Dental Research Journal

Review Article

Factors influencing the accuracy of electronic apex locators:A scoping review

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Received: 09-Oct-2023
Revised: 11-Dec-2024
Accepted: 29-Dec-2024
Published: 27-Jun-2025

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ABSTRACT

Background: The aim of this scoping review (ScR) according to the population, concept, and context question outline was: What factors can affect the accuracy of electronic apex locators (EALs) (concept) when determining the root canal terminus of human permanent teeth (population) in experimental studies (context)?

Materials and Methods: A ScR was performed and reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses for Scoping Reviews checklist using the following databases: PubMed/Medline, Scopus, Web of Science, and ProQuest. Studies that investigated the influence of a factor on the accuracy of the EALs were screened and included according to the inclusion criteria.

Results: A total of 1761 records were retrieved, leading to 805 studies after duplicates were removed. Applying inclusion and exclusion criteria resulted in the inclusion of 166 studies. The 20 potential influencing factors include generation/electrical working mechanism, method for application of EALs, root canal curvature, root canal length, tooth type, maxillary sinus proximity, lateral foramen, major apical foramen diameter/file size, file alloy, apical patency, preflaring, apical periodontitis/resorption, internal root resorption, perforation, irrigants, solvents, and medicaments, pulp contents, pulp vitality, orthodontic brackets, endodontic retreatment, and electromagnetic interferences were detected.

Conclusion: Although the accuracy of EALs is acceptable in most cases, the use of radiography along with EALs remains advisable to confirm the measurement in clinical scenarios.

Key Words: Electronic apex locators, endodontics, review, root canal, working length

INTRODUCTION

Root canal treatment procedures should be limited to the root canal space. Most clinicians consider the canal terminus to be either the minor apical foramen (MiAF) or the apical constriction (AC), as this is where the contact between the root canal filling material and the periapical tissues is minimized. Various techniques have been used to determine the working length (WL) of root canals. The most commonly used technique is radiographs; however, this technique has some inherent shortcomings including the superimposition

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Website: www.drj.ir
https://journals.lww.com/DERJ
www.ncbi.nlm.nih.gov/pmc/journals/1480
DOI: 10.4103/drj.drj_634_23

How to cite this article: Golkar S, Khademi A, Saatchi A, Ghorani A, Iranmanesh P. Factors influencing the accuracy of electronic apex locators: A scoping review. Dent Res J 2025;22:26.

of structures, geometry distortion, and radiation exposure concerns.[1] Using electronic apex locators (EALs) is one of the acceptable methods for root canal length determination.[2]

Custer suggested using electrical conductivity to estimate WL in root canals.[3] Suzuki found a constant resistance between the root canal terminus and oral mucosa.[4] Sunada measured resistance values with an ohmmeter at the apical foramen.[5] This research led to the first commercial product, the "Root Canal Meter," developed by Onuki Medical Co. in 1969,[5] followed by advancements in EALs.[6]

Many factors including method for application of EALs, tooth type, root canal curvature and length, file size and alloy, plup contents and vitality, presence of lateral foramen, perforation, root resorption, apical periodontitis and orthodontic brackets, proximity to the maxillary sinus as well as the type of irrigants, solvents, and medicaments have been proposed to affect the accuracy of EALs.[6] Although some systematic reviews[6] have evaluated the influencing factors of EAL accuracy, there is currently no up-to-date comprehensive review in this regard. This scoping review (ScR) aims to discuss the factors that influence the accuracy of EALs, explain the underlying mechanism for each one, and discuss some of the controversies in the previous literature.

MATERIALS AND METHODS

Protocol and registration

The review was reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for ScRs (PRISMA-ScR) Checklist [Supplementary Table 1]. A review protocol was created and registered on the Open Science Framework (OSF) Registries (osf.io/9sjdg) at https://doi.org/10.17605/OSF.IO/VCEH4.

Formulating the review question

A review question was developed using the population, concept, and context (PCC) framework. This PCC framework was developed to review the factors influencing the accuracy of EALs. What factors can affect the accuracy of EALs (concept) when determining the root canal terminus of human permanent teeth (population) in experimental studies (context)?

Eligibility criteria

Inclusion criteria: Experimental studies that investigated the factors affecting the accuracy of EALs and studies that used multiple-frequency EALs in permanent teeth. Exclusion criteria: Studies in which length determination was done during rotary instrumentation, studies in which the reference length was determined by observing the file through the apex without any magnification, studies that only compared the accuracy of different EALs without investigating an influential factor, and studies that compared the accuracy of different radiographic modalities with EALs. Studies meeting the inclusion criteria were marked as "Eligible" and subjected to data extraction.

Search strategy

Three online databases (PubMed/Medline, Scopus, and Web of Science) were searched in April 2023 with a restriction to the English language. Two reviewers conducted the search using the following six keywords: "Apex finder," "Apex locator," "Electronic apex locator," "Electronic root canal length measurement device," "Electronic foramen locator," and "Electronic working length measurement devices." The search strategy for each database is available in Table 1. Forward and backward reference searches were conducted. Gray literature was searched in the first 100 hits of Google Scholar and ProQuest Dissertation and Theses. The search results were exported to EndNote, and duplicate publications were identified and removed.

Data extraction

The articles were independently reviewed based on their titles and abstracts by two reviewers. In case of a disagreement, a final consensus was reached after a discussion with a third reviewer. The full texts of the possibly relevant studies were accessed. Furthermore, two reviewers independently extracted relevant data using a standard data collection form. The extracted information included the name of article, the first author's name, the year of publication, the influencing factors, and the conclusion. Any disagreements were resolved through discussion with a third reviewer.

RESULTS

A total of 368 records from PubMed/Medline, 672 from Scopus, 673 from Web of Science, and 48 from gray literature and manual search were found, totaling 1761 studies. After removing duplicates, 804 studies remained. Studies selected by their titles were screened by their abstracts and subjected to the eligibility criteria. Altogether, 166 studies were included to be reviewed [Supplementary Table 2]. PRISMA flowchart and the selection process are shown in Figure 1. The

included study assessed 20 potential influencing factors including generation/electrical working mechanism, the method for application of EALs, root canal curvature, root canal length, tooth type, maxillary sinus proximity, lateral foramen, major apical foramen (MAF) diameter/file size, file alloy, apical patency, preflaring, apical periodontitis/resorption, internal root resorption, perforation, irrigants, solvents, and medicaments, pulp contents, pulp vitality, orthodontic brackets, endodontic retreatment, and electromagnetic interferences [Table 2].

DISCUSSION

One of the main concepts in endodontic treatment is determining the endpoint of root canal treatment. The cementodentinal junction is ideal as the endpoint of root canal treatment. Since it is a histological landmark, precise clinical determination is challenging.[1] Therefore, most clinicians prefer to terminate canal preparation at the AC or MiAF, ensuring minimal contact between the root canal filling material and the apical tissues.[6] The AC is typically recognized as

Table 1: Search strategy for the databases

Database	Search strategy	Number of records
Web of Science	TS= ((apex locator*) OR (Electronic apex locator*) OR (Electronic foramen locator*) OR (Electronic AND working AND length measurement device*) OR (apex finder*) OR (Electronic root canal length measurement device*) OR (apex locator*) OR (Electronic apex locator*) OR (Electronic foramen locator*) OR (Electronic working length measurement device*) OR (Electronic root canal length measurement device*))	673
PubMed/Medline	((((((“Apex finder*”[Title/Abstract]) OR (“Apex locator*”[Title/Abstract])) OR (“Electronic apex locator*”[Title/Abstract])) OR (“Electronic root canal length measurement device*”[Title/Abstract])) OR (“Electronic foramen locator*”[Title/Abstract])) OR (“Electronic working length measurement device*”[Title/Abstract]) OR (“Electronic root canal length measurement device *” [Title/Abstract]))	386
Scopus	TITLE-ABS-KEY ((apex AND locator*) OR (apex AND finder*) OR (electronic AND apex AND locator*) OR (electronic AND root AND canal AND length AND measure* AND device*) OR (electronic AND foramen AND locator*) OR (electronic AND working AND length AND measure* AND device*))	672
Gray literature Manual search	ProQuest Dissertation and Theses and 100 first hit of Google Scholar Forward and backward reference searches	48

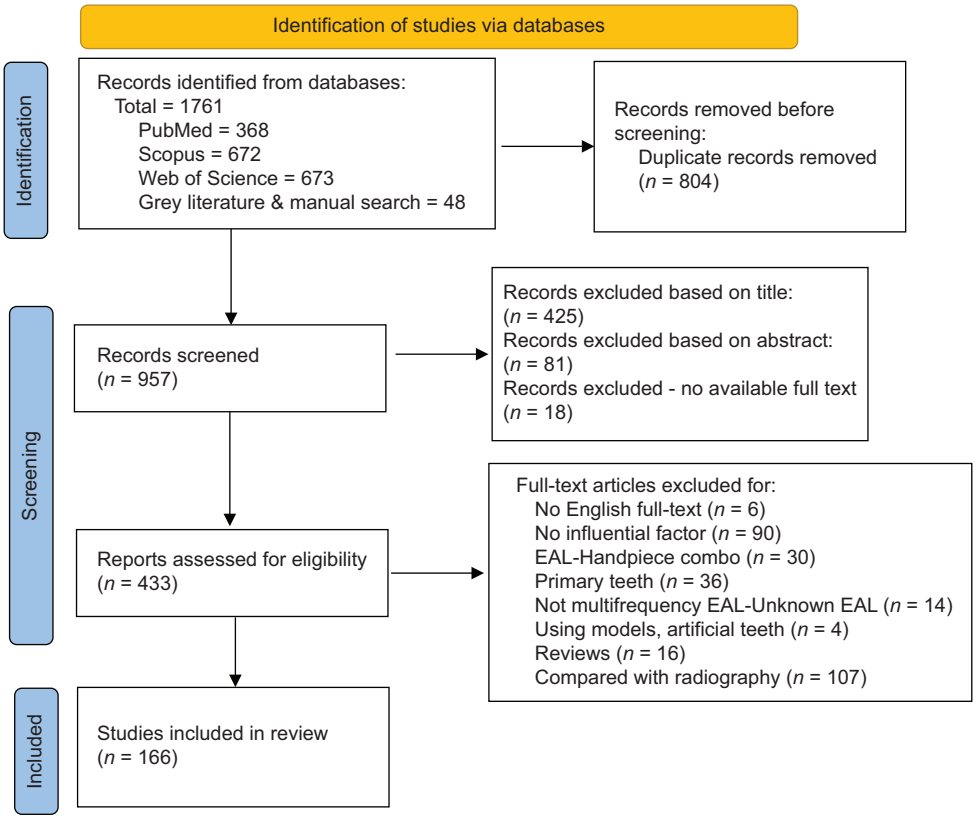

Figure 1: Flowchart of study selection.

Table 2: Summary of the influential factors on the accuracy of electronic apex locators according to included studies

Factor	Conclusion†		
	Positive	Negative	No effect
Generation - electrical working mechanism††			
Method for application of EALs (insertion file to the "apex" reading, not to beyond it)	1		
Root canal curvature	1	1	
Root canal length (longer teeth)		1	
Tooth type (anterior and molar)		1	
Maxillary sinus proximity		2	
Lateral foramen		3	
MAF diameter - file size			
Larger MAF diameter		5	
The fitness of the file to the canal size	3		
File alloy (NiTi alloy)	1	1	10
Apical patency	5		
Preflaring	11		
Apical periodontitis - apical resorption		5	10
Internal root resorption			1
Perforation		14	
Irrigants, solvents, and medicaments			
NaOCL	4	2	14
EDTA			7
Saline	1	2	1
CHX	3	2	1
Calcium hydroxide		3	
Chloroform, orange solvent, or eucalyptol			2
Guttasolv or resosolv		1	
Pulp contents			
Blood in the root canal			2
Dentinal debris		1	
Pulp vitality	2		8
Orthodontic brackets		1	
Endodontic retreatment			11
Electromagnetic interferences			12

†The number in each column indicates the number of studies supporting the conclusion; ††Due to high heterogeneity, a conclusion could not be drawn.
EALs: Electronic apex locators; MAF: Major apical foramen

being located 0.5–1 mm coronal to the MAF. EALs inherently detect MAF and not the AC.[7,8] Although the "0.5" reading indicates a point coronal to the MAF, not necessarily the AC, the apical landmark was considered at this level by various authors.[9-13] Therefore, clinicians should be aware of the inherent differences in the apical anatomy where these points are located.[6] In addition, clinicians should consider the factors that could impact the accuracy of EALs. The present review identifies 20 potential influencing factors that may affect the accuracy of EALs, which are discussed in detail below.

