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Comparison of Accuracy of Different Generations of Apex Locators in Determining Working Length; a Systematic Review and Meta - Analysis

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Abstract: ***The aim of this study was to assess the accuracy of different generations of electronic apex locators. Methods and materials: Articles on different generations of electronic apex locators were selected from the PubMed, Cochrane Library, Google Scholar, and ScienceDirect databases using the search term apex locators. Moreover, eligibility criteria were set and used for the inclusion of articles. Results: Fifteen studies satisfied the eligibility of the criteria and were included in the study. Based on the results of four* meta *- analyses, the Cochran's Q - values were 3.042, 4.569, 0.636, and 0.443. The I^2 value of four heterogeneity tests was zero ($I^2 = 0$). In addition, the risk ratios of the four* meta *- analyses were 1.040, 0.997, 0.935, and 0.959. Conclusions: All four generations of electronic apex locators under reviews were found to be accurate in measuring working length. Therefore, the generation of apex locators does not play a significant role in how accurately electronic devices determine working length.***

Keyword: Electronic working length, Generation apex locators, Meta – analysis

1. Introduction

The working length determination is necessary for the success of endodontic treatment. The radiographic apex traditionally is a reference to establish the working length. As the apical foramen often does not coincide with the root apex, the working length determination based on radiographies may be doubtful (1). The advent of electronic apex locators for determination of the working length allowed to locate the apical foramen. Since the first electronic apex locator introduced by Custer 1918, enhanced by Sunada 1962, many other devices have been presented, based on electric resistance (first generation), impedance (second generation), two - frequency impedance (third generation) and new generations of electronic apex locators, the fourth, fifth, and sixth generations.

The idea of using electronic methods discovered by Suzuki 1942 to detect the apex of the root canal as the constant value is the result of electronic resistance between the periodontal ligament and the oral mucosa then in 1962, Sunadaused Suzuki's idea and developed an apex locator (2). nowadays, many generations of EALs have been developed to measure the WL with higher accuracy.

Based on Kuttler 1955, the narrowest diameter of the root canal is not exactly at the site of exit of the canal from the tooth but usually occurs within the dentin just close to the initial layers of cementum. According to Ricucci and Langeland 1998 said that the apical constriction is the narrowest part of the root canal with the smallest diameter of blood supply, thus creating the smallest wound site and best healing condition (3). This anatomical landmark called the minor diameter of the canal. However, the cemento - dentinal junction and apical constriction do not always coincide, particularly in senile teeth as a result of cementum deposition, which change the position of the minor diameter (4). The minor diameter in the apical area represents the transition between the pulpal and the periodontal tissue which usually located between the range of 0.5 to 1.0 mm from the external foramen or major diameter on the root surface (5). The working length established beyond the minor diameter may lead to apical perforation and overfilling of the root canal system that may increase postoperative pain and delay or prevent healing while the

working length established short of the minor diameter may lead to inadequate debridement and underfilling of the canal so retained pulp tissue may persist and cause prolonged pain. Also, the microleakage entered to the canal space may result in impaired healing (6). The electronic apex locator has provided a great deal of attention as it operates on the basis of electronic principles rather than by a visual inspection. The electronic apex locator is one of the breakthroughs that came to the traditionally endodontic practice from electronic science (7). This review study aimed to compare the accuracy of four different generations of apex locators in measuring the working length through many studies found via searches in electronic databases.

2. Methods and Materials

In this review study, Search strategy got from four databases were PubMed, Cochrane Library, Google Scholar, and Science Direct used to search and find published articles on different generations of apex locators. The general term that searched in all four databases were apex locators. A publication year selected range from 2000 to 2021 was applied in all databases except for Google Scholar. Since the initial search in Google Scholar found to be more than 4810 articles, the publications found 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 program. Data extraction was performed by two investigators.

Inclusion criteria in this review study:

1) English language only.
2) Original articles.
3) In vitro or vivo experiments study.
4) Studies with at least 10 samples used.
5) Studies that compare virous generations of apex locators.
6) Studies in which used two or more devices belong to one generation, only the device with the highest level of accuracy in determining working length should be selected. In this situation, the device with lower accuracy should be selected to avoid entering the same data and thus to be able to run meta - analysis.

