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ORIGINAL ARTICLE

Apex locators in endodontics: *in-vivo* comparison between different devices and radiographic method

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ABSTRACT

BACKGROUND: The precise measurement of the working length (WL) is pivotal for the success of endodontic treatments. Incorrect WL determination can lead to improper reaming and filling of the canal, posing risks of periradicular pathologies onset or failure to heal pre-existing conditions. Presently, apex locators are commonly used for WL determination, available in a variety of characteristics and costs. Alternatively, the traditional method using intraoral radiography remains prevalent.

METHODS: This study, conducted partly *in vivo* and partly *in vitro*, on teeth designated for extraction, compares three WL measurement methods: 1) radiographic method (zero cost); 2) Apex Locator (inexpensive); and 3) Root ZX II (expensive). The correctness of measurements was verified through visual inspection under a stereomicroscope.

RESULTS: Our data indicate that the precision of apex locators surpasses that of the radiographic method, which relies on visual inspection of the instrument inside the canal and is subject to personal interpretations of the images. No significant differences in precision were observed between the two locators examined, despite their differing price ranges and brand histories in the field of endodontics.

CONCLUSIONS: Among the multitude of parameters influencing a dentist‘s choice of electro-medical equipment, cost remains a significant consideration, particularly when equipment exhibits similar characteristics.

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Key words: Electronics; Tooth apex; Costs and cost analysis.

Accurately measuring the working length (WL) is a critical aspect of endodontic treatments. This process involves inserting endodontic instruments into the canal until they reach the apical constriction, which defines the boundary between the endodontic space and the periodontium.[1]

Each root canal possesses a significant funnel-shaped section composed of cementum located in its apical region. This shape resembles an "inverted cone," with its base positioned at the major apical foramen.[2]

The apex of this inverted cone corresponds to the minor foramen, which aligns with the apical constriction typically located at or near the cemento-dentinal junction. The most apical portion of the root canal tapers from the opening of the major foramen to a constriction or minor foramen before expanding within the main canal.[3]

Regrettably, the major apical foramen does not exhibit a uniform shape; it can be asymmetrical, and its position on the root tip varies significantly.[4]

Studies in the literature show that the deviation of the major apical foramen can be attributed to various pathological changes, of which the most common example is the resorption of the external root. Furthermore, with increasing age, the deviation of the major foramen from the root apex tends to increase and the frequency of this deviation varies depending on the type of teeth.[5]

In cases where endodontic instruments ream at a shorter than the correct working length, it becomes challenging to effectively reduce the microbial load within the canal. Conversely, if the WL is exceeded, the instruments may penetrate outside the canal, thereby distorting the border area between the endodontic space and the periodontium and altering its shape and dimensions. The presence of irregularities caused by over-reaming beyond the apex complicates the establishment of a three-dimensional seal using filling material. Consequently, incorrect WL determination can lead to both inadequate cleaning and shaping of the canal, increasing the risk of developing or failing to heal periradicular pathologies of endodontic origin.[6]

Currently, electronic root canal length measuring devices (ERCLMDs) are commonly used to localize the apical constriction. These devices are widely available on the market, offering a variety of features and price points.

The functionality of ERCLMDs relies on the principle of electrical conductivity. Tissues surrounding the root apex exhibit greater conductivity compared to the interior of the root canal system.

When a root canal instrument is inserted into a canal, there is a consistent electrical resistance between the instrument and an electrode applied to the oral mucous membrane. However, once the endodontic instrument tip reaches the periodontal membrane *via* the apical foramen, the electrical resistance between the instrument and the oral mucous membrane becomes a constant value.

All apex locators are designed based on this fundamental principle, enabling them to detect the periodontal tissue at the apical foramen.[7]

The initial apex locators introduced to the market were susceptible to errors, especially in cases where the contents of the canal and the presence of periradicular endodontic lesions, such as granulomas and cysts, could influence their accuracy.[8] However, modern electronic apex locators, equipped with sophisticated electronic circuits capable of accurately measuring and processing impedance values between two electrodes (labial clip and endodontic clip), now provide highly reliable measurements. Additionally, these advanced devices often present measurements in a visually appealing graphic format, further enhancing their usability and reliability.[9]

In the past, simpler apex locators on the market measured resistance, while modern advanced apex locators utilize impedance measurement techniques. These techniques may involve signals at high frequency, a couple of frequencies, or multiple frequencies. The most sophisticated devices employ low frequency oscillation and a voltage gradient method to detect the canal terminus.[10]

When an endodontic file is inserted into the canal near the "canal terminus," the resistance between the tip of the instrument and the apical portion of the canal decreases. This decrease occurs because, within the canal, the effective length of the resistive material decreases.[11]

In addition to its resistive properties, the tooth structure exhibits capacitive characteristics due to the formation of a capacitor between the tooth and the surrounding tissues around the root.

