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Recent developments in the use of AI in the dental field

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Introduction:

A machine-processed simulation of the intelligence demonstrated by animals and humans constitutes artificial intelligence (AI). AI comprises machine learning (ML), natural language processing (NLP), computer vision, robotics, and additional subfields. An array of algorithms and applications are associated with each category, yielding distinct outcomes. AI is capable of performing tasks with greater precision and accuracy than humans with the appropriate training. Early AI implementations in the healthcare industry date back to the 1950s. The initial artificial intelligence (AI) medical systems were established during the 1950s, when a computer program known as the "MIT Programmed Autoanalyzer" was developed by researchers at Technicon Corporation, led by Jack Whitehead, for the purpose of analyzing blood and urine samples (Skeggs & Hochstrasser, 1964).

The 1970s-era MYCIN system was an early expert system that utilized artificial intelligence to diagnose and treat infectious diseases (Yu, et al. 1979). During the 1980s, algorithms for machine learning were implemented in the fields of medical image analysis and drug discovery. The "CardioCom" system, which was utilized to diagnose and treat patients with cardiac disease, and the "IntelliCare" system, which was utilized to diagnose and treat mental health disorders, were both developed in the 1990s (Chen, et al. 2008). NLP and ML advancements in the 2000s and subsequent years enabled the use of AI in a vast array of medical applications, such as patient monitoring, treatment planning, drug discovery, and diagnosis (Rajpurkar, et al. 2022). AI is increasingly utilized in numerous medical specialties to diagnose diseases, interpret results, and assist healthcare providers in achieving positive patient outcomes, despite being a relatively new technology.

Regarding AI search in health care, two categories can be distinguished: virtual and robotic. The robotic type provides assistance with the tangible components of healthcare systems, while the virtual type handles mathematical algorithms. In the 1990s, William Ecenbarger reached the determination that "visiting the dentist is not an enjoyable experience." "Dentisturbance is unbelievably imprecise" (Nguyen, et al. 2023). Since then, dentistry has undergone significant transformations. The integration of sophisticated technology into clinical practice contributes to enhanced precision, efficiency, and patient convenience in the field of dentistry. Artificial intelligence, intraoral scanners, 3D printers for denture fabrication, robotic surgery, regenerative dentistry, and virtual reality are a few of the ways in which technology has enhanced dentistry. In the fields of dental imaging and pathology, dental radiology, caries detection, electronic record keeping, and robotic assistance, the use of artificial intelligence is acquiring traction. The objective of this review is to present a thorough examination of the function of artificial intelligence (AI) in the field of dentistry, investigating its capacity to bring about a paradigm shift and tackle practical obstacles.

An overview of recent advancements in dental field involving artificial intelligence (AI):

1. *Utilization of Al in periodontal disease*

Chronic oral inflammatory diseases are conditions characterized by persistent inflammation of the oral tissues. An assortment of factors, such as environmental exposures, infections, and autoimmune disorders, can give rise to these conditions. Periodontitis and gingivitis are pervasive chronic inflammatory conditions of the mouth. Early detection has the potential to enhance treatment outcomes, impede the spread of the disease to adjacent tissues, and diminish the frequency and severity of complications. Periodontal disease detection is difficult and requires sophisticated skills. Clinical examination, periodontal probing, radiographic evaluation, quantitative light-induced fluorescence (QLF), and oral microbial DNA testing are all utilized in the detection of periodontal conditions. Clinical examination is a subjective method that relies on the expertise and experience of the dentist or dental hygienist to identify periodontal disease; however, it is an effective method. Additionally, it might be constrained by the time allotment for the examination. The acquisition and interpretation of radiographic evaluations may present challenges when it comes to periodontal and endodontic diseases. The implementation and formulation of treatments rely heavily on precise diagnostic images, including radiographs. Moreover, early phases of periodontal disease cannot be detected via radiographic examination. In comparison to other methods, the QLF technique is comparatively less precise, and oral bacteria DNA testing is a relatively new, costly, and uncommon practice (Preshaw, 2015). The application of Al systems for periodontal disease detection could increase dependability and empower clinicians to attain detection accuracy comparable to, if not surpassing, that of seasoned experts. In a systematic review, Revilla-León et al. Revilla-León, et al. (2022) assessed the efficacy of the Al models in the diagnosis of gingivitis and periodontitis. The accuracy of detecting dental plaque, diagnosing gingivitis, and quantifying alveolar bone loss was reported to be 47% and 99%, respectively, in the studies. In spite of the fact that Al models designed for periodontal applications still require further refinement, they have the capacity to serve as potent diagnostic or clinical aids.