The term "generation"

Instead of using the more common "generation" classification, which lacks scientific basis and is more appropriate for marketing concerns, it is suggested to classify EALs based on their electrical working mechanism. Early EALs like Root Canal Meter and Dentometer (Dahlin Electromedicine, Copenhagen, Denmark) used electrical resistance to estimate the position of the MAF. Once the electrical resistance between the file tip and the oral mucosa reached 6.5 kΩ, the device announced the point as MAF.[14] The accuracy of these devices decreased when the root canal was not dry, and the patients felt a "shock sensation" because of the direct electrical current used in these devices.[15]

Later EALs started using the electrical impedance of the root canal system to determine the MAF. Endocater (Yamaura Seisokushu, Tokyo, Japan), Endo Analyzer (Analytic/Endo, Orange, CA, USA), and Sono-Explorer (Hayashi Dental Supply, Tokyo, Japan) are the early examples[14] that used a single frequency alternating electrical current, had to be calibrated for

each tooth, and were also inaccurate when electrolytes such as sodium hypochlorite (NaOCl) were present in the root canal.[16]

Later devices used multiple alternating electrical current frequencies, either simultaneously or to compensate for the presence of different contents in the root canal. Some of them use the "ratio" of the impedance at these frequencies to determine the position of MAF.[17] RootZX (J. Morita Corp., Tokyo, Japan) is an example that calculates the ratio using 8-kHz and 400-Hz alternating electrical currents "simultaneously." This ratio is 0.67 at the MiAF (or AC) and nearly 1 at the MAF.[14] Some devices (Raypex 4 and 5 [VDW, Munich, Germany]) use two or more frequencies "in order" or use the "difference" of the impedance values at two frequencies instead of the "ratio."[14] Recently, neural networks, which are computer algorithms that try to mimic the human brain's data processing mechanism, have been used for WL estimation, and they may be promising for better accuracy in different root canal conditions.[18]

The process through which EALs use the impedance values and locate MAF can vary significantly from one device to another, affecting the inherent and clinical accuracy of EALs.[13]

Due to limited information from manufacturers about the working mechanism of some EALs, classification can be challenging. In general, most modern EALs deliver clinically acceptable results in ideal clinical scenarios.[19-24] Nonetheless, one EAL may outperform another in more complex clinical situations, despite being from the same "generation." Therefore, it is recommended that manufacturers disclose the exact electrical working mechanism and clinicians have a basic understanding of the electrical concepts used in EAL to gain better insight into its behavior in various clinical situations.[13]

Method for application of electronic apex locator

In 2017, Oliveira *et al*. compared four methods for the application of EALs: (1) insertion of the file to "1.0" reading; (2) insertion to the "apex" reading and then withdrawing to "1.0;" (3) insertion to the "apex" reading; and (4) insertion to beyond the "apex" reading and then withdrawing to the "apex." The third method provided the best accuracy.[25] EALs' ability to locate the MAF with the best accuracy was also mentioned in another study.[26] However, the higher accuracy of method 3 (insertion of the file to the "apex" reading) than method 4 (insertion to beyond the "apex" reading and then withdrawing to the "apex." reading) was attributed to the fact that the file size chosen for measurements in this study was fitted to the canal size. Taking a file beyond the MAF enlarges the MAF, and the file is no longer as fit as before in the MAF, affecting the electrical characteristics of the circuit formed by the file, the tooth, and the PDL. Hence, it was suggested that there is no benefit to taking the file beyond the MAF and retracting it for the measurement.[25] The accuracy of the 0.5 reading with passing the MAF, then returning to the 0.5 without passing the foramen, and only reaching the 0.5 point, was also investigated, and both were equally accurate.[27]

Root canal curvature

Two studies have evaluated the influence of root canal curvature on the accuracy of EALs.[7,28] An investigation showed that root canal curvature (9°–58°) did not affect the accuracy of EALs.[7] However, another study found that Root ZX EAL was less accurate when measuring canals with >20° of curvature.[28] The former study used the "0.5" reading of the RootZX and compared it with the actual length of the canal minus 0.5 mm, whereas the latter used the "0.0" reading and compared it to the position of the MAF. It was suggested that the effect of root canal curvature on file contact with dentinal walls might explain the subtle differences observed in the accuracy of EALs. Therefore, it is advisable to reconfirm the WL in curved canals during the preparation steps.

Root canal length

Saatchi *et al*., in 2015, concluded that RootZX is more accurate in shorter teeth, and there is a tendency toward underestimation of length in longer teeth.[29]

Tooth type

In 2011, Mancini *et al*. demonstrated that EALs were more accurate in premolars than in molars and anterior teeth. This difference may be attributed to the wider characteristics of the MAF in molar and anterior teeth, as well as the lateral positioning of MAF on the root surface in those teeth.[30]

Maxillary sinus proximity

El Hachem *et al*., in 2019, showed that the proximity of the maxillary sinus to a root end can also affect the length estimation accuracy. In a cone-beam computed tomography, RootZX was found to overestimate the length of palatal roots in contact with the sinus. As an

explanation, it is suggested that proximity to the sinus may change the impedance characteristics of the root canal system.[31]

Lateral foramen

In teeth with lateral MAF anatomy, the accuracy of the "Apex" reading on the RootZX was affected,[32] and more overextended readings were observed. However, the accuracy of the "0.5" reading was not affected.[32,33] The presence of lateral canals also reduced the accuracy of RootZX but not to a clinically significant level.[34]

Major apical foramen diameter – File size

The accuracy of EALs decreases with wider MAF sizes.[35-37] However, EALs are still "clinically" useful in larger sizes despite the statistically reduced accuracy.[38,39] The accuracy of RootZX with MAF sizes below 0.6 mm was independent of the file size; at 0.7–0.8 mm, the accuracy improved when the file matched the MAF size closely, and in MAF sizes >0.9 mm, the accuracy reduced regardless of the file size.[40] Propex Pixi (Dentsply Maillefer, Ballaigues, Switzerland) was more accurate in MAF sizes <0.6 mm compared to larger sizes, independent of the file size.[41] In an investigation, the AC area of root canals was gradually widened to 1.02 mm using a sequence of hand files to assess the ability of RootZX to detect the narrowest area of the canal. No significant difference in the measured length was noted during the enlargement up to 0.6 mm. However, a significant difference was observed in the accuracy of the EAL in a 1-mm wide AC. These findings show that the accuracy of RootZX is affected by the AC size and also the size and fit of the file in the apical area.[42] The accuracy of RootZX with the MAF sizes below 0.6 mm was independent of the file size; with MAF sizes of 0.7–0.8 mm, the accuracy improved when the file matched the MAF size closely, and in MAF sizes >0.9 mm, the accuracy decreased regardless of the file size.[40] Moreover, the accuracy of RootZX (J. Morita Corp., Tokyo, Japan) started to decrease when the file size reached 0.7 mm, and for RootZX MINI (J. Morita Corp., Tokyo, Japan), this occurred at 0.55 mm, which was attributed to thinner root canal walls in canals with larger diameters, which can affect the measured impedance.[43]

iPex (NSK, Tochigi, Japan) and Propex II showed decreased accuracy as the foramen diameter increased from 0.27 mm to 0.47 mm and 0.72 mm.[35] In addition, the accuracy of RootZX and Raypex 6 (VDW, Munich, Germany) decreased when the MAF size was >0.57 mm.[36]

Propex Pixi was more accurate in MAF sizes <0.6 mm, regardless of the file size.[41] This factor should be considered carefully when the canal is filled with blood rather than NaOCl using RootZX.[44] In addition to the size of the MAF, the readings get more accurate as the file fits more tightly in the apical regions.[45-48]

The fit of the file in the apical regions may affect the accuracy of EALs;[33,34] selecting a file size that closely matches the apical diameter of the canal may improve the accuracy.

Based on these findings, the results of EALs should be interpreted cautiously in wide MAF sizes, but with the correct fit of the measuring file, readings can be clinically acceptable.

File alloy

Ten studies have shown that the alloy of the file does not affect the accuracy of EALs.[45-54] However, one study found that RootZX was more accurate with NiTi files, whereas RootZX MINI was more accurate with stainless steel files.[55] In contrast, another study found that RootZX was more accurate with SS files; the lower accuracy with NiTi files was attributed to the higher flexibility of NiTi instruments or their electrical characteristics.[56] Elements Diagnostic Unit (Sybron Endo, Sybron Dental, Anaheim, CA, USA) and ProPex Pixi were unaffected by the file alloy used.[55] Moreover, the Self-adjusting File (ReDent Nova, Raanana, Israel) has also produced accurate results for electronic length estimation in canals with wide apical diameters.[57]

Apical patency

Lack of foraminal patency reduced the accuracy of Raypex 6 and RootZX, which was more pronounced in the latter.[58] Apex Finder (Endo Analyzer 8001; Analytic Technology, Redmond, WA, USA) was also more stable than RootZX when the canal was not patent.[59] Apex ID was the most accurate in the absence of foraminal patency, followed by Propex II (Dentsply Maillefer, Ballaigues, Switzerland) and RootZX.[60] RootZX and D10 (Parkell Electronic Division, NY, USA) were more accurate in wide AFs than Apex NRG (Kibbutz Afikim, Israel) and Apit 7 (Osada, Tokyo, Japan).[61] This might be due to their different operating mechanisms. It has been claimed that inconsistent readings can be associated with the lack of foraminal patency.[62]

Preflaring

Nine studies have found that preflaring can increase the accuracy and consistency of EALs.[52,63-70] However, no significant difference was observed with iPex[71] and RootZX,[72] irrespective of whether the canal was pre-enlarged or not. Preflaring was found to have a more significant effect on the predictability of the readings compared to using larger file sizes for length determination.[63] It appears that EALs are accurate irrespective of whether the canal is preflared or not. Preflaring of canals before electronic length measurement is advocated by most studies.

Apical periodontitis – Apical resorption

Apical periodontitis might cause root resorption, which can change the root canal morphology, which EALs rely on to determine the apical foramen.[73] Most evidence shows that apical periodontitis does not affect the accuracy of EALs;[8,74-78] also, most studies have found EALs to be accurate in apically resorbed teeth.[79-82] However, lower accuracy of length determination in teeth with apical periodontitis has also been noted.[83,84] A study that used RootZX on freshly extracted human teeth with attached apical lesions showed a negative effect, causing longer readings. This tendency to more frequently locate a point beyond the AC in teeth with apical periodontitis was also reported in another study.[8] The altered apical morphology of the root secondary to the resorption accompanying the apical periodontitis may cause this wrong determination.[85] RootZX and Raypex 6 were more accurate in teeth with simulated apical resorption compared to iPex.[86] Therefore, it can be generally concluded that EALs can be used in teeth with apical periodontitis with clinically acceptable accuracy.

Internal root resorption

In 2011, da Silva *et al*. concluded that an EAL is accurate in canals with internal resorption without perforations.[79]

Perforation

EALs can reliably locate perforations,[87-95] and one study found that EALs are more reliable than radiographs in detecting perforations.[96] EALs were found to more accurately detect perforations in dry conditions[93] and also with CHX as the irrigant compared to NaOCl.[92,97] Normal saline, SmearOff, and EDTA (an EDTA-based solution with added CHX) have also produced more accurate results than NaOCl for the detection of perforations.[98,99] The same experiment has also been carried out with MTAD, Qmix, or NaCl in the root canal. The perforation was most accurately located with NaCl, and the least accurate results were measured using MTAD.[100] Since EALs can detect perforations, clinicians should be aware of this interference when measuring length in root canals with a perforation.

Irrigants, solvents, and medicaments

Studies are controversial regarding the effect of irrigants and solvents on the root canal system. Some studies have found that the accuracy of EALs is not negatively affected by the presence of irrigants or solvents.[9,101-112] Some authors believe that the most accurate results can be achieved with NaOCl since it is conductive and decreases the impedance of the root canal system.[45,101,113,114] However, in an investigation, the most accurate results were achieved in a dry canal.[115] One study stated that the readings were statistically different from the actual length with RootZX in the presence of NaOCl; however, they were all within an acceptable clinical range.[116] No association was found between the concentration of NaOCl and the accuracy of EALs.[114]

An experiment showed that RootZX was accurate in the presence of EDTA and NaOCl using smaller and larger files. However, higher accuracy was achieved with larger files when using saline or CHX.[117] The accuracy of RootZX was not adversely affected by the presence of NaOCl or EDTA in pre-enlarged canals, whether small or large files were used. However, when CHX or RC-Prep was used, larger files produced more accurate results, and smaller file sizes caused long readings.[118] It can be assumed that in low conductive conditions in the canal, the "fit" of the file in the apical regions becomes more critical. Using RootZX, short readings with NaOCl and long readings with CHX and EDTA were observed.[119,120] ProPex had more accurate results with CHX compared to NaOCl in another study.[121] Raypex 5 is more accurate with CHX (whether in solution or gel form) instead of NaOCl.[122] The interaction of the internal mechanisms of EALs and the electrical characteristics of the root canal contents might produce these conflicting results. Interestingly, it has been found that the irrigant itself can act as an active electrode in a wide-diameter canal. Connecting the file holder of an EAL to an irrigation needle and monitoring the displayed number on the EAL screen during irrigation can verify that the irrigants have reached the apical area.[123]

While the 0.9% saline did affect the accuracy, 2.5% NaOCl, 3% H_2O_2, 0.2% chlorhexidine, 17% EDTA, and the anesthetic solution had no impact on the accuracy of the integrated EAL with the Tri Auto ZX (J. Morita Corp., Tokyo, Japan) handpiece.[124]

EndoPilot (Schlumbohm, Brokstedt, Germany) and iPex both showed zero readings regardless of the distance of the file from the canal terminus in the presence of isopropyl alcohol, indicating that isopropyl alcohol acts as a complete isolator. Inaccurate readings were also observed with hydrogen peroxide and citric acid.[50] However, concerning hydrogen peroxide, one study reported accurate readings with RootZX.[101]

A study showed that the accuracy of EALs was not affected when chloroform, orange solvent, or eucalyptol was present in the root canal.[125] However, another study showed that using Guttasolv or Resosolv solvents could decrease the accuracy of RootZX.[126]

It has been demonstrated that isolating the part of the file that passes through the access cavity, regardless of the presence and type of the restoration, can improve the stability and consistency of the EAL reading as it provides an additional means of isolation.[127]

RootZX is designed to work in wet canals with high conductivity; therefore, unstable readings can result in dry canals; the reverse is true for EALs of earlier generations, which give unstable readings in wet canals.[128]

The remaining calcium hydroxide (CH) in the root canal resulted in decreased accuracy of RootZX, proportional to the surface area of the residual CH, as observed through an operating microscope.[129,130] Therefore, it is suggested to use NaOCl or EDTA in combination with hand filing using the master apical file to achieve more accurate results with EALs following the use of CH.[129] However, it has also been observed that CH removal using EDTA in combination with either NaOCl or normal saline solution results in the same accuracy of length measurement in EALs.[131]

Pulp contents

The effect of blood as a root canal content on the accuracy of EALs was also investigated, and it was reported that blood did not negatively affect the accuracy of RootZX, Raypex 5, RootZX MINI, and Propex Pixi.[109,132]

Another study evaluated the effect of the presence of dentinal debris and canal instrumentation on the accuracy of Sonoexplorer EAL. Before instrumentation, 63% of the readings were long, whereas after instrumentation, 70% of the readings were short. Therefore, removing dentinal debris using recapitulation was necessary for accurate length measurements.[133]

In conclusion, the electrical conductivity of root canal contents seems to marginally affect the readings of EALs; however, in most studies, the reported readings are still within a clinically acceptable range; therefore, EALs can be safely used clinically in the presence of various contents.