However, the electrical structure of the canal is far more intricate than just the presence of resistive and capacitive elements. The root canal serves as a complex electrical network, comprising both resistive and capacitive components.

Thanks to advancements in technology, the latest generation devices are capable of analyzing this intricate biological network with precision. They can accurately indicate the location of the endodontic instrument tip within a root canal, offering a level of precision that was previously unattainable.

The localization of the apex through the radiographic method involves traditional measurements on intraoral radiographs. This method typically entails introducing an endodontic instrument into the canal at a depth suggested by average measurements derived from classic endodontic tables. Additionally, preliminary measurements of the canal length can be obtained from diagnostic radiographs.

However, it is widely acknowledged that while the minor apical foramen and apical constriction are generally located 0.5-1.0 mm short of the radiographic apex on average, there can be significant variations in the relationship of these landmarks. These variations can lead to either under- or over-preparation of root canals, with noticeable consequences on the final root filling.

Various clinical conditions can contribute to erroneous measurements during radiographic apex localization. For instance, the presence of curvatures in the buccal or palatal/lingual direction of the roots can obscure the true length of the canal from the operator's view. Additionally, radiographic overlap of multiple roots, such as in upper molars or upper first premolars, can lead to misinterpretation of images.

Furthermore, certain extra-radicular anatomical structures may obscure the root apices, as seen with the zygomatic process, which can limit the radiographic visibility of the upper first molars.[12] In such cases, the "parallax technique" can be employed to enhance the visualization of the root tips.[13] This technique involves adjusting the angle of the incident X-ray beam on the sensor plane to improve the visibility of the root tips.

Indeed, in the parallax technique, selecting an endodontic instrument of appropriate size is crucial for its radiographic localization within the canal. Instruments that are too small, such as a #06·0.02 or #08 0.02, may prove difficult to locate on radiographs. Conversely, larger diameter instruments may be easily visible on radiographs but may not be suitable for use in very narrow canals. This becomes especially critical if the WL is measured during the early stages of reaming, as is common in step-back techniques. Therefore, choosing the right instrument size is essential to ensure accurate radiographic localization without compromising the effectiveness of canal instrumentation.

There is a plethora of studies in the literature focusing on similar apex locators, characterized by comparable technical specifications and price ranges. However, we believe our research can address a notable gap in the literature by comparing devices across significantly different price ranges (with a price ratio of 10:1) and brands that have distinct histories in the field of endodontics.

While the economic aspect may be considered secondary, it holds significance in the economics of clinical activities such as dentistry, where practitioners need to invest in numerous and often expensive pieces of equipment. Evaluating such comparisons could offer valuable insights for practitioners looking to make informed purchasing decisions.

Moreover, the rapid advancements in electronics have revolutionized the field, replacing complex and costly electronic boards with miniaturized electronic chips boasting substantial computing capacity. As a result, it is imperative to assess how these advancements influence the performance and affordability of apex locators across different price ranges and brands.

Indeed, the evolution of electronics in our time has not only led to advancements in functionality but also contributed to a decrease in production costs for companies manufacturing devices such as apex locators. As a result, end users and purchasers, particularly dentists, should ideally experience a notable reduction in the purchase costs of such equipment without compromising on technical characteristics or performance.

This reduction in costs is particularly beneficial for dental professionals, as it allows them to invest in essential equipment without facing exorbitant expenses. Furthermore, the maintenance of high technical standards ensures that dentists can continue to rely on these devices for accurate and reliable measurements during endodontic procedures, ultimately contributing to enhanced patient care and outcomes.

Certainly, in determining the final cost of a device such as an apex locator, several parameters contribute beyond those already described. These include the extent of studies and research conducted to achieve specific technical results, as well as the quality and reliability over time of the materials used in manufacturing.

