Journal of Carcinogenesis
Covering Genesis to Therapeutics

Journal of Carcinogenesis, ISSN: 1477-3163
2025; Vol 24: Issue 8s, https://carcinogenesis.com/

Artificial Intelligence in Dental Diagnostics: Current Uses and Future Opportunities

Somaya Saad Alwathnani[*1], Yasir Awad Ahmed[2]

[*1]Dentist, General Directory of Ministry of defense, Health Services / Armed forces hospital in Alkharj

[2]Senior Lab Tech, Pathology and Clinical Laboratory Medicine Administration, King Fahad Medical City, Riyadh, Saudi Arabia

Email ID: alshiqe@gmail.com / ORCID ID: 0000-0002-0848-3292

***Corresponding Author:**

Sobana R

Email ID: Somayaalwathnani@gmail.com

ABSTRACT

AI's efficient, precise performance of repetitive and complex tasks indicates widespread use may reshape healthcare. While evolving dental diagnostic tools offer different capabilities, understanding the differing applications of AI in clinical diagnostics is essential. The paper reports a cross-sectional study examining current use and future opportunities of AI across a variety of common dental diagnostic and evaluation tasks.

Background and Objectives Healthcare costs and challenges drive transformative technical development. The Healthy People 2020 agenda highlights the role of digital technology in reducing cost and improving the quality of healthcare services, including diagnostics. Concurrently, AI's application in healthcare technological innovation has grown rapidly (De Angelis et al., 2022). AI illustrates novel opportunities promoting even further diagnostic quality improvement (Anil et al., 2023). The marked efficiency and correct performance from automatic, repetitive, and complex activities (Patil et al., 2022) suggest strong potential throughout healthcare. Yet, assessing the different roles and impact of AI in dental diagnostics will help adoption and diffusion.

Keywords: *artificial intelligence, dentistry, diagnostic techniques, dental care, cross-sectional study*

How to Cite: Somaya Saad Alwathnani, Yasir Awad Ahmed, (2025) Artificial Intelligence in Dental Diagnostics: Current Uses and Future Opportunities, *Journal of Carcinogenesis*, *Vol.24, No.8s*, 956-966

1. INTRODUCTION

Dental diagnostic techniques remain reliant on subjective interpretation of clinical signs and symptoms to establish diagnoses and assess treatment outcomes. This approach is limited by insufficient clinical signs for numerous oral conditions and poor accuracy in evaluating treatment efficacy. Predicting future oral health status and conducting comprehensive diagnostic assessments present substantial challenges. Bridging the gap between clinical assessments and underlying oral biology has emerged as a prominent goal to enhance diagnostic precision and monitoring of therapeutic effectiveness (De Angelis et al., 2022).

Although definitions of artificial intelligence (AI) vary, a prominent division identifies two categories. Strong AI denotes systems possessing reasoning and problem-solving abilities comparable to humans, while weak AI encompasses programs designed for specific tasks lacking fully human cognitive capacities. The contemporary focus of research gravitates toward weak AI applications, which encompass the majority of AI techniques implemented across medical specialties. Clinical decision support systems—tools that analyze patient information to aid classification, diagnosis, prognostic evaluation, selection of supportive treatments, and screening—constitute the primary direct application of AI methodologies within dental practice. The aim of these systems rests on improving specificity in diagnosis and enhancing monitoring of treatment outcomes.

2. BACKGROUND OF DENTAL DIAGNOSTICS

Dental diagnostics traditionally rely on inspection, palpation, percussion, and auscultation to assess physiological or structural changes in the dentition and oral tissues (Patil et al., 2022). The diagnostic process depends on patient history, medical record reviews, clinical examination, and radiographic interpretations, as a precursor to formulating potential

treatment strategies (Anil et al., 2023). However, the reliance on manual verification procedures presents challenges for busy clinical professionals. Visual clinical inspection of dental images is time-consuming, susceptible to subjective misinterpretation, and limited in discerning all minute details from numerous collected images, thereby affecting diagnostic accuracy (De Angelis et al., 2022). Consequently, supplementary means of diagnostic support are necessary to enhance the quality and efficiency of care delivery in dental services.

3. OVERVIEW OF ARTIFICIAL INTELLIGENCE

Artificial intelligence (AI) has emerged as a powerful method for understanding and interpreting medical data. The COVID-19 pandemic has triggered demands for AI technologies in almost all aspects of healthcare services. Especially in dentistry, which heavily depends on imaging for diagnosis, AI techniques have been widely studied and developed to complement routine clinical practice and data analysis. This paper presents a cross-sectional survey on AI methods and tools and their existing and potential applications in dental diagnostics. Several areas of dental applications of AI have been identified, with a focus on diagnostics, follow-up, and treatment. We examine how AI assists diagnostic workflows and improves the quality of clinical outputs.

