



REVIEW ARTICLE

Accuracy of different generations of apex locators in determining working length; a systematic review and meta-analysis

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KEYWORD

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Abstract *Background and objective:* The accurate determination of working length has a major influence on the prognosis of root canal treatment. Electronic Apex Locators (EALs) appear to be excellent tools for the determination of working length (WL). This study aimed to assess the accuracy of four generations of EALs.

Materials and methods: For the purpose of the present review study, articles on different generations of EALs were selected from the PubMed, Cochrane Library, Google Scholar, and Science-Direct databases using the search term apex locators. In addition, eligibility criteria were set and used for the inclusion of articles.

Results: Fifteen studies satisfied the eligibility criteria and were included in this study. According to the results of four *meta-analyses*, the Cochran's Q-values were 3.042, 4.569, 0.636, and 0.443. The I² value of four heterogeneity tests was zero (I² = 0). In addition, the effect sizes (risk ratios) of the four *meta-analyses* were 1.040, 0.997, 0.935, and 0.959.

Conclusion: Based on the findings of this study, all four generations of apex locators under review were found to be accurate in measuring working length. Hence, the generation of an apex locator does not play a significant role in how accurately electronic devices determine working

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length. In addition, the results suggest that more clinical and laboratory trials are required in order to evaluate the accuracy of different generations of EALs in measuring working length.

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1. Introduction

Accurately determining working length (WL) in root canal therapy facilitates treatment prognosis (de Morais et al., 2016; Sadaf and Ahmad, 2015). Successful root canal therapy depends on meeting three main criteria: a proper access cavity, cleaning and shaping, and three-dimensional obturation of the root canal system. Except for the access cavity, the other two prerequisites can be accomplished only if the WL is determined precisely (Adams and Tomson, 2014; Golvankar et al., 2019).

Electronic apex locators (EALs) use the human body to produce an electrical circuit. They have two sides: one is connected to the endodontic file in the root canal, and the other is connected to the patient's lip. The electrical circuit will be complete when the tip of the dental file reaches the periodontal tissue. These devices are particularly useful for patients with gag reflex problems or those who cannot tolerate radiography films or sensors. Because each generation of apex locators has a distinct display, they show different images of the apical region (Bahrololoomi et al., 2015; Khattak et al., 2014).

The idea of using electronic methods to detect the apex of the root canal was first proposed by Custer in 1918 and was then revisited by Suzuki in 1942. Suzuki discovered that the constant value is the result of electronic resistance between the periodontal ligament and the oral mucosa. Later, Sunada used Suzuki's idea and developed an apex locator in 1962 (Gutmann, 2017; Puri et al., 2013). With the advancement of technology in dentistry, various generations of EALs have been developed to measure the WL with higher accuracy (Golvankar et al., 2019; Guise et al., 2010). Table 1 (Connert et al., 2018; Guise et al., 2010; Gurel et al., 2017; Saxena et al., 2017; Stoll et al., 2010; Vanitha and Sherwood, 2019) illustrates different generations of electronic apex locators.

This review study aimed to examine the accuracy of four different generations of apex locators in measuring working length through previous studies found via searches in electronic databases.

1.1. Apical terminus of root canal

Apical Constriction (AC): First extensively investigated by Kuttler (Kuttler, 1955), the AC or minor apical diameter is considered the ideal spot for canal preparation and obturation of root canals. The AC is the narrowest spot of the root canal and has the lowest diameter. The morphological location of the apical constriction can vary among roots. The AC is generally located 0.5–1.0 mm short of the apical foramen (Diwanji et al., 2014; Kuttler, 1955).

Apical Foramen (AF): The AF or major apical diameter varies in size and formation among roots. The AF can change from symmetrical to asymmetrical in different physiological and pathological conditions. The AF is open before maturation; however, with time and after maturation, it decreases and takes a funnel shape, which is due to hard tissue deposition. The AF is not always found at the anatomical apex (AA); the distance between the AF and AA is, in particular, higher in the posterior and older teeth than in the frontal and younger teeth (Gordon and Chandler, 2004; Martos et al., 2009).