In our study, conducted both *in vivo* and *in vitro* on teeth designated for extraction, we compared two electronic locators of different price ranges with the radiographic method. We verified the accuracy of measurements through visual inspection, and our main null hypotheses were as follows:

- there is no difference in accuracy between the radiographic method and the use of electronic locators;
- the two electronic locators (with clearly different costs) exhibit different levels of precision.

By testing these hypotheses, we aim to provide valuable insights into the accuracy of two different apex locators, while also considering their cost implications. This information can help dental professionals make informed decisions when selecting apex locators for their practice, balancing both technical performance and financial considerations.

Materials and methods

This study, conducted both *in vivo* and *in vitro* on teeth scheduled for extraction, aimed to compare the accuracy of two electronic apex locators from different price ranges with the radiographic method, using visual inspection for assessment.

The clinical research adhered to the principles outlined in the Declaration of Helsinki and received approval from the Institutional Review Board of the Paolo Giaccone University of Palermo (Protocol Code: #4-19-04-23). All patients participating in the study were provided with a declaration of consent, which they read and signed to express their willingness to participate in the research and to consent to the publication of data.

By conducting the study in accordance with ethical guidelines and obtaining informed consent from participants, we ensured the ethical conduct of the research while also respecting the rights and well-being of the individuals involved.

A total of 84 patients destined for tooth extractions for periodontal or orthodontic reasons were selected in the study.

The patients ranged in age from 14 to 70, 39 male and 45 female, all of Italian nationality.

Patients who were not cooperative due to pathologies were excluded.

Panoramic X-rays were performed on all patients to assess the condition of the periradicular tissues and the endodontium.

This evaluation aimed to exclude teeth with calcified canals or in any case not visible radiographically, which would have hindered the insertion of the 10 mm diameter reamers up to the apex. Furthermore, teeth with loss of periodontal attachment affecting the entire length of the root and with a degree of mobility greater than 2 were excluded from the research.

The research included a total of 134 teeth, with 26 extracted for orthodontic reasons and 108 for periodontal reasons. A total of 225 root canals were examined. Further details regarding the breakdown by type are presented in Table I.

The WL measurement methods employed in the study were as follows:

- X-Ray Method: Utilizing a Trophy Radiologie X-ray tube with settings of 70 kV and a sensor from Owandy;
- root ZX II: A device manufactured by J Morita, Tokyo, Japan;
- apex locator (Xiangfa, China).

The control method involved the use of a stereo-microscope (30X).

Following anesthesia administered for the extraction procedure, an experienced operator with over 20 years of expertise in the endodontic field created access to the pulp chamber. Subsequent-

TABLE I.—*Canals divided by type.*

Type of teeth	Number of teeth	Canals per tooth	Total canals
Upper 1st incisor	6	1	6
Upper 2st incisor	4	1	4
Upper canine	3	1	3
Upper 1st premolar	22	2	44
Upper 2nd premolar	12	1	12
Upper 1st molar	16	3	48
Upper 2nd molar	4	3	12
Lower 1st incisor	12	1	12
Lower 2st incisor	9	1	9
Lower canine	2	1	2
Lower 1st premolar	18	1	18
Lower 2nd premolar	10	1	10
Lower 1st molar	13	3	36
Lower 2nd molar	3	3	9
Total Teeth	134		225
Periodontal extractions	108		
Orthodontic extractions	26		

Figure 1.—Root ZX II on the left and Dental apex on the right.

ly, the operator verified the patency of the canal using a #06·0.02 reamer.

For each tooth, a coronal reference point was established.

The first phase of the experimentation involved the simulation of the radiographic measurement of the canal which was carried out by inserting a file (diameter 10 taper 02) into the canal at a depth based on the average measurements of the teeth, on the pre-measurement on the diagnostic radiograph and finally also on the tactile feedback provided by the instrument as it advanced towards the apex. Once this simulation was completed, the endodontic instrument was then gently removed from the canal and the estimated WL was recorded.

The radiograph to localize the position of the file tip in the endodontic apex was carried out *in vitro*, at a later stage, repositioning the instrument in the canal.

The second *in-vivo* measurement was performed using the Root ZX II, with which a new reamer (#10 0.02) was introduced into the canal until the locator graphically informed the operator that apical constriction had been reached; the depth of measurement was noted.

The third measurement was performed using a new reamer (#10 0.02) *via* the Apex Locator by bringing the canal instrument to the depth suggested by the device.

