Journal of Craniomaxillofacial Research

Vol. 11, Issue. 4 Autumn 2024

Application and Challenges of Artificial Intelligence in Different Branches of Dentistry

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ARTICLE INFO

Article Type:
Original Article

Received: 11 April 2024
Revised: 8 June 2024
Accepted: 10 August 2024

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ABSTRACT

Introduction: Artificial Intelligence (AI) is transforming dental practice through its ability to analyze, learn, and support clinical decisions. By enhancing diagnostic precision and treatment planning, AI tools are revolutionizing patient care. Despite its potential, implementation faces obstacles including ethical considerations and algorithmic limitations. This review examines AI applications across dental specialties.

Materials and Methods: This narrative review was conducted by analyzing recent studies on AI applications in dentistry. The literature was sourced from reputable databases, including PubMed and Scopus, focusing on AI-driven diagnostic and therapeutic advancements in oral and maxillofacial surgery, radiology, restorative dentistry, orthodontics, periodontics, endodontics, prosthodontics, and forensic dentistry.

Results: AI demonstrates remarkable capabilities across dental fields. Deep learning systems excel in detecting caries, periapical lesions, and fractures through radiological analysis. Orthodontic applications include automated cephalometric analysis and treatment simulation. In restorative dentistry, AI enhances cavity detection and restoration assessment. Maxillofacial applications include surgical outcome prediction and pathology identification. Forensic applications facilitate age and gender determination through radiographic analysis. Current challenges include data security, algorithmic bias, and ethical compliance.

Conclusion: While AI shows promise in advancing dental diagnostics and treatment accuracy, successful clinical integration requires addressing privacy concerns, establishing regulatory standards, and developing comprehensive professional training programs.

Keywords: Artificial intelligence; Dentistry; Diagnostic imaging; Machine learning; Digital dentistry.

Please cite this Article as:
Mirzaei A, Mollaei M, Lotfizadeh A, Aryana M, Ebrahimpour A. Application and Challenges of Artificial Intelligence in Different Branches of Dentistry. J Craniomaxillofac Res 2024; 11(4): 215-222. DOI: 10.18502/jcr.v11i4.18709

Introduction

Artificial intelligence (AI) refers to the ability of machines to mimic human cognitive functions such as learning, reasoning, and decision-making [1]. Alan Turing initially proposed using computers to simulate intelligent behavior in 1950. Then, in 1956, the term "artificial intelligence" (AI) was coined by John McCarthy, a mathematician known as the "Father of Artificial Intelligence", to characterize the capability of machines and performing tasks within the domain of intelligent activities [2,3].

Nowadays, any sort of technology capable of mimicking different human cognitive functions, such as problem-solving, learning, reasoning, and language understanding, is referred to as artificial intelligence [4]. The goal of artificial intelligence is to comprehend and construct intelligent creatures, frequently represented as computer programs [5]. Over the past few decades, AI has expanded beyond its original conceptualization, with applications in various domains including healthcare and dentistry [6].

Artificial intelligence systems carry out tasks using rules that have been manually entered. Performing each of these tasks involves technical expertise, knowledge, and manual system adjustment by professionals. Neural networks, machine learning, and deep learning are some of the aspects of artificial intelligence that resemble medical specialties and are regarded as essential components [7]. In machine learning, patterns are found in a large data set which is utilized to analyze a specific issue. The purpose of machine learning is to facilitate the learning of data by machines so that they can solve problems without any human intervention. Neural networks are a series of algorithms which calculate signals and imitate the nervous system of the human brain through artificial neurons.

Deep learning, commonly known as convolutional neural networks (CNNs), is one of the subcategories of machine learning. In this section, a deep neural network is used to merge not just one pattern but a number of different combined patterns in order to examine the raw data to the system. Deep learning aims to create a network that can recognize patterns automatically in order to increase the system's capacity for pattern recognition [8,9]. In the current investigation, the applications of artificial intelligence in different dental specialties were assessed.