Anatomical and radiographic apex: The anatomical apex or true apex is the tip of the root and is the root terminus. The anatomical apex is normally straight; however, it tends to curve distally with time (Kuttler, 1955). The radiographic apex is determined via radiography, and its position can be different because of the distortion of radiographic images (Orosco et al., 2012).

Table 1 Detailed description of different apex locators.

Device	Manufacturer	Generations	Display AC*	Display AF*
Apex ID	SybronEndo, Orange, CA, USA	Third generation	0.5	0.0
Elements Apex Locator	SybronEndo, Orange, CA, USA	Fourth generation	0.5	0.0
iPex	NSK, Tochigi, Japan	Fourth generation	0.5	0.0
iPex II	NSK, Tochigi, Japan	Fourth generation	0.5	0.0
Precision Apex Locator	Brasseler USA, Savannah, GA, USA	Fourth generation	0.5	0.0
Raypex 5	VDW, Munich, Germany	Fifth generation	Third green line	Red bar
Raypex 6	VDW, Munich, Germany	Sixth (modification of a fifth generation)	Third green line	Red bar
ProPex Pixi	Dentsply Sirona, Ballaigues, Switzerland	Fifth generation	0.5	0.0
ProPex II	Dentsply Sirona, Ballaigues, Switzerland	Fifth generation	0.5	0.0
Root ZX (Dentaport ZX)/ Root ZX II	J. Morita MFG. CORP, Kyoto, Japan	Third generation	Middle of APEX and 1 mark (0.5)	0.0
Root ZX Mini	J. Morita MFG. CORP, Kyoto, Japan	Third generation	Middle of APEX and 1 mark	Last green bar

AC*: Apical constriction, AF*: Apical foramen.

Cement-dentinal junction (CDJ): The CDJ is the region in the root canal at the interface between the cementum and dentin. Since the CDJ has a unique organic matrix, the mineralisation in this junction is higher than that of both the cementum and dentin (Sudhakar and Pratebha, 2015). This histological landmark has the best prognosis in root canal treatment when biomechanical instrumentation and obturation are limited in the CDJ. Although the exact location of the CDJ cannot be identified clinically or through radiography, the apical constriction (AC) is an

appropriate and reliable location as an endpoint for root canal treatment (Mousavi et al., 2018). The locations of the CDJ and AC do not always coincide (Sharma and Arora, 2010). Fig. 1 illustrates the longitudinal section of a palatal root of an extracted first maxillary molar, photographed with a camera equipped to a stereomicroscope at 20× magnification (Bresser, Rhede, Germany), as well as its schematic representation of the apical area made via ImageJ (National Institutes of Health (NIH), Bethesda, MD, USA).

