dentaport ZX is comprised of two modules: the Root ZX and the Tri Auto ZX. The handpiece uses nickel-titanium rotary instruments that rotate at 50 to 800 rpm.

Other apex-locating handpieces:

1. Kobayashi et al. reported the development of a new ultrasonic system called SOFY ZX (J. Morita Co., Kyoto, Japan), which uses the Root ZX to electronically monitor the location of the file tip during all instrumentation procedures[77]. The device minimizes the danger of overinstrumentation.
2. The Endy 7000 (Ionyx SA, Blanquefort Cedex, France) is available in Europe.

Problems Associated with the Use of Electronic Apex Locators

Most studies have reported that pulpal vitality or canal irrigants do not affect 3GEALs accuracy[28,50,53,55,56,59,61,78]. Fan et al. used different diameters of glass tubules in their study to mimic root canals[69]. When they filled the canals with less conductive electrolytes such as 3% hydrogen peroxide the accuracy of the real length ±1.0 mm was 75−100% despite the increase in tubule diameter. When they filled the canals with strong electrolytes such as 0.9% saline solution, 2.5% sodium hypochlorite solution and 17% ethylenediamine tetraacetic acid (EDTA), the accuracy of the Root ZX decreased as the tubule diameter increased.

In 1962, Sunada suggested the possibility of using 1GEALs to detect root perforations[4]. It was later reported that 2GEALs could accurately determine the location of root or pulpal floor perforations[79,80]. The method also aided in the diagnosis of external root resorption that had invaded the dental pulp space or internal root resorption that had perforated to the external root surface[20]. Zmener et al. found that the Tri Auto ZX (3GEALs) was able to detect and measure endodontic root perforations within a range of clinically acceptable variations[81].

An *in vitro* study, Goldberg et al. evaluated the accuracy of Root ZX to determine the working length in teeth with simulated apical root resorption[58]. They found that the Root ZX was 62.7%, 94%, and 100% accurate to within 0.5 mm, 1.0 mm, and 1.5 mm of the direct visual measurements, respectively. They concluded that the Root ZX could be used to determine the working length in teeth with apical root resorption.

The electronic measured canal length (2GEALs) is adversely affected by different circumstances such as the diameter of the AF[82]. In 1987, Huang[24] used 2GEALs and found that when the size of the major foramen was less than 0.2 mm measurements were not affected, even in the presence of conductive irrigants, but as it increased above 0.2 mm measured distances from the foramen increased. Stein et al. also concluded that as the width of the major foramen increased the distance between the file tip and the foramen increased[83]. They found that in measuring the CDJ to the probe tip, 31 of the 47 canals (66%) were short of the CDJ. Measuring from the major foramen opening to the probe tip, 43 of the 47 canals (91%) were short of the major foramen opening. Ebrahim et al. evaluated four 3GEALs: Root ZX, Foramatron D10, Apex NRG and Apit 7, to determine the working length in teeth with various foramen diameters[30]. They reported that as the diameter of the AF increased, the length measured with small size files became shorter. This suggests that the size of the root canal diameter should be estimated first and then a snug-fitting file should be chosen for root canal length determination. The four EALs were unreliable in determining the working length of teeth with a wide AF when using a small size file. The Root ZX and Foramatron D10 showed significantly better scores than the Apex NRG and Apit 7, and may be reliable to determine the working length of teeth with a wide AF if a tight-fit file is used[30].

An *in vivo* study has evaluated the usefulness of an 2GEALs in endodontic treatment of teeth with incomplete root formation requiring apexification[84]. They reported that in all cases, the Exact-A-Pex apex locator was 2 to 3 mm short of the radiographic apex at the beginning of apexification therapy. When the apical closure was complete, the EAL was then 100% accurate.

McDonald[35] recommended the use of files with sizes comparable with the root canal diameter, claiming that this would result in more accurate readings. Nguyen et al. conducted an *in vitro* experiment to observe the effect on measurement of the relative diameters of the file and the root canal using the Root ZX[49]. The length of the enlarged canals was measured using small-sized files and large size files matching the canal diameter. They found that the Root ZX was accurate even when the file was much smaller than the diameter of the canal and the measured lengths obtained with small and large size files were comparable. Ebrahim et al. evaluated *in vitro* the effect of file size on the accuracy of Root ZX when sodium hypochlorite or blood was present during electronic measurements in enlarged root canals[29]. They found that as the diameter of the root canal increased, the measured length with the smaller size files became shorter. A file of a size close to the prepared canal diameter should be used for root length measurement in the presence of blood, and possibly serum or pus[29]. In the presence of sodium hypochlorite, the Root ZX was highly accurate even when the file was much smaller than the diameter of the canal[29].

An *in vitro* study evaluated the accuracy of the Root ZX in determining working length of primary teeth[48]. Electronic determinations were compared with direct anatomic and radiographic working lengths. They reported that the electronic determinations were similar to the direct anatomic measurements (-0.5 mm). Radiographic measurements were longer (0.4 to 0.7 mm) than electronic determinations. An *in vivo* study, Kielbassa et al. reported that the Root ZX can be strongly recommended for clinical implementation of endodontics in primary teeth, particularly when treating fidgety children[85].