The exclusion criteria:

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

3. Results

The initial search in the four databases found 2286 studies. After the removal of duplicated studies, the search strategy yielded 1990 studies. A total of 1851 articles were excluded due to they did not contain a comparison of electronic apex locators, giving a total of 139 articles. then the abstracts of the remaining articles were reviewed using the inclusion and exclusion criteria only 20 articles remained. Full - text analysis led to the removal of another five articles for the following reasons: four articles focused on a different outcome rather than generations of electronic apex locators. One article was removed because the inaccuracy of some data on the generation of apex locators. Thus, at the final of the screening process, 15 articles were included in this study. Statistical analysis was conducted by Comprehensive Meta - Analysis 2.0 (CMA).

The results of four meta - analyses of the 15 studies represented the heterogeneity tests resulted in Q - values of 4.569, 3.042, 0.636, and 0.443 for the 3rd and 5th generations, 3rd and 4th generations, 5th and 4th generations, and 6rd and 3th generations, respectively. The I^2 value of four heterogeneity tests was zero that revealed that there was no dispersion. The overall effect sizes of the studies were 1.040, 0.997, 0.935, and 0.959, respectively, represented the risk of measurement error when using 3rd and 4th, 5rd and 3th, 5th and 4th, and 6rd and 3th generations of apex locators is the same. Table 1 gives general information about the articles selected and their results. Fig.1 presents the data of the selected studies within ±0.5 mm from working length except for one study. once the data were within ±0.5 mm of working length in the study by Tselnik et al.2005 provided the same accuracy between two generations, the data were selected within the −0.5 to 0.75 range thus, that the inclusion of the data in the meta - analysis would be possible.

Risk of bias assessment

1) This review study selected studies in which the comparison occurred only among generations of electronic apex locators.
2) The accuracy of electronic apex locators was considered within ±0.5 mm of the working length (except Tselnik et al.).
3) Seven studies were done in vitro, and 8 studies were performed in vivo but the final evaluation of these 8 studies was also conducted in vitro. Thus, all the selected studies were conducted in the same way.
4) In this review study, a comprehensive search was performed in four databases to select studies on the generation of electronic apex locators. For that, the probability of an existing article on this topic is low and not zero.
5) Fifteen articles supported the results of the current study

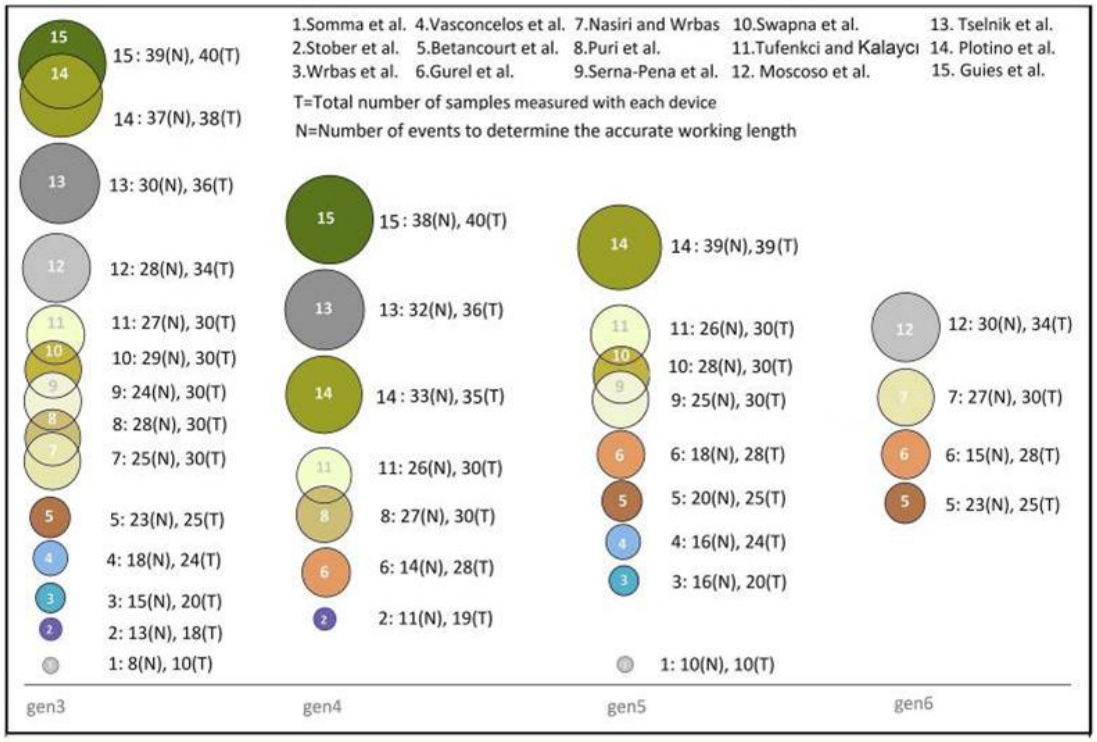

Figure 1: Data visualization of the included studies.