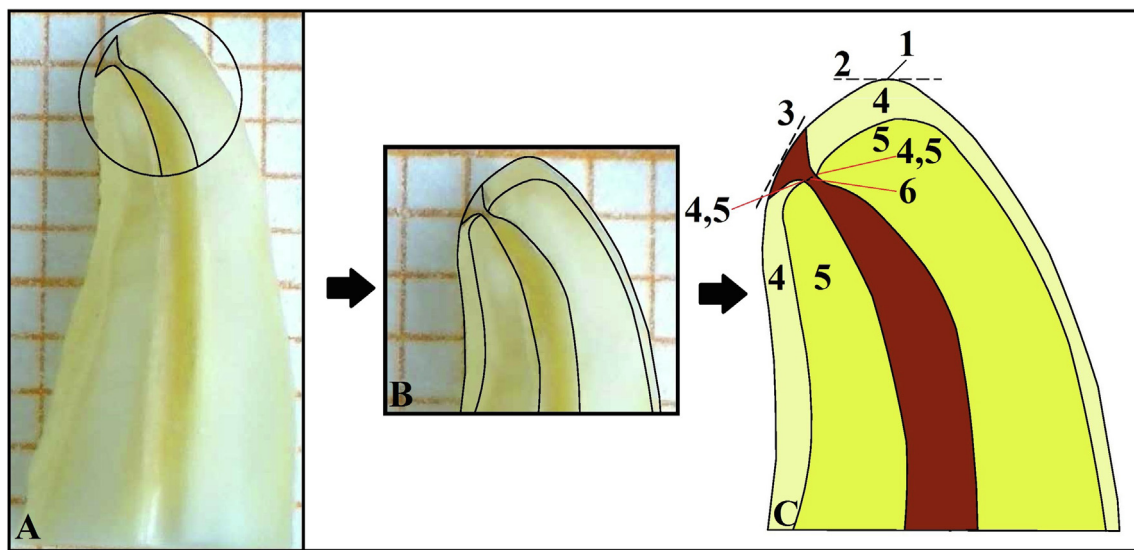


Fig. 1 Microscopic (A and B) and schematic (C) representation of the apical terminus root canal. 1. Anatomical apex (solid line), 2. Radiographic apex (dash line), 3. Apical foramen (dash line), 4. Cementum, 5. Dentine, 4,5. Cement-dentinal junction, and 6. Apical constriction.

2. Materials and methods

2.1. Search strategy

In this review study, four databases, namely, PubMed, Cochrane Library, Google Scholar, and ScienceDirect, were used to search and find published papers on different generations of apex locators. The general term searched in all databases was apex locators. A publication year range from 2000 to 2021 was applied in all databases except for Google Scholar. Since the initial search in Google Scholar yielded more than 4810 articles, publications from the last three years were considered for the next stage of the screening process. The initial search in each database was imported and combined in Microsoft Word. Duplicate publications were identified via the navigation function in Microsoft Word and then removed. Data extraction was performed by two investigators.

2.2. Inclusion criteria

Inclusion criteria in this review study:

1. Language restriction: only English.
2. Original articles.
3. Type of study: in vitro or vivo experiments.
4. Studies with at least 10 samples.
5. Studies that compare different generations of apex locators.
6. In studies in which two or more devices belong to one generation, only the device with the highest level of accuracy in determining working length should be selected (This holds except for the situations in which the most accurate device of one generation has the same level of accuracy (number of events) as that of other generations. In this case, the device with lower accuracy should be selected to avoid entering the same data and thus to be able to run *meta-analysis*).

2.3. Exclusion criteria

The exclusion criteria for the selection of the articles were as follows:

1. Studies excluded: case reports and review studies.
2. Studies involving artificial teeth and teeth with root resorption.
3. Studies with insufficient data.
4. Studies comparing electronic methods and radiography or other methods.
5. Studies investigating the effect of different file sizes, variable irrigation solutions, and horizontal or vertical root fracture on the accuracy of apex locators.
6. Studies on endodontic rotary motors with integrated apex locators.

2.4. Structured question

Which one of the generations of apex locators is most effective at determining working length?

3. Results

The initial search in the four databases identified 2286 studies. After the removal of duplicates, the search strategy yielded 1990 studies, the titles of which were then examined. A total of 1851 articles were subsequently excluded because they did not contain a comparison of electronic apex locators, leaving a total of 139 articles. This process was followed by reviewing the abstracts of the remaining articles using the inclusion and

exclusion criteria. As a result, a further 119 articles were removed, and only 20 articles remained, which were then assessed for eligibility. Full-text analysis led to the removal of another five articles for the following reasons: four of the articles either focused on a different outcome of interest rather than generations of EALs or data on the number of events in the articles were not available. The fifth one was removed due to the inaccuracy of some data on the generation of apex locators. Thus, at the end of the screening process, 15 articles were included in the quantitative synthesis of this study. Fig. 2 shows the flow diagram of the article screening in the review process. Statistical analysis was conducted via Comprehensive Meta-Analysis 2.0 (CMA).

