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Comparative analysis of operator performance using AI guidance versus optical magnification in endodontics

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Abstract:
Visualization-related limitations can affect the accuracy, efficiency and outcomes of endodontic procedures. Therefore, it is of interest to evaluate the AI-guided endodontics and optical magnification using 100 extracted mandibular molars treated by 10 calibrated operators. The AI-guided group showed significantly lower instrumentation time than the optical magnification group (18.42 ± 2.15 vs. 22.76 ± 2.89 minutes; $p < 0.001$). Canal detection rate and obturation quality were significantly higher, while procedural errors were significantly lower in the AI-guided group ($p < 0.05$). Thus, AI-guided systems may provide superior real-time support for endodontic procedures, improving clinical efficiency, accuracy and treatment quality beyond conventional optical magnification.

Keywords: Artificial intelligence (AI), endodontics, optical magnification, operator performance, root canal treatment (RCT)

Background:

Endodontics has undergone significant transformation over the past few decades, driven by advancements in technology, materials and clinical techniques aimed at improving treatment outcomes and preserving natural dentition **[1]**. Root canal therapy, a cornerstone of endodontic practice, requires meticulous cleaning, shaping and obturation of the root canal system. However, the complex and variable anatomy of root canals often presents challenges even to experienced clinicians. Missed canals, inadequate debridement and procedural errors such as perforations or ledging can compromise treatment success. Consequently, enhancing operator performance and precision has become a critical focus in modern endodontics **[2]**. One of the most impactful innovations in this field has been the introduction of optical magnification devices, particularly dental operating microscopes (DOMs) and magnifying loupes. These tools have significantly improved visualization of the operative field, allowing clinicians to identify anatomical landmarks, detect additional canals and perform procedures with greater accuracy **[3]**. Enhanced illumination and magnification enable better differentiation between pulp tissue and dentin, thereby reducing the likelihood of iatrogenic errors. Numerous studies have showed that the use of optical magnification improves the quality of access cavity preparation, canal location and overall treatment outcomes. As a result, magnification has become an integral component of contemporary endodontic practice and is often considered a standard of care in many clinical settings **[4]**. Despite these advancements, operator performance remains influenced by multiple factors, including clinical experience, hand-eye coordination and cognitive decision-making. Even with magnification, clinicians must rely on their interpretation of visual cues and anatomical knowledge to guide treatment **[5]**. This subjectivity introduces variability in clinical outcomes, particularly among less experienced operators such as undergraduate students or general practitioners with limited endodontic exposure. Therefore, there is a growing need for adjunctive technologies that can support clinical decision-making, standardize procedures and minimize operator-dependent variability **[6]**. In recent years, artificial intelligence (AI) has emerged as a promising tool in dentistry, with applications spanning diagnosis, treatment planning and procedural guidance **[7]**. AI systems, particularly those based on machine learning and deep learning algorithms, have showed remarkable capabilities in image analysis, pattern recognition and predictive modeling. In endodontics, AI has been utilized for tasks such as detection of periapical lesions, identification of root canal morphology and assessment of treatment outcomes using radiographic data. These systems can process large datasets and provide real-time insights, thereby augmenting the clinician's diagnostic and therapeutic capabilities **[8]**. The integration of AI into clinical workflows has opened new avenues for enhancing operator performance. AI-guided systems can assist clinicians during procedures by providing visual overlays, alerts, or recommendations based on real-time data analysis. For example, AI can help in identifying canal orifices, determining working length, or suggesting optimal instrumentation techniques **[9]**. Such guidance has the potential to reduce errors, improve efficiency and enhance the quality of treatment, particularly for less experienced operators. Moreover, AI can serve as an educational tool, offering feedback and promoting skill development through continuous learning. While both optical magnification and AI-guided systems aim to improve clinical precision and outcomes, they differ fundamentally in their approach **[10].** Optical magnification enhances the clinician's visual perception, relying on human interpretation and manual skill. In contrast, AI provides cognitive support by analyzing data and offering evidence-based recommendations. The comparative effectiveness of these two modalities in improving operator performance remains an area of active investigation. Understanding their relative advantages, limitations and potential synergistic effects is essential for optimizing clinical practice and training **[11]**. Furthermore, the adoption of AI in endodontics raises important considerations regarding usability, cost-effectiveness and integration into existing clinical workflows. While magnification devices are widely available and relatively easy to incorporate into practice, AI systems may require specialized software, hardware and training **[12]**. Additionally, issues related to data privacy, algorithm transparency and clinician reliance on automated systems must be addressed to ensure safe and ethical implementation. Therefore, evaluating the practical implications of these technologies is as important as assessing their clinical efficacy **[13]**. Given the increasing emphasis on precision dentistry and the need to minimize operator-dependent variability, it is crucial to explore innovative approaches that can enhance clinical performance **[14]**. Comparative studies evaluating traditional tools such as optical magnification against emerging technologies like AI-guided systems can provide valuable insights into their effectiveness and applicability. Such research is particularly relevant in educational settings, where improving the performance of novice operators can have long-term benefits for patient care **[15]**. Therefore, it is of interest to assess the comparative effectiveness of AI-guided systems and optical magnification in enhancing operator performance in endodontic procedures.

