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AI-driven evolution in teledentistry: A comprehensive overview of technology and clinical applications

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ABSTRACT

This scoping review discusses the current state and future of artificial intelligence (AI) in teledentistry. Teledentistry is a form of telehealth in which dental care is offered via electronic communication across distances due to geographic and financial constraints. The application of AI in teledentistry has made remote diagnosis, treatment scheduling, and patient interaction easier than ever. AI-enabled devices have already shown improved diagnostic performance in generating effective analysis of dental images such as radiographs and intraoral scans to prevent oral diseases in the first place. Automated image analysis in orthodontics, periodontics and prosthodontics, customized treatment plans, and dental prosthesis design are just some of its uses.

However, there remain a number of limitations, such as lack of infrastructure, clinical readiness, data privacy, and compatibility with current practice management systems. Future technologies, like 5 G connectivity, XR, IoT, edge computing, and blockchain, may prove to further augment AI-enabled teledentistry. Addressing these issues are important for successful and widespread use of AI technologies in the field of remote dentistry.

The study focuses on how AI can revolutionize the availability, efficacy and performance of teledentistry services. It's also an important reminder that research, ethics and professional training are still needed to properly incorporate AI in order to promote improved dental health.

1. Introduction

Teledentistry is a part of telehealth, that refers to the offering of healthcare services using electronic communications means. Through teledentistry, the dentist can diagnose, treat and even consult (via telephone or videoconference) the patient hence there is no need for them to be present in person. There is no doubt that the development of AI and teledentistry heralds a revolution in delivery of health service. The potential of AI and teledentistry for providing healthcare at scale, decision-making, is unprecedented [1,2].

1.1. Background of teledentistry

In order to provide patient care, consultation, education, and promotion, teledentistry brings together the use of information technology and communication. Originally intended to address disparities in access to dental care due to geography and resource constraints, the goal has expanded to include a wider range of communication tools, such as store-and-forward systems, mobile health applications, real-time consultations, and remote patient monitoring [3]. This method has been demonstrated to engage and reach populations, such as those residing in remote and rural areas, who would otherwise be restricted in their access to dental care by conventional barriers. Given the fact that these benefits exist, teledentistry was actually one of the first strategies used in order to secure dental services during the COVID-19 pandemic (along with lockdowns and social distancing) so as to maintain care delivery and continuity at the same time reducing the spread of the illness [4,5].

1.2. The age of intelligent artificial devices in the health sector

In recent times, AI has actually become increasingly important in the health sector due to the fact that it offers tools and systems that can basically accomplish tasks that were previously thought to be only possible for humans. Applications for these technologies are somewhat emerging rapidly across the board in the healthcare industry: AI-powered personalized medicine treatments are enhancing the efficacy

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of medical care; predictive analytics tools seem to anticipate the risk of infectious disease outbreaks and help to better plan healthcare facilities; and the numerous administrative tools which are leveraging AI systems are lightening the workload of health system administrators. AI encompasses multiple subfields, including computer vision, natural language processing, and machine learning. Better diagnostic precision enables healthcare practitioners to reach decisions faster and with greater impact which enhances both care efficiency and effectiveness [6, 7]. AI is becoming one of the most important tools for improving evidence-based and efficient healthcare service delivery because of its ability to process massive amounts of data and extract insightful knowledge [8].

Defining crucial artificial intelligence terms remains essential for a clear understanding across this review. Artificial Intelligence (AI) represents a wide-ranging field dedicated to constructing machines that replicate human cognitive functions including visual perception and speech recognition as well as decision-making and language translation. Machine Learning represents the field within AI that develops algorithms which learn from data to perform predictions or make decisions without requiring explicit programming for each task. Deep Learning (DL) represents a branch of Machine Learning (ML) which uses multilayer artificial neural networks to detect sophisticated patterns in data through its deep structure. Teledentistry utilizes AI which encompasses the techniques of Machine Learning and Deep Learning for essential tasks such as image analysis and disease prediction as well as treatment planning.

1.3. Intersection of AI and teledentistry

Together, AI and teledentistry represent a major evolution in the provision of dental care. AI technologies improved teledentistry platforms through automated image analysis, disease progression modeling and personalized treatment suggestions [9]. For example, diagnosis of oral cancer, periodontal diseases or dental caries can be predicted by machine learning algorithms which can help to analyze these radiographs and intraoral images with high accuracy [10,11]. AI-assisted chatbots and virtual assistants are capable of giving prompt answers and securing appointments – helping patients with their education and engagement, and improving the effectiveness and efficiency of remote dental services. In general, predictive analytics can actually be used to predict the outcomes of patients, and also to optimize resources [12,13].

1.4. Purpose and scope of the review

The primary purpose of this review is to provide a comprehensive analysis of AI's multifaceted role in teledentistry, specifically examining three interconnected aspects: This review analyzes three main aspects of AI in teledentistry: diagnostic accuracy, patient engagement impact and clinical integration feasibility. The review analyzes each aspect separately while demonstrating how their combined effect determines the overall influence of AI on teledentistry. Our goal is to demonstrate AI's transformative capabilities through its benefits in diagnostic accuracy and patient involvement while integrating with clinical processes while identifying main challenges and opportunities for its effective implementation. The analysis aims to help policymakers, researchers, dental practitioners and other healthcare sector stakeholders understand how AI adoption in teledentistry can lead to better oral health outcomes.

In the course of this review, a number of articles and sources will be cited to offer a thorough and reflective overview of the prospects and challenges that AI can generate in teledentistry for the benefit of policymakers, researchers, experts and other relevant personnel in the health sector to better understand oral health outcomes.

2. Methodology

The purpose of conducting this scoping review was to investigate how, and to what extent, artificial intelligence (AI) is integrated with teledentistry, with the review following Arksey and O'Malley's scoping review framework using structured protocol that integrates systematic review best practices. This was oriented towards mapping the current applications, evaluating the technological developments and assessing clinical outcomes concerning the use of AI in teledentistry. The review is set out to achieve several key objectives: We will identify how AI technologies are being utilized currently in teledentistry, how they are applied in clinical practice to diagnose, treatment planning, and monitor remotely, and evaluate the benefits and challenges for AI in dental practice. The study also aimed to highlight gaps of existing research and suggest what future work should be conducted.

Specific inclusion criteria were applied in defining scope to select the relevant studies. They were peer reviewed articles, conference papers, reviews, case studies and expert opinions about dental practitioners, patients or clinical settings in which teledentistry was used. The scope was restricted to publications discussing the use of AI for diagnostics, treatment planning, or patient monitoring, which were published between 2020 and 2024. The exclusion criteria included studies not involving AI or not related to telehealth, including studies that place no emphasis on dentistry and are not peer reviewed opinion pieces.

