REVIEW ARTICLE

CONTENTS

The use of artificial intelligence in caries detection – literature review

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ABSTRACT

Artificial intelligence plays an increasingly important role in modern dentistry, offering the possibility of precise and quick diagnostic image analysis and supporting the process of pathology detection. Aim: The study aims to discuss the use of artificial intelligence in caries detection, with an emphasis on radiographs and intraoral imaging analysis, and to assess the potential of this technology in the quality and efficiency of dental diagnostics improvement. Methods: A review of the scientific literature covering the years 2015–2024 was carried out, analyzing the results of studies on the effectiveness of artificial intelligence algorithms in caries detection. Publications evaluating parameters such as sensitivity, specificity, and precision compared to traditional diagnostic methods were included. Results: AI algorithms, particularly convolutional neural networks, present high accuracy, sensitivity, and specificity in caries detection, often outperforming traditional methods in detecting early lesions. The use of artificial intelligence standardizes the diagnosis, shortens the time of analysis, and reduces errors caused by a subjective clinical assessment. Major limitations include the need for high-quality training data, implementation costs, and challenges associated with technology acceptance. Conclusions: Artificial intelligence has the potential to significantly improve caries detection, offering precision, efficiency, and algorithms standardization. However, taking full advantage of its capabilities requires further research, standardization of algorithms, and appropriate adaptation of the clinical environment.

KEY WORDS: artificial intelligence, dentistry, dental caries, X-rays, diagnostic imaging

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INTRODUCTION

Early diagnosis of dental caries plays a key role in the prevention and treatment of dental diseases, enabling not only the early detection of lesions, but also their effective therapy before severe complications occur. Detection of carious lesions at an early stage allows for the application of less invasive treatment methods, such as remineralization or minor composite restorations, which leads to a reduced risk of further tooth destruction, reduced health burden for the patient, and lower the costs of therapy. This approach supports not only patients' heath but also optimizes the dentist's working time [1].

Traditionally, caries diagnosis is based on visual and tactile assessment performed during a clinical examination and on the analysis of diagnostic images, such as intraoral radiographs or images taken with intraoral cameras. These tools, although effective, have their limitations. They require a lot of experience, precision, and focus, which can be difficult to maintain during intensive clinical work [2]. Factors such as differences in the dentist's individual diagnostic perception, professional experience, and fatigue, can lead to diagnostic errors, such as missing minor carious lesions or misinterpreting the images resulting in over-treatment of lesions, which should have been left for observation. Such imperfections can result in delayed treatment or inadequate therapy, which consequently affects the patient's health and the costs of dental care [3].

In this context, artificial intelligence (AI) is becoming one of the most promising tools supporting dental diagnostics [4]. The development of AI technologies, in particular advanced machine learning algorithms such as deep neural networks (DNNs), opens up new possibilities in the analysis of diagnostic images. AI allows for precise identification of even subtle pathological alterations, such as early carious foci, which may be difficult to spot using traditional diagnostic tools [5]. Additionally, these algorithms offer standardization of diagnostic results. The use of AI in dentistry also opens

up new perspectives in the context of working time management and increasing the efficiency of clinical work. AI can not only support doctors in making diagnostic decisions but also accelerate the process of image analysis, which is particularly important in conditions of high workload. By automating many aspects of diagnostics, it is also possible to reduce operating costs in dental clinics, which makes this technology increasingly attractive to both dentists and patients [6].

AIM

This paper aims to provide a detailed discussion of the applications of artificial intelligence in caries detection, with particular emphasis on the analysis of X-ray images and intraoral photographs. The article will analyze the key advantages, limitations, and future prospects of this technology. Particular attention is paid to the potential impact of AI on everyday dental practice and the quality of care provided to dental patients.

