Review Article

Revolutionizing Oral Health with the Synergy of AI and Human Expertise in Managing Oral Diseases; A Review

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Abstract

The integration of artificial intelligence (AI) with human expertise is reshaping the field of oral health care by addressing key challenges in the detection, diagnosis, and management of oral diseases. AI technologies, particularly machine learning and deep learning algorithms, have demonstrated the ability to process vast amounts of clinical data, including radiographs, patient histories, and biomarkers, to identify disease patterns with unprecedented accuracy and speed. This capability is particularly impactful in diagnosing conditions like dental caries, periodontal disease, and oral cancers at earlier stages, where early intervention can significantly improve patient outcomes. While AI excels at data analysis and pattern recognition, human expertise is crucial for contextualizing AI findings, making nuanced clinical decisions, and providing the empathetic, patient-centered care that remains the cornerstone of effective dental practice. The synergy between AI and clinicians enhances treatment planning, enabling personalized, evidence-based strategies that are tailored to each patient's unique needs. Furthermore, AI tools offer potential for remote monitoring and real-time patient engagement, empowering individuals to take proactive control of their oral health. Predictive analytics provided by AI can help anticipate disease progression, allowing for preventive measures to be implemented before serious issues arise. This collaboration promises to make dental care more efficient, accessible, and cost-effective, with implications for improved global health equity. As AI continues to evolve, the partnership between technology and human expertise is poised to revolutionize the management of oral diseases, transforming both clinical practice and patient outcomes.

Key Words: Artificial Intelligence (AI), Oral Health Care, Machine Learning, Diagnosis, Personalized Treatment Planning

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Introduction

Oral health is acknowledged as a pivotal component of general health considering its importance in individuals' daily functioning (1). The World Health Organization (WHO) delineates oral health as a state devoid of disease and disorders, which constricts an individual's capacity to bite, chew, and smile influencing its impact on the psychosocial well-being (1). The presence of oral diseases can hinder an individual's growth and development, as well as their psychological, productive, and social capacities. Oral diseases constitute a highly prevalent disease group of pathologies worldwide. Significant compromise of oral health, exemplified by conditions such as severe periodontitis or extensive tooth loss, exhibited a robust correlation with cognitive dysfunction, surpassing the mere presence of oral diseases in isolation (2). The 2017 Global Disease Burden Study indicated that 3.5 billion individuals experienced oral diseases in 2016, accounting for nearly 50% of the global population (3). Understanding the impact of oral diseases on the quality of life related to oral health is crucial for public health systems, research, and decision-making regarding preventive and promotional strategies for oral health across various nations. Additionally, it is concerning that oral health care is frequently deemed not to be a priority by policymakers due to its perceived non-essential nature, particularly in developing countries, owing to its associated high costs (4). Recent research suggests an escalating role of oral infections in the pathogenesis of various systemic diseases. This phenomenon extends beyond individuals already afflicted with illness or immunocompromised conditions, encompassing even those in good health (5). Over the past decade, numerous epidemiological investigations have meticulously scrutinized the correlation between oral infections and systemic diseases (6). These inquiries have consistently corroborated the notion that oral infections, particularly periodontitis, may independently heighten the risk for a spectrum of systemic conditions, including diabetes mellitus (7), pulmonary infections (8), pre-term low-weight births (9), cardiovascular diseases (10), and infections in other anatomical sites (11). Given the staggering prevalence of cardiovascular diseases as the primary cause of mortality globally, heightened attention has been directed towards substantiating the potential link between oral cavity infections and atherothrombotic events such as myocardial infarction, stroke, and peripheral vascular disease (12).