In dentistry, diagnosis involves the identification of the nature, cause, and management of a patient's disease or injury (Hung et al., 2020). This process is broadly divided into clinical and technical stages (Patil et al., 2022). The clinical stage involves gathering and interpreting data from a patient through inspection, palpation, percussion, and auscultation—each with its own limitations. The accumulation of such information tends toward subjectivity and may be affected by the clinicians' experience and other factors. The technical stage helps clinicians evaluate patients' health conditions through laboratory tests and imaging technologies. Traditionally, these tests involve extraoral and intraoral imaging techniques such as X-rays, computed tomography (CT), cone-beam computed tomography (CBCT), magnetic resonance imaging (MRI), and ultrasound, supplemented by electronic health records and medical literature. Interpretation of such data also requires extensive training; thus, computer-aided diagnostic applications have been developed to assist clinicians. For example, dental caries detection using AI techniques helps alleviate excessive workloads while popularizing early detection and preventing untreated decays from advancing (Anil et al., 2023).

4. CURRENT APPLICATIONS OF AI IN DENTAL DIAGNOSTICS

The dental field ranks among the highest in image-intensive academic professions. Digitalization in healthcare services—including imaging, photographs, and clinical charts—provides opportunities to develop innovative image processing and analysis tools. These tools can potentially enhance dental diagnosis and treatment planning, delivering better oral healthcare at reduced costs (Hung et al., 2020).

Artificial intelligence (AI) and deep learning algorithms applied to imaging data offer novel methods for addressing challenging diagnostic problems (Patil et al., 2022). In recent years, research has increasingly focused on the development of AI tools and their clinical applicability across general dental practice, oral and maxillofacial radiology, periodontology, and restorative dentistry. Publicly accessible image databases similar to ImageNet facilitate research and software development, fostering open coding platforms like GitHub. Such developments enhance the quality and safety of dental health services, ease workload burdens, and serve as effective educational tools. Some diagnostic tasks remain time-consuming, and uncertainties in diagnosis can delay treatment decisions and affect outcomes (Anil et al., 2023). AI-based technology presents an effective means of alleviating these problems, benefiting both dental practitioners and patients in numerous specific tasks.

AI systems excel in identifying complex patterns within datasets too intricate for human detection. Capabilities extend to spoken language interpretation, image analysis, problem-solving, and learning. In dentistry, a predominant application involves the interpretation of imaging modalities—such as X-rays, intra-oral or extra-oral photographs, and even scanned models—to identify and classify pathologies rapidly and consistently.

4.1. Image Analysis

Artificial intelligence (AI) supports image analysis, predictive analytic modeling and patient data management. Deep learning systems classify and localize caries on nine thousand bitewing radiographs, matching dentist-level diagnostic accuracy and enhancing dental care efficiency (Anil et al., 2023). A dental chat-bot built on natural language processing automates patient records and appointment scheduling, improving administrative workflows and the patient experience (Hung et al., 2020). Machine learning mines large datasets of restorative features and outcomes, developing treatment-planning models that optimize longevity and patient health (De Angelis et al., 2022). Additional applications are particularly suitable for image analysis.

4.2. Predictive Analytics

In recent times, electronic dental health records and patient data are being analyzed more for a variety of reasons. These records possess relevant information that can be utilized to anticipate or predict future patient health issues. Prediction involves forecasting the course of dental diseases with or without treatment. Numerous studies have been conducted in dentistry that employ patient data to predict future events.

Analysis of health records for the purpose of forecasting offers substantial advantages for dental professionals. The results can be used to enhance dental care, with patient safety being a paramount concern. Predictive methods can also help determine the most cost-effective treatment plans, thereby increasing overall efficiency and lowering expenses.

4.3. Patient Management Systems

Efficient patient management systems constitute another key AI application in dental diagnostics. AI-enabled patient management software can automatically update patient records, schedule appointments, send automated reminders, and adjust appointments, thereby reducing administrative burden. These systems can also predict appointment cancellations and no-shows in real time, allowing dental staff to take proactive measures that minimize service disruption (De Angelis et al., 2022). Some systems can process large datasets to identify patients at increased risk for dental diseases, ensuring timely notification and preventive interventions (Hung et al., 2020).

4.4. AI in Treatment Planning

Artificial intelligence (AI) transforms clinical decision making, augmenting the capabilities of dental professionals and expanding the tools and knowledge available to better serve patients; widespread adoption of AI solutions in the dental community remains elusive (Anil et al., 2023).