For both electronic measurements, the instrument was advanced into the canal until the display indicated that apical constriction had been achieved and for all three measurement techniques, in order not to alter the morphology of the canal in the slightest, no reaming was performed.

Regarding the registration of the measurements for each tooth, the WLs relating to the three different methods were therefore recorded and each individual reamer, used for the registration, was preserved with the silicone stop blocked with cyanoacrylate glue to prevent its movement.

In order to minimize the patient's exposure to X-rays, radiographs were not taken *in vivo* with the instrument inside the canal. Instead, this step was deferred until after the extraction. The instrument was repositioned at the same depth recorded previously, and the radiograph was then taken. The extracted teeth were blocked on the radiographic sensor with thick and totally radiolucent double-sided tape; it made it possible not to alter the correct vision of the images and guaranteed the total immobility of the root during the examination (Figure 1).

This approach ensured accurate measurement while prioritizing patient safety by minimizing unnecessary radiation exposure.

After the endodontic measurements were completed, each tooth was extracted and placed in 5% sodium hypochlorite solution for 15 minutes, followed by storage in physiological solution.

For each extracted tooth, the reamer was reinserted into the canal at the depth noted during the simulation of the *in-vivo* radiographic determination. An *in-vitro* radiograph was then taken to perform the measurement.

The final part of our research involved verifying the precision of all three different WL mea-

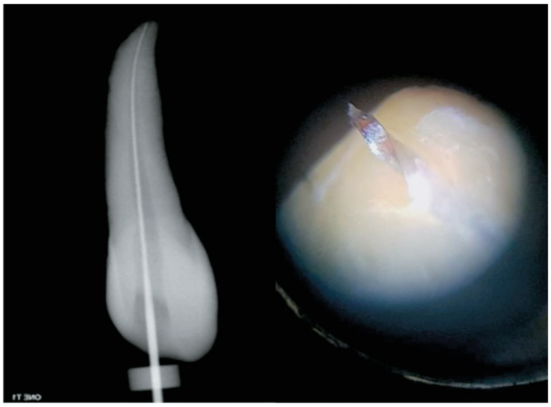

Figure 2.—X-ray measurement and verification of measurements with an optical microscope.

Table II.—*Score.*

0	1	2	3
0 mm	≥0.1 ≤0.2 mm	≥0.3 ≤0.6 mm	≥0.7 mm

surements. To achieve this, a small fenestration of approximately 3 mm was created on each tooth to expose the apical constriction without altering the effective length of the root.

For each tooth, the three reamers of the three measurement techniques were inserted in sequence until the stop (blocked with cyanoacrylate) coincided with the occlusal reference; the tip of the instrument in the apical window was observed under the stereomicroscope (30x magnification) to evaluate the accuracy of each measurement technique. An example of the X-ray measurement and verification of measurements on optical microscope are shown in Figure 2.

To facilitate the grouping of results and mitigate data dispersion, all measurements were categorized and coded into four possibilities as follows:

Score 0: Represents perfect correspondence between the anatomical apex and the clinical measurement.

- Score 1: measurement error between 0.1 and 0.2 mm.
- Score 2: measurement error between 0.3 and 0.6 mm.
- Score 3: measurement error of 0.7 mm or greater.

These categories were used to organize and code the measurements for analysis, as summarized in Table II. This approach allowed for a systematic evaluation of the precision of each measurement method while also facilitating comparisons between them.

The salient phases of the protocol are summarized in Table III.

Results

Considering the 225 canals analyzed, for the X-ray measurement method the cases in which we detected a perfect correspondence with the endodontic apex were 146, the Root ZX II measured with zero error on 198 cases and the Apex Locator reported zero errors on 183 cases.

Considering the success percentages (zero error) for the X-ray measurement method, the study highlighted 57.25%, for the Root ZX II the percentage rises to 77.65% and for the Apex Locator to 71.76%.

By quantifying the errors with the three different measurement methods, our research shows that in the radiographic method, the smallest er-

Table IV.—*Sampler division by score.*

Measurement method	Score 0	Score 1	Score 2	Score 3
X-ray	146	38	36	7
Root ZX II	198	18	9	0
Apex locator	183	26	16	0

Table III.—*Flow chart.*

1. Sample selection	2. Endodontic access	3. *In-vivo* X-ray measurement simulation	4. *In-vivo* Root ZX II measurement
5. *In-vivo* Apex Locator measurement	6. Tooth extraction	7. *In-vitro* X-ray	8. Creation of apical window
9. Radiographic measurement reamer and apex observation (steromicrocopy)	10. Root ZX II measurement reamer and apex observation (steromicrocopy)	11. Apex Locator measurement reamer and apex observation (steromicrocopy)	12. Data analisys

ror found was 0.1 mm and the largest was 0.7 mm (Average 0.4).