Pulp vitality

Pulp condition had no significant impact on the accuracy of EALs.[109,134-140] However, AFA (Analytic Endodontics, Orange, CA) EAL was more accurate in vital cases compared to necrotic ones.[141] Furthermore, extirpating the pulp tissue improved the accuracy of EALs.[142] In conclusion, EALs can be accurately used clinically regardless of the vitality of the pulp.

Orthodontic brackets

Orthodontic brackets bonded to the tooth surface have been demonstrated to affect the accuracy of electronic WL measurement. A short-circuiting mechanism between the brackets on the tooth surface and the EAL lip clip might be responsible for this interference. A minimum distance of 3 cm between the bracket on the tooth being measured and the lip clip has been suggested.[143]

Endodontic retreatment

EALs can be accurately used in retreatments after removing the root-filling material.[61,144-149] Using RootZX in specimens obturated with a carrier-based system led to an overestimation of root canal length.[150] Situations in which EALs fail to provide any data are more common in retreatment cases.[144] RootZX was not able to detect the MiAF (0.5-mm mark) accurately but was accurate in the “apex” mark in retreatment cases,[151] which can be explained by the fact that residual root filling material increased the electrical impedance of the canal.[152] However, regardless of the presence of residual root-filling material, the most distinct decrease in impedance of the root canal occurred at the MAF,[153] which was less affected than the anatomy of the MiAF that could have been disrupted in the primary treatment or retreatment process. Overall, EALs can be used with clinically accepted accuracy in retreatments. It is advisable to rely more on the measurement that

indicates the MAF in each EAL rather than any point short of that in retreatments.

Electromagnetic interferences

Some EAL manufacturers state that the apex locator is intended for use in an electromagnetic environment with controlled radio frequency disturbances. Therefore, several studies were conducted in this regard.[154-165] It has been reported that cell phones do not interfere with EALs' internal mechanisms.[154-157] However, one study showed the direct contact of cell phones with the enclosure of RootZX MINI while an active call might cause instability of the EAL reading at the "Apex" mark.[158] An active call is unlikely to happen in clinical scenarios. In another study using RootZX, the mean error of length estimation increased when a cell phone, ADSL modem, cordless phone, or an MP4 player was within 50 cm of the RootZX. In this study, the cell phone was ringing but not in an active call, which is more likely since clinicians or patients usually do not answer their phones during the procedure.[159] While clinicians should be aware of this potential interaction, available information shows that patients can safely keep their cell phones "on" in the dental operatory without affecting the accuracy of EALs. Evidence has shown that EALs can be safely used in clinical scenarios for patients with cardiac pacemakers.[160-165]

The limitations of the present study should be noted. The critical appraisal of individual sources was not done due to the high number of included studies. Since the optimal WL can be determined through experimental studies by visualizing the endodontic file tip or by histological section, no clinical studies were identified. For future studies, the application of artificial intelligence in EAL could be examined.

CONCLUSION

This article reviews and discusses various factors that might influence the accuracy of EALs of human permanent teeth. Even though factors such as root canal length, maxillary sinus proximity, laterally located apical foramina, larger MAFs, perforations, residual calcium hydroxide, dentinal debris, and orthodontic brackets may negatively affect the accuracy of EALs, the accuracy of EALs is acceptable in most cases. Using radiography along with EALs remains advisable to confirm the measurement in clinical scenarios.

Financial support and sponsorship

Nil.

Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

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Supplementary Table 1: Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for scoping reviews checklist

Section	Item	PRISMA-SCR checklist item	Reported on page number
Title			
Title	1	Identify the report as a scoping review	1
Abstract			
Structured summary	2	Provide a structured summary that includes (as applicable): Background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives	2
Introduction			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach	3
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives	3 and 4
Methods			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number	4
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale	4
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed	5
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated	Table 1
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review	5
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators	5
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made	5
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate)	NA
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted	5
Results			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram	Figure 1
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations	Page 5 and Supplementary Table 2
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12)	NA
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives	Supplementary Table 2
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives	Tables 2 and 3
Discussion			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups	6-19
Limitations	20	Discuss the limitations of the scoping review process	19
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps	19

Contd...

Supplementary Table 1: Contd...

Section	Item	PRISMA-SCR checklist item	Reported on page number
Funding			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review	1

*Where sources of evidence (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and web sites; †A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with information sources (see first footnote); ‡The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBI guidance (4, 5) refer to the process of data extraction in a scoping review as data charting; §The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of "risk of bias" (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document). Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA extension for scoping reviews (PRISMAScR): Checklist and explanation. Ann Intern Med 2018;169:467-73. JBI: Joanna Briggs Institute; PRISMA-ScR: Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for scoping reviews; NA: Not available

Supplementary Table 2: Characteristics of the included studies

Title	Year	First author name	Factors investigated	Findings
Influence of Blood on the Accuracy of Raypex 5 and Root ZX Electronic Foramen Locators: An *In Vivo* Study	2016	Saatchi, M.	Accuracy in the Presence of blood. Accuracy of two brands in the presence of blood	There were no statistically significant differences in the accuracy of the EFLs.·The presence of blood in the root canal space did not influence the accuracy of the EFLs.
Calcium hydroxide dressing residues after different removal techniques affect the accuracy of Root-ZX apex locator	2015	Uzunoglu E.	The effect of calcium hydroxide residues on the accuracy of RootZX.	Residues of CH medication in root canals affected the accuracy of Root-ZX adversely.
The effect of residual calcium hydroxide on the accuracy of a contemporary electronic apex locator	2015	Ustun, Y.	The effect of amount of calcium hydroxide residues on the accuracy of Mini Root ZX as a contemporary electronic apex locator.	Accuracy of Mini Root ZX decreased proportionally with the amount of paste remaining in the canal, especially when calcium hydroxide remained in more than 4 mm of the root.
Influence of the Canal Contents on the Electrical Assisted Determination of the Length of Root Canals	2002	Oliver P.	Accuracy of the EALs in vital, necrotic and retreatment cases.	EALs were more accurate in vital cases than necrotic ones. Due to limited number of retreatment cases, the results for these cases were not statistically comparable.
The Influence of Various Irrigants on the Accuracy of 2 Electronic Apex Locators in Locating Simulated Root Perforations	2017	Altunbaş D.	The accuracy of the Dentaport ZX and the Rootor in detecting root perforations in dry conditions and in the presence of the following irrigation solutions: 2.5% NaOCl, 0.9% saline solution (NaCl), and 17% EDTA.	The most accurate measurements for both EALs were obtained in dry conditions. In the Denta- port ZX group, EDTA gave the most accurate results, and NaOCl gave the least accurate ones. Measurements with NaCl were closer to the AL than those obtained with EDTA for the Rootor group.Significant differences were noted among the EALs when the measurements were taken with NaOCl, NaCl, and EDTA. Dentaport ZX was more accurate compared with the Rootor in the presence of different irrigants.
An Invitro Evaluation of the Accuracy of Two Electronic Apex Locators to Determine Working Length in the Presence of Various Irrigants	2016	Prasad AB.	The accuracy of Root ZX and i-Root apex locator for determining working length in the presence of different irrigating solution.	The content of the root canal did not influence the accuracy while measuring working length using Electronic apex locators (EAL)
The Effect of File Size and Type and Irrigation Solutions on the Accuracy of Electronic Apex Locators: An *Ex vivo* Study on Canine Teeth	2016	Janeczek M.	Effect of file size on the accuracy of EALs. Effect of file type on the accuracy of EALs. Effect of irrigant solutions on the accuracy of EALs	The highest stability of measurements in the NaOCl environment, in the case of both 2.0% and 5.25%, which seems to be the most optimum one. It was also concluded that the use of steel instruments whose size corresponds to MAF (master apical le) brings the best results (compared to Ni-Ti).
A comparative assessment of the accuracy of electronic apex locator (Root ZX) in the presence of commonly used irrigating solutions	2014	Khattak, O.	Accuracy of RootZX in the presence of normal saline 0.9%, 0.2% chlorhexidine and 2.5% NaOCl	No statistical significant difference was found between actual canal length and Root ZX measurements in presence of normal saline and 0.2% chlorhexidine. Highly statistical difference was found between actual canal length and Root ZX measurements in presence of 2.5% of NaOCl, however all the measurements were within the clinically acceptable range of ±0.5mm
Effect of solvents on the accuracy of the Mini Root ZX apex locator	2013	Er, O.	The effects of three solvents on the accuracy of the Mini Root ZX.	There were significant differences between AWL and WL measurements in Resosolv group and Endosolve group. In these subgroups, WL was shorter than AWL. · The accuracy of the Resosolv group was significantly lower than the others.

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Supplementary Table 2: Contd..

Title	Year	First author name	Factors investigated	Findings
Effect of chloroform, orange solvent and eucalyptol on the accuracy of four electronic apex locatorsa	2013	Al-Hadlaq, SM.	evaluate the effect of three retreatment solutions on the accuracy of four electronic apex locators	The accuracy of each apex locator was not affected by the type of retreatment solution present in the root canal. The accuracy of the four apex locators was similar in the presence of each of the tested solutions.
Comparison of accuracy of two electronic apex locators in the presence of various irrigants: An *in vitro* study	2012	Mull JP.	the accuracy of Root ZX and SybronEndo Mini, electronic apex locators (EALs), in the presence of various irrigants.	The accuracy of EL measurement of Root ZX and Sybron Mini within±0.5 mm of AL was consistently high in the presence of NaOCl and found to be least with EDTA. EL measurements were shorter with 1% NaOCl, whereas longer with 2% CHX for both the devices. Sybron Mini was more accurate with 1% NaOCl and 2% CHX than Root ZX.
Comparative evaluation of accuracy of two electronic apex locators in the presence of various irrigants: An *in vitro* study	2012	Jain S.	The aim of this study was to compare the efficacy of electronic apex locators after cleansing and shaping of the root canals and whether there was any alteration in accuracy when used in the presence of irrigants	Within the limitations of this study Root ZX can be considered to be an accurate electronic apex locator . CHX as irrigant, compared to NaOCl and local anesthetic matched more precisely with the actual canal length measurements.
In Vivo Evaluation of the Raypex 5 by Using Different Irrigants	2012	Gomes S.	The aim of this *in vivo* study was to evaluate the performance of the Raypex 5 electronic apex locator in the presence of different irrigant solutions: 2.5% sodium hypochlorite (NaOCl), 2% CHX, and 17% EDTA.	No significant differences were found among the experimental groups (P = .18). The mean distance from the RWL to the file tip was –0.26 ` 1.14 mm when 17% EDTA was used, –0.03 ` 0.92 mm for 2% CHX, and 0.22 ` 0.93 mm for 2.5% NaOCl. The Raypex 5 performed equally well irrespective of the irrigant used
Accuracy of three electronic apex locators in the presence of different irrigating solutions	2010	Carvalho, AL.	The present study compared the accuracy of three electronic apex locators (EALs) – Elements Diagnosti, Root ZX and Apex DSP – in the presence of different irrigating solutions (0.9% saline solution and 1% sodium hypochlorite).	Elements Diagnostic and Root ZX apex locators were able to locate the cementum- dentine junction more precisely than Apex DSP. The presence of irrigating solutions does not interfere with the performance of the EALs.
The influence of irrigating solutions on the accuracy of the electronic apex locator facility in the Tri Auto ZX handpiece	2006	Erdemir, A	The influence of various irrigating solutions (0.9% saline, 2.5% NaOCl, 3% H2O2, 0.2% chlorhexidine, 17% EDTA, Ultracaine on the accuracy of the electronic apex locator facility in the Tri Auto ZX handpiece.	Mean distances from the apical constriction to the file tip were longer in the 0.9% saline group. There was no statistically significant difference on file tip position between the other solutions. Tri Auto ZX gave reliable results with all irrigating solutions apart from in the presence of 0.9% saline.
The Influence of Sodium Hypochlorite Irrigation on the Accuracy of the Root ZX Electronic Apex Locator	2002	Meares, WA.	to determine whether the presence of sodium hypo- chlorite influences the accuracy of the Root ZX electronic apex locator	No significant differences were found be- tween the experimental groups .The results of this study indicate that the Root ZX is not adversely affected by the presence of sodium hypochlorite.
An Evaluation of the Accuracy of the Root ZX in the Presence of Various Irrigants	2001	Jenkins, JA.	to evaluate the ac- curacy of the Root ZX *in vitro* in the presence of a variety of endodontic irrigants.The following irrigants were tested: 2% li- docaine with 1:100,000 epinephrine, 5.25% sodium hypochlorite, RC Prep, liquid EDTA, 3% hydrogen peroxide, and Peridex	Data indicate that the Root ZX electronic apex locator reliably measured canal lengths to within 0.31 mm and that there was vir- tually no difference in the length determination as a function of the seven irrigants used. These results strongly support the concept that the Root ZX is a useful, versatile, and accurate device for the determination of canal lengths over a wide range of irrigants commonly used in the practice of endodontics.