To ensure comprehensive coverage, the review drew data from several major scientific databases: They are searched in PubMed, Scopus, IEEE Xplore, arXiv and Google Scholar. Grey literature as conference abstracts and reports from governmental and organizational bodies were also included. Keywords were used in the search strategy comprising Artificial Intelligence, Teledentistry, Machine Learning, Remote Dental Care, AI in Dentistry, along with Boolean operators to refine and enhance the inclusion of relevant information.

From these initial searches, 314 records were identified. After removing 22 duplicates and 2 non-English studies, 290 records remained. Of these, 56 were excluded based on title and abstract screening (Reasons: Not related to teledentistry = 29, Not related to AI in dentistry = 27, Other = 10), leaving 234 records sought for retrieval. 86 records could not be retrieved (Reasons: Unable to locate full text = 36, Conference only = 9, abstract level = 42). Full-text assessment was performed on 148 articles, and 46 were further excluded (Reasons: focusing on broader AI topics = 26, Wrong study design = 20, no clinical application = 11). A total of 91 studies met the eligibility criteria and were included in this review (Fig. 1)

The data extraction process followed a structured form to gather publication details (author, year, country), specific AI technologies, clinical applications (diagnostic tools, treatment planning, remote monitoring), and outcomes (benefits, limitations, clinical implications). A thematic data synthesis approach was used organizing findings into technology and clinical aspects so as to provide a descriptive narrative of the development and application of AI in teledentistry. Main outcomes, challenges, and gaps were also highlighted from this synthesis in the current body of literature.

The broad exploratory nature of this scoping review did not involve a formal risk-of-bias assessment with established tools like Cochrane Risk of Bias tool, ROBINS-I, or QUADAS-2. Study quality was analyzed implicitly throughout the study selection and synthesis phases. This review process follows scoping review principles that prioritize comprehensive coverage over detailed critical analysis [14]. Specifically, the relevance and credibility of potential sources were evaluated based on: Publication Venue (prioritizing peer-reviewed articles in reputable journals and conferences); Study Design (giving greater weight to randomized controlled trials (RCTs) than case reports or expert opinions, while acknowledging the limitations of each design); Sample Size (considering sample size as an indicator of power and generalizability for quantitative studies); Clarity of Reporting (assessing for clear and complete descriptions of AI technology, data sources, population, and outcomes); and Relevance to Teledentistry and AI (requiring a clear connection to the application of AI in teledentistry). The absence of a formal risk-of-bias assessment is acknowledged as a

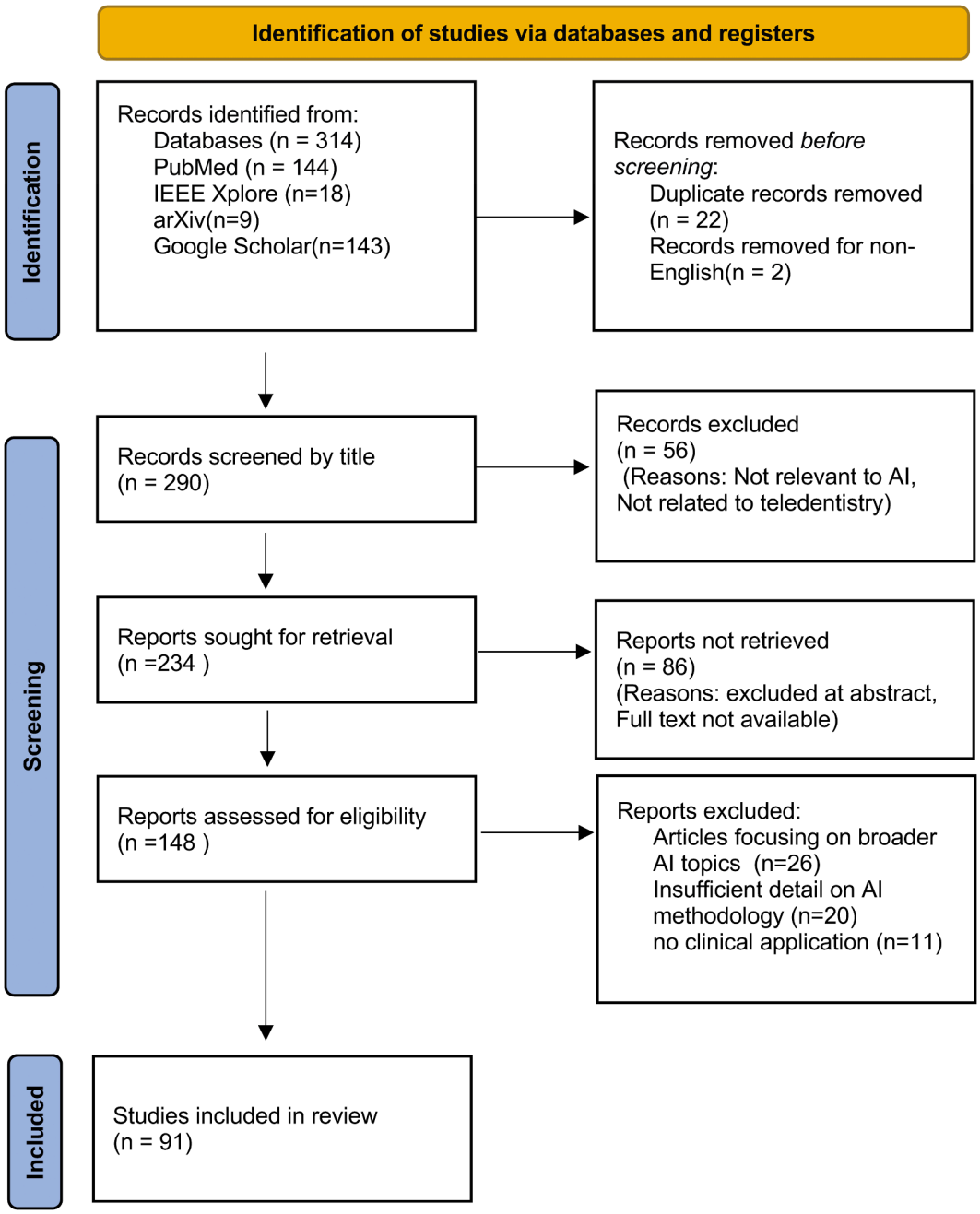

Fig. 1. *Consider, if feasible to do so, reporting the number of records identified from each database or register searched (rather than the total number across all databases/registers).
**If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools. [14]. Source: Page MJ, et al. BMJ 2021;372:n71. 10.1136/bmj.n71. This work is licensed under CC BY 4.0. To view a copy of this license, visit https://creativecommons.org/licenses/by/4.0/.

limitation. The approach provided an extensive overview of AI in teledentistry by identifying major themes, technologies and research gaps despite being less rigorous than systematic reviews' quality assessments.