MATERIAL AND METHODS

In order to develop this paper, a review of the scientific literature covering the years 2000–2024 was conducted, analyzing the results of studies on the application of AI algorithms in dentistry, with particular emphasis on their effectiveness in caries diagnostics. The PubMed database was used to identify publications on the implementation of AI in the analysis of X-ray images and intraoral photographs. The selection criteria included articles describing the detailed application of AI algorithms in dental diagnostics and studies comparing the effectiveness of AI with the diagnoses made by dentists, including assessments of parameters such as sensitivity, specificity, and precision of detecting carious lesions.

REVIEW AND DISCUSSION

THE USE OF ARTIFICIAL INTELLIGENCE ALGORITHMS IN DENTAL DIAGNOSTICS

Artificial intelligence is becoming increasingly broadly used in dental diagnostics, based on advanced algorithms capable of analyzing diagnostic images. Among the most commonly used technologies, neural networks stand out, including convolutional neural networks (CNN), which are particularly effective in image analysis due to their ability to recognize patterns and structures [7].

Deep Learning models, which are an extension of neural networks, allow for a more comprehensive analysis of large data packages, making them an ideal tool for diagnosing complex cases. In addition, decision support algorithms (Decision Support Systems) provide dentists with precise diagnostic tips, which can significantly improve the quality of decision-making [8]. One of the key areas is the detection of carious lesions in X-ray images, where algorithms can identify early changes, often invisible to the human eye are interproximal spaces. Another important application is the evaluation of intraoral images for early signs of caries, which allows for rapid intervention and limiting the progression of the disease. Additionally, AI supports image segmentation, enabling precise identification of the boundaries of carious lesions, which is invaluable in treatment planning. Thanks to these capabilities, AI algorithms significantly improve the accuracy and efficiency of dental diagnostics [9].

ADVANTAGES AND LIMITATIONS OF ARTIFICIAL INTELLIGENCE IN CARIES DETECTION

The use of AI in caries diagnostics brings many benefits that can significantly improve the process of detecting pathological changes in tooth structures. One of the most important advantages is high sensitivity and specificity in detecting carious lesions, which allows for precise diagnosis, especially in the case of diagnostic images that are difficult to interpret. The speed of image analysis by AI algorithms is another important advantage, enabling shorter time needed for diagnostics purposes and improved efficiency of clinical work [10]. The use of AI also contributes to reducing errors resulting from human perception, such as fatigue, differences in clinical experience, or subjectivity of image interpretation. In addition, AI offers the potential to standardize diagnosis by eliminating the influence of individual differences in clinical judgment and ensuring consistency in the diagnostic process [11]. Despite these advantages, the application of AI in caries diagnosis is associated with some significant limitations. One of the biggest challenges is the need for large, high-quality data sets for training models, which requires significant time and technological resources [12]. The costs of implementing and adapting AI in dental practices can be a barrier, especially for smaller practices. Another limitation is the problems with the acceptance of the technology by both dentists, who may fear a reduction in their role in the diagnostic process, and patients, who may express distrust towards automatic analysis systems. Furthermore, the current lack of standardization in the development of algorithms is an obstacle to the wide application of AI, hindering the comparability of results and implementation in different clinical environments [13]. Al-Khalifa et al. found that artificial intelligence,

especially neural networks, significantly improves the precision and efficiency of caries diagnosis, surpassing traditional methods and the skills of many clinicians in early detection and risk assessment of the disease [14]. Anil et al. concluded that artificial intelligence, especially machine learning and deep learning techniques such as CNN, significantly improves the accuracy, efficiency, and objectivity of dental caries diagnosis compared to traditional methods, with the potential to move from reactive dental care to preventive and personalized care [15]. Zhang et al. demonstrated that AI-assisted caries detection using intraoral images based on MobileNet-v3 and U-net architectures provides high diagnostic accuracy (93.40%) and specificity (95.65%), with promising clinical potential despite the variability of sensitivity depending on tooth position and caries type, indicating the need for further refinement and multimodal integration [16]. Negi et al. synthesized the findings from systematic reviews, emphasizing that AI models, especially CNN-based systems, show significant potential for the detection and diagnosis of dental caries, achieving high sensitivity, specificity, and accuracy, although ethical issues and solid validation remain crucial for clinical integration [17].