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Supplementary Table 2: Contd..

Title	Year	First author name	Factors investigated	Findings
Clinical accuracy of two electronic apex locators in teeth with large periapical lesions	2013	Caliskan, MK.	Accuracy of two EALs (ProPex and Apex Pointer) in determining the position of the apical foramen of teeth with large periapical lesions and persistent intracanal exudate.	ProPex and Apex Pointer were accurate (within 0.5 mm) 97% and 94% of the time. No sig- nificant differences were detected between the apex locators.
The influence of apical lesions on electronic tooth-length measurements - An *in vitro* study	2006	Kuźmiński, M.	The influence of apical lesions on tooth-length measurements with the Root ZX apex locator and checking a modified method of uncovering the apical part of the canal.	The presence of apical lesions negatively affects electronic tooth-length measurements.
In vivo evaluation of the accuracy of working length determination using an electronic apex locater IPEX (NSK) on vital uninfected teeth and teeth with radiographic evidence of periapical lesions	2014	Raghu, KN.	Evaluate the accuracy of working length determination of an electronic apex locator, IPEX, on vital uninfected teeth and teeth with radiographic evidence of periapical lesions.	In case of teeth with radiographic evidence of periapical lesions, the radiographic method appeared to be relatively more dependable; however, this difference was not statistically significant.
Influence of Apical Periodontitis on the Accuracy of 3 Electronic Root Canal Length Measurement Devices: An *In Vivo* Study	2014	Saatchi, M.	Evaluation of the influence of apical periodontitis (AP) on the accuracy of Dentaport ZX, Raypex 5, and i-Root electronic root canal length measurement	The presence of AP did not influence the accuracy of ERCLMDs.
Evaluation of the Reliability of Cone-beam Computed Tomography Scanning and Electronic Apex Locator Measurements in Working Length Determination of Teeth with Large Periapical Lesions	2016	Ustun, Y.	Endodontic working-length measurements in teeth with large periapical lesions and persistent intracanal exudate by using preexisting CBCT. It compares the measurements with clinical root canal lengths determined by using 2 electronic apex locators.	In teeth with large periapical lesions and persistent intracanal exudate, measurement of the root canal length by using CBCT was as reliable as measurements that used apex locators.
Influence of Instrument Size on the Accuracy of Different Apex Locators: An *In Vitro* Study	2008	Briseno-Marroquin, B.	Determine the accuracy of 4 different electronic apex locators (EALs) with 3 different instrument sizes.	No significant differences were found between the actual working length and EALs/instrument size. A nonsignificant higher number of unstable measurements were observed in all EALs with instrument size 15.
Accuracy of the root ZX II using stainless-steel and nickel-titanium files	2011	da Silva, EJNL.	To evaluate the accuracy of the Root ZX II electronic apex locator (EAL) using hand stainless-steel file, nickel-titanium hand file and nickel-titanium rotary file	No statistically significant differences was found among the tested files.
The effects of file size, sodium hypochlorite and blood on the accuracy of Root ZX apex locator in enlarged root canals: an *in vitro* study	2006	Ebrahim, A. K.	Evaluate the effect of file size on the accuracy of Root ZX apex locator using an agar model when sodium hypochlorite solution or blood was present during electronic measurements in enlarged root canals.	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. In the presence of NaOCl, the Root ZX was highly accurate even when the file was much smaller than the diameter of the canal.
An *in vitro* evaluation of the accuracy of four electronic apex locators using stainless-steel and nickel-titanium hand files	2016	Gehlot, PM.	Evaluate the accuracy of working length (WL) determination of four electronic apex locators (EALs), namely, Root ZX (RZX), Elements diagnostic unit and apex locator (ELE), SybronEndo Mini Apex locator (MINI) and Propex pixi (PIXI) using Stainless steel (SS) and nickel-titanium (NiTi) hand les.	Root ZX was statistically more accurate with NiTi les compared to SS les, while MINI was statistically more accurate with SS les compared to NiTi les. ELE and PIXI were not affected by the alloy type of the le used to determine WL.

Contd...

Supplementary Table 2: Contd..

Title	Year	First author name	Factors investigated	Findings
The Effect of File Size and Type and Irrigation Solutions on the Accuracy of Electronic Apex Locators: An *In Vitro* Study on Canine Teeth	2016	Janeczek, M.	Assessing the influence of the size and type of instruments and the type of irrigation solution on the accuracy of electrical measurement of the working length.	Analogical measurements were obtained only for sodium hypochlorite solutions. In other environments the measured sections were shortened. Comparative examinations with the use of steel instruments demonstrated insignificant measurement differences. Compared to these results, the measurements in nickel titanium group were characterized by more considerable deviations.
Determination of H-file sizes being more suitable for measuring of working length in immature teeth using an EAL	2014	Miyashin, M.	Find the sizes of H-files that are more suitable for root canal length measurements of immature teeth using Apit 11®	Of the H-files of sizes No. 10 to No. 70, No. 15 is probably the most reliable to locate the apical foramen when it is used with Apit 11®
Electronic length measurement using small and large files in enlarged canals.	1996	Nguyen, HQ.	In this study, the length of enlarged canals was measured using small size files and files matching the canal diameter to observe a possible discrepancy.The accuracy of electronic length control during canal preparation with rotary files was also assessed	In the enlarged canals, length measurements obtained with small and large size files were comparable.
The effect of file size on the accuracy of the raypex 5 apex locator: an *in vitro* study	2008	Sadeghi, S.	Evaluate the effect of file size on the ac- curacy of the Raypex 5 electronic apex locator for working length determination of uninstrumented canals.	There was no significant difference between electronic and actual working lengths when a size 15 K-file was used.
The accuracy of the Raypex5 electronic apex locator using stainless-steel hand K- le versus nickel-titanium rotary Mtwo le	2010	Sadeghi, S.	evaluate the accuracy of the Raypex5 electronic apex locator using stainless-steel hand K- le versus nickel-titanium rotary Mtwo le	Under the conditions of this in-vitro study, Raypex5 registered more measurements in acceptable range using 15/0.02 stainless-steel hand K- le and 10/0.04 NiTi rotary Mtwo le. It is possible to use them inter- changeably without compromising the working length.
Comparison of measurements obtained with hand files or the Canal Leader attached to electronic apex locators: an *in vitro* study	1999	Steffen, H.	combine directly the Canal Leader handpiece (SET, Olching, Germany) with the electronic apex locators ROOT ZX and JUSTY (Yoshida, Tokyo, Japan) to find out whether the working length values thus obtained were identical to those resulting from the combination of the same electronic devices with hand files.	Under the conditions of this study the working length of canals obtained with electronically assisted hand files were similar to those obtained with the electronically assisted mechanical handpiece Canal Leader.
The accuracy of the Root ZX electronic apex locator using stainless-steel and nickel-titanium files	2003	Thomas, AS.	The purpose of this study was to determine if there is a measurable difference in accuracy of length determination when stainless-steel and nickel- titanium files were used for this purpose in the same tooth.	It seems that these files may be used interchangeably during the course of root canal therapy without compromising the working length.
Ex vivo accuracy of three electronic apex locators using different apical file sizes	2012	Vasconcelos, BC.	Evaluate the accuracy of three electronic apex locators (Root ZX, Novapex, and Justy II) in root canal length determinations using different apical file sizes, considering the apical constriction (AC) and the major foramen (MF) as anatomic references	Under the conditions of the present study, all devices provided acceptable electronic measurements regardless of file adjustment, except for Root ZX which had its performance improved significantly. Justy II and Novapex provided electronic measurements nearest to the AC. when the precisely fit apical file was used.

Contd...

Supplementary Table 2: Contd..

Title	Year	First author name	Factors investigated	Findings
An *ex vivo* investigation of the relationship between apical root impedance and canal anatomy	2011	Ardeshna, SM.	Investigate a possible relationship between apical root impedance and canal anatomy.	Canal anatomy had a significant effect on the equivalent circuit describing its impedance characteristics. It is theoretically possible to use impedance spectroscopy to clinically predict and image apical canal complexities.
Investigation of apex locators and related morphological factors	2010	Ding, J.	Investigate the ability of three (EALs) (Root ZX, Elements and Raypex 5) to detect the minor foramen and morphological influencing factors relative to working length determination.	When the ''minor foramen'' reading was given, the file tip connected to the Root ZX was much closer to the major foramen than the other two EALs. The minor for- amen's morphology and the major foramen's location were both important influencing factors on the performance of EALs
Histomorphometric Study of the Root Apex of Mandibular Premolar Teeth: An Attempt to Correlate Working Length Measured with Electronic and Radiograph Methods to Various Anatomic Positions in the Apical Portion of the Canal	2008	Hassanien, EE.	Relate the position of the cementodentinal junction (CDJ) and the apical constriction to that of the apical foramen in mandibular premolars, as well as to measure the canal diameter at these various points.	There was a statistically significant difference between file-tip position from apical foramen in group I working length measured by Root ZX and group II working length measured radiographically. Also this significant difference was found between file-tip position in both groups and CDJ and apical constriction.
Electronic detection of root canal constrictions	2002	Oishi, A.	Investigate the possibility of detecting root canal constrictions by using an apex locator.	It was suggested that the Root ZX might be useful for detecting root canal constrictions.
Influence of Root Canal Curvature on the Accuracy of Root ZX Electronic Foramen Locator: An *In Vitro* Study	2017	Saatchi, M.	Evaluate the correlation between accuracy of Root ZX electronic foramen locator and root canal curvature.	Root canal curvature did not influence the accuracy of Root ZX foramen locator.
Influence of tooth length on the accuracy of the Root ZX electronic apical foramen locator: an *ex vivo* study	2015	Saatchi, M.	Determine whether tooth length influenced the accuracy of the Root ZX device.	Root ZX device was more accurate in shorter teeth compared to longer ones.
Influence of root canal curvature on the accuracy of an electronic apex locator: An *in vitro* study	2014	Santhosh, L.	Investigate whether the canal curvature has an influence on the accuracy of Electronic Apex Locator.	Considering ± 0.5 mm as tolerance limit for accuracy, the device was 95% accurate for the mild curvature group and 80% accurate for moderate and severe groups.
Effects of simulated lateral canals on the accuracy of measurements by an electronic apex locator	2012	Uzun, O.	To evaluate the accuracy of a ratio-based electronic apex locator (Justy II, Toesco, Japan) for roots with simulated lateral canals.	Measurements obtained with the ratio-based electronic apex locator were not affected by the preparation of simulated lateral canals, and the instrument was able to accurately determine the location of the tooth apex.
Effect of pre-flaring and file size on the accuracy of two electronic apex locators	2010	Brito-Junior, M.	Effect of preflaring and le size on the accuracy of the Root ZX and Novapex EALs	The tested EALs showed acceptable accuracy, whereas the preflaring procedure revealed a more significant effect than the used le size.
Influence of preflaring on the accuracy of length determination with four electronic apex locators	2009	de Camargo, EJ.	Compare the influence of preflaring on the accuracy of 4 electronic apex locators (EALs): Root ZX, Elements Diagnostic Unit and Apex Locator, Mini Apex Locator, and Apex DSP.	The Root ZX and the Mini Apex Locator devices increased significantly the precision to determine the real working length after the pre- flaring procedure. All the EALs showed an acceptable determination of the working length between the ranges of 0.5mm except for the Apex DSP device, which had the lowest accuracy.

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Supplementary Table 2: Contd..