2. *Utilization of Al in endodontic disease*

Endodontics is a specialized field within dentistry that investigates the pathology, physiology, and morphological characteristics of the periradicular and dental pulp tissues. Endodontic disease encompasses the progression and onset of injury or disease within the dental pulp and periradicular tissues. It can be induced by infection, trauma, caries, or other factors. The opportune identification of endodontic disease is critical in order to facilitate appropriate treatment, preserve the compromised tooth, and impede the progression of the infection. An enhanced ability to diagnose inflamed pulp facilitates the implementation of vital pulp therapies (VPT), which aid in the preservation of pulp vitality (De-Deus, et al. 2022).

The automated detection of endodontic diseases in periapical radiographs is a classification task amenable to deep learning techniques. The majority of studies assisted dentists in the detection and diagnosis of a single disease through the use of machine learning. Recent research, on the other hand, has concentrated on multidisease detection methods, which are more prevalent in clinical practice. Li et al. (2022) proposed an automated deep learning method to detect both caries and periapical lesions utilizing periapical radiographs. The model exhibited a notable capacity for acquiring features from periapical radiographs that were annotated manually. In comparison to expert detection, their model demonstrated high accuracy (86%) and excellent performance (F1-scores of 0.8288) in detecting dental caries and periapical lesions.

Two significant obstacles encountered in endodontic treatment are the accurate determination of the working length and the intricacy of the root canal anesthesia. The root canal anatomy of some teeth is intricate, consisting of multiple canals or atypical morphologies, which may complicate treatment. Working length can be determined through a variety of means, including electronic apex locator (EAL)+ measurement, radiographic examination, and ruler measurement of the tooth in radiographs. An improper working length may result in incomplete treatment and an elevated likelihood of failure. In root canal therapy, radiographic examination is the most frequently used technique for determining the effective length. However, a number of limitations apply. The precise determination of the root length is complicated by factors such as the tooth's location, dense bone and other structures in the vicinity, and the two-dimensional image. It has been shown that cone-beam computed tomographic (CBCT) imaging provides a more precise evaluation of the composition of roots and root canals than radiography (Saghiri, et al. 2012a). However, routine clinical practice does not recommend it and many clinicians do not have easy access to the system due to concerns regarding radiation exposure. In various methods, machine learning demonstrated the capacity to enhance the precision and effectiveness of working length determination in root canal therapy. Saghiri et al. (2012b) obtained a 93% improvement in the accuracy of apical foramen localization from radiographs through the implementation of ANNs. They reported that their model was more precise than endodontists' estimations when compared to the actual length of the root measurements taken after tooth extraction using the stereomicroscope as the gold standard. In addition, by training algorithms on extensive datasets comprising root canal treatment cases, it is possible to forecast the technical treatment outcome for a specific tooth by considering a multitude of factors, including tooth anatomy and position.

Herbst et al. (2023) compiled 555 complete root canal treatment datasets in order to generate machine learning-based insights for predicting treatment outcomes. The length of root-filling was regarded as a straightforward and appropriate criterion for evaluating treatment quality. In order to forecast outcomes, six machine learning models were implemented: logistic regression (logR), support vector machine (SVM), random forest (RF), decision tree (DT), gradient boosting machine (GBM), and extreme gradient boosting (XGB). They reached the conclusion that root canal visibility was the most influential risk factor across the dataset. As a result of certain study limitations, the ML's ability to predict the technical outcome of root canal treatment was inadequate. An additional prevalent technique for ascertaining the functional length of root canal therapy is EAL. Nevertheless, its precision is called into question, especially when confronted with intricate root canal anatomy or substantial root resorption. Qiao et al. (2020) utilized a neural network to conduct EAL in order to measure the extent of the root canal. The dataset was compiled through the collection of numerous measurements of 21 teeth utilizing combinations of multifrequency signals. Optimal neural network architecture improved measurement precision. This approach has the potential to mitigate the impact of environmental and human variables on the measurement of root canal length, thereby enhancing the efficacy of EAL.