To help ensure transparency and reduce the risk of duplicating this research, the protocol for this review was registered on the open science framework (https://doi.org/10.17605/OSF.IO/459GP). Any amendments to the protocol were recorded, along with their rationale in the final manuscript. With this approach we offered a structured, holistic view of AI's relevance in teledentistry and pointed to avenues for future research and public policy directions.

3. Influence of AI on the development of teledentistry

Adoption of AI in healthcare has given the a large impetus: improving diagnostic accuracy, suggesting treatment plans and reducing the complexity of routine clinical processes [15], and the entrainment of AI into dentistry is necessary for the success of teledentistry to improve its functionalities and the quality of dental caregivers in remote areas.

3.1. Evolution of AI in healthcare and its extension into teledentistry

Diagnostic imaging alongside personalized healthcare and operational efficiencies represent key prescriptive applications of AI

technology in the healthcare field [15]. The precision and timeliness provided by modern machine learning and deep learning algorithms for medical data analysis now enable teledentistry to break through fundamental obstacles faced in remote dental care delivery. AI analysis of dental radiographs and intraoral scans provides improved diagnostic accuracy which allows for earlier detection of dental issues and helps to establish more accurate treatment plans [15,16].

Artificial Intelligence enhances personalized treatment planning through individual patient history and data analysis which leads to better clinical outcomes and higher patient satisfaction [17]. AI-driven automation of administrative duties allows dental professionals to allocate more time towards patient treatment and complex medical assessments. By minimizing routine duties through streamlining processes patients become more actively engaged.

AI enables constant patient observation in orthodontics and preventive dentistry which eliminates the need for repeated office visits. Remote monitoring allows for prompt treatment adjustments which leads to improved outcomes in dental care. The integration of AI in teledentistry has revolutionized the field through improved diagnostic precision and customized treatments while streamlining procedures and supporting continuous patient follow-up.

3.2. Key milestones in the integration of AI with teledentistry

Several important milestones have emerged with the implementation of AI into teledentistry. Fig. 2 presents the evolution of AI in dentistry. One big breakthrough is AI-driven diagnostics. The development of AI systems that are capable of analyzing dental images has greatly improved remote diagnostics [16]. This development allows improved determination of dental problems without the need of an in-person visit.

A major development is the FDA's approval of AI diagnostic tools. The acceptance of AI devices like Videa Perio Assist (VPA) validated the effectiveness of AI in dental diagnostics, indicating a significant innovation [18]. This endorsement not only confirms the effectiveness of AI in dentistry but also promotes wider adoption of this technology.

The use of AI has significantly contributed to remote monitoring systems. AI-driven solutions improve the provision of ongoing assistance and allows the remote adjustment of treatment plans [17]. It also allows dental professionals to monitor outcomes of treatments and make adjustments without requiring patient visits.

Innovations in Clinical Decision Support Systems (CDSS) are another important milestone. AI-enabled CDSS deliver evidence-based recommendations, improving treatment planning and outcomes [17]. These systems help dentists to make educated decisions based on a large amount of clinical data.

The Internet of Dental Things (IoDT) adoption has changed the face of teledentistry by advanced remote monitoring and data acquisition [19]. Using AI and IoDT together can help to analyze data and keep track of patients efficiently for better service delivery.

AI-powered chatbots and virtual assistants can help patients communicate and engage, making dental care more accessible [15,20]. Research on AI-driven chatbots in teledentistry is still maturing; however, current studies in telehealth and healthcare shows that these chatbots can improve patient engagement and outcomes in healthcare. Fan et al. [21] found that health chatbots designed for self-diagnosis substantially improve patients' understanding of symptoms while encouraging better health management practices. Behers et al. [22], in a study on cardiac catheterization, showed how AI chatbots could provide high-quality educational materials for patients, which are crucial for treatment understanding and compliance. Although in urology, Talyshinskii et al. Talyshinskii et al. [23] examined how AI chatbots could assess patient data to discover trends for healthcare improvement. Studies outside of direct medical applications, such as Abdallah et al. [24] work on customer acceptance and Khana et al. [25] on customer loyalty in the tourism sector shows personalised interactions can lead to increased satisfaction. Moreover, several reviews and studies suggest positive outcomes. Kurniawan et al. [26] found that AI chatbots can considerably improve adherence by patients with treatment protocols. Aggarwal et al. [27] showed how chatbots efficiently promoted modifications in health behaviors. Kim et al. [28] documented improvements in patient engagement and satisfaction in the study. The results show that AI chatbots can significantly benefit patient communication and education while ensuring adherence to treatment plans which leads to better oral health results when used in remote healthcare settings. To determine their exact effects in teledentistry applications additional studies and practical trials must be performed.

These milestones collectively represent the future of AI in teledentistry and the technological innovations that have enabled remote dental care.

3.3. The role of AI in advancing remote dental diagnostics and treatment

AI has played a crucial role in the advancement of remote dental diagnostics and treatment. AI powered imaging analysis is one such contribution. Machine learning algorithms and convolutional neural networks (CNNs) are able to detect diseases early and diagnose by accurately processing complex dental images [16]. This capability is