a. Introduction to the use of AI in general and oral healthcare

The phrase "artificial intelligence" was initially coined by John McCarthy, widely recognized as the founding figure of AI in 1956. He used this term to describe computers capable of performing tasks that mimic human intelligence, operating independently of human intervention (13). Artificial Intelligence (AI) is characterized by the utilization of specialized algorithms that leverage extensive datasets to execute cognitive functions and emulate human intelligence (14). Within AI algorithms, there exist distinct subfields such as machine learning (ML), deep learning (DL), artificial neural networks (ANN), and convolutional neural networks (CNN). ML endeavors to furnish computers with knowledge extracted from data and observations, as opposed to relying solely on explicit programming. The datasets are subsequently inputted into ML models to generate outputs aimed at interpreting images. DL is characterized by its structure of multiple deep layers of artificial neurons forming convolutional neural networks (CNNs). These CNNs are primarily utilized for processing large and complex images due to their ability to extract numerous features from intricate layers of filters (15-17). Since its inception, the application of artificial intelligence (AI) has yielded significant advancements that have greatly enriched our daily lives and routine activities across various domains such as facial recognition, self-driving cars, and image classification, among others. A burgeoning array of disciplines stands to gain from AI assistance, including the surgical realm (e.g., intelligent systems for assisted surgery and video-surgery), automated disease diagnosis (e.g., diagnostic decision support systems based on image analysis), and the emergent field of personalized medicine, which encompasses disease predisposition assessment, diagnosis, and the tailored selection of optimal treatments for individual patients (18). The clinical utilization of AI has experienced notable growth and has demonstrated promising outcomes in the realms of diagnosis, monitoring, and disease treatment (19). The integration of Information and Communication Technology (ICT) and digital health technology is reshaping the methodologies through which healthcare professionals engage in their practices, acquire knowledge and training, and establish communication channels with both patients and their particular professional networks (20). While dentistry may not initially appear to be profoundly influenced by advancements in AI, specific domains such as image-based automatic disease detection and other diagnosis-support systems, image segmentation for automated identification of oral characteristics, and resolution enhancement of dentistry-related images are experiencing notable enhancements facilitated by AI utilization. Furthermore, in the realm of robotics, various advancements are similarly fostering the integration of robotic assistance within oral health care disciplines. Thus, the potential for AI techniques remains expansive across numerous facets of dental and oral health care domains, all within the framework of the expanding digital dentistry paradigm (18). AI has been acknowledged for its utility in disease diagnosis, prognostic forecasting, and the formulation of patient-tailored therapeutic interventions. Specifically within the field of dentistry, AI offers invaluable support to practitioners when rapid decision-making is imperative. By mitigating human errors in decision-making processes, AI facilitates the delivery of superior and uniform medical care, concurrently alleviating the workload borne by dentists (13).

b. Current challenges in management of oral pathoses

The management of oral pathoses poses a multifaceted challenge in contemporary dental practice, necessitating a nuanced understanding of disease etiology, diagnostic modalities, and therapeutic interventions. Oral pathoses encompass a diverse array of conditions affecting the oral cavity, ranging from common ailments such as dental caries and periodontal disease to more complex entities like oral cancer and autoimmune disorders. While significant strides have been made in elucidating the underlying mechanisms of these pathologies, their effective management remains a formidable task due to a myriad of factors. The integration of AI technologies could significantly impact dentistry, especially given the alarming rise of mouth cancer as a public health concern. Late detection of mouth cancer complicates treatment and increases mortality rates. Despite numerous research efforts to enhance available treatments, the situation has not improved significantly in recent years. However, premalignant lesions frequently observed in the oral cavity can serve as indicators for diagnosing this type of cancer in a significant number of cases (21-23). Mouth ulcers are recognized as significant pathological entities necessitating precise diagnosis and proficient management. Timely detection is paramount, as delayed identification or inadequate management can precipitate life-threatening conditions. Due to limited understanding of the medical conditions underlying mouth ulcers and their morphological similarities, their identification and management often pose challenges. While persistent trauma commonly precipitates oral ulcers, they may also manifest as symptoms of systemic disorders such as gastrointestinal dysfunction, cancer, immunological abnormalities, or dermatological conditions. Clinicians specializing in oral mucosal pathoses prioritize the attainment of accurate and definitive diagnoses of oral ulcers. Many of these conditions are chronic, characterized by symptoms such as desquamation, and in certain instances, they may exhibit contagious properties. A comprehensive knowledge of the immunopathological nature of the lesion is imperative for the administration of efficacious treatment (13).