3. *Utilization of Al in orthodontics and dentofacial orthopedics*

Orthodontics and dentofacial orthopedics are closely related dental specialties and branches that diagnose, prevent, and treat abnormalities associated with the developing or mature dentofacial structures, as well as oversee, guide, and correct these structures. Initial investigations and implementations of Al in orthodontics concerned the treatment and diagnosis of patients (Monill-González, et al. 2021). Researchers began utilizing Al to assist orthodontists in developing more precise diagnoses and treatment plans by analyzing dentofacial images and patient data. One of the primary prerequisites for orthodontic treatment is the categorization and preservation of orthodontic images. It has been suggested that the deep convolutional network (DCN), which has more layers than the standard CNN, be utilized for continuous image acquisition in orthodontics.

In their study, Li et al. (2022) introduced a leveraged DCN-based automated deep learning approach to categorize and archive orthodontic images. The findings of the study demonstrated that a deep learning model is capable of rapidly and accurately classifying and monitoring orthodontic issues with a remarkable 99.4% precision. Small, manually annotated training sets were, nevertheless, crucial to the efficacy of their deep learning models. Automatic image quality evaluation prior to classification should be the subject of future research. Particularly crucial in the context of handling exceedingly sizable datasets. Automated cephalometric X-ray analysis for orthodontic applications was the subject of research by Faber, et al. (2019). All orthodontic parameters, with the exception of mandibular tilt, were determined without bias using a customized CNN model or the current gold standard (human expert analyses).

It is crucial to anticipate the results of orthodontic treatment, including the final tooth position and treatment duration, because doing so enables more precise treatment planning and improved patient communication, all of which contribute to enhanced treatment outcomes, reduced treatment duration, and heightened patient satisfaction. By predicting the probable outcomes of various treatment options, Al assists orthodontists in making more informed decisions. Deep learning and landmark-based geometric morphometric methods (GMMs) were utilized in one study to forecast the three-dimensional facial topography subsequent to fixed edgewise orthodontic treatment and orthognathic surgery (Tanikawa & Yamashiro, 2021). Al is capable of generating three-dimensional models of the jaw and teeth, which can be utilized to simulate and plan treatment outcomes (Tsolakis, et al. 2022). In recent times, digital impressions have been incorporated into the application of Al in orthodontics. These impressions serve various purposes, including diagnosis, treatment planning, appliance fabrication, and treatment progress monitoring (Saccomanno, et al. 2022). In addition, chatbots designed to interact with patients, respond to inquiries, and arrange appointments have been developed (Hansa, et al. 2021).

4. *Utilization of Al in oral medicine and pathology*

The majority of patients who present to the hospital network with oral cancer do so at an advanced stage, which contributes to a significant morbidity and mortality rate. Early diagnosis, precise oral cancer classification, minimal human error in detection and treatment, individualized treatment planning, cost-effectiveness, and the aforementioned factors all contribute to the prognosis of oral cancer. Al can aid in various ways to enhance the prognosis for oral cancer. In the late 1990s, one of the earliest investigations employing Al to diagnose oral cancer was published. Based on clinical and histologic characteristics, this study classified oral lesions as benign or malignant using a neural network (Van Staveren, et al. 2000). The utilization of Al as a diagnostic aid for oral cancer is gaining in popularity. Automating early detection of oral cancer lesions with performance comparable to that of seasoned specialists is the primary objective. Al has the potential to significantly improve the speed and accuracy of oral cancer diagnosis, according to a recent systematic review of 36 studies that used machine learning techniques in conjunction with early cancer detection to diagnose precancerous lesions (García-Pola, et al. 2021). However, the evidence is insufficient to validate any of the algorithms for the detection of specific precancerous lesions.

