Medical Journal of Europe

ISSN: 2995-7907 doi: 10.5281/zenodo.18214925

Electronic Apex Locators: Past, Present And Development

Ümray Özden ÖZGÜL[1], Aytül ÇELİKKOL[1], Cemre ÇELİK YALÇIN[1], Berk ÇELİKKOL[1]

[1] Department of Endodontics, Usak University Faculty of Dentistry, Uşak, Turkey

Article Info

Received: 4 January 2026

Revised: 10 January 2026

Accepted: 11 January 2026

Published: 11 January 2026

Keywords:

Root Canal Length Measurement, Endodontic Devices, Adaptive Apex Locators, Apical Foramen, Clinical Accuracy.

Corresponding author:

Ümray Özden ÖZGÜL

Department of Endodontics, Usak University Faculty of Dentistry, Uşak, Turkey

umray.ozgul@usak.edu.tr

ABSTRACT

Achieving clinical success in root canal treatment depends on performing all procedures within the biological and anatomical limits of the root canal system. Therefore, accurate determination of the extent to which instruments and filling materials should be advanced along the canal is of great importance. The ideal termination point in root canal therapy is defined as the apical constriction (AC), which represents the physiologically narrowest part of the root canal. Over time, various methods have been developed to determine working length. Today, electronic root canal length measurement devices are among the most commonly preferred methods for determining working length. The fundamental operating principle of these devices is based on the electrical conductivity properties of the tissues forming the root canal system. While dentin and cementum exhibit resistance to electrical current, the periodontal ligament and intracanal fluids possess conductive properties, allowing the system to be evaluated as an electrical circuit. Studies have demonstrated that the electrical resistance between the oral mucosal membrane and the periodontium is approximately 6.5 kΩ, and electronic systems capable of measuring root canal length have been developed based on this constant value. The aim of this review is to evaluate the electrical operating principles and clinical performance of electronic apex locators developed from past to present.

INTRODUCTION

Successful endodontic treatment depends on accurate diagnosis, effective cleaning, shaping, disinfection, and three-dimensional obturation of the root canal system (1). Determination of root canal length and maintaining treatment within biological boundaries remain among the major challenges in endodontics, and debates on this issue have continued for many years (2). It is generally accepted that the ideal termination point for root canal preparation and obturation is the apical constriction, which represents the narrowest part of the root canal (3,4).

Various methods have been used to determine the location of the apical foramen and the working length of root canals (5). Radiography is the most commonly used method for working length determination; however, obtaining two-dimensional images of three-dimensional structures and superimposition of anatomical structures make accurate assessment difficult. Additionally, projection-related distortions may lead to incorrect determination of canal length (6,7).

Advances in electronic device technology have led to significant innovations in this field, and electronic apex locator devices have rapidly been integrated into modern endodontic practice (5).

The aim of this review is to evaluate the electrical operating principles and clinical performance of electronic apex locators developed from past to present.

Anatomy of the Apical Canal Region

The root canal system begins to narrow from the major apical foramen toward the minor apical foramen, also known as the apical constriction (AC), which represents the narrowest part of the canal (3). The region between the major and minor apical foramina has an inverted conical shape, where pulpal tissue gradually transitions into periodontal tissue and cementum is present. Coronal to the minor apical foramen, the canal begins to widen again.

The cemento-dentinal junction (CDJ), theoretically defined as the point where cementum ends and dentin begins, has long been considered the ideal termination point for root canal obturation (3). However, the CDJ is a histological landmark that can only be identified after sectioning extracted teeth and cannot be determined clinically. Moreover, the CDJ does not exhibit

consistent anatomical characteristics, as the extent of cementum extending into the canal varies as one moves coronally from the apical constriction (8). This variability clearly indicates that the CDJ and the apical constriction are not usually located in the same area and therefore the CDJ does not serve as a reliable clinical reference point.

Due to morphological variations in the topography of the apical constriction, defining the apical limit of the root canal solely based on the CDJ or AC may be unreliable (9). In clinical practice, the minor apical foramen demonstrates more consistent anatomical characteristics as the narrowest portion of the canal system and is therefore preferred as the reference point for apical termination (8,10). It is the most commonly used landmark by clinicians for concluding shaping, cleaning, and obturation procedures during root canal preparation (11).

Operating Principles of Electronic Apex Locators

The electrical structure of the root canal system constitutes a complex circuit composed of resistive and capacitive elements (12). When the tooth is considered as a capacitor, the endodontic file with a defined surface area acts as one plate, while the conductive tissues outside the dentin, such as the periodontal ligament, function as the opposing plate. The insulating cementum and dentin surrounding the root, together with intracanal tissues and fluids, act as dielectric materials separating the conductive plates.

As an endodontic file advances toward the apex, the electrical resistance between the file tip and the apical region decreases due to the reduction in the effective length of resistive material within the canal. This configuration forms a capacitor system that is far more complex and difficult to model than a simple electrical circuit (4).

Classification of Electronic Apex Locators

1. First-Generation Electronic Apex Locators (Resistance Type)

First-generation apex locators are based on the assumption that the circuit formed between the endodontic file and the lip clip can be represented as a simple resistive circuit (4). These devices measure resistance to direct current. When the file tip reaches the apical foramen, the device displays the constant electrical resistance of approximately 6.5 kΩ, which is consistent throughout the oral mucosa and periapical tissues.