d. The role of artificial intelligence in enhancing dental care

Within dentistry, AI stands out as a valuable tool for aiding quick and critical decision-making processes. By leveraging AI technologies, dentists can mitigate human errors in decision-making, thereby enhancing the quality and consistency of medical treatments while simultaneously alleviating the workload burden on dental professionals. Despite recognizing its potential benefits, the studies in this area often lack a cohesive framework or systematic methodology. To fully harness the capabilities of AI in diagnosing oral ulcers, it is imperative to establish a structured approach that encompasses various aspects such as data collection, algorithm development, validation processes, and clinical implementation. By adopting a systematic approach, researchers can ensure that AI technologies effectively contribute to enhance diagnostic accuracy, prognostic capabilities, and the development of tailored therapeutic strategies for oral ulcer management. Additionally, structured research frameworks facilitate the accumulation of robust evidence, fostering trust and confidence in the reliability and efficacy of AI-driven solutions among dental professionals and patients alike (13, 24). AI has emerged as a valuable asset in healthcare, contributing significantly to disease diagnosis, prognosis prediction, and the development of tailored therapy approaches [25]. Within the realm of dentistry, AI offers particular advantages, empowering dentists to swiftly navigate critical decision-making scenarios. By leveraging AI, dentists can not only streamline their workflows but also minimize the potential for human error in decision-making processes, thereby ensuring consistent and superior medical care. One of the primary benefits of AI in dentistry lies in its capacity to enhance diagnostic capabilities, improving accuracy and enabling early detection of diseases. This advancement holds the potential to yield better patient outcomes while reducing the need for invasive procedures. Moreover, AI facilitates the creation of personalized treatment plans by analyzing vast datasets and patient-specific information. Dentists stand to gain from more efficient workflows and diminished administrative burdens, allowing for greater focus on patient care. Furthermore, AI-powered tools such as chatbots and virtual assistants have the potential to revolutionize patient interactions and satisfaction levels. By offering timely and accurate information, these technologies enhance communication between patients and dental professionals, ultimately improving overall patient experiences.

Artificial intelligence offers valuable applications in diagnosing and treating oral cavity diseases and detecting suspicious mucosal changes indicative of premalignant or malignant alterations. AI can detect subtle changes at the single-pixel level that may go unnoticed by the diagnostician’s eye and potentially identify genetic predispositions for oral cancer within large populations. AI-based machine learning systems serve as useful tools for determining dental prognosis based on treatment strategies, allowing for a thorough review to ensure long-term oral health and function (25).

Three primary types of data collection utilizing artificial intelligence (AI) hold promise for advancing patient care in dentistry: pre-appointment, inter-appointment, and post-appointment dental care (26). Pre-appointment data collection methods include AI Patient Manager, AI Patient History Analyzer, and AI Scientific Data Library. Prior to dental appointments, it is imperative to consider patient preferences regarding appointment scheduling, environmental factors such as music and room temperature, and the provision of relaxing fragrances. Moreover, thorough evaluation of patient information, encompassing vital signs, allergies, overall health status, current medications, and potential drug interactions, is essential (18). During dental appointments, AI aids in generating diagnoses and treatment recommendations, aiming for optimal accuracy. Additionally, predicting final outcomes and treatment prognosis as accurately as possible is paramount for effective patient care. Following dental appointments, AI facilitates the generation of digital workflows and expedites the fabrication of dental restorations, ensuring both speed and precision (26).

It is crucial to underscore that while AI facilitates various aspects of dental practice, it does not supplant the role of dental professionals. While an increasing number of dental practices adopt digital workflows and integrate AI into diagnosis and treatment planning, the prevalence of fully integrated AI methodologies, colloquially termed "smart dental clinics," remains relatively low.

d.1. Specific applications of AI in oral health management

The utilization of AI within the field of dentistry initially centered predominantly on computer vision techniques which involved the use of automatic segmentation and analysis to effectively manage extensive medical image repositories, thereby facilitating precise and efficient diagnoses. Recent research endeavors have shifted towards exploring the application of AI in diagnosing various dental conditions such as caries, gingivitis, root fractures, oral cancer, radiolucent lesions of the jaws, as well as orthodontic treatments. The findings derived from these studies suggest that AI possesses considerable potential for advancement, promising to enhance dental care efficacy while concurrently reducing costs, thereby benefiting patients (19, 27). Artificial intelligence offers valuable applications in diagnosing and treating oral cavity diseases and detecting suspicious mucosal changes indicative of premalignant or malignant alterations. AI can detect subtle changes at the single-pixel level that may go unnoticed by the diagnostician's eye and potentially identify genetic predispositions for oral cancer within large populations. AI-based machine learning systems serve as useful tools for determining dental prognosis based on treatment strategies, allowing for a thorough review to ensure long-term oral health and function (25).