About the Root ZX II the smallest error found was 0.1 mm and the largest was 0.3 mm (Average 0.2).

For the Apex Locator the smallest error was 0.1 mm and the largest was 0.4 mm (Average 0.25) (Table IV).

As regards the measurements with X-ray, there were 38 (16.88%) cases with score 1 (error >0.1<0.2) out of 225 canals, 36 canals (15.99%) with score 2 (error>0.3<0.6) and finally 7 canals (3.11%) with score 3 (error>0.7).

As regards the measurements by Root ZX II, there were 18 (7.99%) cases with score 1 (error >0.1<0.2) out of 225 channels, 9 canals (3.99%) with score 2 (error>0.3<0.6) and finally 0 canals (0%) with score 3 (error>0.7).

As regards the measurements by Apex Locator, there were 16 (11.55%) cases with score 1 (error >0.1<0.2) out of 225 canals, 16 canals (7.11%) with score 2 (error>0.3<0.6) and finally 0 canals (0%) with score 3 (error>0.7).

The comparison between the results relating to the radiographic method and those relating to the two electronic locators highlights a greater precision of the ERCLMDs; the difference is statistically significant (P=0.03).

However, when comparing the two apex locators, statistical analysis shows no significant difference in the level of accuracy (P=0.04).

Considering the different types of tooth, the study highlighted that they do not influence the level of precision of the measurement (P=0.02). The data are summarized in Table IV, V and Figure 3, 4. Statistical analysis was performed via ANOVA Test (P=0.05) using Systat13 software (Alphasoft Grafiti LLC).

TABLE V.—*Minimum and maximum error per method.*

Measurement method	Minimum error	Maximum error	Average	Standard deviation
X-ray	0.1	0.7	0.4	0.424
Root ZX II	0.1	0.3	0.2	0.141
Apexlocator	0.1	0.4	0.25	0.212

Discussion

Modern endodontics is founded upon well-established principles and protocols, with each step of endodontic treatment backed by extensive international scientific research. Among these steps, the determination of the WL remains pivotal as the precision of this measurement significantly influences endodontic success.[14, 15]

Ultimately, thanks to the development of apex locators, the evaluation of the WL has become more predictable, reducing some defects of intraoral radiographs and the very number of radiographs performed during endodontic treatment as highlighted in research of Chandler, Koshy and Brunton *et al.*[16, 17] Furthermore, Stein and Corcoran as early as 1992 and Ravanshad *et al.* in 2010 demonstrated that the use of an apex locator could also prevent inadvertent overinstrumentation.[18, 19]

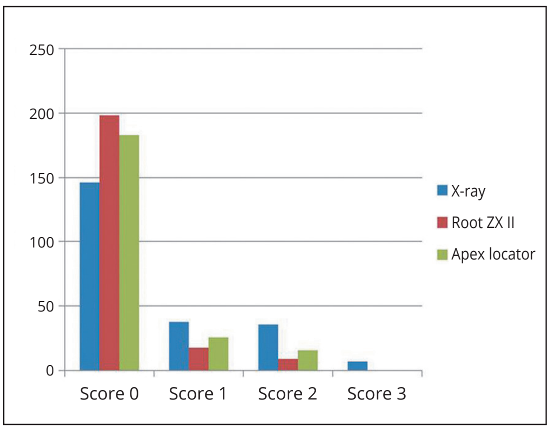

Figure 3.—Sampler division by score.

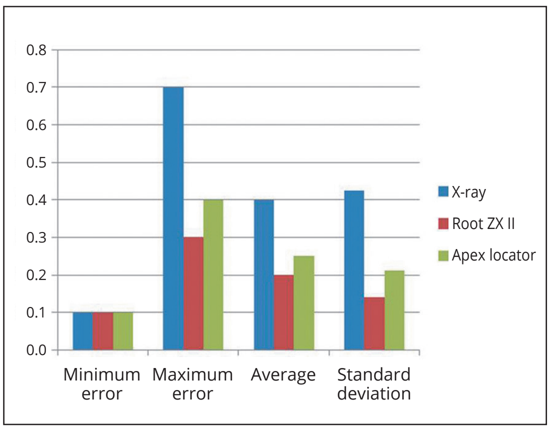

Figure 4.—Minimum and maximum error per method.