Title	Year	First author name	Factors investigated	Findings
An *in vitro* evaluation of the accuracy of Dentaport ZX apex locator in enlarged root canals	2007	Ebrahim, AK.	Examine the effects of root canal irrigants on the accuracy of Dentaport ZXTM® electronic apex locator (EAL) in enlarged root canals	The Dentaport ZX was accurate and not adversely affected by the presence of 0.5% or 2.5% NaOCl and EDTA in the enlarged canals, and the measured lengths obtained with small and large size files were comparable. However, it was accurate in the presence of CHX and RC Prep only when large size files were used, and the length measured with small size files was greater than the actual length.
Effect of preflaring on Root ZX apex locators	1999	Ibarrola, JL.	To determine if preflaring of canals would facilitate the passage of files to the apical foramen by elimi- nating cervical interferences and to see what effect this would have on the performance of the Root ZX apex locator.	Results of this study suggest that preflaring of canals will allow working length files to more consistently reach the apical foramen (p = 0.015), which in turn increases the efficacy of the Root ZX apex locator.
Effect of endodontic preflaring on electronic determination of working length	2011	Lopez, FU.	To evaluate the effect of preflaring on the electronic measurement of working length in mesiobuccal roots of maxillary molars.	Based on the lack of clinical significant relevance of the comparisons carried out in the present study, it is possible to conclude that electronic working length measurement can be carried out either before or after cervical preparation.
Preflaring effects on the accuracy of three electronic apex locators	2011	Morgental, RD.	To compare the accuracy of three electronic apex locators (EALs) and evaluate the influence of cervical preflaring in them.	The Novapex was more accurate compared to the Mini Apex and Propex II. Preflaring procedure was advantageous for all EALs.
Changes in Root Canal Length Determined during Mechanical Preparation Stages and Their Relationship with the Accuracy of Root ZX II	2016	Vasconcelos, BC.	To determine the variations in root canal length (RCL) occurring dur- ing endodontic treatment stages (initial, preflared, and concluded) and correlate them with the accuracy of Root ZX II (RZX).	Under the conditions of this study, the authors concluded that during endodontic treatment, the extent of the RCL was reduced, thereby jeopardizing control of the apical limit during instrumentation and/or obturation. The RZX was extremely accurate in all evaluated stages.
Accuracy of an Electronic Apex Locator for Working Length Determination in Primary Anterior Teeth	2015	Bahrololoomi, Z.	To evaluate the accuracy of Root ZX EAL for working length determination in primary anterior teeth.	Root ZX EAL can be used as a reliable tool for obtaining root canal length in primary anterior teeth with resorption.
Electronic determination of root canal working length in primary molar teeth: an *in vivo* and *ex vivo* study	2011	Beltrame, AP.	To evaluate *in vivo* and *ex vivo* the accuracy of an electronic apex locator in primary molar teeth with or without root resorption.	The Root ZX apex locator was accurate in determining *in vivo* and *ex vivo* the working length ±1 mm in primary molar teeth in over 90% of roots regardless of the presence of root resorption
Accuracy of two different apex locators in primary teeth with and without root resorption	2008	Bodur, H.	To assess the accuracy of two frequency apex locators, Root ZX (Morita, Kyoto, Japan) and Endex (Osada, Tokyo, Japan) in primary teeth with and without root resorption *in vitro*	There were no significant differences between the two apex locators considering the presence of root resorption. The two frequency apex locators can be recommended for use in root canal therapy for primary teeth with and without root resorption, only if electrical determination of root canal length is supported with other diagnostic measures.
A comparative evaluation of root canal length measurement techniques in primary teeth	2012	Chougule, RB.	To comparatively evaluate the accuracy of radiograph-based and apex locator-based measurements of working length in primary molars with physiological root resorption.	Apex locators can be considered a viable substitute for radiographs in estimating working length during pulpectomies of primary teeth.

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Title	Year	First author name	Factors investigated	Findings
Formulating a regression equation for determination of working length in primary molars using apex locators: a clinical study	2013	Dandempally, A.	To evaluate, *in vivo*, the accuracy of the electronic apex locators in determining working lengths in primary teeth with and without resorption in comparison with Ingles radiographic method.	Apex locators are reliable when compared with Ingles radiographic method and can enhance the safety of treatment in specific situations such as presence of root resorption.
Effectiveness of electronic apex locator during the root canal length in primary teeth: An *in vitro* study	2015	de Sousa, DL.	To evaluate the use of electronic apex locator to measure the root canal length in primary teeth, comparing this measure with the measurements obtained by conventional radiography and by the direct measurement of the root canal length.	Electronic apex locator was an accurate method measure the root canal length in primary teeth, and its use is indicated in endodontic treatment of these teeth.
Determining the apical terminus of root-end resected teeth using three modern apex locators: a comparative *ex vivo* study	2005	ElAyouti, A.	To assess *ex vivo* the accuracy of various electronic apex locators in locating the apical terminus of root-end resected teeth.	Under the conditions of this study all three apex locators were able to detect the apical terminus of root-end resected teeth with an acceptable range. The Root ZX device was the most accurate without over-instrumentation of the root canals.
Evaluation of the Root ZX apex locator in primary teeth	2008	Ghaemmaghami, S.	to evaluate the accuracy of the Root ZX electronic apex locator in determining canal length in primary incisors	Root ZX can accurately assess the length of canals in primary incisors.
A comparative evaluation of electronic and radiographic determination of root canal length in primary teeth: An *in vitro* study	2012	Krishnan, I. S.	To compare the root canal length determination by Electronic apex locator (EAL) (Raypex 5) and conventional radiography, and then compare them with the actual measurements obtained by direct visualization	EALs proved to be more accurate in determining the root canal length than the radiographic method.
Ex vivo evaluation of the accuracy of two electronic apex locators during root canal length determination in primary teeth	2008	Leonardo, M. R.	To evaluate *ex vivo* the accuracy of two electronic apex locators during root canal length determination in primary incisor and molar teeth with different stages of physiological root resorption.	Root ZX II and Mini Apex Locator proved useful and accurate for apex foramen location during root canal length measurement in primary incisors and molars.
Ex vivo performance of five methods for root canal length determination in primary anterior teeth	2010	Mello-Moura, A. C.	To evaluate in a laboratory setting the performance of five methods for the determination of root canal length in primary anterior teeth.	The EAL method performed best for root canal length determination in primary teeth.
Accuracy of the iPex multi-frequency electronic apex locator in primary molars: an *ex vivo* study	2010	Nelson-Filho, P.	To evaluate *ex vivo* the accuracy of the iPex multi-frequency electronic apex locator (NSK Ltd, Tokyo, Japan) for working length determination in primary molar teeth	In this laboratory study, the iPex accurately identified the apical foramen or the apical opening location for working length measurement in primary molar teeth.
Clinical evaluation of apex locator and radiography in primary teeth	2015	Oznurhan, F.	To evaluate the accuracy and reliability of electronic apex locater and radiographic determination of root canal length in primary teeth.	The electronic apex locators could be useful in determining working length and thereby decreasing the need for radiographs and exposure to ionizing radiation in pediatric dental patients.
Clinical evaluation of Root ZX II electronic apex locator in primary teeth	2012	Saritha, S.	To evaluate the accuracy of Root ZX II electronic apex locator (EAL) for root canal working length determination in primary teeth.	Root ZX II EAL can be used as a reliable device for obtaining root canal length in primary maxillary incisor teeth.

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Title	Year	First author name	Factors investigated	Findings
An *in vitro* comparison of root canal measurement in primary teeth	2005	Subramaniam, P.	Compare the accuracy of root canal lengths in primary teeth determined by tactile sense, electronic apex locator, conventional radiography, and digital radiography in primary teeth.	No statistically significant differences were seen between the techniques (Using EALs and Radiography).
Accuracy of two electronic apex locators in primary teeth with and without apical resorption: a laboratory study	2008	Tosun, G.	To evaluate the accuracy of the Root ZX (J Morita Corp., Kyoto, Japan) and Tri Auto ZX (J Morita Corp.) devices for measuring root canal length in primary teeth with and without apical resorption.	Within the limitations of this laboratory study, the presence of resorption affected the performance of the Tri Auto ZX more than the Root ZX.
Root canal length determination by different methods in primary teeth: an *in vivo* study	2013	Wankhade, A. D.	To evaluate and compare the accuracy of root canal lengths (RCLs) in primary teeth using different clinical methods.	A fifth-generation electronic apex locator was found to be useful in accurately determining root canal lengths of primary teeth with or without physiological root resorption.
Detection and measurement of endodontic root perforations using a newly designed apex-locating handpiece	1999	Zmener, O.	Detection and measurement of endodontic root perforations using a newly designed apex-locating handpiece (Tri Auto ZX)	The results of this study revealed that the Tri Auto ZX detected and measured endodontic root perforations within a range of clinically acceptable variations.
Comparative evaluation of the accuracy of two electronic apex locators in determining the working length in teeth with simulated apical root resorption: An *in vitro* study	2016	Saraswathi, V.	This study was done to compare the accuracy of two generations of apex locators (Raypex 5 and Apex NRG XFR) in teeth with simulated apical root resorption	There was no significant difference in the accuracy between the two apex locators. Neither of the two apex locators were 100% accurate in determining the WL.
In vitro detection of simulated apical root perforation with two electronic apex locators	2010	Nazari Moghaddam, K.	To evaluate the accuracy of two electronic apex locators (Smarpex and NovApex) in detecting apical perforation.	Although no significant difference was shown between Smarpex and NovApex, these results suggest that electronic apex locators can effectively and reproducibly detect root canal perforation
Accuracy of electronic apex locators to detect root canal perforations with inserted metallic posts: an *ex vivo* study	2014	Marroquin, B. B.	To investigate the accuracy of apex locators to diagnose perforations with with inserted metallic posts with five different apex locators (ProPex II, Elements Apex Locator, Apex NRG, Raypex 5 and Raypex 6).	All devices determined root canal perforations, due to metallic posts, within clinical acceptable ranges
The effectiveness of two apex locators in detecting simulated horizontal root fractures: An *in vitro* study	2016	Handa, A.	To evaluate the accuracy of two electronic apex locators (EALs): Root ZX and Propex II, in the detection of fractures in teeth having simulated horizontal root fractures (HRF)	The investigated EALs are capable of determining the working length of the HRF and that Root ZX showed a higher accuracy rate in detection of simulated horizontal root fractures.
The evaluation of four electronic apex locators in teeth with simulated horizontal oblique root fractures	2008	Goldberg, F.	The accuracy of four electronic apex locators (EALs) (ProPex (Dentsply Maillefer, Ballaigues, Switzerland), the NovApex (Forum Technologies, Rishon Le-Zion, Israel), the Root ZX (J. Morita Corp, Kyoto, Japan), and the Elements Apex Locator (SybronEndo, Orange CA) to locate the apical limit in teeth with simulated horizontal oblique root fractures was investigated	No statistical significant differences between the EALs at either tolerance level.

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Title	Year	First author name	Factors investigated	Findings
In vitro measurement accuracy of an electronic apex locator in teeth with simulated apical root resorption	2002	Goldberg, F.	To evaluate the accuracy of Root ZX apex locator to determine the working length in teeth with simulated apical root resorption.	The Root ZX was 62.7%, 94.0%, and 100.0% accurate to within 0.5 mm, 1 mm, and 1.5 mm of the direct visual measurements, respectively.
Determination of location of root perforations by electronic apex locators	1996	Fuss, Z.	To evaluate the accuracy of two electronic apex locators, the Sono Explorer Mark 2 Junior (Hakusui, Osaka, Japan) and Apit 2 (Osada, Tokyo, Japan) in detecting root perforations. The adequacy of radiographs for identifying root perforations was also assessed.	Under the *in vitro* conditions of this study, both devices determined the location of the perforations in an acceptable clinical range short of the root surface. · Radiographs were found to be less reliable in identification of perforation locations.
Accuracy of three different electronic apex locators in detecting simulated horizontal and vertical root fractures	2006	Ebrahim, A. K.	To evaluate the accuracy of three electronic apex locators (EALs): Root ZX, Foramatron D10 and Apex NRG, in the detection of fractures in teeth having simulated horizontal and vertical root fractures	The three EALs tested were accurate and acceptable clinical tools in the detection of horizontal root fractures. However, the three EALs were unreliable in detecting the position of vertical root fractures.
In vitro efficiency evaluation of an electronic apex locator in teeth with simulated root resorption	2011	da Silva, E. J. N. L.	This *in vitro* study evaluated the efficiency of electronic apex locator Novapex (Forum Technologies, Israel) in determining the working length, when used in different clinical situations, as in teeth with simulated external and internal resorption.	The results showed that Novapex was highly accurate when considering 1-mm changes in the pre-determined measure. Through this study, we found that the apical locator Novapex was effective, showing to be a reliable method and no significant interference in his reading was detected when simulated external and internal resorption were present.
Accuracy and repeatability of 3 apex locators in locating root canal perforations: an *ex vivo* study	2014	D'Assuncao, F. L.	*Ex vivo* evaluation of the accuracy and repeatability of 3 electronic apex locators (EALs) (Mini Apex Locator, Root SW, and Root ZX II) in locating simulated root canal perforations.	It was concluded that each of these 3 EALs provided excellent *ex vivo* accuracy in locating root perforations and that all tested devices possess excellent *ex vivo* repeatability.
Accuracy of the Justy II Apex locator in determining working length in simulated horizontal and vertical fractures	2004	Azabal, M.	To study the effectiveness of an electronic apex locator (EAL; Justy II; Yoshida Dentcraft, Tokyo, Japan) in locating simulated horizontal and vertical fractures in single roots.	In this laboratory study, the Justy II EAL was able to determine accurately the position of simulated horizontal fractures, but was unreliable when measuring simulated vertical fractures.
Accuracy of an electronic apex locator in primary teeth with root resorption	2009	Angwaravong, O	The aim of this study was to investigate the accuracy of apex locators (ProPex II, Elements Apex Locator, Apex NRG, Raypex 5 and Raypex 6) to diagnose perforations caused during a metal post placement	All devices determined root canal perforations, due to metallic posts, within clinical acceptable ranges.
An *in vivo* comparison of gradient and absolute impedance electronic apex locators	1996	Lauper, R.	Two electronic apex locators based on the gradient (Apit) and absolute (Odontometer) impedance principles were evaluated.	The Apit tended to yield the more reliable results because of the narrower range.
Evaluation of the multifrequency electronic apex locator Joypex 5 in primary teeth	2014	Silva, E. J.	To evaluate *ex vivo* the accuracy of the multifrequency electronic apex locator (EAL) Joypex 5 in primary molars.	The multifrequency EALs Joypex 5 showed adequate accuracy in the root length determination of primary teeth.