The results of four *meta*-analyses of the 15 studies showed that the heterogeneity tests resulted in Q -values of 3.042, 4.569, 0.636, and 0.443 among the 3rd and 4th generations, 3rd and 5th generations, 4th and 5th generations, and 3rd and 6th generations, respectively. The I^2 value of four heterogeneity tests was zero, which revealed that there was no dispersion. As depicted in Fig. 3, the risk ratio was selected as the effect size. The overall effect sizes of the studies were 1.040, 0.997, 0.935, and 0.959, respectively, indicating that the risk of measurement error when using 3rd and 4th, 3rd and 5th, 4th and 5th, and 3rd and 6th generations of apex locators is the same. Table 2 (Betancourt et al., 2019; Guise et al., 2010; Gurel et al., 2017; Moscoso et al., 2014; Nasiri and Wrbas, 2019; Plotino et al., 2006; Puri et al., 2013; Serna-Pena et al., 2020; Somma et al., 2012; Stober et al., 2011; Swapna et al., 2015; Tselnik et al., 2005; Tufenkci and Kalayci, 2020; Vasconcelos et al., 2014; Wrbas et al., 2007) gives general information about the selected articles and their results. Fig. 4 presents the data of the selected studies within ± 0.5 mm from working length except for one study. Since the data within ± 0.5 mm of working length in the study by Tselnik et al. (Tselnik et al., 2005) provided the same accuracy between two generations, the data were selected within the -0.5 to 0.75 range so that the inclusion of the data in the *meta-analysis* would be possible.

3.1. Risk of bias assessment

1. This review study selected studies in which the comparison occurred only among generations of EALs.
2. The accuracy of EALs was considered within ± 0.5 mm of the WL (except Tselnik et al.).
3. Seven studies were performed in vitro, and 8 studies were conducted in vivo; however, the final evaluation of these 8 studies was also performed in vitro. Thus, all selected studies were performed in the same way.
4. In this study, a comprehensive search was conducted in four databases to select studies on the generation of EALs. For this reason, the probability of an existing article on this topic is not zero but low.
5. Fifteen articles supported the quantitative results of the current study. Although new articles will be published in the future in this regard, they cannot affect the results of the current review study because of the high number of studies included. Hence, the risk of bias in this study is low.

4. Discussion

The use of electronic apex locators for the determination of working length has increased in popularity. Apex locators are classified according to their generations (Mull et al.,