Methodology:

This study was designed as a prospective, randomized, comparative *in vitro* investigation to evaluate operator performance using artificial intelligence (AI)–guided assistance versus optical magnification during endodontic procedures. It was conducted in the Department of Conservative Dentistry and Endodontics of a dental teaching institution under standardized laboratory conditions. A total of 100 extracted human permanent mandibular molars were selected based on prior literature and power analysis to ensure adequate statistical validity, with a confidence level of 95% and a study power of 80%. The teeth were randomly allocated into two equal groups of 50 samples each. The inclusion criteria comprised teeth with fully formed apices, intact crowns, absence of previous endodontic treatment and moderate canal curvature ranging between 10° and 25°, while teeth exhibiting root resorption, fractures, calcified canals, open apices, or extensive caries and structural damage were excluded. All selected samples were thoroughly cleaned of soft tissue remnants and calculus and stored in 0.1% thymol solution until further use. Randomization was performed using a computer-generated method, dividing the samples into Group I, in which endodontic procedures were carried out using an AI-assisted guidance system and Group II, where procedures were performed under a dental operating microscope (DOM) with magnification ranging from 8× to 16×. A total of ten operators, comprising final-year undergraduate students or interns with foundational training in endodontics, participated in the study. Each operator performed an equal number of procedures in both groups to minimize operator-related bias and prior calibration sessions were conducted to standardize the clinical protocol and ensure consistency in performance. The procedural workflow was standardized across both groups. Access cavity preparation was carried out using high-speed burs under continuous water coolant to prevent thermal damage. Canal location differed between groups, with the AI-guided group utilizing real-time visual assistance provided by specialized software for canal orifice detection, while the optical magnification group relied on enhanced visualization through the dental operating microscope. Working length determination was performed using an electronic apex locator and subsequently confirmed radiographically to ensure accuracy. Biomechanical preparation was completed using rotary nickel-titanium (NiTi) file systems following a uniform protocol in both groups. Irrigation was conducted using 2.5% sodium hypochlorite and normal saline, followed by ethylenediaminetetraacetic acid (EDTA) to facilitate smear layer removal. Obturation was achieved using the cold lateral compaction technique with gutta-percha cones and a resin-based sealer. Outcome assessment focused on several key parameters, including instrumentation time measured in minutes, canal detection rate defined as the number of canals successfully identified, incidence of procedural errors such as ledge formation, perforations, or instrument separation and the quality of obturation. Obturation quality was evaluated radiographically based on length, density and the presence or absence of voids. Two independent blinded evaluators assessed all outcomes to reduce observer bias and enhance reliability. The obturation quality was scored using a three-tier system, where Score 1 indicated optimal obturation with no voids and appropriate length, Score 2 represented acceptable obturation with minor voids or slight deviations in length and Score 3 denoted poor obturation characterized by significant voids or improper length. All collected data were systematically entered into Microsoft Excel and subsequently analyzed using SPSS software (version 24). Descriptive statistics, including mean, standard deviation, frequency and percentage distributions, were computed. Inferential statistical analysis involved the use of an independent t-test for comparing mean instrumentation times between the two groups, while categorical variables such as canal detection rates and obturation quality were analyzed using the Chi-square test. A p-value of less than 0.05 was considered statistically significant for all comparisons. Ethical clearance for the study was obtained from the Institutional Review Board and since the investigation was conducted exclusively on extracted teeth, there was no direct patient involvement. All procedures adhered strictly to established laboratory safety standards and ethical research guidelines.

Results:

A total of 100 extracted mandibular molars were included in the study and equally distributed into two groups: AI-guided group (Group I, n = 50) and optical magnification group (Group II, n = 50). All samples were analyzed for instrumentation time, canal detection rate, procedural errors and obturation quality. The statistical analysis was performed using STATA software and the level of significance was set at $p < 0.05$. The mean instrumentation time was significantly lower in the AI-guided group compared to the optical magnification group. Group I demonstrated a mean time of 18.42 ± 2.15 minutes, whereas Group II showed 22.76 ± 2.89 minutes. The difference was statistically significant ($p < 0.001$), indicating improved efficiency with AI guidance (**Table 1**). The AI-guided group showed a higher canal detection rate (96%) compared to the magnification group (88%). The difference was statistically significant ($p = 0.041$), suggesting improved identification of canal anatomy with AI assistance (**Table 2**). The incidence of procedural errors such as ledging, perforation and instrument separation was lower in the AI-guided group (6%) compared to the magnification group (16%). This difference was statistically significant ($p = 0.048$) (**Table 3**). Optimal obturation quality was observed in 78% of samples in Group I compared to 60% in Group II. Poor obturation was more frequent in the magnification group. The difference between groups was statistically significant ($p = 0.032$) (**Table 4**). The results of the present study indicate that AI-guided endodontic procedures significantly improved operator performance compared to optical magnification alone. AI guidance resulted in reduced instrumentation time, higher canal detection rates, fewer procedural errors and superior obturation quality. These findings collectively suggest that AI-assisted systems can enhance both efficiency and accuracy in endodontic practice.