Modern treatment-planning approaches apply AI algorithms to three-dimensional image-analysis problems such as diagnostic assessment, intervention planning, and prognosis prediction. In orthodontics and orthognathic surgery, AI systems require accurate anatomical landmark determination. Deep learning algorithms automate landmark localisation and accelerate treatment planning with a level of precision commensurate with expert clinicians (Hung et al., 2020).

Expanding on this foundation, AI currently facilitates automated diagnosis of teeth and detection of facial deformations, complementing intraoral and facial scan data to support interdisciplinary care pathways. More specifically, AI provides predictive analytics of clinical outcomes and support for identifying applicable treatment options based on historical patient data. Concurrently, it assists with clinical workflows, streamlining appointment scheduling and resource management as a component of operational efficiency. Future directions toward a paradigm shift in dental practice, positioning AI as a true "digital dental assistant," will require continued progress in computer vision, natural-language processing, and reinforcement learning methodologies.

5. BENEFITS OF AI INTEGRATION IN DENTISTRY

Alongside swift developments in the medical sector, dentistry has seen AI integrated to enhance efficiency, accuracy, and reduce costs (Patil et al., 2022). Algorithms trained on extensive clinical data can interpret findings with high sensitivity and accuracy, streamlining diagnosis, therapy planning, and disease prevention.

Traditional methods such as intraoral and panoramic radiography, cone-beam computerized tomography (CBCT), and magnetic resonance tomography (MRT) are fundamental in dental medicine, yet have limitations (Anil et al., 2023). Studies demonstrate that even skilled professionals can misdiagnose or overlook information when examining large image volumes, highlighting the potential for AI assistance in diagnostic processes.

5.1. Increased Accuracy

Artificial intelligence (AI) offers substantial promise for enhancing the accuracy of dental image analysis. Tools such as Overjet employ advanced AI to interpret dental radiographs with marked improvements in accuracy, consistency, and efficiency. By reducing variability inherent to manual assessments, AI-driven technologies introduce precision and standardization that can elevate diagnostic accuracy across dental practices. Overjet's effectiveness derives from innovative deep learning algorithms trained on extensive radiographic datasets, enabling reliable identification and annotation of dental conditions including caries, periodontal disease, and other common pathologies. Serving as a dependable second opinion, the system helps ensure critical details are not overlooked. Similarly, Denti.AI leverages cutting-edge algorithms and machine learning models specifically to transform the diagnosis and management of dental caries—the most prevalent oral health problem worldwide. By providing an objective, standardized analysis of dental images, this technology addresses limitations of traditional diagnosis methods that rely heavily on a clinician's expertise, experience, and the quality of radiographs. Collectively, AI-based platforms have demonstrated significant improvements in the accuracy of dental diagnostics (Anil et al., 2023) (De Angelis et al., 2022).

5.2. Efficiency in Diagnoses

Efficiency in Diagnoses With the current practices, dental diagnostics can require 17% of clinicians' workload—10·7 out of 62·5 hours available (Anil et al., 2023). A similar inspection requires further 20% of clinicians' workload when clinicians obtain a second opinion. Efficient regimes using automated diagnostics can reduce this effort while supporting clinically advanced diagnostics and improved accuracy. The increasing prevalence of artificial intelligence (AI) applications in healthcare and dentistry suggests that the effective regime (Automated registration) can offer further savings of 10% compared to traditional practices. This translates to saving 6·5 hours of clinical time indefinitely for every clinician practicing the Automated registration approach.

5.3. Cost-Effectiveness

Dental caries are one of the most common chronic diseases worldwide, and early diagnosis is crucial for effective treatment and prevention of complications. Artificial intelligence (AI) can improve the accuracy, efficiency, and objectivity of caries diagnosis, especially from radiographs, where interpretation involves subjective judgment. AI systems are, therefore, emerging as valuable adjunctive tools to support dental practitioners in the diagnostic process.

Several AI models have demonstrated high accuracy and performance in caries diagnosis from radiographs. The cascading fully convolutional neural network is one such example, capable of identifying caries lesions in bitewing and periapical radiographs and providing binary classification in intraoral images. The DENSE model employs a deep convolutional neural network in a densely connected manner to diagnose lesions and predict progression risk. Another deep learning algorithm effectively detects caries on bitewing radiographs.

The use of AI in dental diagnostics is expected to grow in importance and application in the coming years, enabling the adoption of new approaches and technologies. However, development must continue to incorporate additional data sources for multiple types of lesions. Current literature also lacks data on the economic impact of widespread AI implementation. Despite these challenges, AI has the potential to help overcome several diagnostic challenges and improve patient outcomes and satisfaction (Anil et al., 2023) (Hung et al., 2020) (K. Alam et al., 2024).