Table 1: 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
Guise 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

4. Discussion

Classification of apex locators according to their generations (8). First generation of electronic apex locators use a direct current (resistance) to measure the apical area causes pain to the patient because the high currents. The electronic apex locators in this generation, such as Dentometer (Dahlin Electromedicine, Copenhagen, Denmark) and Endo Radar (ElettronicaLiarre, Imola, Italy) were found to be inaccurate especially in comparison to radiography methods in determining working length that considered to be the main

drawback (9, 10). Second generation electronic apex locators known as impedance - based apex locators. Some modifications were made to improve first generation apex locators by using an alternating current (impedance) for the detection of the apex. An impedance has a sinusoidal amplitude trace include resistance and capacitance. The main drawback 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 (9, 10).

A new generations of electronic apex locators has been developed with the advancement of science and technology in dentistry, the third, fourth, fifth, and sixth generations (modified fifth generation), with higher accuracy in measuring working length (11). Third - generation apex locators, such as J. Morita MFG electronic devices, use a dual frequency that is based on the ″ratio method″ to measure working length with high accuracy in endodontic therapy. In the ratio method, the impedance values at two frequencies high (8 kHz) and low (400 Hz) are simultaneously measured. According to the result, a quotient of impedances is calculated while the quotient value shows the location of the dental file in the canal. Thus, third generation can locate the point or the narrowest part of the root canal while the fourth generation is incapable of processing the impedance values as a mathematical algorithm. Thus, this generation measures the capacitance and resistance of the circuit separately and compares them with a database for detect the narrowest part of the root. This generation can perform well in dry canals (10). Fifth - generation electronic apex locators have several benefits which include safety, reliability, clinician and patient friendliness and accurate detection of working length in case there are exudates or weeping in the canal (9). Adaptive apex which is termed for sixth generation apex locators is a modification of the fifth generation and shows the highest consistency for measurements in case of root perforation or apical root resorption (12). Among the different generations of electronic apex locators, the first and second generations are no longer manufactured and used in modern dentistry. so, studies examining the efficacy of first - and second - generation electronic apex locators were excluded in this study.

To perform search strategies in systematic reviews, a ″PICO″ framework is often formed. The PICO's elements are problem/patient/population, intervention/indicator, comparison, and outcome (13). four generations of apex locators were evaluated in this review study. once the intervention factor in PICO framework 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 (14). Instead, the question guiding the study was framed as follows: which one of the generations of apex locators is most accurate in determining working length? also, since various studies reported different agreement and disagreement of accuracy among generations of electronic apex locators (15), *meta* - analysis was used to reach a comprehensive conclusion. The four *meta* - analyses of the 15 studies along 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 agreed with the results of previous studies (16). Therefore, the response to the structured question is which the third, fourth, fifth, and sixth generations of apex locators are not different in how accurately they determine working length.

According to the inclusion criteria in the studies by Betancourt et al., Guise et al., and Somma et al. (17, 18, 19) there were two devices of the same generation data of the more accurate device were employed but in the studies by Gurel et al. and Serna - Pena et al. (20, 21) selected the device data with lower accuracy. The reason 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 because of choosing the data of less accurate devices, this problem was addressed.

It also needs to be mentioned that Dentaport ZX and Root ZX are similar, Dentaport ZX has the capability to attach an endomotor (22). In the four selected studies that examin the accuracy of Dentaport ZX along with other devices, Dentaport ZX was evaluated without endomotors (23, 24, 19, 25). Therefore, studies on endodontic rotary motors with integrated apex locators (the exclusion factor) was eliminated and after the screening process, the four studies were included in the study. Finally, the limitation of this review study was that the data existed on the four generations of electronic apex locators are insufficient. Four separate meta - analyses were performed.

5. Conclusions

No significant difference in the determination of working length between the four generations of apex locators under review. therefore, it can be concluded that all generations of electronic apex locators can be equally useful and accurate in determining working length.

Ethical statements

Based on the German Ethics Council for research studies, ethical statements only require for in vivo studies. In this is a review study only we summarized already existing data from several databases. Thus, an ethical statement is not required for this study.

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