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Title	Year	First author name	Factors investigated	Findings
An evaluation of the durability of apex locator insulated probes after autoclaving	1993	Himel, V. T.	To evaluate the durability of insulated probes designed to be used with the Endocater Apex Locator when put through multiple cleaning and autoclaving cycles.	The quality of the probes as they came from the manufacturer was excellent; no defects were found in the coating prior to autoclaving.
Evaluation of the accuracy of three electronic apex locators using glass tubules	2006	Fan, W.	The Root ZX, Propex and Neosono Ultima EZ were used to measure the tubule length with tubules dry, or filled with 0.9% NaCl, 3% H(2)O(2), 2.5% NaOCl or 17% EDTA.	The accuracy of the Root ZX decreased as the tubule diameter increased when tubules were filled with electrolytes. The electrolytes in the tubules decreased the accuracy of Propex when the tubule diameter was large. The electrolytes in tubules and tubule diameter had no influence on the accuracy of Neosono Ultima EZ. The Propex and Neosono Ultima EZ were more accurate than the Root ZX under various conditions in this laboratory study.
Evaluation of electrical impedance ratio measurements in accuracy of electronic apex locators	2015	Kim, P. J.	Evaluating the ratios of electrical impedance measurements reported in previous studies through a correlation analysis in order to explicit it as the contributing factor to the accuracy of electronic apex locator (EAL).	Using the ratio method, the apical constriction was located within a linear interval. Therefore, using the impedance ratio between electrical impedance measurements at different frequencies was a robust method for detection of the apical constriction.
In vivo characterization of the electrical impedance between the electrodes of the electronic foramen locators	2013	Gamba, H. R.	Characterizing Z E as a function of frequency and endodontic file tip position.	The spectral attenuation of Z E has an exponential decay for all file tip distances from the AF. It supports the feasibility of ESAC to accurately locate the root canal AF. Moreover, using frequencies steps of one octave makes the implementation of ESAC in an embedded system easier.
Comparison of third generation versus fourth generation electronic apex locators in detecting apical constriction: An *in vivo* study	2015	Swapna, D. V.	Comparing the accuracy of Root ZX and Raypex 5 in detecting minor diameter in human permanent single-rooted teeth.	On analyzing the results of our study it can be concluded that Raypex 5 was as effective as Root ZX in determining the minor diameter.
Accuracy of root canal length determination with the impedance ratio method	2009	Jan, J.	To provide insight into the principles of operation of electronic apex locators, determine optimal measuring parameters of the impedance ratio method, and to evaluate its accuracy.	With the obtained optimal measuring parameters, the impedance ratio method determined position of the major foramen within +/-0.5 mm. Accuracy varied depending on the set of frequencies used for evaluation as well as on the selected impedance ratio.
Accuracy of five electronic foramen locators with different operating systems: an *ex vivo* study	2013	Vasconcelos, B. C.	To evaluate, *ex vivo*, the precision of five electronic root canal length measurement devices (ERCLMDs) with different operating systems: the Root ZX, Mini Apex Locator, Propex II, iPex, and RomiApex A-15, and the possible influence of the positioning of the instrument tips short of the apical foramen.	Under the conditions of the present study, all the ERCLMDs provided acceptable measurements at the 0.0 position. However, at the -1.0 position, the ERCLMDs had a lower precision, with statistically significant differences for the Propex II, iPex, and RomiApex A-15.
In vivo accuracy of two electronic foramen locators based on different operation systems	2014	Vasconcelos, B. C.	To compare *in vivo* the accuracy of two electronic foramen locators (EFLs) based on different operation systems - Root ZX and Propex II.	Despite having different measurement mechanisms, both EFLs were capable of locating the apical foramen with high accuracy *in vivo*. Under the tested clinical conditions, Root ZX and Propex II displayed similar results.

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Title	Year	First author name	Factors investigated	Findings
An *in vivo* comparison of two frequency-based electronic apex locators	2003	Welk, Ar	To compare the accuracy of a two-frequency (Root ZX) and a five- frequency (Endo Analyzer Model 8005) electronic apex locator under clinical conditions.	The use of EALs is a reliable method for determining root canal length. The Root ZX was able to predictably locate the minor diameter (0.5 mm) (90.7% accuracy) more frequently than the Apex Finder AFA Model 8005 (34.4% accuracy)
Anatomical challenges, electronic working length determination and current developments in root canal preparation of primary molar teeth	2013	Ahmed, H. M.	This review aims to discuss the application of electronic apex locators in primary molars	Application of EALs in pediatric endodontics demonstrate the following advantages: (i) accurate determination of the working length; (ii) reduced tension amongst the operator, child and family attributed to the simplicity of the procedure (which is the opposite case in radiographic examination, with cooperation from children usually achieved with difficulty); (iii) reduced exposure to radiation; (iv) shorter treatment time due to favourable attitude and cooperation of children; and (v) detection of root perforations resulting from internal or external root resorption, which can be undetected radiographically.
Ex vivo evaluation of the accuracy of Raypex® 5 In determining the minor diameter	2011	Cimilli, H.	Assessing the accuracy of Raypex® 5 electronic apex locator (EAL) in determining the minor diameter	Although the Raypex® 5 could not determine the minor diameter 100 % under *ex vivo* experimental conditions; the results of this study clinically could be acceptable.
Comparing the accuracy of four electronic apex locators for determining the minor diameter: An *ex vivo* study	2013	Cimilli, H.	Assessing the accuracy of the minor apical diameter, as measured by the Root ZX II, Raypex 5, Propex, and ATR EndoPlus electronic apex locators (EALs).	The accuracy of these instruments for detecting the minor diameter is acceptable for clinical practice.
Ex Vivo Evaluation of the Accuracy of Electronic Foramen Locators in Root Canals with an Obstructed Apical Foramen	2015	de Vasconcelos, B. C.	To evaluate the accuracy of electronic foramen locators (EFLs), Root ZX II (RZX; J. Morita, Tokyo, Japan), Propex II (Dentsply Maillefer, Ballaigues, Switzerland), and Apex ID (AID; SybronEndo, Glendora, CA), in root canals with an obstructed apical foramen (OAF) and to compare them with those 1.0 mm short of the apical foramen (AF; -1.0) and at the AF (0.0).	No significant differences were found between the devices at 0.0; however, for the measurements at -1.0 and the OAF, the AID offered significantly better results than RZX ($P < .05$). The absence of foraminal patency caused by dentin debris obstruction affects the accuracy of the EFLs differently, suggesting distinctive interactions with their operating mechanisms.
Ex vivo evaluation of the ability of four different electronic apex locators to determine the working length in teeth with various foramen diameters	2006	Ebrahim, Ak	The aim of this study was to evaluate the accuracy of four electronic apex locators (Root ZX, formatron D10, Apex NRG, Apit 7) to determine the working length in teeth with various foramen diameters.	The four EALs were unreliable to determine the working length of teeth with a wide apical foramen, when using a small size file. The Root ZX and Foramatron D10 showed significantly better scores than the other two EALs and may be more reliable to determine the working length of teeth with a wide apical foramen, if a tight-fit file is used.

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Title	Year	First author name	Factors investigated	Findings
Influence of apical constriction diameter on Root ZX apex locator precision	2007	Herrera, M.	To assess the influence of apical constriction diameter on the precision of the Root ZX apex locator by using files of varying diameter on teeth with 3 different degrees of apical widening: 0.37, 0.62, and 1.02 mm.	In those teeth whose apical width had been increased to 1.02 mm, there was no statistically significant difference between initial and final working lengths as measured by files from #10-#25; however, significant differences were apparent between #10 and #30, #35, or #40 (P<.05), and the degree of significance increased considerably (P<.001) for files #45 or greater. These results suggest that Root ZX apex locator precision varies as a function of apical constriction diameter.
Evaluation of Correlation Between apical Diameter and File Size Using Propex Pixi Apex Locator	2014	Kolanu, S. K.	To evaluate the influence of critical diameter of apical foramen and file size using propex pixi apex locator in working length determination.	Propex pixi is accurate for foramen diameter of 0.6mm, independent of file size. Its accuracy decreases as apical foramen widens, so care should be taken when using clinically.
The influence of determining the working length with an apex locator on the amount of apically extruded debris following instrumentation with ProTaper Next and HyFlex CM	2016	Çiçek, E.	To compare the amount of apically extruded debris with/ without an apex locator.	The usage of apex locator to determine the WL decreased the amount of apically extruded debris.
Evaluating Electromagnetic Interference of Communication Devices with Root ZX Mini Apex Locator	2017	Shafiebavani M,	To investigate the possibility of Electromagnetic interference.	EMWs of 2G and 3G not causes malfunctions of the Root ZX mini apex locator except conversation with 2G at the direct contact.
Do Cell Phones Affect Establishing Electronic Working Length?	2015	Hurstel, J.	The purpose of this *ex vivo* study was to determine the ef- fect of a cell phone (Apple iPhone 5 [Apple, Cupertino, CA] or KP100 [LG, Seoul, Korea]) placed into direct con- tact with an electronic apex locator (EAL) (Dentaport Root ZX module [J Morita Corp, Tokyo, Japan] or Propex II [Dentsply Maillefer, Ballaigues, Switzerland]) on work- ing length determination .	Neither the cell phone type nor the EAL affected the measurements (not significant). The electronic working length measurements gave the same results as the visual examination, and this length was not influenced by direct contact with a cell phone (not significant). It was also possible to determine the elec- tronic working length under all the experimental conditions.
Evaluation of Interference of Cellular Phones on Electronic Apex Locators: An *In Vitro* Study	2016	Sidhu, P.	The purpose of this *in vitro* study was to evaluate the effect of a smart phone (Samsung Galaxy Note Edge) on working length determination of electronic apex locators (EALs) Propex II and Rootor.	The EWL measurements were not influenced by the presence of cellular phone and could be determined under all experimental conditions
Influence of pulp vitality on length determination by using the Elements Diagnostic Unit and Apex Locator	2007	Akisue, E.	To compare the influence of the pulp condition (vital or necrotic) on the determination of the root canal length by using Elements Diagnostic Unit.	Under clinical conditions within an acceptable range lower than 0.5 mm, the concordance between the 2 measurements was 96.6%. This new EAL showed no significant difference (P .05) on accuracy of root canal length determination between vital cases (94.8%) and necrotic cases (97%).
An *in vivo* evaluation of an electronic apex locator that uses the ratio method in vital and necrotic canals	1998	Dunlap, C. A.	To compare the canal length determined by an apex locator (Root ZX) to the apical constriction in both vital and necrotic canals.	There was no statistical difference between the ability of the Root ZX to determine the apical constriction in vital canals versus necrotic canals.

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Title	Year	First author name	Factors investigated	Findings
Influence of pulp condition on the accuracy of an electronic foramen locator in posterior teeth: an *in vivo* study	2012	Renner, D.	The aim of this study was to assess, *in vivo*, the accuracy of the NovApex(R) electronic foramen locator in determining working length (WL) in vital and necrotic posterior teeth.	Pulp condition had no significant effect on the accuracy of NovApex(R).
In vitro evaluation of the accuracy of five different electronic apex locators for determining the working length of endodontically retreated teeth	2007	Ebrahim, A. K.	To evaluate the accuracy of five electronic apex locators (EALs) in determining the working length (WL) of teeth after removal of the root canal obturation materials.	The Dentaport ZX, ProPex and Foramatron D10 were more accurate than the other two EALs in determining the WL in teeth after removal of the root canal obturation materials. However, the Apex NRG and Apit 7 were also reliable for determination of the WL in the majority of the cases.
In vitro evaluation of the ability of three apex locators to determine the working length during retreatment	2005	Goldberg, F.	To evaluate the accuracy of three apex locators in determining the working length during the retreatment process.	ProPex, NovApex, and Root ZX were accurate within 0.5 mm 80, 85, and 95% of the time, and within 1 mm 95, 95, and 100%, respectively. No significant differences were detected between the three apex locators ($p > 0.05$).
Accuracy of an electronic foramen locator in determining working length during retreatment: An *in vitro* study	2015	Lassen, C.	To assess, *in vitro*, the accuracy of MiniApex® for electronic working length (EWL) determination during three stages of root canal treatment/ retreatment: EWL-1 (during treatment), EWL-2 (after filling removal), and EWL-3 (after reinstrumentation).	MiniApex® was highly accurate to determine the location of the instrument tip at 0.5 to 2.0mm from the radiographic apex during treatment and retreatment (EWL-2 and EWL-3)
Accuracy of an electronic apex locator in the retreatment of teeth obturated with plastic or cross-linked gutta-percha carrier-based materials: an *ex vivo* study	2014	Mancini, M.	To evaluate the accuracy of the Root ZX electronic apex locator (EAL) (J Morita Corp, Kyoto, Japan) in determining the working length during retreatment of canals sealed with 2 different carrier-based obturating materials (ProTaper Obturator [Dentsply Maillefer, Ballaigues, Switzerland] and GuttaCore [Dentsply Maillefer]) and also evaluated whether they influenced its accuracy differently.	The measurements obtained with the EAL tested during orthograde retreatments can lead clinicians to overinstrumentation and consequent overfilling of the endodontic space.
In vitro evaluation of the precision of four different electronic apex locators in determining the working length of teeth after removing root canal obturation materials	2008	Stavrianos, C. H. R.	To evaluate *in vitro* the accuracy of 4 different Electronic Apex Locators (EALs) (Dentaport ZX (J. Morita Co. Kyoto, Japan), RayPex 5 (VDW GmbH, Germany), Endo Master (Electro Medical Systems SA, Switzerland) and Bingo-1020 (Dent Corp research and development U.S.A.)). For determining the Working Length (WL) of endodontically retreated teeth.	The EALs Dentaport ZX and Endo Master were more accurate than the other two EALs in determining WL in retreated teeth. However, the RayPex 5 and the Bingo 1020 were also reliable in the majority of cases.
Apical accuracy of two apex-locating handpieces in root canal retreatments of root-end resected teeth	2007	Uzun, O.	To evaluate the accuracy of 2 apex locator integrated endodontic motors (Tri Auto ZX and TCM Endo V) during retreatment of root-end resected teeth by using 40 extracted incisor teeth.	Electronic apex locator functions of both devices might be used for apical accuracy, but the auto reverse functions might not be useful to 0.0-mm accuracy in retreatment procedures of root-end resected teeth.

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Supplementary Table 2: Contd..

