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Artificial Intelligence in endodontics

Katarzyna Dębska[1, A], Katarzyna Olczak[2, B] ✉

[1] Central Clinical Hospital of the Medical University of Lodz, Postgraduate Dental Internship, Pomorska 251, 92-213 Łódź, Poland
[2] Medical University of Lodz, Department of Endodontics, Pomorska 251, 92-216 Łódź, Poland

[A] ORCID: 0000-0002-8231-2360; [B] ORCID: 0000-0002-0592-2448

✉ katarzyna.danuta.olczak@umed.lodz.pl

ABSTRACT
Artificial Intelligence (AI) operates by replicating human cognitive processes, which enables its broad application across various fields. In endodontics, AI technologies are increasingly utilized to assist in root canal treatment. Artificial Intelligence holds significant potential to enhance both diagnosis and therapy, particularly by facilitating detection of periapical lesions and root fractures. Additionally, it facilitates analysis of the pulp status through radiographic imaging, assessment of tooth morphology, determination of the length of the root canal, and prediction of treatment outcomes. This article aims to explore the role of AI in endodontics. It highlights its current applications and analyzes its prospective contributions to future root canal therapy.
Keywords: artificial neurons; root canal treatment; future of AI; periapical lesions; working length.

INTRODUCTION

Artificial Intelligence (AI) is an interdisciplinary field that integrates computer science, mathematics, and cognitive psychology [1]. Its functioning is based on the replication of human cognitive processes for the purpose of analysis and decision-making [2]. Artificial Intelligence impacts every aspect of human life, including health, economics, and security [3]. Artificial Intelligence, since its introduction into dentistry, has been applied in a wide range of areas, including the diagnosis of oral cancers and periodontal diseases, detection of dental caries, and planning of orthognathic surgeries [4]. In endodontics, the application of AI enhances both diagnostic and therapeutic processes [5]. Nevertheless, the level of awareness and knowledge of AI among endodontists is still limited [2]. The aim of this article is to present crucial information about AI and its potential applications in one branch of dentistry – endodontics.

ARTIFICIAL INTELLIGENCE

The term "Artificial Intelligence" was coined by John McCarthy in 1956. In 1980, the first system simulating human decision-making processes was developed. Although it could achieve its intended objectives, the process proved to be extremely time-consuming. Subsequent innovations have facilitated the advancement of AI, particularly through the development of 2 key subsets: machine learning (ML) and deep learning (DL) [6]. Machine learning refers to models and algorithms that do not follow predetermined rules but learn from data instead. Deep learning, a more advanced subset of ML, utilizes extensive artificial neural networks that can be trained. Communication within these artificial networks enables to resolve complex problems [7]. These systems operate as a series of algorithms that process signals via artificial neurons, modeled after the human brain. This allows for analysis of diverse cases, assessment of nonlinear and imprecise data, and generalization of findings. Consequently, they are considered valuable research tools [8].

APPLICATION OF AI IN ENDODONTICS

A particularly important role in medicine is played by a subset of AI known as DL, included in the broader category of ML. Within DL, convolutional neural networks (CNNs) emulate the activity of human neurons to perform complex analyses and interpretations of 2- and 3-dimensional radiographic images. These networks enable to accurately detect periapical lesions and root fractures, assess root canal morphology, and create 3-dimensional models of the dental pulp or the entire tooth based on cone-beam computed tomography (CBCT) scans [5]. Data from a 2024 study confirmed high efficacy of AI in recognizing periapical lesions and its ability to detect root fractures in CBCT images, as well as additional unobliterated canals in maxillary molars. Furthermore, the authors of the study noted that AI may precisely determine the working length of the root canal, predict postoperative pain, and facilitate making clinical decisions regarding the type of management – endodontic treatment or extraction, with an accuracy of up to 84.4% [4].

Detection of periapical lesions

Interpretation of radiographic images can be challenging, even for experienced clinicians. Artificial Intelligence has increasingly been employed to avoid subjectivity of evaluations and minimize the risk of overlooking subtle changes [6]. Detection of periapical lesions through DL algorithms may even outdo diagnostic capabilities of experienced radiologists [9]. It has been proven that an AI algorithm could identify periapical lesions on panoramic radiographs as effectively as a group of 24 maxillofacial surgeons [10, 11]. Similarly, researchers have confirmed that the use of DL to detect periapical changes on CBCT scans is highly precise. Moreover, enhanced AI models are believed to further improve the accuracy with which voxels are matched to specific anatomical structures within the tooth and surrounding periapical tissues. The accuracy rate might be as high as 93% [8, 12].

Distinguishing between lesions such as granulomas and cysts on radiographic images is significantly important in clinical practice, as accurate diagnosis directly influences the choice of treatment. While granulomas often resolve following nonsurgical endodontic therapy, epithelial-lined cysts may require surgical intervention. Research on the use of AI for differential diagnosis of such periapical pathologies has proved high accuracy and specificity of the employed algorithms. Thus, AI facilitates taking more informed therapeutic decisions, hereby improving quality of endodontic care [13]. Studies on the application of AI in automatic detection and classification of periapical lesions further highlight the potential of this technology to enhance diagnostic precision and treatment planning in endodontics [14].