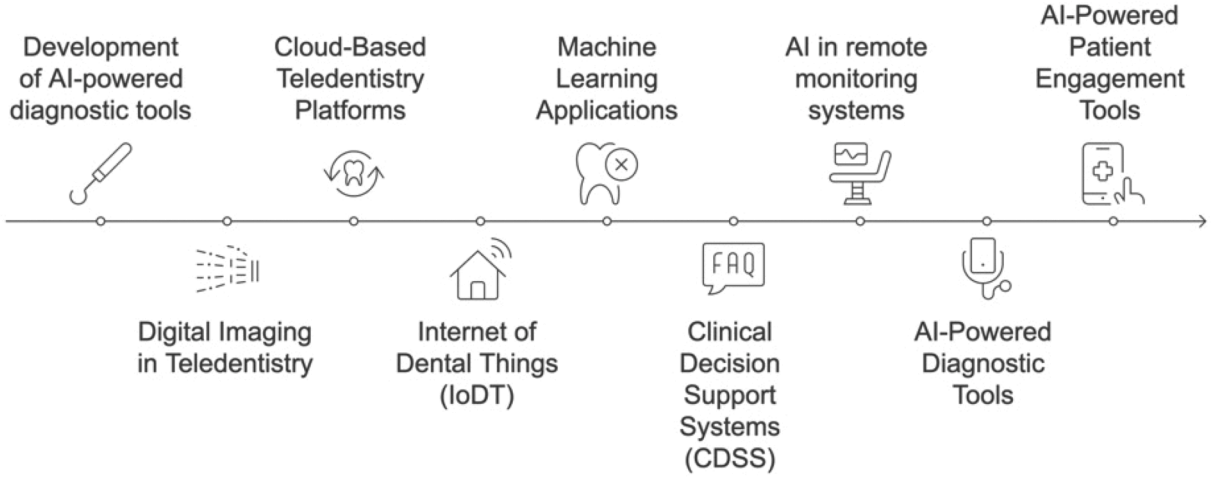

Fig. 2. Title: Evolution of AI in Dentistry.
Legend: Visual representation to understand the progression and evolution of AI in teledentistry (Left to Right).

crucial for remote examination in the absence of physical examination.

Also, Videa Perio Assist (VPA) is an FDA approved diagnostic tool, which automatically measures and visualize the bone level from radiographic images and shows a high sensitivity and specificity for the periodontal disease detection [18]. As remote periodontal assessments become more accurate, this software aims to improve.

The combination of AI and enhanced cone-beam computed tomography (CBCT) can automatically process the images and detect the pathology. This combination offers better diagnosis at reduced radiation levels [29]. AI algorithms are better at detecting abnormalities in CBCT images than traditional ones.

AI can also support individualized treatment planning by leveraging on comprehensive data in patients to develop individualized treatment regimens and maximize outcomes [11,17]. Predictive analytics makes it possible to intervene before a dental health problem worsens.

Another advantage of AI driven applications is improved patient engagement. Smart treatment coaching apps enhance patient compliance and treatment efficiency especially in clear aligner treatments [30]. Such apps also give the patient targeted feedback and reminding during treatment.

AI also supports remote monitoring and continuum of care systems. Orthodontics and preventive dentistry also make use of such devices for rapid adjustments with treatments with minimal visit [6,17]. At last, AI-based clinical decision support systems (CDSS) enable dental practitioners to make informed choices with the support of evidence from a wide array of clinical data [17].

The use of these advancements improved the efficiency, personalization and accessibility of remote delivery of dental care. But they also presents challenges by making data privacy and security a concern. AI technologies are rapidly becoming an integral part of teledentistry; therefore, ethical considerations and ongoing professional training for practitioners is needed [8,16].

4. Technological scope of AI in teledentistry

4.1. Overview of AI technologies used in teledentistry

AI technologies are an increasingly common part of teledentistry as the technology seeks to further enhance the provision of dental care over a distance. Notable AI technologies currently employed include machine learning, computer vision, object recognition, and predictive analytics.

Machine learning algorithms, including several deep learning models, can be used to develop predictive models for risk assessment and screening for oral diseases, complications, and patient stratification. These algorithms also support remote screening, diagnosis and monitoring of dental patients [31].

Computer Vision techniques have been used to analyze dental images. With a one-stage object detection method, YOLOv3, panoramic X-ray pictures have been examined for the presence of certain dental issues. This improves the accuracy of remote diagnosis [32].

Object Recognition AI systems that use gaze-guided wearable cameras to identify objects and activities – such that these can be recognized during dental treatments – could be used to identify therapy [33].

Predictive analytics is used to create risk-scoring models and patient-stratification models for oral health-related disorders. AI uses patterns across large datasets to predict potential dental complications and help with early intervention measures [31].

Natural Language Processing (NLP), though not explicitly mentioned in the existing literature, is likely to be employed in teledentistry applications for the processing of voice commands, as well as for amplifying communication between patients and dentists.

4.2. Comparison of AI tools with traditional dental diagnostic methods

AI tools have proven to be more effective than conventional methods in diagnostic dentistry. Recent research indicates that AI-based methods are more reliable than traditional dental diagnosis techniques in multiple aspects of the treatment process.

Firstly, AI applications, especially convolutional neural networks and deep learning models, have shown increased diagnostic accuracy, improved prognosis assessments, and enhanced treatment decision-making. In certain complex cases, AI has occasionally been more precise than conventional methods [11].

The FDA has given approval to the AI model Videa Perio Assist (VPA) for use in diagnosing periodontal disease. This VPA has demonstrated increased in sensitivity and specificity during clinical testing. It can determine and visualize by itself the bone levels of each tooth based on radiographic images, and may yield better, more consistent outcomes than any other diagnostic device [18].

AI-based systems are also reshaping radiography. These algorithms allow us to interpret data in more consistent and accurate ways than humans do. AI can also be more accurate at detecting dental anomalies on orthopantomograms (OPGs) than conventional human analysis [34].

Moreover, the use of AI-assisted methodologies in treatment planning allows dentists to provide more personalized, precise, and efficacious care. These methods enable the creation of individualized and optimized treatment plans that surpass the precision of previous approaches [11].

Finally, AI's strong analytical abilities and pattern recognition capabilities can lead to better early identification of oral health conditions, ultimately improving treatment results and outcomes for patients [35].

4.3. Challenges in the development and deployment of AI in teledentistry

Despite promising advances, there are still some technological challenges in applying AI to widespread teledentistry. A major obstacle is infrastructure and connectivity issues. Absence of internet access and reliability, especially in rural or underserved areas, limit the availability of digital oral healthcare systems, such as AI-driven teledentistry platforms [36].

The other issue is that intraoral imaging isn't easily obtainable. AI systems depend on very high-resolution images to diagnose and treat a patient; without precise imaging, their utility is restricted [37]. Integration with existing systems is also a challenge. The lack of interoperability between AI-enabled teledentistry systems and current dental practice management platforms makes it challenging to adopt.

Professional readiness and training are important for the successful deployment of AI in teledentistry. Dental professionals must be trained to engage with AI systems and make sense of their results, making expertise a key determinant of the eventual diffusion of such technologies [37]. Additionally, the technology and resources available in the dental clinics are usually inadequate, limiting AI implementation [36].

Economic and financial factors contribute to these gaps. Funding problems can impede the diffusion of new technologies, and factors pertaining to remuneration are causative factors of the slow uptake of teledentistry [37]. Finally, data security and privacy issues emerge as a result of AI systems' access to critical patient information, leading to concerns around data protection and adherence to regulatory requirements in the healthcare industry [62].