Title	Year	First author name	Factors investigated	Findings
Combination of apex locator and endodontic motor for continuous length control during root canal treatment	2009	Altenburger, M. J.	To compare *ex vivo* an experimental setup consisting of an electronic apex locator (EAL) (Raypex 5)and endodontic motor with an established product (Tri Auto ZX) for accuracy of length control during root canal treatment with three different types of files.	With the limitation of this laboratory study the combination of EAL and endodontic motor was as accurate as the Tri Auto ZX system in terms of length control during root canal preparation.
Accuracy of electronic apex locater-controlled handpieces	2009	Barthelemy, J.	An *in vitro* model was used to test a hypothesis that the manual (apex locator) and motor-driven (apex locator-controlled handpiece) operating modes of 3 newly developed apex-locator-controlled handpiece devices (Dentaport ZX, Endomaster, XSmart Dual) give the same working length.	We concluded that although the motor-driven mode of these devices appeared to be clinically safe, measurements obtained in manual and motor-driven operating modes are not equivalent.
Apical extent of rotary canal instrumentation with an apex-locating handpiece *in vitro*	1998	Campbell, D.	The purpose of this investigation was to examine the apical extent of rotary canal instrumentation and the ability to maintain apical constriction with the Tri Auto ZX at different automated settings.	Instrumentation with the automatic apical reverse feature set at 1 consistently approximated the apical constriction; however, the constriction was frequently enlarged.
Accuracy of 2 Endodontic Rotary Motors with Integrated Apex Locator	2017	Cruz, A. T. G.	To evaluate *in vitro* the efficacy of both the electronic apex locator (EAL) and auto apical reverse (AAR) functions of the endodontic motor MM Control (Micro-Mega, Besancon Cedex, France) compared with Root ZX II (J Morita, Tokyo, Japan).	The AAR function of both MM Control and Root ZX II provided an adequate apical limit of preparation *in vitro*. However, the use of only the EAL function of MM Control resulted in significantly more cases of overextended readings.
An *in vivo* evaluation of the auto apical reverse function of the Root ZX II	2012	Fadel, G.	To evaluate *in vivo* the accuracy of the Root ZX II (J. Morita) apex locator in controlling the apical extent of rotary instrumentation when using the Auto Apical Reverse (AAR) set at the levels 0.5, 1.0 and 1.5.	The AAR function of the Root ZX II was not an accurate method for controlling the apical extent of rotary instrumentation *in vivo*. The setting 0.5 presented overinstrumentation in most of the canals, the setting 1.5 was short in all cases, and the setting 1.0 provided an adequate working length in only 50% of the teeth.
In vivo determination of root canal length: a preliminary report using the Tri Auto ZX apex-locating handpiece	2002	Grimberg, F.	To assess the clinical perfomance of a cordless handpiece with a built-in apex locator - the Tri Auto ZX - designed for root canal preparation with nickel-titanium rotary files.	It was concluded that the Tri Auto ZX was useful and reliable. The Tri Auto ZX measurements protected against overpreparation.
Evaluation of Two New Electronic Apex-Locator-Controlled Handpieces Using a NiTi Rotary File: An *In Vitro* Study	2013	Nazarimoghadam, K.	To compare the accuracy of two new electronic apex-locator controlled handpieces (EALHs) using the first rotary Mtwo file while rotating in the canal.	Both Dentaport ZX and VDW Gold were suitable for determining working length using a rotary file. To avoid over instrumenting the canal, we recommend setting the devices to automatically stop or reverse the rotary file at 1 mm level.
An *in vivo* comparison of the Root ZX II, the Apex NRG XFR, and Mini Apex Locator by using rotary nickel-titanium files	2009	Siu, C.	To compare the accuracy of working length (WL) measurements by using the Root ZX II, Apex NRG XFR, and Mini Apex Locator with rotary nickel-titanium (NiTi) instruments.	The Root ZX II, Apex NRG XFR, and Mini Apex Locator used with rotary NiTi files were able to locate the apical constriction within +/-0.5 mm only 50% or less of the time.

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Title	Year	First author name	Factors investigated	Findings
An *in vitro* stereomicroscopic comparative evaluation of a combination of apex locator and endodontic motor with an integrated endodontic motor	2013	Swarupa, Ch	To compare the efficacy of an integrated apex locator and an apex locator and endodontic motor assembly in maintaining the working length when operated under autoreverse mode.	The assembly of ProPex-NSK Endo-mate DT and the apex locating endomotor TCM Endo V Nouvag are clinically acceptable.
Accuracy of two apex-locating handpieces in detecting simulated vertical and horizontal root fractures	2008	Topuz, O.	To evaluate *in vitro* the effectiveness of TCM Endo V and Tri Auto ZX handpieces in detecting simulated horizontal and vertical root fractures.	Both handpieces detected the root fractures in an acceptable range. Furthermore, electronic apex locator function of both devices was more efficient in the process than auto reverse function.
Effects of dissolving solutions on the accuracy of an electronic apex locator-integrated endodontic handpiece	2013	Ustun, Y.	The effects of three dissolving agents on the accuracy of an electronic apex locator-(EAL-) integrated endodontic handpiece during retreatment procedures were evaluated.	The ARL function of the handpiece gave acceptable results. There were significant differences between the EL mode measurements and the TL ($P < 0.05$). In these comparisons, Tri Auto ZX EL mode measurements were significantly shorter than those of the TL.
Accuracy of two root canal length measurement devices integrated into rotary endodontic motors when removing gutta-percha from root-filled teeth	2008	Uzun, O.	To evaluate *ex vivo* the accuracy of the integrated electronic root canal length measurement devices within TCM Endo V® and Tri Auto ZX® motors whilst removing gutta-percha and sealer from filled root canals.	The auto reverse function of the Tri Auto ZX® and TCM Endo V® devices, set to start at 0.5 level, were initiated beyond the foramen in the majority of root-filled teeth during active (rotating) penetration of root filling material. Thus, this automatic function must be used with caution when removing gutta-percha root fillings. There were significant differences between the accuracy of measurements in active (rotating) and passive (not-rotating) modes; both devices were more accurate when used in passive mode. However, the Tri AutoZX® was significantly more accurate in a greater proportion of cases.
Accuracy and reliability of working length determination by Gold Reciproc Motor in reciprocating movement	2014	Wigler, R.	The purpose of this study was to assess the accuracy and reliability of the apex locator function of the Gold Reciproc Motor (VDW GmbH, Munich, Germany) during reciprocating movement.	With the limitation of this *ex vivo* study, the Gold Reciproc Motor's integrated electronic apex locator was found to be as reliable and accurate as the Root ZX and Bingo 1020 apex locators in terms of length control during root canal preparation in the reciprocation mode.
Interference of apex locator, pulp tester and diathermy on pacemaker function	2015	Sriman,N	The purpose of this study was to evaluate the effects of three electronic apex locators (EAL), electric pulp tester (EPT) and diathermy on pacemaker function *in vitro*.	The tested EALs do not interfere with cardiac pacemaker function.
Electromagnetic interference effect of dental equipment on cardiac implantable electrical devices: A systematic review	2020	Niu, Y	The electromagnet interference (EMI) effect resulting from using dental equipment near cardiovascular implantable electronic devices (CIEDs) is controversial based on *in vitro* and *in vivo* studies. We aimed to summarize the available evidence to investigate the safety of using dental equipment on patients with CIEDs.	This systematic review indicates that most dental instruments can be used safely in routine dental practice. The EMI effect of dental equipment depends on the exposure distance and lead-related parameters of the CIEDs.

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Title	Year	First author name	Factors investigated	Findings
Risk of electromagnetic interference induced by dental equipment on cardiac implantable electrical devices	2016	Miranda-Rius, J	This study evaluated *in vitro* the risks associated with different types/makes of cardiac devices and types of dental equipment.	Among the dental equipment, the electric pulp tester had the greatest risk of inducing interference and therefore this device was used as the benchmark. The electronic apex locator (PR = 0.29), Periotest M (PR = 0.47), and the ultrasonic dental scaler (PR = 0.59) were less likely to induce interference than the electric pulp tester. The risk was lowest with the electronic apex locator.
The effects of six electronic apex locators on pacemaker function: an *in vitro* study	2013	Gomez, G	To assess the effects of six electronic apex locators (EALs) on pacemaker function *in vitro*.	EMI occurred when the EALs were placed close to the tip of the electrode and occasionally when close to the pacemaker; however, no EMI was detected when the EALs were placed near to or 15 cm from the sensing arc in this laboratory experimental model.
Electromagnetic interference of endodontic equipments with cardiovascular implantable electronic device	2016	Dadalti, MT	Assess the electromagnetic interference (EMI) of endodontic equipment with cardiovascular implantable electronic devices (CIEDs) and related factors.	EALs and GH caused EMI which ranged according to type and sensitivity setting of the CIEDs and the distance. However, no endodontic equipment caused permanent damage to the CIED. The use of GH caused a cumulative effect of electromagnetic fields. It suggests that during the treatment of patients with CIEDs, only the necessary equipments should be kept turned on.
Influence and safety of electronic apex locators in patients with cardiovascular implantable electronic devices: a systematic review	2019	Alrahabi, MK	This systematic review investigated the effects and safety of using electronic apex locators in patients with cardiovascular implantable electronic devices.	Although the present review suggests that electronic apex locators can be used safely in patients with implantable cardioverter defibrillators, consultation with patients' cardiologists remains advisable.
Effect of Various Electronic Devices on the Performance of Electronic Apex Locator	2019	Parirokh, M	The aim of this study was to determine whether a cordless phone set, MP4 player, FM radio, asymmetric digital subscriber line (ADSL), or a mobile phone could influence the accuracy of working length determination by the Dentaport ZX apex locator.	Based on this *in vitro* study, the use of ADSL, MP4 player, mobile phone, and cordless phone during root canal treatment may influence working length determination with the Dentaport ZX apex locator.
Evaluating Electromagnetic Interference of Communication Devices with Root ZX Mini Apex Locator	2016	Iranmanesh, P	The correct determination of working length is a critical factor in the success of endodontic treatment. Nowadays, the electronic apex locators (EALs) is more used because of their ease of use, high accuracy, and the uncertainty of other methods. Because EALs use the electronic method, it is likely that electromagnetic waves (EMWs) affect their performance. This study aims to investigate the possibility of this interference	EMWs of 2G and 3G not causes malfunctions of the Root ZX mini apex locator except conversation with 2G at the direct contact.
Electromagnetic interference of smartphones on apex locators: An *in vivo* study.	2016	Silva, E	To assess the effects of EMIs on EAL function *in vitro*.	No adverse effect was found.

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Title	Year	First author name	Factors investigated	Findings
Evaluation of Interference of Cellular Phones on Electronic Apex Locators: An *In Vitro* Study	2016	Sidhu, P	The purpose of this *in vitro* study was to evaluate the effect of a smart phone (Samsung Galaxy Note Edge) on working length determination of electronic apex locators (EALs) Propex II and Rootor.	Within the limitations of this study, it can be concluded that mobile phones do not interfere with the EWL determination.
Do cell phones affect establishing electronic working length?	2015	Hurstle, J	The purpose of this *ex vivo* study was to determine the effect of a cell phone (Apple iPhone 5 [Apple, Cupertino, CA] or KP100 [LG, Seoul, Korea]) placed into direct contact with an electronic apex locator (EAL) (Dentaport Root ZX module [J Morita Corp, Tokyo, Japan] or Propex II [Dentsply Maillefer, Ballaigues, Switzerland]) on working length determination.	Within the limitations of the present study, it can be concluded that patients can keep their cell phones on during root canal therapy without any adverse effect on electronic working length determination.
Electrical impedance measurements of root canal length	1997	Meredith, N	The aims of this investigation were to determine the electrical impedance characteristics of the root canal and periapical tissues *in vivo*, measure the changes relative to the distance of an endodontic instrument from the apical constriction and propose an equivalent circuit modelling the periapical tissues.	The impedance characteristics of a root canal were a complex electrical network comprising resistive and capacitive series and parallel elements.
Effect of canal preparation and residual root filling material on root impedance	2008	Al-Bulushi, A	To investigate the effect of root canal preparation and residual root filling material on the impedance characteristics of extracted human roots.	Impedance was influenced by corono-apical position, chemo-mechanical preparation and residual root canal filling material.
Evaluation of the accuracy of different apex locators in determining the working length during root canal retreatment	2020	Tufenkci, P	his study aimed to assess the accuracy of three electronic apex locators (EALs) (Dentaport ZX [J Morita, Tokyo, Japan], Propex Pixi [Dentsply Maillefer, Ballaigues, Switzerland], and iPex II [NSK, Tokyo, Japan]) during root canal retreatment.	Under the limitations of this study, Dentaport ZX, Propex Pixi, and iPex II can be a useful adjunct during retreatment. Clinicians should be aware that residual materials in the root canal during retreatment can affect the accuracy of EALs.
An *in vitro* evaluation of performance of two electronic root canal length measurement devices during retreatment of different obturating materials	2010	Aggarwal, V	he purpose of this *in vitro* evaluation was to study the accuracy of Root ZX and ProPex system during retreatment of canals obturated with different obturating materials	Root ZX and ProPex can be a useful adjunct with a high accuracy rate during root canal preparation and retreatment.
In vitro comparison of working length determination using three different electronic apex locators	2008	Stavrianos, CHR	The aim of this study was to compare the accuracy of the apex-locating functions of DentaPort ZX, Raypex 5 and Endo Master electronic apex locators (EALs) *in vitro*.	The accuracy of the EALs was evaluated and all of the devices showed an acceptable determination of electronic working length between the ranges of ±0.5 mm.