According to Baniulyte & Ali (2022), the mean sensitivity of Al in the detection of oral cancer was 83%. In studies, the mean specificity of Al was 87%, suggesting that the test may effectively detect patients who do not have the disease. Numerous studies have implemented Al algorithms in an effort to develop predictive models. The objective of this category of research is to discern patterns, analyze historical data, and generate an automated conclusion regarding the probability that an individual possesses a malignant or potentially malignant oral lesion using an Al model. The historical data may comprise clinicopathological information, risk factors for specific conditions, and systemic medical conditions (Alhazmi, et al. 2021). Furthermore, Al can be utilized in the development of predictive models that aid in the identification of individuals at high risk for cancer, as well as those who lack symptoms but are classified as having an average risk for specific forms of cancer due to demographic characteristics, lifestyle choices, and other relevant factors (Kar, et al. 2020).

The Growing Landscape of AI-Powered Solutions in Dentistry:

Dental Al market refers to the utilization of Al-based technologies within the dental field. It involves the implementation of Al algorithms and models to aid dental professionals with patient care, treatment planning, and diagnosis. A multitude of Al-powered solutions are presently accessible in the dental industry. These solutions comprise systems designed for image analysis, diagnostic aides, and treatment planning. The market for dental Al is expanding at a rapid rate, propelled by the need to better patient treatment outcomes, increased demand for more precise and efficient diagnostic tools, and the increased use of digital technology in dentistry. It is anticipated that the dental Al market will attain a value of $1.3 billion by 2028, demonstrating a compound annual growth rate (CAGR) of 27.4% between 2023 and 2028 (Schwendicke, et al. 2020). The CAGR is frequently employed to forecast the future expansion of a market. It is computed by raising the ratio of the final value to the initial value by a factor of 1/n, where n denotes the number of years in the period under consideration. By application—including patient management, treatment planning, and diagnosis—the market can be segmented. The segment devoted to diagnoses is anticipated to maintain the largest market share. The segment devoted to treatment planning is anticipated to experience the greatest CAGR over the period of the forecast. Conversely, an alternative approach involves segmenting the market according to end-users, which may consist of dental schools, clinics, and research institutions. The market share anticipated to be the highest is that of dental clinics. North America is anticipated to hold a dominant position in the market from a regional standpoint, owing to the abundance of dental technology companies operating within the area and the widespread adoption of advanced technologies. Europe is anticipated to be the second-largest market on account of the increasing number of dental clinics and the region's expanding adoption of advanced technologies.

Unveiling the Potential and Challenges of AI Integration in Dental Practice:

A thorough investigation into the application of Al in diverse dental domains has revealed tremendous potential and encouraging advancements within the sector. In the identification and treatment planning of chronic oral inflammatory diseases, caries, endodontics, prosthodontics, orthodontics, and oral pathology, substantial progress has been achieved through the utilization of diverse Al systems, including supervised, unsupervised, and deep learning. The incorporation of Al technology into these domains has exhibited exceptional enhancements in accuracy, efficiency, and individualized patient treatment. Regrettably, the integration of Al technologies in the field is hindered by a number of obstacles. In this discourse, we shall examine some of the principal challenges that confront the implementation of Al in the dental industry.

1. *the scarcity of comprehensive and standardized data challenges*

In order to improve and refine their functionality, Al algorithms rely on vast datasets. Regrettably, dental datasets often lack sufficient size and diversity, rendering the construction of robust Al models challenging. The acquisition of medical and dental information is notably difficult owing to concerns regarding data security and the existence of organizational barriers. The acquisition and application of such data pose challenges for researchers and healthcare professionals due to the aforementioned concerns. In addition, the datasets are frequently devoid of organization and relatively modest in size when compared to other datasets utilized in AI research. The issue of data completeness is exacerbated by the restricted accessibility of comprehensive data, as systematic gaps and absent information can lead to selection bias. Consequently, the process of validating and triangulating intricate and confidential patient data becomes a formidable undertaking, thereby restricting the range of viable solutions that can adequately tackle these issues. As a result, it is critical to obtain reliable datasets that encompass a wide variety of dental issues and patient demographics in order to integrate Al technologies effectively.