In any case, an error in WL determination can have serious consequences. Underestimating the length may result in leaving microbial debris within the canal, potentially leading to the formation of periapical lesions. Conversely, over-reaming beyond the apical constriction can irreversibly alter its morphology, creating irregularities that hinder proper sealing and may inadvertently push microorganisms beyond the apex. These scenarios elevate the risk of postoperative pain.[20, 21] Therefore, meticulous attention to WL determination is essential to mitigate such risks and ensure optimal outcomes in endodontic treatments.

The data at our disposal indicate that the radiographic method, which has been employed for years prior to the widespread use of apex locators, remains a relatively precise technique. The maximum error observed with this method is 0.7 mm, which could be deemed clinically acceptable, especially considering that it occurred in only 3.11% of cases.

In fact, out of the 225 root canals measured in the study, visual inspection under the stereo microscope revealed a perfect correspondence between the tip of the reamer and the apical constriction in 146 cases (64.88%).[22] This suggests that the radiographic method, when used judiciously and in conjunction with other clinical parameters, can still yield accurate results in determining the WL during endodontic procedures.

While validating the precision of the radiographic method, our research revealed a statistically significant difference between the precision of this method and that of electronic devices for determining the working length.

Both apex locators tested exhibited greater precision compared to the radiographic method. Specifically, the Root ZX II demonstrated a maximum error of 0.3 mm, occurring in only 3.99% of the canals. Remarkably, 87.99% of the samples exhibited no error.

Similarly, the Apex Locator demonstrated slightly lower precision compared to the Root ZX II but still yielded significantly better results than the radiographic method. The maximum error recorded with the Apex Locator was 0.4 mm, observed in only 7.11% of the canals (16 out of 255).

These findings underscore the superior precision and reliability of electronic devices, such as apex locators, in determining the WL during endodontic procedures, compared to traditional radiographic methods.

Although some studies such as that of Kim *et al.* indicate that the use of the electronic apex locator combined with radiographs could help determine the WL more accurately.[23]

In addition, other studies, such as those by Ebrahim *et al.*, have highlighted the importance of the diameter of the endodontic instrument used inside the canal during the measurement, highlighting that beyond size 80, there was a measurement error of 2.24 and 0.88 mm with the use of size 10 and 80 K-files, respectively, using the Root ZX. The Apit 7.[24]

In our research, it is worth noting that in measurements conducted with both electronic devices tested, no scores of 3 (indicating an error >0.7 mm) were observed. This indicates a high level of precision and accuracy with these devices.

Conversely, the less favorable results obtained with the radiographic method may be attributed to the inherent challenge in interpreting X-ray images. In our study, we aimed to minimize this interpretation error by involving an expert endodontist with over twenty years of experience in the field. Importantly, this expert had practiced endodontics at a time when apex locators were not widely available on the market.[25]

It is evident that the interpretation of radiographic images by a novice with limited experience may have yielded inferior results. This underscores the importance of expertise and experience in accurately interpreting radiographic images for endodontic procedures.[26]

Indeed, certain anatomical conditions such as buccal or lingual/palatal curvatures of the root apex can pose challenges in accurately interpreting radiographs of the root apical third. Additionally, anatomical overlaps can further complicate length measurements, leading to potential inaccuracies. While the radiographic method remains clinically acceptable, it appears to be operator-dependent.[27, 28]

In contrast, the results obtained with the two tested electronic apex locators appear to be less prone to personal and erroneous interpretations compared to the radiographic method. With electronic apex locators, the instrument provides objective information to the operator regarding the distance between the tip of the instrument and the apical constriction. This reduces the likelihood of subjective interpretations.[29, 30]

Moreover, the intrinsic error of electronic apex locators is shown to be very low, as demonstrated by our research. Therefore, electronic apex locators offer a reliable alternative to the radiographic method for determining WL in endodontic procedures.

In cases where there are discordant values between the radiographic method and electronic devices for determining working length, it may be instinctive to lean towards what is seen or interpreted in the X-ray. However, it is more logical to follow the suggestions provided by electronic apex locators, particularly if the dentist lacks extensive experience in endodontics.