4.4. Future directions: emerging technologies and innovations in AI-Driven teledentistry

Future developments of AI-powered teledentistry are likely to drive more rapid growth in personalized treatment planning, expanded remote diagnostics via high-resolution imaging, wearables for patient tracking in real-time, access to care in the less accessible areas, and AI-based virtual assistants for patient engagement — thereby expanding access and preventive dentistry (Table 1).

New technologies have the potential to revolutionize AI for teledentistry further. The rollout of 5 G and advanced connectivity is just one such step. 5 G may support teledentistry by enabling faster, more

Table 1
Future advancements in AI-powered teledentistry.

Technology	Description	Potential Impact
5G and Advanced Connectivity	Ultra-fast, low-latency networks enabling real-time data transmission and remote procedures	Facilitates seamless remote consultations, instant sharing of high-resolution images, and potential for remote-controlled procedures
Extended Reality (XR) Technologies	Immersive technologies including AR, VR, and MR for enhanced visualization and training	Improves dental education, treatment planning, and patient communication through 3D visualizations
Internet of Things (IoT)	Network of connected dental devices and sensors for data collection and monitoring	Enables continuous patient monitoring, predictive maintenance of dental equipment, and personalized treatment plans
Advanced 3D Printing	High-precision 3D printing for dental prosthetics, implants, and surgical guides	Accelerates production of custom dental products, reduces costs, and improves treatment outcomes
Edge Computing	Localized data processing for faster analysis and reduced latency	Enhances real-time diagnostics, improves AI model performance, and ensures data privacy
Blockchain Technology	Decentralized, secure ledger for managing patient records and transactions	Improves data security, enhances interoperability between dental practices, and streamlines insurance claims
Advanced Imaging Technologies	High-resolution, AI-enhanced imaging systems for detailed oral scans	Facilitates early detection of dental issues, improves treatment planning, and enhances patient education

Legend : This table provides an organized overview of technologies that can drive future advancements in AI-powered teledentistry. These emerging technologies have the potential to revolutionize dental care by improving diagnostics, treatment planning, patient engagement, and overall efficiency of dental practices.

stable connections, real-time, full-resolution video consultations, and high-resolution imaging files quickly to be transmitted [38].

Extended Reality (XR) technologies such as Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) can be augmented by AI to provide immersive experiences for the provision of teledentistry. These technologies can provide interactive patient education, virtual treatment planning, and remote procedure guidance [6,39,40].

The Internet of Things (IoT) also seems to have a bright prospect in this areas. Modern devices enabled using the IoT can help track the oral health status of patients in granular details and in real time wherein AI can be utilized for continuous monitoring and alerting of dental ailments [39,38]. Such ongoing monitoring can result in interventions and individualized treatment.

Advanced 3D printing technologies and AI would enable the creation of dental appliances from AI-scanned images and be produced remotely within a short time period [6]. This feature can improve production efficiency and accessibility of dental prosthetics.

Edge computing is another exciting possibility. Since AI processing is closer to the data, diagnosis and treatment planning can be done faster in teledentistry apps [41]. This reduces latency and increases the responsiveness of AI systems.

Blockchain can help ensure the safety and transparency of patient records administration for AI-based teledentistry applications and avoid privacy breaches [39,38]. Blockchain is a means of data sharing that can help build confidence in platforms. Even though blockchain holds considerable promise for improving data security in teledentistry, the creation of regulatory frameworks applicable to informatics in dentistry is still nascent. While existing regulations from HIPAA and GDPR authorities lack specialized guidelines for dental informatics, their fundamental data protection standards would necessarily govern blockchain systems that manage health information. [42,43]. The AMA recognizes the potential of blockchain technology and calls for privacy-centered frameworks alongside the WHO which stresses the importance of data security and system interoperability. Studies show that blockchain applications must comply with HIPAA and GDPR regulations according to existing literature [44–46]. The ACTION-EHR pilot program [47] alongside blockchain implementations in clinical trials [48,49], FHIRChain [50], blockchain applications in smart cities [51], and blockchain data validation testing through a regulatory sandbox [52] represent real-world examples of current initiatives to navigate regulatory issues. Regulatory bodies demonstrate active consideration of blockchain's implications and will likely establish future guidelines as blockchain matures and becomes more prevalent in healthcare sectors such as teledentistry.

Further improvements in imaging technologies, combined with AI analyses, may provide better and more detailed remote dental diagnoses. Advanced imaging can enhance the accuracy of AI diagnostics, leading to more effective treatment plans.

When paired with AI, these new technologies could transform the scope, effectiveness and affordability of teledentistry services. But it's going to be crucial to make sure that data security, compliance and equal accessibility of technologies are addressed for them to be implemented and broadly adopted.

5. Clinical scope of AI in teledentistry

Artificial Intelligence (AI) is changing the way teledentistry works by bringing new solutions that improve clinical and patient care. AI using powerful algorithms and machine learning algorithms allows remote dental care to reach diagnostic and treatment efficiency levels previously available only with in-person visits. Table 2 presents the main application areas of AI in teledentistry, the technologies employed, and the benefits they offer.

This section explores the clinical application of AI in teledentistry with a focus on improving diagnostic accuracy and personalized treatment. It will explore its use in different areas of dentistry — such as orthodontics, periodontics, and prosthodontics — and key clinical case studies that illustrate how AI integration has succeeded and failed. We will also explore how AI can enable remote patient tracking and follow-up to enable a better and more accessible dental solution. Fig. 3 shows

Table 2
Applications of AI and their benefits.

Application Area	AI Technologies	Used Benefits
Diagnostic Imaging	Convolutional Neural Networks (CNNs), Deep Learning	Improved accuracy in detecting dental pathologies, enhanced radiographic analysis, automated cephalometric evaluations
Treatment Planning	Machine Learning, Neural Networks	Optimized treatment outcomes, personalized treatment plans, improved surgical and prosthetic treatment prediction
Remote Monitoring	Internet of Things (IoT), Edge Computing	Continuous patient monitoring, predictive maintenance of dental equipment, real-time diagnostics
Patient Engagement	Natural Language Processing, Chatbots	Enhanced communication, improved patient education, streamlined appointment scheduling
Clinical Decision Support	Machine Learning, Artificial Neural Networks (ANNs)	Assistance in disease diagnosis, evaluation of oral cancer occurrence or recurrence, improved treatment planning

Legend : This table highlights the practical applications of AI and their contributions to teledentistry. AI technologies are transforming various aspects of dental practice, from diagnostic imaging to clinical decision support, ultimately enhancing patient care and treatment outcomes. The integration of these technologies is improving the efficiency and accuracy of dental procedures while also facilitating remote care and patient engagement.

