



Comparative Evaluation of Three Working Length Determination Techniques: *In Vitro* Study

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Abstract

Objective: The objective of this study is to compare the accuracy of three methods for determining working length (WL) in an *in vitro* study: conventional radiography, digital radiovisiography (RVG), and electronic apex locator (EAL).

Materials and Methods: Thirty fresh single-rooted teeth were selected. The actual length (AL) was determined by advancing a K10 file until its tip emerged at the apex, as confirmed under stereomicroscopic visualization. Three measurement techniques were then performed and compared to the AL: conventional radiography, digital radiovisiography (RVG), and Endopilot® electronic apex locator (EAL). Repeated measures ANOVA was used to evaluate differences ($p < 0.05$). **Results:** The mean AL was 21.60 mm. The measured lengths were: conventional radiography = 21.60 mm; RVG = 21.47 mm; EAL = 21.62 mm. No significant difference was observed ($p = 0.576$). **Conclusion:** All three techniques demonstrate comparable accuracy. In clinical practice, the combination of an EAL with radiographic control remains recommended.

Subject Areas

Dentistry

Keywords

Endodontics, Working Length, Apex, Radiography, Apex Locator

1. Introduction

Precise determination of working length (WL) is an essential factor for successful

endodontic treatment [1]. It ensures optimal cleaning of the canal system while avoiding instrumental or obturator overfilling that could be harmful to periapical tissues.

The apical region presents complex anatomy, with frequent eccentricity of the apical foramen, variability of the apical constriction, influence of aging, and the presence of multiple constrictions or parallel zones [2].

Available techniques for determining working length (WL) include empirical methods, such as tactile and paper point methods, which are poorly reproducible; two-dimensional radiographic methods, considered the reference standard [3]; and electronic apex locators (EAL), whose performance has improved through the development of multi-frequency systems [4].

However, disagreements persist regarding the actual superiority of one method. Numerous studies have shown comparable accuracy between radiography and EAL [5] [6], while others emphasize the value of combining methods [7].

Among electronic apex locators, the Endopilot® system (VDW GmbH, Munich, Germany) was specifically selected for this study based on its distinct technological characteristics that differentiate it from devices tested in previous comparative studies. The Endopilot® represents a new-generation, multi-frequency apex locator that employs dual-frequency impedance measurement technology operating at 8 kHz and 400 Hz simultaneously. This dual-frequency approach differs fundamentally from earlier single-frequency devices and from many EALs evaluated in prior research, which typically relied on single-frequency measurements that were more susceptible to interference from conductive canal contents. The simultaneous dual-frequency measurement allows the Endopilot® to achieve more stable and reliable localization of the apical foramen even in the presence of conductive irrigants, residual moisture, or bleeding—conditions that frequently compromise the accuracy of single-frequency devices. Furthermore, the Endopilot® features an advanced signal processing algorithm that has been demonstrated to reduce signal instability and improve measurement reproducibility compared with first-generation EALs. This specific technological configuration has not been extensively evaluated in direct comparison with radiographic methods in the existing literature, thereby justifying its selection for the present investigation. Consequently, the inclusion of the Endopilot® device allows this study to reflect contemporary endodontic clinical practice while providing relevant comparative data that addresses a gap in the evidence base regarding this specific multi-frequency technology.

The objective of this *in vitro* study is to compare the accuracy of three techniques: conventional radiography, RVG, and EAL.

2. Materials and Methods

2.1. Sample Selection

Thirty single-rooted teeth with mature apices and free from lesions or restorations were selected.

2.2. Determination of Actual Length

The actual length was determined using a precise and objective method. A small file was introduced into the canal and advanced until its extremity was flush with the external edge of the major apical foramen, which was visually verified using a stereomicroscope at high magnification ($\times 20$). This measurement, defined as the patency length, served as the anatomical reference for all subsequent comparisons.

2.3. Sample Mounting

To allow valid electronic apex locator measurements, the apical two-thirds of each root was embedded in freshly mixed alginate, a conductive medium simulating the electrical properties of the periodontal ligament (PDL) [8]. The alginate was prepared according to the manufacturer's instructions and used immediately to maintain adequate conductivity throughout the experimental procedures.

2.4. Blinding and Reliability Protocol

To reduce measurement bias, a blinded study design was implemented. The determination of the reference anatomical length was performed by one examiner, while all experimental measurements were carried out by a second examiner who was blinded to the reference values and to previous measurements for each tooth. The order of the measurement techniques was randomized. Intra- and inter-examiner reliability were assessed on a subset of 10 randomly selected teeth using repeated measurements and intraclass correlation coefficients.