A REVIEW OF CLINICAL AND EXPERIMENTAL STUDIES

Clinical and experimental studies on the use of AI in caries diagnosis provide ample evidence of the effectiveness and limitations of this technology. One seminal study compared the performance of AI algorithms with the results of diagnostics made by dentists. The results showed that AI achieved comparable and in some cases higher, sensitivity and specificity rates, especially in detecting early carious lesions on X-ray images. Another important area of research was the analysis of the results obtained by different algorithms, such as CNN, to assess their ability to identify the borders of pathological lesions. These studies highlight the differences in effectiveness between algorithms, indicating the important role of training data quality and technological parameters [18]. The practical application of AI has also been assessed in the context of real clinical cases some of which AI identified carious lesions undetected by dentists, which allowed for earlier treatment. However, studies have also revealed limitations, such as difficulties in interpreting AI results in the presence of image artifacts or in diagnostically complex situations [19]. The summary of the research results indicates that AI demonstrates high effectiveness in caries diagnosis, comparable to the results obtained by dentists, while significantly reducing the time of image analysis. Additionally, the use of AI contributes to cost reduction by increasing the efficiency of diagnostic processes. However, despite these benefits, full integration of AI in dental practice requires further research on the standardization of algorithms and their adaptation to diverse clinical conditions [14-19].

PERSPECTIVES AND THE FUTURE OF ARTIFICIAL INTELLIGENCE IN DENTAL DIAGNOSTICS

The development of artificial intelligence opens up wide possibilities in dental diagnostics, which can significantly change the way medical services are provided in this field. One of the most promising directions is the creation of integrated diagnostic systems that will be built into dental equipment, such as dental chairs, enabling automatic analysis of diagnostic images in real-time. Another important area is the development of personalized algorithms, adapted to individual patient characteristics, such as age, oral health, or medical history, which will allow for even more precise diagnostics. Additionally, combining AI with advanced imaging technologies, including 3D imaging, may enable a more detailed assessment of tooth and bone structures, which will significantly affect the quality of diagnoses [20]. In order for the application of AI in dental diagnostics to become a standard, it is necessary to develop appropriate guidelines for its implementation. A key element of this process is training dentists in the use of AI systems and interpretation of results generated by algorithms, which will allow for their effective use in clinical practice. In addition, it is necessary to develop legal regulations that will define standards for the use of AI in dentistry, including requirements related to the security of patient data and responsibility for diagnostic decisions. An important step will also be the integration of AI with clinics' IT systems, which will enable smooth data flow between different diagnostic tools, as well as facilitate the archiving and analysis of results [21-22]. The prospects for the use of AI in dental diagnostics are extremely promising, but full application of its potential not only requires further technological innovations but also the adaptation of the clinical environment to new tools and work methods.

CONCLUSIONS

Artificial intelligence is becoming a promising tool supporting the diagnosis of caries, especially in the analysis of X-ray images and intraoral photographs. Thanks to the use of advanced algorithms, such as CNN, it is possible to precisely detect early carious changes,

often invisible to the human eye, and standardize the diagnostic process. Clinical studies have shown that AI algorithms achieve high sensitivity, specificity, and accuracy, surpassing traditional methods in some areas, which allows for faster and more objective diagnosis. Despite numerous advantages, such as reducing human errors and improving the efficiency of clinical work, this technology faces challenges, including the need to ensure high-quality training data, acceptance by dentists and patients, and standardization of algorithms. The future of AI in dental diagnostics is associated with the development of integrated diagnostic systems, personalized algorithms, and advanced imaging technologies. However, full integration of AI in clinical practice requires the development of legal regulations, training for dentists, and further research on the adaptation of these solutions to various clinical conditions. The prospects for the development of AI in dentistry are promising, offering the potential to improve the quality of care and the efficiency of diagnostic processes.

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CONFLICT OF INTEREST
The Authors declare no conflict of interest

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