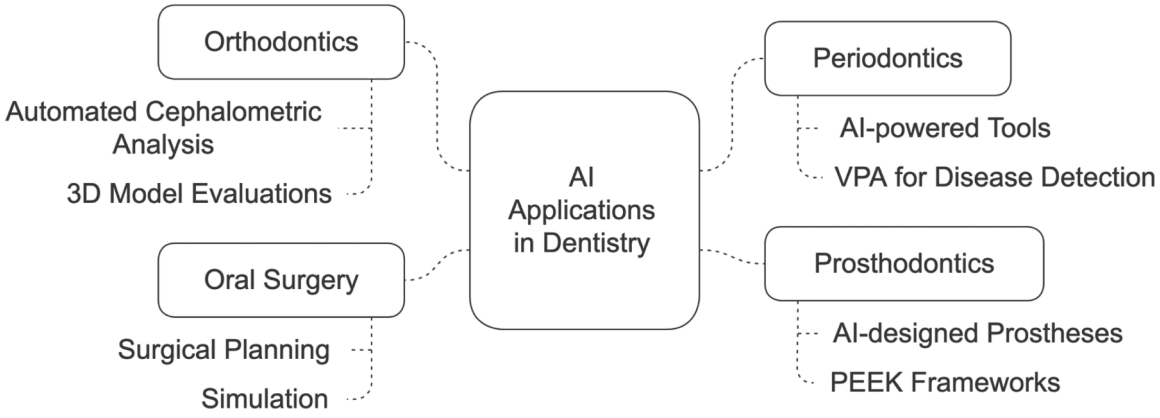

Fig. 3. Title: Clinical applications across specialties.
Legend: Provide a visual summary of how AI is utilized across multiple areas in dentistry.

clinical applications across specialties.

5.1. Improvements in diagnostic accuracy and treatment planning through AI

AI in dentistry has significantly affected teledentistry treatment planning and led to improved diagnostic accuracy. Most importantly, AI has contributed to better performance concerning the analysis of dental images and data using optimized accuracy and time for dental disease detection, for which deep learning models and convolutional neural networks have exhibited better performance [53,54]. For example, caries or periodontal diseases and lesions can be better detected with higher precision by AI, which is especially important in telehealth settings where patients cannot be examined in person.

AI technologies improve the evaluation of dental imaging modalities such as panoramic radiographs, cone-beam computed tomography, and intraoral radiographs, which aid in better characterization of conditions like root fractures and periapical radiolucent lesions [29,54]. This enhanced diagnosis is of utmost importance in complex situations where a number of factors have to be considered.

Besides, AI enables personalized treatment planning since it can analyze enormous amounts of patient data for their personalized strategy in treatment, which may lead to better therapeutic efficiency and, hence, better clinical outcomes [8,55]. AI-powered clinical decision support systems deliver evidence-based guidelines to the dentist and knowledge acquired from wide clinical data sets that ensure quality care decisions at distant sites [8,75].

5.2. AI applications in orthodontics, periodontics, and other dental specialties

The application of AI has been increasingly adopted in many dental specialties, such as orthodontics, periodontics, and prosthodontics. For instance, in orthodontics, this includes automated cephalometric analysis and three-dimensional model evaluations that provides comprehensive information for the orthodontist to base treatment decisions upon [56]. This automation saves time spent on diagnosis and, therefore, does much to help improve the efficiency of treatments.

The FDA-approved Videa Perio Assist, for example, is an AI model for periodontics that achieved excellent sensitivity and specificity to diagnose periodontal diseases. This tool automatically measures and visualizes bone levels associated with each tooth from radiographic images, and was suggested as an alternative for limitations in accuracy and standardization found in traditional diagnostic methods [57].

Another branch of dental oral surgery, prosthodontics, has already been incorporating AI to design dental prostheses. AI-designed polyetheretherketone (PEEK) frameworks for full-mouth fixed dental prostheses supported by implants showed similar survival rates and less bone loss compared with titanium prostheses, which are traditionally used for this purpose [58,57]. These developments indicate that AI can also contribute to more durable and effective prosthetic solutions.

Artificial Intelligence presents potential for remote monitoring of postoperative wound recovery following periodontal surgeries and tooth extractions. Although large-scale research focused on oral surgery continues to develop, the foundation of this technology is under active refinement. Khanagar et al. [59] highlight AI's potential in analyzing patient-provided images and data to track healing and detect early signs of complications, such as infection or delayed healing. Schwendicke et al. [60] explore how AI technology can enhance patient outcome monitoring while Sharma et al. [61] suggest that AI-driven platforms may allow continuous evaluation through image analysis which could decrease the necessity of regular face-to-face follow-up exams.

Mobile applications powered by AI were developed to improve the commitment of patients to clear aligner therapy. Thurzo et al. [30] developed an application that makes use of image analysis that can monitor aligner wear and send reminders to patients, thus enhancing communication with the orthodontist. This conforms with the general trend of automated image evaluations in orthodontics, as noted in a bibliometric analysis by Wong et al. [63]. Although not strictly focused on compliance, Kim et al. [64] illustrated the potential of intraoral picture analysis for screening gingivitis in orthodontic patients, suggesting that similar techniques may be used to monitor aligner utilization. Płotka et al. [65] investigate the potential use of convolutional neural networks in orthodontic procedures like tooth segmentation, a technique that may be used for compliance monitoring.

AI algorithms are being used to predict oral decay risk by examining patient data from dietary habits to oral care routines and past dental records. The study done by Ramos-Gómez et al. [66] showed that the application of a machine learning algorithm can be used predict caries in children using questionnaire data, providing targeted preventive measures. The risk score model from Nobre et al. [67] integrates past caries history to demonstrate the significance of historical data in evaluating caries risk. Through the application of multiple machine learning models Çiftçi and Aşantoğrol [68] managed to classify caries risk effectively as the random forest model demonstrated substantial accuracy. Téllez et al. [69] reviewed current caries risk assessment systems, stressing the importance of longitudinal data. The work by Zanella-Calzada et al. [70] investigated how deep neural networks can merge socioeconomic and nutritional information to demonstrate AI's ability to integrate multiple data sources for personalized risk evaluation and preventive health measures using teledentistry platforms.