Materials and Methods

This narrative review examines the applications and challenges of artificial intelligence (AI) in various branches of dentistry. A comprehensive search of PubMed, Scopus, Web of Science, and Google Scholar was conducted using keywords such as "Artificial Intelligence," "Machine Learning," "Deep Learning," "Neural Networks," "Dentistry," "Dental Technology," "Oral and Maxillofacial Surgery," "Orthodontics," "Endodontics," "Prosthodontics," "Periodontics," "Forensic Dentistry," and "Dental Radiology." The inclusion criteria encompassed peer-reviewed studies published in English between 2008 and 2024 that discussed AI applications in dentistry, with a focus on diagnosis, treatment planning, prognosis, and workflow optimization.

Studies that did not directly address AI in dentistry, lacked sufficient methodological details, or were non-peer-reviewed sources such as blogs and editorials were excluded. Relevant data were extracted from selected articles, including AI techniques used (e.g., machine learning, deep learning, convolutional neural networks), dental specialties involved, reported advantages and limitations, and performance metrics such as accuracy, sensitivity, specificity, and predictive power. Given that this study is a literature-based review with no direct human or animal involvement, ethical approval was not required. However, academic integrity and proper citation of sources were strictly maintained.

Results

The findings of this narrative review highlight the diverse and expanding role of artificial intelligence (AI) in dentistry, particularly in diagnostic imaging, treatment planning, prognosis, and workflow optimization across different specialties. In oral and maxillofacial radiology, AI-based models have demonstrated high accuracy in detecting dental structures, caries, apical lesions, and maxillofacial pathologies using periapical, panoramic, and CBCT images [10,11], with convolutional neural networks (CNNs) proving effective in classifying cysts, tumors, and other abnormalities [12]. In maxillofacial and oral surgery, AI has been applied in diagnosing oral squamous cell carcinoma [13], predicting postoperative facial swelling [14], assessing nerve injury risks after wisdom tooth extraction [15], and enhancing treatment planning for orthognathic surgery and implantology, thereby improving surgical precision and outcomes [16]. In periodontics, AI has shown efficacy in diagnosing periodontal diseases such as periodontitis and gingivitis using panoramic radio-

DOI: 10.18502/jcr.v11i4.18709

graphs and clinical data [17], as well as in assessing bone loss and predicting disease progression [18,19]. In endodontics, AI-assisted models have demonstrated a 96% accuracy in working length determination for root canal treatments, surpassing expert human evaluation [20], while also improving the detection of vertical root fractures [21], apical lesions [22], and root morphology classification, leading to enhanced treatment success [23]. In orthodontics, AI has contributed to cephalometric analysis [19], identification of cephalometric landmarks [24], prediction of treatment outcomes, and improved treatment planning, including decisions regarding extractions and facial attractiveness predictions following orthognathic surgery [25,26]. In pediatric dentistry, AI applications have facilitated the early detection of dental caries [27], diagnosis of anterior open bite [16], predictive analysis of cleft lip and palate surgeries, and more precise classification of mesiodens using panoramic radiographs [28]. In prosthodontics, AI-based tools have been employed for automated restoration design, crown shape selection, and occlusion analysis, enhancing the efficiency and accuracy of prosthodontic treatments [29]. Furthermore, AI has demonstrated potential in forensic dentistry, particularly in age and gender determination based on dental radiographs [30,31], with CNNs and artificial neural networks (ANNs) being utilized to stage third molar development [32] and analyze mandibular morphometry for personal identification [33]. Despite the significant advancements AI has brought to dentistry, challenges such as data privacy concerns, algorithm bias, and ethical considerations remain barriers to widespread clinical implementation [34]. Future research should focus on refining AI models, ensuring interpretability, and integrating AI into routine clinical workflows while maintaining ethical and legal compliance.

Discussion

There are two types of artificial intelligence in medicine: virtual and physical. The virtual branch uses a number of methods, including electronic health record management, deep learning-related information management, control of health management systems, and guidance for physicians in making treatment decisions based on neural networks. On the other hand, using robots to assist elderly patients or doctors during surgery, smart prosthetics for patients with disabilities, and targeted nanorobots in the creation of a novel medicine system are the best examples of the application of the physical branch in medical sciences [3,35]. Lack of basic training [36], increased administrative burden associated with electronic records [37], worry that doctors will be replaced by artificial intelligence [38], and absence of a global legal framework defining the idea of responsibility regarding the acceptance or rejection of algorithm recommendations [39], are among the main issues of AI application in medicine. Recent studies highlight AI's increasing role in dentistry, particularly in diagnostic imaging and treatment planning. AI has been successfully employed in maxillofacial radiology, orthodontics, and forensic dentistry to enhance precision and efficiency [40,41].