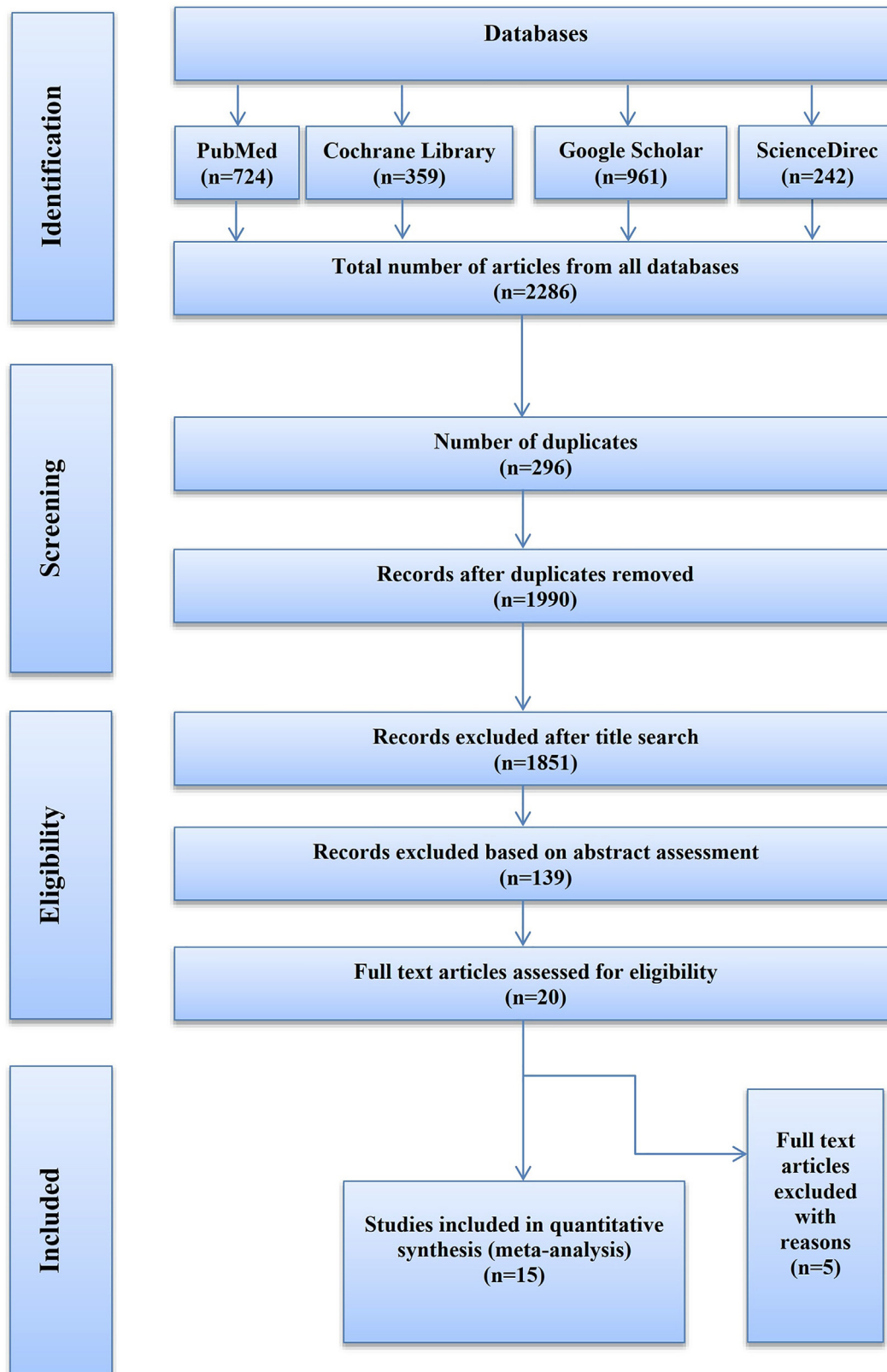


Fig. 2 Flow chart of study selection.

2012). First-generation EALs or resistance apex locators use a direct current (resistance) to measure the apical area, which causes pain to the patient due to the high currents. Moreover,

the EALs in this generation, such as Dentometer (Dahlin Electromedicine, Copenhagen, Denmark) and Endo Radar (Elettronica Liarre, Imola, Italy), were found to be inaccurate,