5.3. Review of key clinical case studies showcasing AI success and limitations

A number of clinical case studies have documented both the successes and limitations of AI in the clinical application of the remote dental practice. In a retrospective cohort study, Wang et al. compared PEEK and titanium frameworks for full-mouth fixed dental prostheses (FDP) supported by implants. The study found that there was no difference in the 5-year survival rate between the PEEK (93.1 %) and titanium (93.5 %) prostheses. PEEK prosthesis also resulted in significantly less vertical bone loss (0.70 mm) when compared with the titanium (0.96 mm) after five years. The study concluded that the AI designed PEEK prosthesis was successful in long-term use [58].

In contrast, a prospective cohort study by Mangano et al. on removable maxillary overdentures secured by implants and PEEK bars, reported 20 % of dentures failed due to lack of passive fit, peri-implantitis developed around two implants, and two fractured dentures needed repair. These findings help to highlight the ongoing challenge in achieving consistent fit and durability with AI-designed prostheses [71].

In their randomized controlled trial, Sharaf and Eskandar compared attachment-retained obturators with PEEK frameworks to metallic frameworks and conventional clasp-retained obturators, and found the same positive results for both PEEK and metallic attachment-retained obturators regarding bone preservation and patient satisfaction, and exceeding those of the conventional methods [72]. On the other hand, there was no difference according to Russo et al. between ridge changes using AI-designed removable partial dentures and untreated patients after one year, which suggested that AI-designed prostheses may not provide additional benefits for bone loss in alveolar preservation [57].

Such case studies highlight that, while AI might be able to design effective dental prostheses, the technical challenges associated with maintaining consistent quality and demonstrating clear superiority to the conventional approach remain to be resolved. More large-scale randomized trials are needed to ascertain the clinical efficacy of AI applications in remote dental care [73,57].

5.4. Potential for AI to enhance remote patient monitoring and follow-up care

Another important area where AI can be of great help is in remote patient monitoring and follow-up care. Using AI-powered teledentistry, patients can be continuously monitored by AI-based platforms, making effective follow-up possible, as well as offering remote care and prompt intervention and modification of treatment plans without requiring patients to undergo frequent office visits [9,74]. This is particularly useful for patients living in remote areas or who lack access to dental care.

Based on real-time data, AI can predict dental problems beforehand and, consequently, help with preventive care plans to enhance long-term clinical outcomes [8]. Moreover, customized educational materials and support for patient engagement via AI-powered applications can lead to more successful adherence to treatment plans and better follow-up care [8,74]. The integration of artificial intelligence into remote monitoring systems provides dental professionals with more responsive and personalized healthcare, translating into overall more satisfying and successful health experiences and outcomes within teledentistry.

6. Discussion

The use of AI in teledentistry has transformed the provision of remote dental care, improved the diagnostic and treatment planning processes, and the extent of patient involvement. Use of the AI technologies will overcome the barriers to opportunities and access to dental services in remote areas, improve the range and quality of services (Table 3) [15–17].

6.1. Key insights

Algorithms powered by AI have transformed how dental diagnostics works by making it possible for practitioners to evaluate a variety of diagnostic images such as X-rays and intraoral scans with more precision than ever before [15,16]. For example, the Videa Perio Assist (VPA), FDA-approved, maintains the high sensitivity and specificity characteristics of periodontal disease detection, showcasing AI's potential in improving diagnostic procedures [18]. AI applied in decision-making leading to optimized outcomes, when it comes to developing a new treatment plan that is highly individualized for the patient after reviewing the comprehensive patient data [11,17].

In orthodontics and prevention, for instance, the patient does not have to match follow-up care considering that AI technology takes in the monitoring of the patient continuously, therefore any modification to the treatment plan can be done timely [6,17]. There are also applications that integrate AI in treatment coaching in which adherence of patients to treatment is enhanced leading to efficient treatment of patients such as the case of treatments for clear aligners [30].

6.2. Gaps and opportunities

Despite these advancements, several barriers exist that hinder the effective use of AI in teledentistry today (Table 3). These include infrastructure and connectivity issues, especially in remote or medically underserved areas where the technological infrastructure for effective

Table 3
Challenge associated with AI implementation in teledentistry.

Challenge	Description	Impact on Teledentistry Proposed	Solution
Infrastructure and Connectivity Issues	Limited broadband access and unstable connections hinder telecommunication and data transfer	Reduces the effectiveness of remote consultations and diagnostics	Invest in robust telecommunication infrastructure and explore satellite internet solutions for rural areas
Lack of Professional Readiness and Training	Dental professionals may lack the necessary skills and knowledge to effectively use AI technologies	Results in underutilization of AI tools, leading to inefficiencies in practice	Implement comprehensive training programs and continuous education initiatives focused on AI applications in dentistry
Data Security and Privacy Concerns	The handling of sensitive patient information raises concerns about data breaches and unauthorized access	Erodes patient trust and could lead to legal repercussions for dental practices	Adopt strong cybersecurity measures, including encryption, regular audits, and compliance with regulations like HIPAA
Integration with Existing Systems	Difficulty in integrating AI solutions with current dental practice management systems can disrupt workflows	Causes delays in adoption and may lead to resistance from practitioners	Develop standardized APIs and interoperability frameworks to facilitate seamless integration of AI tools
Cost and Financial Considerations	High costs associated with implementing AI technologies may deter practices from adopting them	Limits access to advanced technologies, particularly for smaller practices or those in underserved areas	Explore funding opportunities, grants, or partnerships to subsidize costs for dental practices adopting AI solutions

Legend : The challenge associated with AI implementation in teledentistry, along with corresponding solutions or emerging technologies that can help overcome these obstacles.

implementation of AI-based solutions is lacking. [37,36] Lack of adequate intraoral imaging resolution can also limit the usefulness of AI systems, particularly those that require quality images for correct diagnosis. [37]

Professional preparedness is another big obstacle. Dentists need training in how to use AI technologies and interpret their outputs, and new educational programmes might need to be developed to help dental practitioners become adept at using AI in their field of work [37]. Privacy and data security concerns could also be an issue, since AI systems would need access to patient information in order to function properly. Healthcare regulations must be strongly adhered to in this regard [8,16].

6.3. Strengths and limitations

The diagnosis with AI systems has turned out to be more effective than the conventional dental diagnosis methods. Both the machine learning programs and deep learning models have improved the performance of the diagnosis in some aspects especially in complex cases, at times even more than conventional methods [11]. AI offers more precise interpretation of radiographic images for early detection and prevention of oral diseases [34,35].