Nahmias et al.[20] and Chong & Pitt Ford[86] reported that if there is any connection between the root canal and the periodontal membrane, such as root fracture, cracks and internal or external root resorption, it would be recognized by the EALs. Azabal et al. found the Justy II apex locator (3GEALs) was able to detect simulated horizontal root fractures but was unreliable when measuring simulated vertical root fractures[87]. Ebrahim et al. evaluated *in vitro* the accuracy of three 3GEALs: Root ZX, Foramatron D10 and Apex NRG, in the detection of fractures in teeth having simulated horizontal and vertical root fractures[31]. They found that the three EALs were accurate and acceptable clinical tools for detecting the position of horizontal root fractures but were unreliable in detecting the position of vertical root fractures.

Oishi et al. investigated whether constriction of the root canal could be recognized by using an EAL[60]. They reported that the Root ZX apex locator was not only effective for accurately detecting the location of the AF but also useful for detecting root canal constrictions.

It does not appear that the type of alloy used in the instrument for length assessment affects accuracy, with the same measurements obtained in the same root canal using stainless steel and nickel-titanium instruments[88]. Nekoofar et al. evaluated the accuracy of Neosono Ultima EZ apex locator (3GEALs) using nickel-titanium and stainless steel files[89]. The accuracy of the nickel-titanium and stainless steel was 94% and 91%, respectively, and there was no statistically significant difference.

Lack of patency, the accumulation of dentin debris and calcifications can affect accurate working length determination with 2GEALs[90]. It has been suggested that preflaring of root canals as used in modern crown-down preparation techniques would increase the accuracy of readings. This was found to be true for tactile sensation[91] and accuracy with the Root ZX[52]. Canal patency appears to be more important, as dentin debris may disrupt the electrical resistance between the inside of the canal and the periodontal ligament. Constant recapitulation and irrigation ensures accurate electronic length readings during instrumentation[92].

Pommer et al. compared *in vivo* the influence of the root canal status on the determination of the root canal length by an 3GEAL in vital and necrotic canals and canals with root canal obturation retrieval[93]. They stated that the AFA Apex Finder is a reliable tool for determining the root canal length in vital and necrotic teeth, with an accuracy of 86% within ± 0.5 mm range of the radiographic apex. Goldberg et al. evaluated *in vitro* the accuracy of three 3GEALs in determining the working length of teeth during retreatment[64]. They found that the ProPex, NovApex, and Root ZX were accurate within 0.5 mm 80%, 85%, and 95% of the time, and within 1.0 mm 95%, 95%, and 100% of the time, respectively. Ebrahim et al. evaluated *in vitro* the accuracy of five different 3GEALs: Dentaport ZX, ProPex, Foramatron D10, Apex NRG and Apit 7, in determining the working length in teeth after removal of root canal obturation materials[32]. They found that the Dentaport ZX, ProPex and Foramatron D10 were more accurate than the other two EALs in determining the working length in teeth after removing the root canal obturation materials. However, the Apex NRG and Apit 7 were also reliable for determination of the working length in majority of the cases.

・ **Cardiac Pacemaker**

Electrical devices such as electric pulp tester, EALs, and electrosurgical instruments has been potential interfere with cardiac pacemaker[94]. As there are many therapeutic uses and types of pacemakers some may not be influenced by electric pulp tester's use[95-97]. A 1996 case reported on a patient with a fixed-rate cardiac pacemaker requiring root canal treatment. Under consultation with the patient's cardiologist, an EAL was used. The patient experienced no adverse effects immediately or with follow-up[98]. In 2002, Garofalo et al. reported that four out of five 3GEALs tested with a single cardiac pacemaker showed normal pacing and only one produced an irregular pace recording on an oscilloscope[99]. Recently, Wilson et al. was determine *in vitro* if EALs or electric pulp testers interfere with the function of implanted cardiac pacemakers or cardioverter/defibrillators[100]. They found that no evidence of any interference was encountered when the 3GEALs or electric pulp tester were used as described by patients with working, implanted cardiac devices. They concluded that EAL or electric pulp testers are safe for use in patients with cardiac pacemakers or cardioverter/defibrillators.

Conclusions

The EAL device has attracted a great deal of attention because it operates on the basis of the electrical impedance rather than by a visual inspection. EALs are particularly useful when the apical portion of the canal system is obscured by certain anatomic structures, such as impacted teeth, tori, the zygomatic arch, excessive bone density, overlapping roots, or shallow palatal vaults. In the presence of metallic restorations, severely undermined caries, serous, purulent or hemorrhagic exudates or when there are cracks, root fractures, internal or external root resorption, wide-canal, or a wide-open apex —a comparison of the EAL readings with the radiograph will assist practitioners to achieve predictable results.

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