d.1.a: Use of AI-based virtual dental assistance

Virtual dental assistants leveraging AI technology are increasingly being deployed across diverse sectors in dentistry. Similar to their counterparts in other industries, these meticulously crafted systems exhibit the capacity to execute specific tasks within dental clinics with heightened precision and accuracy, all while consuming minimal energy resources. Consequently, they often outperform human operators in terms of error reduction. Several notable functions performed by virtual dental assistants in the field of dentistry include:

- Facilitating the scheduling of patient appointments to mitigate potential disruptions and accommodate the high volume of daily patient influx.
- Providing timely notifications to both dentists and patients regarding upcoming appointments, particularly in cases where hereditary or lifestyle factors indicate a heightened susceptibility to oral health issues (e.g., conducting periodontal screenings for diabetic patients or oral cancer screenings for regular users of smoked or smokeless tobacco).
- Providing timely telephone-based support in instances where dentists are unavailable onsite and urgent medical intervention is warranted.
- Furnishing dentists with pertinent information pertaining to patients' allergies and pre-existing medical conditions prior to their appointments.
- Managing administrative tasks such as paperwork and insurance processing.
- Assisting in the enhancement of diagnostic accuracy and treatment planning following the completion of patient diagnoses.
- Supplying dentists with comprehensive medical backgrounds of patients, thereby facilitating informed decision-making in diagnosis and treatment planning, including surgical interventions.

In essence, virtual dental assistants play a crucial role in streamlining dental practice operations, enhancing patient care quality, and ensuring efficient communication between healthcare providers and patients (28).

d.1.b: Use of AI in dental education

Since its inception in the 1980s, intelligent tutoring systems in dental education have seen significant advancement. Integration of AI into dental education heralds a new era of innovation and transformation in the training of future dental professionals. With its vast potential to enhance teaching methodologies, streamline learning processes, and personalize educational experiences, AI is revolutionizing the landscape of dental education. AI technologies offer a wide array of applications across various facets of dental education. Machine learning algorithms can analyze large datasets of dental knowledge, including textbooks, research articles, and clinical case studies, to identify trends, patterns, and best practices. By harnessing these insights, AI-powered educational platforms can deliver tailored learning materials and adaptive curriculum recommendations to students, catering to their individual learning styles and needs (29). Furthermore, AI-driven virtual simulation and augmented reality tools provide immersive learning experiences that simulate real-life clinical scenarios. These interactive platforms enable students to practice clinical skills, such as tooth restoration techniques and surgical procedures, in a risk-free environment, fostering competence and confidence in their clinical abilities (30). Moreover, AI-powered assessment tools offer objective and standardized evaluations of students' performance, providing valuable feedback and insights for continuous improvement. These assessment systems can analyze students' responses to questions, clinical simulations, and case presentations, helping educators identify areas of strength and areas for further development (29). Additionally, AI technologies facilitate collaborative learning and knowledge sharing among students and educators through online forums, discussion groups, and social learning platforms. By connecting learners with peers and experts from around the world, AI-enabled educational networks foster a culture of collaboration, innovation, and lifelong learning in the dental community. Integration of AI in dental education holds tremendous promise for advancing teaching and learning practices, improving student outcomes, and preparing future dental professionals to meet the evolving challenges of oral healthcare. As AI continues to evolve and mature, its role in dental education is poised to expand, offering transformative opportunities to shape the future of dental practice and education (29). AI is commonly used to simulate clinical scenarios, minimizing risks associated with live patient-based training. This approach enhances preclinical virtual patient feedback, enabling students to assess their work and compare it to ideal standards. Studies indicate that students develop competency-based skills more rapidly using these interactive systems compared to conventional simulators (31).

d.1.c: Use of AI in oral medicine

Integration of AI into oral medicine represents a significant advancement with profound implications for diagnostic accuracy, treatment planning, and patient care within the field of dentistry and medicine. Oral medicine encompasses the diagnosis and management of a wide range of oral and maxillofacial conditions, including oral mucosal diseases, oral manifestations of systemic diseases, and oral cancer. AI technologies offer a promising solution to augment the capabilities of oral medicine practitioners in several key areas (32). Machine learning algorithms can analyze diverse datasets comprising clinical images, patient histories, laboratory results, and radiographic findings to identify patterns and features indicative of various oral diseases and conditions. By training AI models on large datasets of annotated oral pathology images and patient data, these algorithms can learn to recognize subtle changes and deviations from normal oral anatomy and physiology, aiding clinicians in making timely and accurate diagnoses (33). Furthermore, AI-driven diagnostic tools can assist in risk assessment, prognosis prediction, and treatment planning for oral diseases. By integrating with electronic health records systems and other clinical databases, AI systems can provide real-time decision support to clinicians, facilitating personalized and evidence-based care (34). Moreover, AI technologies hold promise for improving patient outcomes through enhanced surveillance and monitoring of oral health conditions (35). Remote monitoring systems equipped with AI algorithms can analyze patient-generated data, such as images of oral lesions taken with smartphones, to detect changes in disease status and alert clinicians to potential concerns. Totally, the use of AI in oral medicine has the potential to revolutionize clinical practice by improving diagnostic accuracy, enabling personalized treatment approaches, and ultimately, enhancing patient outcomes in the management of oral and maxillofacial diseases and conditions.