The main disadvantages of these devices include frequent patient discomfort due to high current levels and unreliable measurements when compared with radiographic methods, often resulting in measurements that are significantly longer or shorter than the accepted working length (13,14). Examples include Root Canal Meter, Endodontic Meter, Dentometer, and Endo Radar (15). These devices have generally been found to be unsafe and unreliable (14).

2. Second-Generation Electronic Apex Locators (Impedance Type)

Second-generation apex locators measure impedance, which is resistance to alternating current (16). Based on the observation that impedance values between the periodontal ligament and gingival sulcus are similar to those between the periodontal ligament and oral mucosa, Inoue and Skinner developed the Sono Explorer device (17).

The primary limitation of impedance-type devices is the requirement to eliminate conductive materials from the root canal to obtain accurate measurements. The presence of tissue remnants or conductive irrigants alters electrical properties and often results in inaccurate, typically shorter measurements (18). Devices such as Formatron IV, Digipex I–III, Endo Analyzer, and Exact-A-Pex belong to this category (15).

3. Third-Generation Electronic Apex Locators (Frequency-Dependent Comparative Impedance Type)

These devices operate similarly to impedance-type apex locators but use multiple frequencies to measure impedance and determine the apical position (19). The frequency-dependent method calculates the difference between two direct potentials obtained through filtering when a 1 kHz linear waveform is applied to the canal (20).

This principle was used by Saito and Yamashita to develop the original third-generation apex locator, Apit (marketed as Endex) (20,21). Although Apit can accurately determine working length even in the presence of electrolytes, it requires calibration for each canal (15).

Root ZX, developed by Kobayashi et al. (22), has been extensively studied since its introduction. Accuracy rates of approximately 90% within ±0.5 mm of the apical foramen or CDJ and up to 100% accuracy within ±1.0 mm have been reported (23). Other frequency-dependent devices include Justy II, Apex Finder, ProPex, Bingo 1020, Elements Diagnostic, and Raypex-5 (24).

4. Fourth-Generation Electronic Apex Locators (Ratio Type)

In 2003, the Elements Diagnostic Unit was introduced, capable of separately calculating resistance and capacitance and comparing these values with internal reference data to determine the distance of the file from the apex (25). While consistent results have been reported in dry or nearly dry canals, the presence of electrolytes, moisture, blood, or exudate may lead to inaccurate readings (26).

Devices in this category include AFA Apex Finder, Elements Diagnostic Unit and Apex Locator, ProPex, and Root ZX II. These systems utilize composite waveforms generated from multiple frequencies and processed through digital-to-analog conversion before being applied to the patient circuit model (18).

5. Fifth-Generation Electronic Apex Locators (Multifrequency Type)

To address the limitations of previous generations, a new measurement approach based on comparing electrical data obtained from the canal with additional mathematical processing was developed (24). These devices separately measure resistance and capacitance and are less affected by intracanal fluids than fourth-generation devices. However, difficulties have been reported when measurements are performed in completely dry canals (19).

6. Sixth-Generation Electronic Apex Locators (Adaptive Type)

Sixth-generation apex locators are adaptive systems designed to adjust to varying canal moisture conditions. These devices reportedly overcome the reduced accuracy of multifrequency systems in dry canals (27). Reliable measurements have been documented in both dry canals and situations where moisture, pus, or blood cannot be fully eliminated. Raypex 6 and ProPex Pixi are examples of adaptive apex locators (28).

RESULTS

The success of root canal treatment depends on accurate working length determination and adherence to biological limits. The apical constriction remains the most reliable anatomical reference point for termination of root canal procedures. Due to the limitations of radiographic methods, electronic apex locators have become an effective and widely used alternative for working lenfte deterministin. Differences in measurement principles and accuracy exist among various generations of these devices. Modern multifrequency and adaptive systems provide reliable measurements even in the presence of moisture and electrolytes within the canal. Consequently, appropriate device selection and correct clinical use play a critical role in improving endodontic treatment outcomes.

DISCUSSION

The success rate of modern electronic apex locators exceeds 90% (29,30). However, numerous factors influence measurement accuracy, including apical foramen diameter, file size, root resorption, and the presence of conductive fluids within the canal (15,29,30). Studies have shown that increasing apical foramen diameter may result in shorter measurements when smaller files are used, while files matching the apical diameter yield more accurate results (13,31). Conductive irrigants significantly reduce impedance, leading to premature readings in some devices (32).

Earlier devices were associated with patient discomfort, inaccurate measurements in the presence of blood or irrigants, and the need for frequent calibration (15,32). Subsequent technological advancements have aimed to overcome these limitations. Recently developed multifrequency apex locators do not require calibration, allow comfortable clinical use, maintain accuracy in the presence of sodium hypochlorite, and provide reliable measurements with both stainless steel and nickel-titanium instruments (27).

Electronic apex locators demonstrate superior performance in working length determination compared to other methods (15). Their advantages include ease of use, lack of patient discomfort, reduced treatment time, decreased number of radiographs, and improved usability in patients with gag reflex. Current devices detect the periodontal ligament at the root apex, which is commonly displayed as 0.0 mm or “apex” on device screens. The distance indicators shown on these displays do not represent true millimetric measurements (4). Therefore, manufacturers recommend advancing the file to the apex or 0.0 reference point during electronic measurement, determining the measured length, and subtracting 0.5 mm to establish the final working length.

ORCIDS

Ümray Özden ÖZGÜL: 0009-0001-6784-8693

Aytül ÇELİKKOL: 0000-0002-8797-3133

Cemre ÇELİK YALÇIN: 0000-0003-1246-055X

Berk ÇELIKKOL: 0000-0002-7365-5476

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