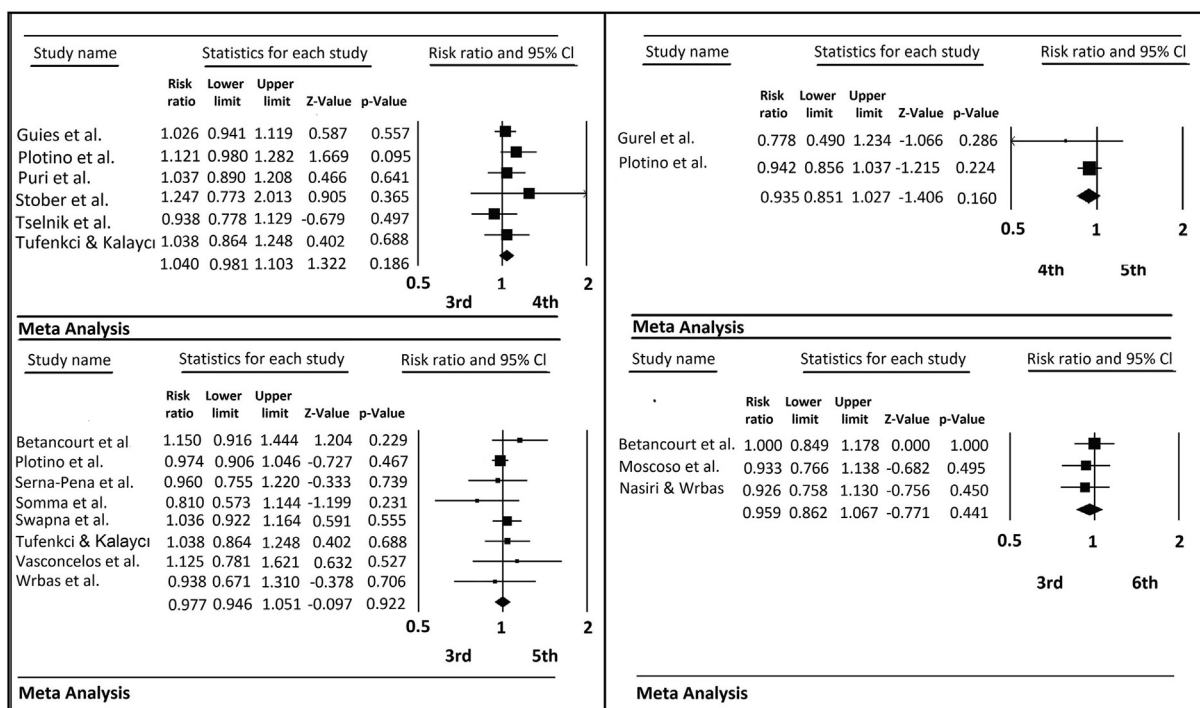


Fig. 3 Forest plot of the meta-analysis: 3rd and 4th generations, 3rd and 5th generations, 4th and 5th generations, and 3rd and 6th generations.

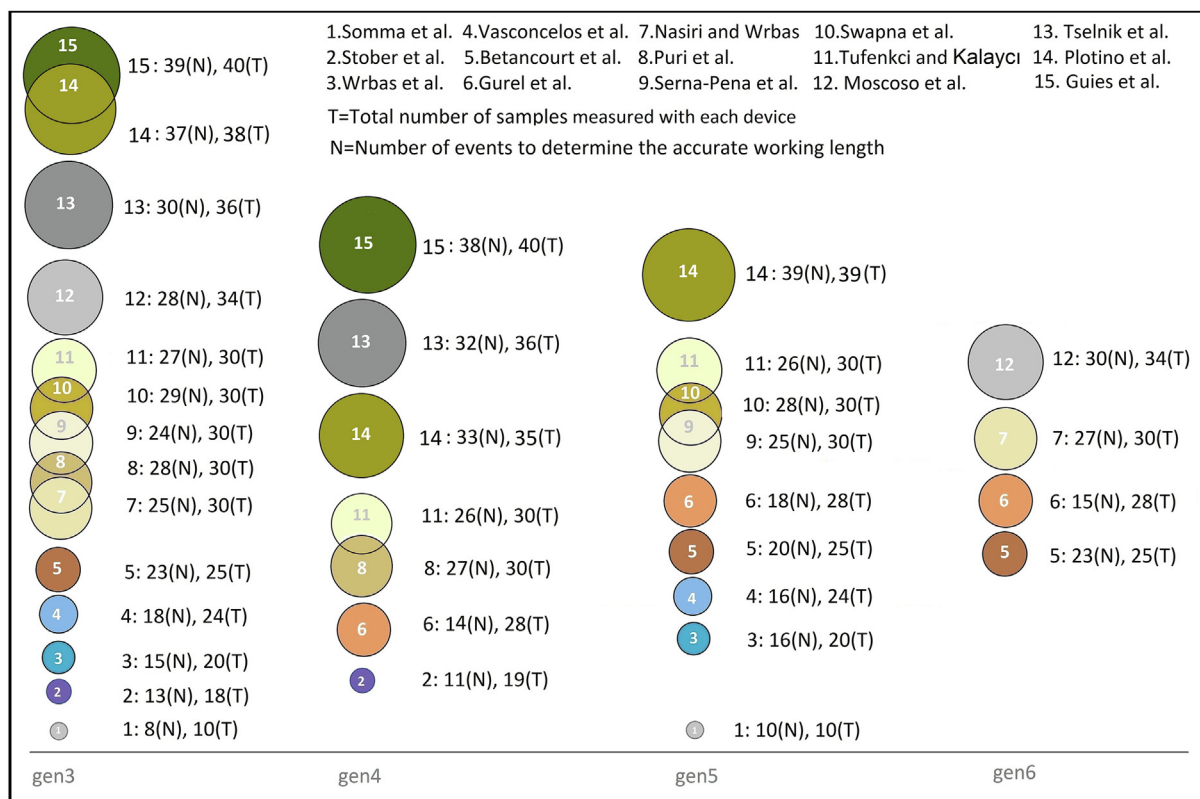


Fig. 4 Data visualisation of the included studies.

Table 2 General information of included articles.