d.1.d: Use of AI in endodontics

The integration of artificial intelligence (AI) in endodontics, a specialized field of dentistry focusing on the diagnosis and treatment of dental pulp and surrounding tissues, has revolutionized traditional practices. AI applications in endodontics encompass various areas, including diagnosis, treatment planning, and outcome prediction. AI algorithms can analyze radiographic images, such as periapical radiographs and cone beam computed tomography (CBCT) scans, to assist in the detection of dental pathologies like periapical lesions, root fractures, and anatomical variations. Additionally, AI systems aid in automating the segmentation of tooth structures and root canal systems, enhancing the precision of treatment planning and execution. Furthermore, AI-driven decision support systems provide clinicians with valuable insights into prognosis prediction and treatment outcomes based on patient-specific data and clinical parameters. By leveraging machine learning and deep learning techniques, AI models continuously improve their accuracy and efficiency in assisting endodontists in making informed clinical decisions. Overall, the incorporation of AI technologies in endodontics holds immense potential to optimize diagnostic accuracy, treatment efficacy, and patient outcomes, ultimately advancing the quality of care in this specialized dental discipline.

d.1.d.a: Root and root canal morphology

Understanding root and root canal systems is crucial for effective nonsurgical root canal therapy. Cone-beam computed tomography (CBCT) imaging and periapical radiography are commonly used for this purpose. CBCT imaging is more accurate in determining root and root canal geometries compared to radiography but may not be suitable for standard clinical practice due to radiation concerns (36). Deep learning algorithms applied to panoramic radiographs can differentiate distal roots of mandibular first molars, as demonstrated by Hiraiwa et al. Lahoud et al. utilized a CNN approach for automated three-dimensional teeth segmentation. In evaluating 433 CBCT segmentations, artificial intelligence performed as well as human operators, offering rapid and accurate clinical reference evaluation (37, 38).

d.1.d.b: Periapical lesion detection

Periapical lesions in teeth, with apical periodontitis represent a prevalent condition causing around 75% of radiolucent jaw lesions. While traditional 2D diagnostic methods like intra-oral periapical and panoramic radiographs are commonly used, they have limitations in accurately detecting periapical lesions due to the inherent 3D nature of the anatomy. CBCT imaging emerges as a more precise 3D technique for detection. Additionally, there is a growing interest in using Artificial Intelligence (AI) models for detecting periapical pathology and periodontitis, with promising results in accuracy. Various AI models have been developed for identifying alveolar bone loss, predicting periodontally challenged teeth, categorizing the severity of periapical lesions, and detecting periapical radiolucencies as accurately as oral surgeons. These advancements suggest potential improvements in diagnosis and treatment planning for periapical lesions, offering promising alternatives to traditional methods (39-41).

d.1.d.c: Detection of root fracture

Vertical root fractures (VRFs), constituting 2% to 5% of crown/root fractures, often require root resection or tooth extraction. Diagnosis is challenging due to the low sensitivity of traditional radiography. While cone beam computed tomography (CBCT) and radiographs assist in identification, they still present challenges. Research indicates potential in using Convolutional Neural Networks (CNN) on panoramic radiographs for VRF detection. Neural networks from periapical radiographs and CBCT images show promise in identifying VRFs in intact and root-filled teeth, with CBCT images being more accurate than 2-D radiographs. Techniques like wavelet analysis show promise in detecting fractures in high-resolution CBCT images, despite limited sample sizes. These advancements aim to enhance diagnostic accuracy for VRFs, potentially reducing unnecessary surgeries or extractions (42-44).

