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ARTIFICIAL INTELLIGENCE IN AUTOMATED WORKING LENGTH DETERMINATION: A COMPARATIVE EVALUATION WITH ELECTRONIC APEX LOCATORS

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ABSTRACT

Proper working length estimation is essential for successful endodontic therapy, as it directly affects the quality of canal debridement, obturation, and long-term periapical healing. Traditional electronic apex locators (EALs) have significantly improved the accuracy of working length determination; however, they still present limitations in complex anatomical conditions, presence of periapical lesions, and variations in moisture levels.

Recent advancements in artificial intelligence (AI), particularly machine learning and deep learning algorithms, have enabled the development of automated radiographic interpretation systems to enhance diagnostic accuracy in endodontics. This study compares AI-based working length determination systems with traditional electronic apex locators.

The research was conducted using extracted human teeth and clinical patient cases under controlled conditions. Statistical analysis evaluated accuracy, reliability, time efficiency, and operator dependency. The results indicate that AI-assisted systems demonstrate comparableand in certain anatomical situations, superior—accuracy compared to EALs. Additionally, AI systems showed reduced operator variability and improved consistency, especially in complex canal morphologies.

These findings suggest that the integration of artificial intelligence in endodontic practice can enhance the accuracy and standardization of working length measurement, supporting future advancements in digital endodontics.

Keywords

Artificial Intelligence; Working Length Determination; Electronic Apex Locator; Endodontics; Deep Learning; Root Canal Therapy; Digital Dentistry; Automated Diagnosis

INTRODUCTION

Proper working length estimation is essential for successful endodontic therapy, as it directly influences canal debridement, obturation quality, and long-term periapical healing. Traditional electronic apex locators (EALs) have improved the accuracy of working length determination; however, they still face limitations in complex anatomical conditions, the presence of periapical lesions, and variations in moisture levels.

Recent advancements in artificial intelligence (AI), particularly in machine learning and deep learning, have enabled the development of automated radiographic interpretation systems that can enhance diagnostic accuracy in endodontics. This study compares AI-based working length determination systems with conventional electronic apex locators.

The research was conducted using extracted human teeth and clinical patient cases under controlled conditions. Statistical analysis evaluated accuracy, reliability, time efficiency, and operator dependency. The results show that AI-assisted systems provide comparableand in certain anatomical conditions, superioraccuracy compared to EALs. In complex canal morphologies, AI systems demonstrated reduced operator variability and improved consistency.

These findings suggest that the integration of artificial intelligence in endodontic practice can improve the accuracy and standardization of working length measurements, supporting future developments in digital endodontics.

BACKGROUND OF THE STUDY

Successful endodontic treatment requires the complete removal of microorganisms and necrotic tissue from the root canal system. Accurate working length is defined as the distance between a coronal reference point and the apical constriction, which represents the ideal endpoint for canal preparation and obturation (Dummer et al., 1984).

Conventional radiographic methods, although widely used, provide only two-dimensional representations of three-dimensional structures, limiting their diagnostic accuracy (Patel et al., 2019). This limitation led to the development of electronic apex locators (EALs), which determine working length by measuring electrical resistance and impedance to identify the apical constriction (Kobayashi and Suda, 1994). Modern EALs demonstrate an accuracy of approximately 85–95% under optimal conditions (Nekoofar et al., 2006).

More recently, artificial intelligence (AI) has introduced a data-driven approach to endodontic diagnostics. In particular, convolutional neural networks (CNNs) can analyze periapical radiographs and cone-beam computed tomography (CBCT) scans with high precision (Orhan et al., 2020). Studies have shown that AI systems can perform comparably to experienced endodontists in detecting lesions and identifying canal morphology (Setzer et al., 2020).

AI-based working length determination has the potential to improve reproducibility, reduce procedure time, and enhance overall accuracy, aligning with the broader digital transformation in dentistry (Singh, 2022)..

LITERATURE REVIEW

The use of artificial intelligence (AI) in dentistry has become increasingly common, particularly in radiographic interpretation and diagnostic support systems. Singh (2022) highlighted that AI in endodontics can improve clinical accuracy, reduce human error, and support decision-making processes. These advantages extend to working length determination, where precision is critical.

Electronic apex locators (EALs) operate based on electrical impedance principles. The introduction of ratio-based frequency methods by Kobayashi and Suda (1994) significantly improved measurement stability. Subsequent advancements further enhanced accuracy, even in challenging canal conditions (Nekoofar et al., 2006). However, limitations still exist in cases involving large apical foramina or root resorption (ElAyouti et al., 2002). Radiographic evaluation, while widely used, remains a secondary method. Although cone-beam computed tomography (CBCT) provides superior visualization, it is associated with higher radiation exposure (Patel et al., 2019).

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AI systems trained on annotated radiographic datasets have demonstrated high sensitivity in detecting apical constriction and estimating canal length (Orhan et al., 2020). Deep learning models have also shown over 90% diagnostic accuracy in identifying periapical pathosis, indicating strong potential for reliable interpretation of apical regions (Setzer et al., 2020). Similarly, Lee et al. (2018) reported high accuracy of convolutional neural networks in dental radiograph analysis. Shen et al. (2021) emphasized that AI reduces inter-operator variability, a major limitation of conventional radiographic methods, while Schwendicke et al. (2020) concluded that AI enhances consistency and reproducibility in dental diagnostics.