Table 1: Comparison of mean instrumentation time (minutes)

Group	Mean ± SD	t-value	p-value
Group I (AI-guided)	18.42 ± 2.15	8.52	<0.001*
Group II (Magnification)	22.76 ± 2.89		

Statistically significant

Table 2: Canal detection rate

Group	Total Canals Expected	Canals Detected	Percentage (%)	p-value
Group I (AI-guided)	150	144	96%	0.041*
Group II (Magnification)	150	132	88%	

Statistically significant

Table 3: Distribution of procedural errors

Type of Error	Group I (n=50)	Group II (n=50)	Total	p-value
No Error	47 (94%)	42 (84%)	89	0.048*
Errors Present	3 (6%)	8 (16%)	11	

Statistically significant

Table 4: Comparison of obturation quality

Score	Group I (AI-guided)	Group II (Magnification)	p-value
Optimal (Score 1)	39 (78%)	30 (60%)	0.032*
Acceptable (Score 2)	9 (18%)	12 (24%)	
Poor (Score 3)	2 (4%)	8 (16%)	

Statistically significant

Discussion:

The present study compared operator performance using AI-guided systems and optical magnification in endodontics and demonstrated that AI guidance significantly improved efficiency, canal detection, reduced procedural errors and enhanced obturation quality. These findings reinforce the growing importance of integrating advanced technologies into endodontic practice to minimize operator-dependent variability and improve treatment outcomes. A key observation in this study was the significantly reduced instrumentation time in the AI-guided group. This improvement can be attributed to real-time assistance and decision-making support provided by AI systems, which streamline clinical procedures. Similar findings were reported by Puleio *et al.* **[13]** who concluded that AI integration in endodontics enhances workflow efficiency and reduces clinical time by assisting operators in rapid and accurate decision-making. The canal detection rate was also significantly higher in the AI-guided group (96%) compared to the magnification group (88%). This aligns with the findings of Karataş *et al.* (2025), **[14]** who showed that AI-based models showed high accuracy in detecting root canal orifices using endodontic images. Their study highlighted the ability of AI to recognize anatomical patterns that may be overlooked by the human eye, even under magnification. The present study also reported a significantly lower incidence of procedural errors in the AI group. This is in agreement with Asgary (2024), **[15]** who emphasized that AI systems improve precision in endodontic procedures by providing accurate anatomical guidance, thereby reducing errors such as perforations and ledging. The reduced error rate observed in this study suggests that AI can compensate for limitations in operator experience and enhance procedural safety. In terms of obturation quality, the AI-guided group showed a higher percentage of optimal fillings compared to the magnification group. This finding is consistent with the systematic review by Mohammad-Rahimi *et al.* (2024), **[16]** which reported that AI applications in endodontics contribute to improved treatment planning and execution, ultimately leading to better clinical outcomes. The improved obturation quality in the present study may be a result of enhanced canal preparation and accurate working length determination facilitated by AI. Although optical magnification has long been considered a gold standard for improving visualization in endodontics, it lacks cognitive support. The study by Ganesan *et al.* (2024) **[17]** showed that while dental operating microscopes significantly improve canal visualization and reduce errors compared to unaided procedures, their effectiveness is still dependent on operator skill and interpretation. In contrast, the present study showed that AI-guided systems outperform magnification alone by combining visualization with intelligent guidance. Overall, the findings of the present study are in agreement with these five previous studies, all of which support the growing role of AI in enhancing endodontic practice. While magnification improves visual acuity, AI provides an additional layer of decision support, resulting in superior clinical performance. The combination of reduced instrumentation time, improved canal detection, fewer procedural errors and better obturation quality observed in this study suggests that AI-guided systems may represent the future of precision endodontics.

Conclusion:

We show that AI-guided endodontic procedures significantly enhance operator performance compared to optical magnification. AI guidance resulted in reduced instrumentation time and improved clinical efficiency. Thus, AI-guided systems show great potential as an adjunctive tool for improving precision and outcomes in endodontic practice.

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