In the realm of electronics, significant advancements have been made, especially in the past decade, leading to exponential improvements in devices across various fields of application. While the two tested devices provided different results, with the Root ZX II demonstrating superior precision by accurately measuring the WL for 198 out of 225 canals, both devices remain valid options.

From a clinical perspective, the observed differences may not be significant, especially considering the numerous variables influencing the success of an endodontic treatment. Therefore, clinicians may confidently rely on electronic apex locators, such as the Root ZX II, for precise WL determination, even in cases of discordance with radiographic measurements.[31, 32]

Ultimately apex locators appear indispensable nowadays even if particular clinical conditions such as the absence of foraminal patency caused by obstruction of dentinal debris could influence the accuracy of the measurers in various ways, as highlighted by de Vasconcelos *et al.*[33]

The two ERCLMDs examined in our study belong to distinct price ranges and are associated with brands that possess varying histories in the field of endodontics. Our research was solely focused on evaluating and analyzing the results obtained with mathematical rigor.

Furthermore, our study did not evaluate factors such as aesthetic appearance, graphical display methods of measurements, or the quality of materials used in the construction of the devices. These parameters could influence preferences for one locator over another.

Given the nearly identical performance demonstrated by both electronic devices in our research, potential buyers may be inclined to choose the device with the lower cost. However, it is essential to consider factors beyond cost, such as long-term reliability and additional features, when making purchasing decisions for ERCLMDs in clinical practice.

Both ERCLMDs were new, and thus, there is limited information in the literature regarding their long-term reliability and the consistency of results over time. It is possible that calibration issues or internal oxidation phenomena may arise with electronic devices over time, potentially impacting the reliability of electrical impedance measurements, which are highly sensitive to such issues.[34-36]

Indeed, the global evaluation of an electro medical device as crucial as an electronic root canal length measuring device necessitates further investigation from various perspectives. One such avenue for future research could involve assessing the long-term reliability of measurements for both devices, even after years of intensive use.

This longitudinal study could involve monitoring the performance of ERCLMDs over an extended period, tracking any changes in measurement accuracy, consistency, and reliability over time. Such research could provide valuable insights into the durability and longevity of these devices in clinical practice.

Additionally, further studies could explore other aspects of apex locators, such as their user interface, ergonomic design, durability of materials, ease of calibration, and compatibility with other endodontic equipment. These factors are essential considerations for endodontists when selecting an electronic root canal length measuring device for routine use in clinical settings.

By comprehensively evaluating ERCLMDs from various perspectives, future research endeavors can contribute to enhancing the understanding of these devices and informing evidence-based decision-making in endodontic practice.

Conclusions

In conclusion, the modern landscape of endodontic practice underscores the indispensability of apex locators. These devices have emerged as highly precise instruments that are essential for ensuring accurate WL determination during endodontic treatments. They have become particularly useful in cases where radiographic examinations are not feasible or highly inadvisable, such as in pregnant women.

While the radiographic method remains a cornerstone of endodontic practice, its role has become somewhat secondary in light of the advancements in electronic apex locators. These locators offer superior precision and reliability, often outperforming traditional radiographic methods.

Based on the results of our *in vivo* study, both electronic apex locators tested demonstrated similar levels of accuracy even though they have completely different prices. Furthermore, both apex locators gave more precise measurements than the radiographic method.

Therefore, in the selection of an electronic root canal length measuring device dentists have the opportunity to consider various factors, including purchase costs, to better inform their decisions.

In essence, the ERCLMD has become an indispensable tool in modern endodontic practice, providing dentists with the means to achieve optimal treatment results with greater precision and efficiency. Added to this is the possibility of purchasing apex locators, of excellent quality even at low costs, even if not all devices sold at a low price could guarantee quality in operation. It remains necessary to point out that in case of use of these economical endodontic locators they should be preliminarily tested by the users.

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Conflicts of interest
The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Authors' contributions
Conceptualization, investigation: Enzo Cumbo and Giuseppe A. Scardina; methodology, formal analysis, data curation, writing—original draft preparation, Enzo Cumbo; validation: Pietro Messina and Giuseppe Gallina; writing—review and editing: Giuseppe A. Scardina; visualization: Pietro Messina; supervision: Giuseppe Gallina. All authors read and approved the final version of the manuscript.

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