Authors and year of publication	Study type	Type of EALs	Type of generations	Main study result	Conclusion
Betancourt et al. 2019	In vitro study	Pixi, Root ZX II Propex II Raypex 6	Fifth, third, fifth, sixth	No significant difference	Root ZX II and Raypex 6 showed the best overall performance
Guisse et al. 2010	In vitro study	Root ZX II, Elements Apex Locator, Precision Apex Locator	Third, fourth, fourth	Significant difference	Root ZX II was the most accurate in locating the apical foramen
Gurel et al. 2017	In vitro study	Raypex 5, Raypex 6, iPex, iPex II	Fifth, sixth, fourth, fourth	No significant difference	All devices showed the same accuracy
Moscoso et al. 2014	In vivo study	Dentaport ZX, Raypex 6	Third, sixth	No significant difference	Both devices were effective in determining working length
Nasiri and Wrbas 2019	In vitro study	Root ZX and Raypex 6	Third, sixth	No significant difference	Both devices were capable of determining canal length
Plotino et al. 2006	In vitro study	Root ZX, Elements Diagnostic Unit, ProPex	Third, fourth, fifth	Significant difference	The majority of ProPex readings were long.
Puri et al. 2013	In vitro study	DentaPort ZX, iPex,	Third, fourth	No significant difference	Both devices showed the same precision
Serna-Pena et al. 2020	In vivo study	Root ZX Mini, Apex ID, Propex Pixi	Third, Third, fifth	No significant difference	All devices showed satisfactory precision
Somma et al. 2012	In vivo study	Dentaport ZX, Raypex 5, ProPex II	Third, fifth, fifth	No significant difference	All devices can detect the major foramen
Stöber et al. 2011	In vivo study	Root ZX, iPex	Third, fourth	No significant difference	Both devices showed the same accuracy
Swapna et al. 2015	In vivo study	Root ZX, Raypex 5	Third, fifth	No significant difference	Both devices showed the same accuracy
Tselnik et al. 2005	In vivo study	Root ZX, Elements Diagnostic	Third, fourth	No significant difference	Devices were found equally accurate
Tufenkci and Kalayci 2020	In vitro study	Dentaport ZX, iPex II, Propex Pixi	Third, fourth, fifth	No significant difference	All devices had the same satisfactory accuracy
Vasconcelos et al. 2014	In vivo study	Root ZX, Propex II	Third, fifth,	No significant difference	Both devices were capable of locating the apical foramen
Wrbas et al. 2007	In vivo study	Root ZX, Raypex 5	Third, fifth	No significant difference	Both devices can accurately determine working length

particularly in comparison to radiography methods, in determining working length, which is considered to be a main drawback (Chopra et al., 2008; Gordon and Chandler, 2004; Mull et al., 2012). Thus, in second-generation EALs, also known as impedance-based apex locators, some modifications were made to improve first-generation apex locators. One improvement was using an alternating current (impedance) for the detection of the apex. Impedance has a sinusoidal amplitude trace and consists of resistance and capacitance. The main shortcomings of second-generation devices, such as Sono-Explorer (Hayashi Dental Supply, Tokyo, Japan), were poor accuracy in the presence of electroconductive irrigations and tissue fluids and no digital read-out (Chopra et al., 2008; Gordon and Chandler, 2004; Mull et al., 2012).

With the advancement of science and technology in dentistry, new generations of EALs, the third, fourth, fifth, and sixth generations (modified fifth generation), with higher accuracy in measuring working length have been developed (Gurel et al., 2017; Jadhav et al., 2018). Third-generation apex locators, such as J. Morita MFG electronic devices, use a dual frequency, which is based on the "ratio method", to measure canal length with high accuracy in endodontic therapy. In the ratio method, the impedance values at two frequencies, i.e., high (8 kHz) and low (400 Hz), are simultaneously measured. Based on the result, a quotient of impedances is calculated, and the quotient value shows the location of the dental file in the canal. This generation is capable of locating the point or the narrowest part of the root canal (Chopra et al., 2008; Golvankar et al., 2019; Gordon and Chandler, 2004; Mull et al., 2012).