Oral and Maxillofacial Radiology

As a diagnostic tool, radiographic images have a very special role in dentistry. Most of the conducted studies in this field are also related to teeth and jaws because most of the AI systems in this field are based on radiographic image interpretation [42]. As of now, the applications of AI in the field of oral and maxillofacial radiology include detecting teeth and determining their number in periapical images [43], finding root caries and interdental caries in periapical and bitewing images [10,44], detecting the location of dental lesions [42], finding the location of apical lesions in panoramic radiographs [20], diagnosis and finding osteoporosis in panoramic images [45], diagnosis of maxillary sinusitis in panoramic Images [11], diagnosis of Sjogren's syndrome in computed tomography (CT) images [46], diagnosis of lymph node metastasis in CT scans [13], vertical root fracture [21], classification of cysts and maxillofacial tumors [12], finding root canal entries and cephalometric landmarks [42], identification of periodontitis and apical diseases [42]. Deep learning models have demonstrated significant success in analyzing panoramic and CBCT images for automated diagnostics [47,48]. The use of AI in restorative dentistry started with the detection of dental cavities. Following this, the use of AI to detect dental and root caries, vertical root fractures, tooth preparation finish line, and restoration failure prediction has increased significantly [49], in addition, this technology has recently been used to classify and detect fissure sealants [50].

Maxillofacial and oral surgery

AI is widely applied in maxillofacial surgeries. CNN is useful in the diagnosis of oral squamous cell carcinoma [51]. Furthermore, the amount of swelling of the face after tooth extraction can be predicted with the help of this technology [14]. One of the most common problems after lower wisdom teeth extraction is the inferior alveolar nerve anesthesia. With the use of AI, the paresthesia probability of the inferior alveolar

nerve can be estimated after tooth extraction [15]. This technology has had positive effects in predicting the influence of orthognathic surgery on facial attractiveness and promotion of treatment plans [19]. Deep Learning has been used in diagnosing odontogenic tumors and cysts, the most common of which are odontogenic keratocyst and ameloblastoma [52]. In another study, the ability of machine learning to predict the incidence of bisphosphonate-dependent osteonecrosis after tooth extraction was investigated [53]. Diagnosis of mandibular condyle fracture is another application [54]. AI is also being implemented in implant therapy. Treatment planning is facilitated by AI using cone beam computed tomography (CBCT) images [4]. This technology is capable of identifying the implant brand and evaluate the quality of osseointegration [52], and to determine the bone loss around the implant [18].

Periodontics

Periodontal diseases are among the frequent human diseases and the leading cause of tooth loss [4]. Therefore, timely diagnosis and treatment of these diseases is crucial. Artificial intelligence is helpful in diagnosing and predicting periodontal diseases [4], diagnosing periodontitis and gingivitis [42], and finding bone loss in panoramic images [17].

Endodontics

Accurate evaluation of the working length is very important in the root canal treatment success. Studies have shown that the accuracy of AI in evaluating working length is 96%, which is more than the accuracy of expert dentists. Other applications of this technology include detecting vertical root fractures in panoramic and CBCT images [4], apical lesions [23], finding root canal entries, helping to find small apical foramina in radiographic images [23], dental pulp stem cell viability prediction [23], and identifying root morphology of teeth for a successful treatment and prevention from bacterial colonization in the canal [22].

Orthodontics

Diagnosis and presentation of a detailed treatment plan is considered as the key to the orthodontic treatment success [19]. The evaluation of cervical vertebrae maturation [24], analysis of the need for tooth extraction [26], helping to provide a standard treatment plan [19], diagnosis of cephalometric landmarks with high accuracy [25,55], prediction of facial attractiveness after orthognathic surgery [52], and increasing the likelihood of achieving therapeutic goals are among the applications of AI in orthodontics [19].