2.5. Measurement Procedures

2.5.1. Conventional Radiography

Parallel technique with a K15 file positioned at the pre-estimated WL [3] [9]. After radiographic exposure, the radiograph was examined to verify that the file tip was visible and appropriately positioned relative to the radiographic apex. The working length was then determined by direct measurement on the radiographic image using the integrated measurement ruler calibrated for the known file length. This approach represents the standard clinical radiographic method for working length determination, where the operator visually assesses the file-to-apex relationship on the two-dimensional radiographic image and makes any necessary adjustments based on the apparent distance between the file tip and the radiographic apex. The final working length value recorded for the conventional radiography group was the measurement obtained from this radiographic interpretation.

2.5.2. Digital Radiovisiography (RVG)

Analysis of the digital image using integrated measurement software. The digital sensor was positioned using the parallel technique, and the resulting image was analyzed using the calibrated measurement tools within the digital imaging software to determine the working length based on the file-to-apex relationship visible on the digital radiograph.

2.5.3. Electronic Apex Locator (EAL)

Electronic working length determination was performed using the Endopilot® apex locator with the roots embedded in alginate to simulate the periodontal ligament. The lip clip was attached to the alginate medium, and a K-file was connected to the file holder. The file was slowly advanced into the canal while continuously monitoring the digital display. The Endopilot® device provides a numeric scale ranging from approximately 2.0 (when the file is far from the apex) to 0.0 (when the file tip reaches the major apical foramen, corresponding to the patency length). For this study, working length measurements were recorded when the device display indicated “0.0”, representing the position at which the file tip had reached the major apical foramen according to the manufacturer’s calibration. At this “0.0” reading position, the silicone stop was carefully adjusted to the reference point, and the file was withdrawn. The working length was then measured directly from the silicone stop to the file tip using a digital caliper with 0.1 mm precision. This measurement protocol was chosen to directly compare the EAL’s localization of the major apical foramen with the stereomicroscopically confirmed patency length used as the anatomical reference. It should be noted that in clinical practice, most manufacturers and clinicians recommend establishing the working length at a position 0.5 to 1.0 mm short of the ‘0.0’ reading (*i.e.*, at the apical constriction rather than at the major foramen). However, for the specific purpose of this *in vitro* validation study comparing the EAL’s ability to locate the major apical foramen against a stereomicroscopically confirmed reference, the “0.0” position was intentionally used as the measurement point.

2.6. Statistical Analysis

Data normality was verified using the Shapiro-Wilk test, confirming the appropriateness of parametric analysis. Mauchly’s test then validated the sphericity condition. Comparisons between the three techniques were performed using repeated measures ANOVA with a significance threshold set at $p < 0.05$.

3. Results

The data collected during our work are summarized in **Table 1**.

Table 1. Working lengths collected according to different techniques.

Tooth Number	Actual Length (mm)	File Length/Conventional Radiography (mm)	File Length/Digital Radiography (mm)	File Length/Locator (mm)
1	22	22	21	22
2	26	26	26	26
3	21	21	22	22
4	20	20	19	20
5	23	23	23	23

Continued

6	20	19	20	20
7	22	21	22	22
8	21	22	21	21
9	23	22	22	23
10	23	23	24	23
11	22	23	23	23
12	20	20	20	20
13	17	17	18	18
14	22	22	22	23
15	22	21	22	22
16	23	23	23	23
17	21	22	23	22
18	22	22	23	22
19	19	20	19	20
20	24	24	23	24
21	21	21	21	21
22	21	21	21	21
23	23	23	23	23
24	22	21	21	21
25	23	23	22	22
26	21	21	21	20
27	22	22	21	21
28	23	23	22	23
29	20	21	21	20
30	19	19	18	19

Descriptive analysis of data related to different techniques for determining working length is summarized in **Table 2**:

Table 2. Descriptive data analysis.

Techniques	Actual Length	Conventional Radiography	RVG	Apex Locator
Mean Length (mm)	21.60	21.60	21.47	21.62
Median	22.00	22.00	21.00	22.00
Standard Deviation	1.734	1.714	1.655	1.633
Variance	3.007	2.938	2.740	2.667
Minimum	17	17	18	18
Maximum	26	26	26	26

Interpretation

Comparisons of mean lengths between the three different techniques for determining working length and in relation to the reference length were performed using repeated measures ANOVA.

The sphericity and normality conditions were verified; the p-value is 0.576, which is higher than the significance threshold set at 0.05. Therefore, the means for determining working length are not statistically significantly different from each other or from the actual length. The three techniques for determining working length have similar accuracy and are as precise as the handheld tooth determination of working length.

Statistical analysis revealed a p-value of 0.576, well above the significance threshold of 0.05, indicating that no significant difference was observed between the three methods studied. Clinically, the electronic apex locator (EAL) showed a very slight tendency to overestimate working length by approximately 0.02 mm, while digital radiovisiography (RVG) had an inverse tendency, underestimating it by approximately 0.13 mm.

However, these variations are extremely small and remain negligible in the clinical context, confirming that all the techniques studied are comparable and reliable for determining working length.