Unlike the third generation, the fourth generation is incapable of processing impedance values as a mathematical algorithm. This generation measures the capacitance and resistance of the circuit separately and compares them with a database to detect the narrowest part of the root. This generation can perform well in relatively dry canals (Gordon and Chandler, 2004; Mull et al., 2012). Fifth-generation EALs provide several benefits, including safety, reliability, clinician and patient friendliness, as well as an accurate detection of working length in case there are exudates or weeping in the canal (Chopra et al., 2008). The sixth generation, also called adaptive apex locators, is a modification of the fifth generation and shows the highest consistency for measurements in the case of root perforation or apical root resorption (Haupt and Hülsmann, 2018; Jadhav et al., 2018). Among the different generations of EALs, the first and second generations are obsolete and no longer manufactured and used in modern dentistry. Therefore, studies examining the efficacy of first- and second-generation EALs were not included in this study and thus are not presented in Table 1.

To develop search strategies in systematic reviews, the question is often formed by the "PICO" framework. The elements of PICO are problem/patient/population, intervention/indicator, comparison, and outcome (Neelakantan et al., 2020; Siddique and Nivedhitha, 2019). In this review study, four generations of apex locators were evaluated. Since the intervention factor in PICO could be any of the generations of devices in the subset, the question under review, in line with a previous study, was not formed according to the "PICO" framework (Hartmann et al., 2019). Instead, the question guiding the study was framed as follows: which one of the generations of apex locators is most effective in determining working length?

In addition, since various studies reported different agreement and disagreement of accuracy among generations of EALs (Golvankar et al., 2019; Haupt and Hülsmann, 2018), meta-analysis was used to reach a comprehensive conclusion.

The four meta-analyses of the 15 studies among the 3rd and 4th generations, 3rd and 5th generations, 3rd and 6th generations, and 4th and 5th generations showed that there was no significant difference among the generations of EALs, which is consistent with the results of previous studies (Chaudhary et al., 2018; Golvankar et al., 2019). Therefore, the response to the structured question is that the third, fourth, fifth, and sixth generations of apex locators are not different in how accurately they determine working length.

Regarding the inclusion criteria, in the studies by Betancourt et al., Guise et al., and Somma et al. (Betancourt et al., 2019; Guise et al., 2010; Somma et al., 2012), as there were two devices of the same generation, data of the more accurate device were employed. However, in the studies by Gurel et al. and Serna-Pena et al. (Gurel et al., 2017; Serna-Pena et al., 2020), the device data with lower accuracy were selected. The reason, as mentioned earlier in the article, is using the same data of devices with the highest level of accuracy across generations of apex locators. Meta-analysis cannot be run using the same data; and consequently, comparison would not be feasible. By choosing the data of less accurate devices, this problem was addressed.

Moreover, since the accuracy of EALs decreases as the file size increases (Sadeghi and Abolghasemi, 2008), in the study by Tufenkci and Kalayci (Tufenkci and Kalayci, 2020), only the data from root canals before preparation were used, and the data during retreatment were excluded. Considering the aim of this study, in the last selected study (Nasiri and Wrbas, 2019), only the root canal measurement data were selected, and the perforation site data were excluded.

It also needs to be mentioned that while Dentaport ZX and Root ZX are similar, Dentaport ZX has the capability to attach an endomotor (Pascon et al., 2009; Puri et al., 2013). In the four selected studies examining the accuracy of Dentaport ZX along with other devices, Dentaport ZX was evaluated without endomotors (Moscoco et al., 2014; Puri et al., 2013; Somma et al., 2012; Tufenkci and Kalayci, 2020). Therefore, the exclusion factor (studies on endodontic rotary motors with integrated apex locators) was eliminated; and after the screening process, the four studies were included in the study. Finally, the limitation of this study was that the existing data on the four generations of EALs are insufficient; therefore, in order to use meta-analysis, four separate meta-analyses were performed.

5. Conclusions

The findings of this systematic review showed no significant difference in the determination of working length among the four generations of apex locators under review. Hence, it can be concluded that all generations can be equally useful and accurate in determining working length. It is suggested that more in vivo or in vitro studies, in which all generations of devices are examined and compared, be performed to obtain more precise and valid data on the accuracy of different generations of EALs.

Ethical statements

According to the German Ethics Council for research studies, only in vivo studies require ethical statements. This is a review study, in which we only summarized already existing data from various databases. Thus, an ethical statement is not required for the current study.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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