Pediatric dentistry

Appropriate childhood dental care can greatly help in preventing dental caries and minimizing the health care costs. In recent years, AI has come to the aid of dentists to increase accuracy and speed of these treatments. Its applications include the evaluation of supragingival plaque characteristics and oral microbiomes in children suffering from severe premature cavities [56], diagnosis of anterior open-bite [27] and predictive factors of cleft lip and palate orthognathic surgery in children [16], improvement of children's oral health assessment [57], and classification of mesiodense in deciduous or mixed dentition using panoramic images [28].

Prosthodontics

AI-based tools in prosthodontics are being employed for automated restoration design, crown shape selection, and occlusion analysis. Machine learning is now being integrated into endodontics to enhance working length determination and predict treatment outcomes [29,58].

Forensic dentistry

Even though forensic dentistry is a new subject, it plays a significant role in dentistry [4]. Dentists play an important role in identifying victims of sexual harassment, child abuse, crimes, and other legal issues [4]. CNN was used to determine the developmental stage of the 3rd molar, followed by determining the patient's age, the results of which were remarkable [30]. Patil et al. applied Artificial Neural Network (ANN) to determine the patient's age based on panoramic radiographs, and the results were noticeable [31]. Personal and gender identification are other subjects that AI has come to the aid of in forensic dentistry [32,33].

Review studies conducted in recent years have shown that CNN and ANN have been used in majority of investigations; however, some other researches were based on probabilistic neural networks, short-term memory, Siamese networks, and Bayesian networks. Although most of the studies in this field focus on teeth, deep learning has also been used to study other fields such as anatomical landmarks, dental arches, gingiva and periodontium, and osteoporosis. These neural networks are used to determine CT scans, CBCT images, bitewing, lateral cephalometric, and panoramic radiographs, as well as facial pictures [4,59]. In CNN, digital signals like audio, picture, and video are processed using the connections between specific neurons

DOI: 10.18502/jcr.v11i4.18709

and complex mathematical calculations. In order to assess a larger signal, CNNs scan a small area of inputs from top to bottom and left to right using a sliding window. These networks are the most popular algorithms for image recognition due to their ability to classify images [34]. In a study by Zhang et al., dental periapical radiographs were identified and classified using CNNs powered by artificial intelligence. In this study, the efficient detection of teeth was assessed using the label tree and the cascade network topology, and the findings revealed a high accuracy of 95.8% in this model [60]. On the other hand, in the study by Ekert et al., 2001 panoramic images were analyzed using CNN to detect apical lesions and the results indicated a sensitivity of 0.65 and a specificity of 0.87 [20].

Despite AI's potential, challenges such as data privacy, algorithm bias, and ethical concerns remain significant barriers to widespread implementation in dental practice. Synthetic datasets and federated learning models are emerging as potential solutions [61,62]. Current artificial intelligence algorithms have made it challenging for humans to comprehend and alter diagnostic criteria; consequently, the algorithms of this system must therefore be understandable to humans and modified to increase the credibility of artificial intelligence. This will allow health workers to fully comprehend the choices and predictions made by an artificially intelligent system as well as how to protect their patients. On the other hand, as the legal system holds health workers accountable for any treatment-related errors and omissions, replacing humans with automated technology will result in several issues for the legal system [34,59].

Conclusion

Artificial intelligence has advanced significantly in the medical sciences over the past few decades, including dentistry, and has been able to remarkably improve diagnosis accuracy, predict treatment outcomes, and adapt to individual needs. Artificial intelligence tools can assist dentists in a variety of ways, including accelerating workflow, ensuring high levels of infection control, and increasing the quality of care. However, it is essential that artificial intelligence be employed in a controlled and safe manner to ensure the dentist's direct capacity to treat and make proper judgments. Training future generations of physicians about artificial intelligence and how it operates effectively in the workplace is one of the important tenets for increasing the usage of such technologies in the healthcare system. Nevertheless, the wide use of artificial intelligence, its algorithms, and applications requires further research and validation.

Conflict of Interest

There is no conflict of interest to declare.

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