4. Discussion

This study demonstrates that conventional radiography, digital radiovisiography (RVG), and the electronic apex locator (EAL) exhibit comparable accuracy for working length determination, a result that is consistent with several previous studies [4]-[6]. The measurements obtained show clinically negligible discrepancies, and statistical analysis (repeated measures ANOVA) confirms the absence of significant differences among the three techniques ($p = 0.576$).

This study was specifically designed to validate the accuracy of the Endopilot® electronic apex locator in single-rooted teeth under controlled *in vitro* conditions. The use of a conductive alginate model allowed appropriate simulation of the electrical behavior of the periodontal ligament, which is essential for meaningful evaluation of electronic apex locator performance [8].

Despite these methodological improvements, the *in vitro* model cannot fully reproduce the complex biological conditions encountered *in vivo*, such as the presence of vital tissues, blood, inflammatory exudates, and anatomical variability of the apical region [2] [10].

In addition, the inclusion of only single-rooted teeth limits the generalization of the present findings. Teeth with multiple roots and complex canal anatomy may present greater challenges for electronic working length determination and should be investigated in future studies.

The slight underestimation observed with the RVG method (mean difference: 0.13 mm) may be attributed to several technical factors inherent to digital radiographic imaging. First, minor variations in projection geometry can result in fore-

shortening effects, particularly when perfect perpendicular alignment between the sensor, tooth, and X-ray beam is difficult to achieve in the experimental setup. Even slight deviations from ideal parallel technique can systematically reduce the apparent tooth length on the radiographic image [3] [9]. Second, the intrinsic resolution of digital sensors and their pixel dimensions may limit the precise identification of the file tip, especially in the apical region where contrast between the metallic file and the surrounding root structure can be subtle. The finite pixel size (typically 20 - 40 μm for intraoral sensors) introduces a degree of measurement uncertainty when attempting to identify the exact position of structures smaller than individual pixels. Third, software calibration algorithms used to convert pixel measurements to millimeter values may introduce systematic deviations if the calibration reference (typically based on the known file length) is not perfectly aligned with the measurement axis. Finally, operator-dependent interpretation of radiographic landmarks remains an inherent limitation of two-dimensional imaging, as the observer must visually identify and mark the file tip position on a digital display, which can introduce subjective variation. Nevertheless, despite these potential sources of error, the magnitude of this underestimation (0.13 mm) remains clinically negligible and falls well within the generally accepted margin of error for working length determination (± 0.5 mm).

Two-dimensional radiographs, despite their limitations related to anatomical superimpositions and distortions, remain reliable when used in conjunction with an EAL [3] [9]. RVG, although subject to the same geometric constraints, offers better readability thanks to contrast and zoom options, which facilitates interpretation of measurements. These observations align with the conclusions of previous studies [5] [6], who also demonstrated an absence of significant differences between radiography and EAL. ESE recommendations [7] emphasize the importance of combining EAL use with radiographic control to optimize clinical safety and accuracy.

One of the strengths of this study lies in the use of natural teeth, allowing faithful reproduction of actual anatomy and minimizing biases related to artificial models [1] [2]. Direct determination of actual length at the apex constituted a reliable and precise reference for comparing techniques. The strict protocol and application of repeated measures ANOVA reinforced the robustness of statistical analyses and the reliability of results obtained.

Nevertheless, certain limitations must be acknowledged. This *in vitro* study does not reproduce the biological conditions encountered clinically, such as humidity, tissue fluids, or bleeding, which can influence the behavior of apex locators. Additionally, only one brand of EAL was tested, which limits the generalization of results to other devices. Finally, only single-rooted teeth were included, excluding the complex anatomical variations found in molars.

5. Conclusion

This *in vitro* study was specifically designed to validate the accuracy of the En-

dopilot® electronic apex locator on single-rooted teeth under controlled experimental conditions. Within the limitations of the sample (single-rooted teeth only) and the experimental protocol, the Endopilot® demonstrated accuracy comparable to conventional radiography and digital radiovisiography when validated against a stereomicroscopically confirmed anatomical reference. However, the *in vitro* model employed, even with the use of a conductive alginate medium, cannot fully replicate the complex biological environment encountered *in vivo*, including the presence of vital tissues, blood, inflammatory exudates, and the anatomical variability of the apical region [2] [10]. Furthermore, the restriction to single-rooted teeth limits the generalizability of these findings to teeth with multiple roots and complex canal anatomy. Although electronic apex locators represent reliable tools for working length determination in single-rooted teeth under controlled conditions, their clinical use should remain systematically combined with radiographic control [3] [7] [9]. Further *in vivo* studies, including multi-rooted teeth, are required to confirm these findings under true biological conditions and to better understand how the *in vitro* model may differ from clinical reality.

Conflicts of Interest

The authors declare no conflicts of interest.

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