d.1.d.d: Working length determination

Radiography and electronic apex locators are commonly used by clinical dentists, with digital radiography's image clarity being essential for accurate interpretation. However, factors affecting radiographic interpretations may lead to misdiagnosis, necessitating computer-based techniques for consistent precision. Research suggests that artificial neural networks (ANNs) can improve WL assessment accuracy, serving as a valuable second opinion for locating the radiographic apical foramen. Studies demonstrate that ANNs exhibit consistent accuracy comparable to real measurements and outperform endodontists in determining minor anatomical constriction from periapical radiographs. Therefore, ANNs offer a reliable method for determining WL with high accuracy (45, 46).

d.1.e: Use of AI in oral and maxillofacial surgery

The utilization of artificial intelligence in oral surgery has notably advanced through the development of robotic surgery, which replicates human body motion and intellect. Notable applications include dental implantation, tumor and foreign object removal, biopsies, and temporomandibular joint (TMJ) surgery, all guided by imaging technology. Clinical studies demonstrate marked improvements in surgical accuracy compared to traditional freehand techniques, irrespective of the surgeon's experience level. Benefits include reduced operation time, enhanced intraoperative precision, and safer manipulation around delicate anatomical structures. Moreover, image-guided procedures allow for more extensive surgical resections, potentially minimizing the necessity for revision surgeries. This paradigm shift in surgical approaches owing to AI has led to the emergence of several robotic surgeons proficiently conducting semi-automated procedures under skilled surgical supervision (31).

d.1.f: Use of AI in Prosthodontics

Utilization of AI in prosthodontics, a dental specialty focused on the restoration and replacement of missing teeth and oral structures, has emerged as a transformative force in modern dental practice. AI applications in prosthodontics encompass a wide range of functionalities aimed at enhancing treatment planning, design, fabrication, and clinical outcomes. One significant area where AI excels is in digital smile design and virtual treatment planning (47). AI algorithms can analyze facial features, dental morphology, and patient preferences to generate customized treatment plans for restorative and prosthetic procedures. By incorporating AI-driven software, prosthodontists can simulate treatment outcomes, enabling patients to visualize potential results and participate actively in decision-making processes. Moreover, AI technologies play a crucial role in the fabrication of prosthetic restorations, such as crowns, bridges, and dentures.(48) AI-driven CAD/CAM (computer-aided design/computer-aided manufacturing) systems automate the design and milling processes, resulting in precise and aesthetically pleasing restorations with minimal human intervention. This not only improves efficiency but also ensures consistency and accuracy in prosthetic fabrication. Furthermore, AI-enabled diagnostic tools assist prosthodontists in assessing treatment needs and predicting long-term outcomes (25, 49). Machine learning algorithms analyze patient data, including medical history, radiographic images, and intraoral scans, to provide personalized treatment recommendations and prognostic insights. This aids in optimizing treatment planning and minimizing the risk of complications. In summary, the incorporation of AI technologies into prosthodontics represents a significant potential for revolutionizing conventional practices, enabling the implementation of personalized treatment modalities, and augmenting both patient satisfaction and clinical outcomes within the domain of dental prosthetics.

Design assistants tailored for use in prosthodontics have been introduced that integrate various factors such as anthropological calculations, facial dimensions, ethnicity, and patient preferences to offer the most esthetically optimal prostheses. They operate by linking databases, knowledge-based systems, and computer-aided designs through logic-based frameworks. Furthermore, advancements in neural networks enable laboratories to employ AI for autonomously crafting innovative dental restorations that adhere to rigorous standards of fit, function, and esthetics. While this technological progression is poised to enhance dentistry, its impact is anticipated to extend significantly to orofacial and craniofacial prosthetics (50).