Fracture detection

Vertical root fractures (VRFs) account for approx. 2–5% of all crown or root fractures. Diagnosing VRF is often challenging due to its nonspecific clinical presentation and low sensitivity of conventional radiographic methods [10]. Detection of VRF using CBCT is successful in only 78% of cases [6]. Therefore, AI might serve as a valuable adjunct in the diagnosing process of VRF. Data from a 2023 systematic review confirmed high accuracy and quality of VRF detection with the use of AI. However, the authors pointed out need for further large-scale studies [9]. It was reported that the use of CNNs facilitates VRF detection even on panoramic radiographs [15]. Studies included in a 2024 publication demonstrated that AI could detect fractures in both untreated and endodontically treated teeth using CBCT and periapical radiographs. Additionally, the feasibility of *in vivo* VRF detection through DL approaches was also confirmed [14].

Detection of pulpal pathologies

In 2014, Tumbelaka et al. introduced an AI model capable of diagnosing pulpitis and accurately differentiating between reversible and irreversible pulpitis, as well as pulp necrosis, based on periapical radiographs [16]. A similar study, published in 2021, revealed that the use of CNNs in analysis of periapical images, along with incorporating clinical parameters, significantly improved the diagnostic accuracy of deep caries and pulpal inflammation [14].

Assessment of root canal morphology

Despite high accuracy provided by CBCT in evaluating root canal morphology, its routine use is limited by concerns regarding patient exposure to ionizing radiation. For this reason, researchers have explored the use of AI to assess the canal shape and configuration [10]. In 2019, a DL algorithm was shown to successfully detect an additional distal root in mandibular first molars using panoramic radiographs [17]. Furthermore, AI algorithms have been effectively applied to identify C-shaped canals in mandibular molars, additional mesiobuccal canals in maxillary molars, and pulp calcifications [13]. A 2024 scoping review also cited studies supporting the efficacy of AI in detecting obliterations on periapical images, segmenting individual parts of the tooth, and identifying and classifying C-shaped canals [14]. AI-based systems, such as Diagnocat (LLC Diagnocat, Moscow, Russia) and Diagnocat (Diagnocat Inc., San Francisco, CA, US), already assist clinicians in the analysis of radiographic images and assessment of tooth canal morphology [6, 18].

Determination of the working length

The success of root canal treatment depends on accurate determination of the canal working length. Studies utilizing artificial neural networks have demonstrated that AI can determine the working length based on intraoral radiographs with greater precision than a trained endodontist [10]. It was confirmed that AI can identify the location of the apical constriction in 96% of cases [6], significantly outperforming human endodontists, who correctly determined the working length in 73% of cases [19]. In order to determine the working length, the researchers employed a neural network based on multi-frequency impedance. Although the number of analyzed cases was not specified, the authors showed that this approach also improved measurement accuracy [14].

Prediction of treatment outcomes

Artificial Intelligence appears to be beneficial in assessing the likelihood of success in endodontic retreatment; it improves treatment planning and facilitates taking more informed therapeutic decisions. Due to its ability to process complex datasets and generate clinically relevant insights AI allows for a more precise and personalized approach to retreatment decisions [15]. A study by Lee et al. utilized CNNs and preoperative periapical radiographs to predict endodontic treatment outcomes. The authors analyzed 598 single-rooted premolars, and the application of AI enabled to identify radiographic features influencing treatment success, such as coronal defects, intracanal materials, canal visibility, and periapical radiolucency. Therefore, the use of well-designed AI systems provides a precise and efficient method to support clinical decision-making in endodontics [20].

The future of AI in endodontics

Future projections regarding the role of AI in endodontics suggest a growing synergy between skilled clinicians and objective AI systems, aiming to deliver optimal diagnostic accuracy and patient care [21]. Artificial Intelligence is also closely related to the field of robotics, supporting the integration of robotic systems into endodontic procedures such as apical surgery or canal preparation. These systems are designed to ensure controlled, precise movements and real-time haptic feedback using intraoral sensors [13]. However, prior to clinical integration, additional research is needed to assess AI's reliability, cost-effectiveness, and appropriateness for practice [21]. Current results regarding AI implementation in endodontics must also be validated using external data from new patient cohorts and various dental facilities. Future investigations should focus on increasing AI's efficiency and its capability to detect changes that are imperceptible to the human eye [19].

CONCLUSION

Artificial Intelligence is a multidisciplinary field that integrates computer science, mathematics, and cognitive psychology. Development of trainable artificial neural networks capable of intercommunication has resulted in creating a powerful research tool equipped with significant applications in dentistry. In endodontics, AI algorithms have demonstrated high accuracy in detecting periapical lesions and root fractures based on radiographic imaging. Additionally, studies have confirmed that AI supports the assessment of canal morphology and pulp status by differentiating between inflammation and necrosis. Furthermore, it has been shown that AI can localize the apical constriction in 96% of cases, and its application in predicting the likelihood of successful endodontic retreatment may facilitate clinical decision-making. The future of AI in endodontics is identified with improvement of system performance and development of robotic technologies. However, the promising results of AI in endodontics must be validated by studies involving larger patient populations before its widespread clinical implementation can be considered.

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