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Title	Year	First author name	Factors investigated	Findings
Accuracy evaluation of three electronic apex locators in teeth with immature apices	2012	Chita, JJ.	The aim of this randomized controlled study was to evaluate the accuracy of Root ZX, iPex and YS-RZ-A apex locators in tooth with incomplete apices.	The Root ZX apex locator showed the higher accuracy (53.3%), with statistical difference in relation to iPex apex locator (33.3%) and YS-RZ-A apex locator (26.7%)
Effect of Orthodontic Brackets on the Accuracy of Apex Locators: A Pilot Study	2021	Sen, O	The purpose of this study was to evaluate the effect of metal orthodontic brackets on the accuracy of electronic apex locator (EAL).	Use of orthodontic metal brackets can negatively influence the accuracy of the electronic apex locator when the distance between the lip clip and bracket was short. A minimum of 3 cm distance should be kept between the lip clip and tooth in order to make consistent electronic measurements.
In vivo evaluation of ProPex electronic apex locator	2007	Ozsezer, E	The aim of this *in vivo* study was to evaluate the performance of ProPex apex locator after extirpation and in presence of different irrigation solutions: 2.5% NaOCl, 0.9% NaCl, and 0.2% chlorhexidine gluconate solutions.	The results of this study showed that measurements after extirpation had the smallest distance to the ALs. Among the irrigation solution groups, chlorhexidine gluconate group had the smallest distance to the ALs, whereas saline group had the greatest. Most accurate measurements were obtained after extirpation.
Influence of the canal contents on the electrical assisted determination of the length of root canals	2002	Pommer, O	The purpose of this study was to compare the influence of the root canal status on the determination of the root canal length by an electronic apex locator in vital and necrotic canals and canals with root canal filling retrieval.	The authors concluded that the AFA Apex Finder is highly accurate in vital canals.
Comparison of three different apex locators in determining the working length of mandibular first molar teeth with irreversible pulpitis compared with an intraoral periapical radiograph: A block randomized, controlled, clinical trial	2019	Vanitha, S	The aim of the present study was to assess the clinical accuracy APEX and 0.5 marks of three different apex locators - iPex II, Root ZX, and Apex ID - before and after canal preparation in the mandibular first molar.	In the present study, we observed the negligible differences in readings between the EAL at the APEX mark readings, coinciding with the radiographic observation. Clinically, we recommend the apical foramen be located with the apex locators' APEX mark readings prior to identifying the apical constriction position.
Determination of apical constriction and apical foramen using electronic apex locator *in vivo* Comparison between vital and nonvital teeth	2018	Aggarwal, G	The aims of the present study were (1) to compare the *in vivo* accuracy of electronic apex locator (EAL) to locate the apical foramen and apical constriction (AC) in vital and nonvital teeth and (2) to measure and compare the distance between the AC and apical foramen based on EAL readings and those obtained by direct observation under stereomicroscope following extraction of the tooth.	The study supports that EAL measures the location of AC and apical foramen with similar accuracy in vital and nonvital teeth. Furthermore, the distance between the two is reliable when compared with the actual distance observed under stereomicroscope supporting its widespread usage in clinical endodontics.
In vivo measurement accuracy in vital and necrotic canals with the Endex apex locator	1993	Mayeda, DL	This study was undertaken to see what is actually being measured and if the pulp status, i.e. vital or necrotic, makes a difference in the determination.	Results indicate that all measurements were within a narrow range (-0.86 mm to 0.50 mm). There was no statistical difference in measurements between vital and necrotic canals.

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Title	Year	First author name	Factors investigated	Findings
Effect of recapitulation on accuracy of electronically determined canal length	1993	Rivera, EM	The purposes of this study were (1) to compare actual with electronic canal length before and after instrumentation, and (2) to compare the accuracy of electronic length in recapitulated and nonrecapitulated canals.	Data showed that for electronically determined versus actual lengths: 1) 63% were longer, 23% equal, and 13% shorter before instrumentation, 2) 30% were longer, 0% equal, and 70% shorter after instrumentation, 3) instrumentation caused a mean shortening of 0.63 mm, and 4) recapitulation of nonpatent canals was necessary to obtain length reading with the electronic apex locator.
Influence of calcium hydroxide residues after using different irrigants on the accuracy of two electronic apex locators: An *in vitro* study	2020	Shojaee, NS	The purpose of this study was to evaluate the effect of calcium hydroxide (Ca[OH] 2) residues on the accuracy of two electronic apex locators (EALs) (Root ZX and Raypex 6) in the presence of different irrigants.	The present study revealed that no statistically significant differences were observed between the two apex locators after Ca(OH)2 paste removal with different irrigants.
A comparison between two electronic apex locators: an *ex vivo* investigation	2007	Venturi, M	To compare *ex vivo* the performance of the Apex Finder and the Root ZX apex locators, with and without irrigant, in canals having different diameters.	Under the different *ex vivo* conditions both EALs provided accurate measurements when the file tip was at the foramen. 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.
An *ex vivo* evaluation of a new root canal irrigation technique with intracanal aspiration	2006	Fukumoto, Y	To evaluate the effectiveness of a new root canal irrigation technique with intracanal aspiration in removing the smear layer and to assess irrigant extrusion *ex vivo*.	Irrigation using the intracanal aspiration technique allowed more effective removal of the smear layer than that performed by the conventional method in an apically resected canine tooth. The intracanal aspiration technique produced limited extrusion of the irrigant beyond the apical foramen
The influence of two forms of chlorhexidine on the accuracy of contemporary electronic apex locators	2020	Marek, E	The aim of this study was to determine the influence of 2% chlorhexidine digluconate solution, 2% chlorhexidine digluconate gel and 2% hypochlorite solution on the accuracy of two devices: the Raypex 5 and the ApexDal.	The EALs Raypex 5 and ApexDal had higher accuracy in the anatomical foramen of the root containing chlorhexidine in the gel or in the solution form than in the canal containing sodium hypochlorite.
A comparative evaluation of working length with digital radiography and third generation apex locator (ProPex) in the presence of various intracanal irrigants: An *in vivo*/*ex vivo* study	2014	Khursheed, I	he purpose of this *in vivo*/*ex vivo* comparative study was to determine the accuracy in measuring the working length of root canal using Direct Digital Radiographic Method (Radiovisiography or RVG) and ProPex electronic apex locator in the presence of three different irrigating solutions: 0.9% normal saline, 2% chlorhexidine, 3% NaOCl solutions.	Electronic apex locator ProPex yielded best result in the presence of chlorhexidine, whereas the largest error was demonstrated with NaOCl indicating that higher electroconductive irrigating solutions affect the precision of multi-frequency apex locators.
Comparative Evaluation of Accuracy of Two Electronic Apex Locators in the Presence of Contemporary Irrigants: An *In vitro* Study	2018	Baruhah, Q	The present study was aimed to compare the accuracy of Root ZX Mini and Propex II in the presence of 0.1% octinidine dohydrochloride (OCT), 2% chlorhexidine gluconate (CHX), and 5% sodium hypochlorite (NaOCl) heated and nonheated before and after preparation.	Electronic length measurements were shorter with heated and nonheated 5% NaOCl and longer with 0.1% OCT and 2% CHX for both the electronic apex locators.

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Title	Year	First author name	Factors investigated	Findings
Accuracy of Electronic Apex Locator in Enlarged Root Canals with Different Root Canal Irrigants :An *in vitro* Study	2013	Dinapadu, S	To evaluate the accuracy of Root ZX-II (J Morita Corp) apex locator in enlarged root canals with different root canal irrigants.	Root ZX-II was accurate in the presence of 3% NaOCl and 17% EDTA when measured with smaller and larger files. However, it was accurate in the presence of saline and 2% CHX when larger files were used.
The Influence of Various Irrigants on the Accuracy of 2 Electronic Apex Locators in Locating Simulated Root Perforations	2017	Altunbas, D	The aim of this study was to assess the accuracy of the Dentaport ZX (Morita Co, Kyoto, Japan) and the Rootor (Meta Biomed, Cheongwon-gun, Korea) electronic apex locators (EALs) in detecting root perforations in dry conditions and in the presence of the following irrigation solutions: 2.5% sodium hypochlorite (NaOCl), 0.9% saline solution (NaCl), and 17% EDTA.	The Dentaport ZX was more accurate compared with the Rootor in the presence of different irrigants. The content of the root canal affected the accuracy of both EALs. The most accurate measurements were obtained in dry canals.
The effects of sodium hypochlorite concentrations on the accuracy of an apex locating device	2002	Tinaz, AC	This study aimed to evaluate Root ZX accuracy with different NaOCl concentrations and to observe effects of the alginate model when NaOCl was used in the canal during electronic measurements.	Root ZX could be used in root canal length measurements with various NaOCl concentrations. Designation of apical constriction needs more care. The alginate model could be used for *in vitro* electronic measurements with various NaOCl concentrations.
In vitro comparison of working length determination using three different electronic apex locators	2014	Kustarci, A	The aim of this study was to compare the accuracy of the apex-locating functions of DentaPort ZX, Raypex 5 and Endo Master electronic apex locators (EALs) *in vitro*.	The accuracy of the EALs was evaluated and all of the devices showed an acceptable determination of electronic working length between the ranges of ±0.5 mm.
Evaluation of the Accuracy in Four Electronic Apex Locators toward determination of working length of root canal: an in-vitro study	2022	Diemer, F	This *ex vivo* study aimed to measure the performance of an electronic apex locator (EAL) in the presence of sodium hypochlorite irrigants with different concentrations.	Sodium hypochlorite concentration in irrigants does not affect the accuracy and reliability of either the Root ZX Mini or the Locapex 6. Electronic apex locators are reliable with any concentration of sodium hypochlorite irrigants.
Ex Vivo Evaluation of the Accuracy of 3 Electronic Apex Locators in Different Environments: A Micro-Computed Tomography Study	2020	Cinar, F	The aim of this study was to compare the accuracy of three electronic apex locators (EALs) (Propex Pixi, Mini Root ZX, Raypex 5) in determining working length (WL) under different environments (existence of blood-pulp/sodium hypochlorite in root canal space) using micro-computed tomography (micro-CT) measurements.	The accuracy of the tested EALs is not affected by pulp tissues and blood or NaOCl.
Comparison of four electronic root canal length measurement devices	2017	Subay, RK	The objective of this study is to evaluate the performance of four electronic root canal length measurement devices (ERCLMDs) [Root ZX, Raypex 6, ProPex II, and VDW Gold with ERCLMD] in wet and dry root canals with different major foramen diameters, in association with three file positions within the final 1 mm of canals.	All ERCLMDs provided highly accurate measurements within the final 1 mm of the foramen. Wet or dry canals and apex conditions did not adversely affect the accuracy of the ERCLMDs' readings. ProPex II located the file positions in the teeth with different foramen diameters more accurately than the other ERCLMDs.

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Title	Year	First author name	Factors investigated	Findings
An Invitro Evaluation of the Accuracy of Two Electronic Apex Locators to Determine Working Length in the Presence of Various Irrigants	2016	Parsad, AB	The question is whether the presence of irrigation solution alters working length determination using apex locators. The purpose of this study was to compare the accuracy of Root ZX and i-Root apex locator for determining working length in the presence of different irrigating solution.	Root ZX and i-Root can be used safely to determine working length in the presence of various irrigants. The content of the root canal did not influence the accuracy while measuring working length using Electronic apex locators (EAL)
Accuracy of electronic apex locator in length determination in the presence of different irrigants: An *in vitro* study	2006	Muthu, MS	This *in vitro* study had attempted to compare the effectiveness of electronic apex locator in the presence of various canal contents.	The results of the study had shown that the length of root canals can be accurately made irrespective of the canal contents.
Comparison of two electronic apex locators on human cadavers	2016	Marigo, L	The aim of this study on human cadavers was to compare the accuracy of two electronic apex locators (EALs) Dentaport ZX (J. Morita Corporation, Tokyo, Japan) and Raypex 6 (VDW, Munich, Germany).	Both apex locators showed a high accuracy in the presence or not of NaOCl.
Accuracies of seven different apex locators under various conditions	2008	Kang, JA	The purpose of this study was to evaluate the accuracies of 7 different frequency-dependent electronic apex locators (EALs) on using different irrigants in the root canal.	here were some differences in accuracies among EALs; however, some of the differences were not statistically significant. All EALs were less accurate when the apical foramen size was larger.
Comparative Evaluation of Effect of various irrigants and dry canal on Electronic Apex Locators in locating Simulated Root Perforations: An *in vitro* study.	2020	Sirvastava, S	This study aimed to evaluate the effects of irrigants and dry canal on the accuracy of the EAL's in locating simulated root perforations.	In the present study, both Root ZX mini and i Root were affected in different canal conditions. The most accurate measurements were seen in presence of saline and SmearOFF.
The The Accuracy of Three Apex Locators in Determining the Location of Strip Root Perforation in Different Environments	2021	Shekarchizadeh, N	The purpose of this study was to assess the accuracy of Root ZX (J. Morita USA, Inc., Irvine, CA, USA), Raypex 6 (VDW, Munich, Germany) and i-Root (S-Denti Co. Ltd Seoul, Korea) electronic apex locators (EALs) in detecting strip root perforations in dry condition, and in presence of 0.9% saline (NaCl), 2.5% sodium hypochlorite (NaOCl), 2% chlorhexidine (CHX), 17% ethylenediaminetetraacetic acid (EDTA) and blood.	Based on this ex-vivo study, the most accurate measurements were seen for all three EALs in CHX medium. The presence of irrigation solution affected the accuracy of all EALs. Root ZX showed better results compared to other EALs in determining the location of perforation in different environments, but this difference was not significant.