The advancement of AI in remote medical diagnosis and treatment planning faces challenges because training datasets that lack diversity or exhibit bias can unintentionally create algorithmic bias [59,76,77]. Dental diagnostic models commonly depend on radiographic images and clinical data which fail to capture the full spectrum of demographic populations especially in terms of race and economic background or specific age groups [78,79]. Diagnostic accuracy decreases and pathologies go undetected in populations that lack adequate representation [80,81]. The training data's inadequacy in rare conditions and complex presentations leads to their potential oversight [82]. To prevent AI-driven tools from worsening existing oral health disparities it requires intentional data augmentation alongside cross-population validation and multi-site data collection. The benefits of AI in teledentistry can reach all patient groups equitably when researchers and clinicians focus on fairness-aware modeling and transparent performance reporting.

Another critical limitation is the potential for over-reliance on automated systems in clinical decision-making. The benefits of AI in dental practice include increased efficiency and enhanced analytical insights but it should serve as a supplementary tool to dental professionals instead of substituting their expert judgment. Guidelines and consensus statements emphasize that AI should serve as an adjunct to clinical practice which improves but does not replace professional judgment [83–85]. Dental professionals need to maintain their critical thinking abilities while evaluating broader clinical contexts through ethical frameworks like HIHT and EAIFT [86,87] and including patient-specific information that algorithms fail to capture. Research shows that dentist-assisted AI evaluations produce more accurate dental diagnoses and thorough assessments compared to using AI systems by themselves [88–91]. Research findings show that pairing AI analysis with dentist evaluations in caries diagnosis lowers both false positive and negative results [88]. The qualified dental professional maintains ultimate responsibility for patient care because their intricate judgment along with ethical thinking and personalized patient care remains unparalleled.

Nevertheless, challenges exist when trying to incorporate AI into the already established dental practice management, and electronic health record systems. Other factors also account for slow adoption of AI in dentistry. For instance, the cost of adaptation determines the rate of acceptance of such AI technologies because of limited finance resources [36,37].

6.4. Comparison with other work

AI-designed prosthetics show promising results when compared to standard practices. For instance, polyetheretherketone (PEEK) frameworks designed using AI for full mouth fixed prostheses supported by implants showed comparable survival rates but less bone loss when compared to titanium prostheses [58,57]. However, other studies report questionable issues of consistency of fit and durability, which suggest that AI will not always be superior to conventional approaches [71,57].

6.5. Future directions

The possibilities offered by new technologies are also fueling the future of AI-powered teledentistry. 5 G connectivity can aid in faster data transmission and live video consultations; Extended Reality (XR) technologies composed of Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) can create virtual environments to provide patient education and perform remote procedural support [6,39,40]. The integration of Internet of Things (IoT) devices can keep a track of real-time data with AI helping to predict critical dental issues in time.

The issues related to data security and privacy can be overcome by the use of blockchain technology, which enhances the security of patient records and data sets in AI systems [39,38]. By tackling these issues and embracing tech innovation, teledentistry services can grow in scale, efficiency and accessibility.

6.6. Practical steps for clinicians to adopt AI in teledentistry

Dental professionals and clinics need to focus on discovering implementable approaches for adopting AI-driven solutions. Although full-scale AI implementation remains under development numerous actionable steps exist to help healthcare providers and institutions make effective transitions.

- Pilot Programs: Start with specific AI pilot projects that have clear objectives (such as an AI tool for caries detection) to assess real-world effectiveness as well as patient acceptance and workflow effects.
- Training and Education: Training staff through workshops and continuing education courses builds their ability to understand AI outputs and apply validated results in clinical decision-making.
- Data Stewardship: Create defined protocols to manage data collection processes alongside secure storage methods and proper sharing practices. The data stewardship process requires adherence to privacy laws like HIPAA and GDPR while implementing strong data security measures to protect patient information.
- Collaborations and Partnerships: Collaborate with AI developers, academic researchers, and technology vendors to create customized solutions for specific practice needs which include remote diagnostics through patient scheduling to follow-up care.
- Continuous Evaluation: Regularly assess AI systems' predictive accuracy and clinical usefulness before making improvements or expansions according to clinician and patient feedback.

Through incremental adoption clinicians will be able to assess AI system performance in existing clinical procedures while detecting biases and limitations which enables the scaling of effective solutions to improve dental patient outcomes and healthcare access.

7. Conclusion

The findings from this scoping review reveal that artificial intelligence holds substantial promise for revolutionizing teledentistry by enhancing diagnostic precision and enabling customized treatment plans while boosting patient involvement. AI-powered solutions such as image analysis algorithms along with chatbots and predictive analytics enable improved remote dental services and better oral health results while expanding access to dental care for marginalized groups.

The realization of AI's potential demands the resolution of

fundamental constraints. Non-representative training datasets create algorithmic bias which threatens equitable care delivery but this issue can be addressed through careful dataset curation practices along with bias mitigation strategies like data augmentation and cross-population validation combined with continuous monitoring of disparities. Automated systems should not be overly relied upon because AI must function as a support tool for dental professionals who rely on their own expertise and judgment according to existing guidelines and evidence from comparative studies. Addressing infrastructure and connectivity issues along with professional training needs and data privacy concerns as well as establishing regulatory frameworks for emerging technologies such as blockchain remains essential for successful implementation.

Developing strong AI systems that are free of bias and adhere to ethical standards should become the main focus of future teledentistry research. Development of diverse datasets and representative data should be combined with long-term evaluations of clinical and cost outcomes from AI interventions while also implementing clear guidelines to protect data security and privacy. The ongoing investigation of cutting-edge technologies such as 5 G, XR, and IoT together with thorough assessment and ethical analysis will be essential to unlock AI's full capabilities to transform remote dental care. To ensure equitable and effective benefits from AI-driven teledentistry for every patient requires the combined efforts of researchers, clinicians, policymakers, and technology developers.

Ethical statement

This scoping review did not involve human participants, and no primary data were collected. All data in this review came from the public, namely peer-reviewed papers and grey literature. So ethical approval was not required for this study. The scoping review was performed according to the established scope of review procedures to keep the research process open and honest.

Data Availability Statement:

We have registered this protocol on OSF. Required data will be uploaded

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Declaration of generative AI and AI-assisted technologies

During the preparation of this work, the author(s) used Quillbot, Grammarly, and Linguix to enhance language clarity, improve grammar, and ensure concise phrasing. After using these tools/services, the author (s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Declaration of competing interest

Dr. Richa Kaushik and Mr. Ravindra Rapaka disclose no potential or actual competing financial interests or other conflicts of interest in relation to this work. The reported study was conducted independently without any influence of financial interests or other factors from outside the scientific process.

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