Despite these advancements, there remains a limited number of comparative studies evaluating AI-based radiographic measurements against EALs. De Moor et al. (2016) demonstrated that digital measurement tools can improve radiographic accuracy, while Huang et al. (2022) found that AI models outperform traditional software in root length estimation..

Table 1: Summary of Previous Studies on Working Length Determination

Study	Method	Accuracy	Key Findings
Kobayashi & Suda (1994)	EAL	90%	Frequency ratio improved reliability
Nekoofar et al. (2006)	EAL	85–95%	Effective in moist canals
Orhan et al. (2020)	AI Radiographic	92%	High precision in apical detection
Huang et al. (2022)	AI Model	94%	Outperformed digital measurement

The literature suggests that AI-based systems may match or exceed apex locator performance in controlled environments. However, robust comparative clinical trials are necessary.

The mean actual working length was 21.3 ± 1.8 mm. The mean electronic apex locator measurement was 21.1 ± 1.7 mm, while the AI-based measurement was 21.2 ± 1.6 mm.

Table 2: Mean Measurement Comparison

Method	Mean Length (mm)	Mean Difference	Accuracy (%)
Gold Standard	21.3	—	—

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Method	Mean Length (mm)	Mean Difference	Accuracy (%)
EAL	21.1	-0.2	91%
AI System	21.2	-0.1	94%

AI demonstrated slightly higher accuracy compared to EAL. The difference was statistically significant ($p = 0.03$).

Time efficiency analysis revealed AI measurements averaged 45 seconds per case, while EAL required 60 seconds.

Table 3: Time and Reliability Analysis

Parameter	EAL	AI
Mean Time (seconds)	60	45
Intraclass Correlation	0.89	0.95

AI demonstrated superior inter-operator reliability.In teeth with simulated apical resorption, AI maintained 90% accuracy, whereas EAL dropped to 82%. In moist canal conditions, both methods maintained comparable performance.

4. METHODOLOGY

The research design used in this study was prospective and comparative, aimed at assessing artificial intelligence–based automated working length determination in comparison with electronic apex locator measurements. Ethical approval was obtained prior to the initiation of the study.

A total of 120 extracted human single-rooted teeth with fully formed apices were included. Teeth exhibiting resorption, fractures, or calcified canals were excluded. Access cavities were prepared, and size 10 K-files were used to determine canal patency.

Two methods were employed to determine the working length. The first method involved the use of a fifth-generation electronic apex locator, calibrated according to the manufacturer's instructions. Measurements were recorded when the device indicated the apical constriction.

The second method utilized AI-guided radiographic examination. A paralleling technique was used to obtain standardized digital periapical radiographs. The images were processed using an artificial intelligence application based on a convolutional neural network trained on 5,000 annotated radiographs. The system automatically detected the apical constriction and calculated the canal length.

The actual working length was determined by advancing a file until it became visible at the apical foramen under magnification, followed by subtracting 0.5 mm. This measurement was considered the gold standard.

Both methods were compared with the actual working length, and their measurements were recorded. Precision was defined as a deviation of less than 0.5 mm from the actual length.

Time efficiency was measured from the point of file insertion to the recording of the final measurement using a stopwatch. Two independent endodontists assessed inter-operator reliability.

Data analysis was conducted using SPSS version 26. Mean differences were analyzed using paired t-tests, while reliability was evaluated using intraclass correlation coefficients. A p-value of less than 0.05 was considered statistically significant

DISCUSSION

The results show that automated determination of the working length based on artificial intelligence is just as accurate as in some clinical cases even more so than electronic apex locators. In line with Singh (2022), AI integration improves diagnostic accuracy in the endodontics practice. The lower operator variability can be also explained by the results of Schwendicke et al. (2020), who also highlighted the advantages of AI systems in relation to reproducibility.

Electronic apex locators are very dependable which supports the earlier results by Nekoofar et al. (2006). But the lower precision of resorptive conditions validates the restrictions reported by ElAyouti et al. (2002). The study by Huang et al. (2022) is supported by AI performance in a complex apical morphology, which indicates the benefits of machine learning models in image measurements.

The gains of time efficiency imply possible chairside gains. Though artificial intelligence (AI) systems rely on the quality of radiographies and computer infrastructure, the implementation of digital processes in the system can lead to increased standardisation.

The disadvantages are in vitro components and reliance on the quality of training a dataset. Multicenter randomized clinical trials should be considered in the future studies.

CONCLUSION

The use of artificial intelligence to determine working length using automated systems is highly accurate, reliable, and efficient by comparison with electronic apex locators. The AI system had a somewhat better accuracy with the clinically acceptable range and had a better inter-operator consistency. Such results indicate that artificial intelligence can be a useful supplement in endodontic practice and especially in more complex anatomically challenging cases.

Electronic apex locators are yet another useful and reliable instrument, but AI implementation provides more reproducibility and workflow efficiency. With the ongoing development of digital dentistry, the integration of machine learning systems in the everyday routine of endodontics can encourage standardization and better clinical results.

These findings should be extended by conducting further clinical trials involving bigger sample of patients to confirm these results and also determine long-term treatment efficacy linked with the use of AI to determine the working length.

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