d.1.g: Use of AI in orthodontics

Artificial intelligence (AI) has found integration into the field of orthodontics, a specialized discipline within dentistry dedicated to the diagnosis and treatment of misaligned teeth and jawbone discrepancies. This incorporation has emerged as a pivotal transformative force, restructuring conventional orthodontic methodologies. AI applications within orthodontics encapsulate a diverse array of functionalities intended to elevate diagnostic accuracy, refine treatment planning processes, and augment overall patient care standards. One pivotal area where AI demonstrates its utility is in the analysis of cephalometric and dental radiographs (19). AI algorithms can accurately identify and quantify craniofacial skeletal and dental anomalies, aiding orthodontists in the comprehensive assessment of malocclusions and treatment needs (51). This assists in streamlining diagnosis and developing tailored treatment plans for individual patients. Additionally, AI-driven software facilitates the segmentation and three-dimensional reconstruction of dental models derived from intraoral scans or cone beam computed tomography (CBCT) scans. These digital models allow for precise evaluation of tooth and jaw relationships, enabling orthodontists to plan orthodontic interventions with heightened accuracy and efficiency. Furthermore, AI technologies play a crucial role in treatment monitoring and outcome prediction (52). Machine learning algorithms analyze longitudinal patient data, including treatment progress images and clinical parameters, to forecast treatment trajectories and anticipate final outcomes. This empowers orthodontists to make informed decisions and adjust treatment plans as necessary to optimize patient outcomes. In summation, the integration of AI technologies into orthodontics portends to revolutionize traditional treatment methodologies, elevate diagnostic precision, and enhance treatment outcomes. Through the strategic utilization of AI capabilities, orthodontists are poised to administer care that is both more individualized and efficient, consequently fostering heightened patient contentment and advancing orthodontic efficacy.

One of the most noteworthy recent advancements is the advent of personalized orthodontic care facilitated by AI. Through AI technology, orthodontic diagnosis, treatment planning, and monitoring have become feasible. The analysis of radiographs and images captured by intraoral scanners and cameras serves as a basis for diagnosis and treatment planning, eliminating the need for numerous laboratory procedures and traditional patient impressions. Moreover, the precision of AI-driven assessments often surpasses that of human perception. By leveraging precise 3D scans and virtual models, the fabrication of aligners tailored to individual treatment strategies becomes straightforward through 3D printing. Through the processing of vast datasets, algorithms are developed to intelligently determine the optimal application of pressure and movement for patient teeth, including specific pressure points for each tooth or group of teeth. AI-assisted aligners not only hold the promise of reducing treatment durations and streamlining appointment schedules but also ensure precise treatment execution and facilitate comprehensive progress monitoring (39).

e: Challenges and opportunities in integrating AI into oro-dental health

The integration of AI into dental healthcare facilities represents a pivotal frontier in modern dentistry, promising transformative impacts on patient care, clinical workflows, and overall operational efficiency. However, this endeavor is not without its challenges and complexities. As dental practices increasingly explore AI-driven solutions to enhance diagnostic accuracy, treatment planning, and patient engagement, they must navigate a landscape marked by technological hurdles, ethical considerations, and regulatory frameworks. Simultaneously, this integration presents unprecedented opportunities to revolutionize traditional dental practices, optimize resource allocation, and deliver more personalized and effective care to patients.

AI streamlines data integration across various domains, enhancing their utilization and understanding. It complements traditional research frameworks, aiding in scientific discoveries, especially in *in-silico* experimentation. AI also improves healthcare by simplifying tasks, prolonging patient-provider interactions, and utilizing patient-generated data like speech patterns. Continuously acquired data reduces the episodic nature of healthcare encounters, enabling a personalized understanding of health dynamics and disease progression. (28)

In addition to its advantages, the rapid advancement of digital health technology presents various challenges, including ethical, social, legal, policy, and funding considerations, which could impede its adoption. These challenges encompass concerns about the quality of care, reimbursement, liability, safety, usability, privacy, equity, and accessibility. Despite the positive effects of digital health on care quality and cost-efficiency, several legal issues have emerged from these innovations (20) These legal concerns persist regardless of whether healthcare is delivered via teledentistry or traditional face-to-face methods, as patients retain rights and responsibilities. However, certain technological issues, although beyond practitioners' control, remain their responsibility (53,54). Despite this, there is a notable lack of discourse surrounding legal matters in digital oral health. There is mounting evidence indicating that the therapeutic alliance between practitioners and patients in telehealth settings can be as effective as in-person care, with patients expressing satisfaction (20, 55). Nevertheless, the shift to digital oral health disrupts some conventional norms governing the practitioner-patient relationship. For instance, effectively conveying oral health information during telehealth consultations may pose challenges. Patients should be informed about potential risks associated with teleconsultation, including threats to confidentiality posed by electronic communications.

Conclusion

The integration of artificial intelligence with human expertise is set to revolutionize oral health care by enhancing the accuracy, efficiency, and personalization of disease detection, diagnosis, and treatment planning. As AI technologies continue to evolve, their collaboration with clinicians promises to improve patient outcomes, increase accessibility, and drive global health equity in dental care.

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