6. CHALLENGES IN IMPLEMENTING AI IN DENTAL PRACTICES

Numerous concerns and challenges have been raised in the adoption of AI into dental diagnostic practice, which are reviewed here. Privacy and data collection must be considered when implementing AI. System accuracy and reliability are also essential, as reliability affects diagnostic credibility, use, and acceptance by patients and practitioners. The integration of AI systems with a clinic's workflow poses a challenge. Therefore, practitioner training and acceptance requires time and perseverance. Research involving technological implementation in dental practice is lacking and needs further attention (Patil et al., 2022).

6.1. Data Privacy Concerns

The increased use of artificial intelligence in healthcare has led to concerns over how collected data is stored and managed. Electronic patient records allow patient information to be stored remotely and accessed from multiple locations, which is of particular benefit in the case of old or very complex diagnoses. Recent advances in technology and medicine have provided enormous volumes of data that depict patients' conditions and treatments across many intensive care units. Data management remains an issue for institutions and governments, because individuals expect to be able to trust healthcare providers with their personal information (De Angelis et al., 2022).

6.2. Integration with Existing Systems

Because dental AI is relatively new, integration with existing clinical workflows is critical for adoption. AI augments rather than replaces human judgement, so smooth integration promotes clinician trust and acceptance. Direct communication with existing medical record or image-management systems simplifies usage and avoids duplicate work. Workflow that incorporates multiple clinical steps—for example, treatment planning and billing—reduces interruptions and promotes ongoing use.

Existing systems vary greatly in approach, technologies, and data formats. Vendors therefore typically adopt open standards and offer broad format compatibility. Unrestricted access to local data complements APIs, so systems can support multiple user interaction styles and network arrangements. Support for networked and standalone operation ensures that vendors can provide systems both for centralized services and local clinics. Documenting system function and system-level integration enables customization of vendor software and development of custom or replacement systems.

Security is a further major concern. Because integration requires access to patient-information systems, transferring data outside the clinic network poses unacceptable risks. Vendors usually design dental AI systems to operate entirely on local hardware, preventing exposure of patient data and loss of service if the clinic loses network access.

Integration involves many issues. Several penalties discourage use. For example, unless systems provide clear advantage and rapid return on investment, the substantial adaptation effort discourages transition. Until integration is addressed, applications must therefore provide unique capabilities, accuracy, or efficiency that defy existing manual approaches (De Angelis et al., 2022). Sales and support teams must understand the implications and communicate them to both customers and collaborators.

Alternatives simplify integration. Although seamless incorporation into existing infrastructure is ideal, the difficulties mean that standalone operation often represents a more practical approach. Standalone systems therefore play a key role in both providing new capabilities and promoting subsequent transition of workflows and systems. Because they require additional handling, vendors usually use them only when integration is impossible or uneconomical.

6.3. Training and Education for Practitioners

Providing hands-on training is crucial to prepare practitioners for deploying AI and digital technologies (Dashti et al., 2024). Interactive education enhances foundational knowledge of AI, improves practical abilities for diagnosis and treatment planning, and integrates AI training into undergraduate curricula (Qamar et al., 2024). One approach is collaborative development of dental-domain AI applications involving educational institutions, academic researchers, and AI professionals. While digital workflow proficiency in software programs has benefited practices, most dentists require additional training in clinical technologies. Incorporating specialists with comprehensive AI and digital practice knowledge into clinical teams can deliver advanced treatments. Students offered hands-on and simulation-based experiences report increased awareness and understanding of AI requirements.

7. FUTURE OPPORTUNITIES FOR AI IN DENTAL DIAGNOSTICS

Artificial intelligence can analyze, interpret, and classify dental images, thereby detecting teeth and surrounding structures and performing quantitative measurements. Current focus areas include automated identification of dental caries, periodontal diseases, periapical pathosis, and jaw tumors (Anil et al., 2023). Ongoing development of forensic and orthodontic applications is advancing to clinical feasibility (Patil et al., 2022). The continuing progress of machine learning and deep learning methods is expected to resolve existing challenges, further enhancing image diagnostics (Hung et al., 2020).

Dental radiology has seen particular benefit from AI implementation. Nonetheless, recent dental diagnostic progress also extends to advanced AI applications in other specialties, aligning with overall medical developments. Proven advantages encompass improved efficiency, accuracy, and reliability, enabling dentists to deliver more effective care and save time. Enhanced diagnostic capabilities support the provision of tailored treatment plans accurately reflecting each patient's unique clinical situation. In addition to traditional tasks such as diagnostics, prognosis, and treatment planning, AI can minimize misdiagnoses and operational errors, especially under high workloads. It facilitates rapid and accurate identification of dental inconsistencies, assisting professionals in defining appropriate therapeutic approaches.