2. *Interoperability and Integration Challenges:*

A multitude of dental practices employ diverse software and imaging systems, which might lack compatibility with Al platforms. This absence of integration could impede the adoption of Al technologies and disrupt the free movement of data. To surmount this obstacle, the development of standardized interfaces and protocols that facilitate the integration of Al systems with pre-existing dental software is of the utmost importance (Ducret & Mörch, 2023).

3. *Ethical and Legal Considerations challenges:*

Strict regulations, including the Health Insurance Portability and Accountability Act (HIPAA), must be adhered to in order to implement Al systems. Ensuring the confidentiality of patient data and protecting sensitive information is of the utmost importance for establishing and maintaining the trust and confidence of both patients and dental professionals. In order to effectively tackle these ethical and legal considerations, it is critical to establish robust frameworks for data governance and enforce stringent security protocols (119). Furthermore, data encryption may serve as a feasible resolution to privacy apprehensions regarding the utilization of patient information within Al systems utilized in dentistry. Encrypting data entails transforming confidential information into a formatted code, which is exclusively decipherable using the corresponding decryption key. This feature effectively fortifies the security against unauthorized entry (Khandare, et al. 2019). Furthermore, data encryption may serve as a feasible resolution to privacy apprehensions regarding the utilization of patient information within Al systems utilized in dentistry. Encrypting data entails transforming confidential information into a formatted code, which is exclusively decipherable using the corresponding decryption key. This feature effectively fortifies the security against unauthorized entry (Schwendicke, et al. 2023).

4. *Cost and Resource challenges:*

Due to limited resources, procuring licenses for all systems, hardware, and software can be particularly difficult for smaller dental practices. In addition, the process of educating dental practitioners on how to effectively utilize Al technologies and incorporate them into established processes can be a laborious and expensive undertaking. It is of the utmost importance that these financial and resource obstacles be surmounted so that Al can be utilized extensively in dentistry.

5. *Resistance to Change challenges:*

This assertion holds particular validity in fields such as dentistry, where deep-rooted customs prevail. Concerns may be expressed by dental professionals regarding the dependability and precision of Al systems, in addition to alterations to their duties and obligations. It is crucial to provide training programs, highlight successful case studies, and educate and raise awareness regarding the potential benefits of Al in order to surmount these obstacles. This strategy can facilitate the integration of Al into dentistry and promote the development of an accepting culture.

6. *Limited Availability of AI Expertise challenges*

In actuality, the dental sector has not allocated significant resources towards research and development pertaining to artificial intelligence. Consequently, a dearth of knowledge regarding Al has developed within the dental community. For Al technologies to be effectively integrated, the gap between Al research and dentistry must be closed. By promoting cooperation between dental practitioners and specialists in aluminum (Al), and integrating Al-oriented instruction and learning into dental timetables, we can develop a labor force that possesses the ability to effectively employ Al to improve oral hygiene (Schwendicke, et al. 2023).

In order for the dental industry to maximize the potential of AI to improve patient care, diagnoses with greater accuracy, and enhance treatment outcomes, it is critical that these obstacles be surmounted.

Conclusion:

By automating tedious duties and freeing up clinicians to concentrate on more complex and challenging cases, Al possesses the capacity to enhance patient care and alleviate the burden on healthcare systems. Al should never be utilized in medicine without adhering to ethical principles, as it should never be regarded as a substitute for human expertise. Professionally, Al is limited to aiding clinicians in the execution of their duties. It is not a substitute for the expertise, knowledge, or treatment planning of humans. Al is widely recognized as a valuable tool for dentists, notwithstanding the obstacles posed by data collection, interpretation, computational capacity, and ethical considerations. Al is impartial, replicable, user-friendly, and transparent due to its meticulous design and ongoing clinical validation. Ongoing advancements in big data processing must coexist with a steadfast commitment to human interests in future Al development. Dentistry is a multidisciplinary discipline in which the dentist must ultimately make the determination, despite the fact that Al can benefit in numerous ways. According to the findings of this review, Al has made significant strides in recent years and may soon be considered a standard instrument in contemporary dentistry.

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