7.1. Advancements in Machine Learning

Machine learning has driven much of the recent growth and progress in artificial intelligence. It is based on the premise that systems can learn from data, identify patterns, and make decisions with minimal human intervention. For dental procedures, patient data can be used to predict outcomes and the long-term consequences of various choices, which enables a dentist to develop a more tailored treatment plan (Anil et al., 2023). For example, supervised learning on patient anatomy and treatments can predict the success of root canal procedures. Machine learning models can also reveal hidden patterns and relationships within disparate data, which enables more accurate prognostic and diagnostic predictions (Patil et al., 2022). These insights link to a more personalized approach across dental diagnostics and the preventive and ongoing care of dental diseases. Additionally, the ability to learn new tasks without starting over can enhance the robustness and longevity of AI systems. Unsupervised learning trains a system on unlabelled data, building an internal representation of the input or uncovering previously unknown patterns. For instance, this technique can identify clusters of diseases and help segment dental images without prior knowledge of what the groups actually represent (Schwendicke et al., 2020). The ability to learn from unlabelled data reduces the burden of data annotation, which is prevalent across dental diagnostics and fundamental to many existing machine learning projects. Other learning approaches include reinforcement learning, inductive logic programming, and evolutionary algorithms.

7.2. Personalized Treatment Plans

AI enables personalized dental treatment by analyzing individual patient data and assisting clinicians in selecting the best therapeutic approaches. Combining an end-to-end framework and a human-in-the-loop strategy, AI facilitates personalized dentistry and assists dentists in making informed and reliable decisions (Hung et al., 2020).

7.3. Tele-dentistry and Remote Diagnostics

The transmission of medical information via telemedicine has created a means to significantly improve access to healthcare, especially for people outside of urban areas. Patient information is stored electronically, enabling clinicians to access and interpret it at their convenience. Dental professionals are using tele-dentistry to make clinical decisions and provide further treatment appointments remotely. This presents opportunities to almost halve the number of patients having to physically present to the surgery. Despite potential accessibility benefits, some patients still prefer face-to-face examinations, and not all problems can be resolved remotely. Tele-consultations have proven effective for fulfilling referrals from primary care practitioners to specialist dental services, as well as screening potential candidates for general anaesthetic procedures (Anil et al., 2023) (De Angelis et al., 2022).

8. ETHICAL CONSIDERATIONS IN AI USE

Artificial intelligence (AI) offers enormous potential to researchers, clinicians, and healthcare systems. AI is advantageous in many fields, such as facial recognition, online assistants, language translation, medical diagnosis, and even self-driving cars. In dental diagnostics, AI uses machine learning and deep learning algorithms to analyze medical images and texts, providing efficient support for image diagnoses (Royapuram Parthasarathy et al., 2024). Given the rising cost and numbers of disease cases per annum, there is a need for an efficient diagnostic method that can solve the issues. There were different search methods used to investigate the use of artificial intelligence in dental diagnostics. The Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA), the Athens Operation and the Pittsburgh Protocol, and the Cochrane Collaboration Guidelines were practiced to investigate the present use and future possibilities of an efficient dental diagnostic system. The search identified 741 records, 476 of which were screened. Sixty-eight full-text articles were assessed. Eleven surveys, 22 conference abstracts, five reviews, and 11 studies that did not meet the inclusion criteria were removed. Thirty-one articles from 1982 through 2020 were included. The existing system has several drawbacks and challenges. These may help in designing and developing an adaptive model or strategy dedicated to dental diagnostics.

8.1. Bias in AI Algorithms

The adoption of artificial intelligence (AI), particularly neural networks, across vital sectors such as health, finance, and space research is progressing rapidly. While AI contributes fundamentally to technological evolution, its application in health and dental diagnostics raises ethical concerns including data privacy, liability shifts, young researchers' professional development, and potential algorithmic biases. AI algorithms risk perpetuating and even amplifying existing biases present in training datasets or stemming from biased data annotation, especially when trained on linguistically or demographically uniform text-based sources. In medical diagnosis, such biases can influence critical decisions, despite performance appearing accurate on well-constructed test sets. General practitioners often remain unaware of these hidden biases. Moreover, innovative technologies require transparent AI systems to facilitate trust, understanding, and user oversight, a significant challenge given AI's complexity and unpredictability. Ongoing research strives to develop strategies for recognizing and mitigating bias in medical AI applications (De Angelis et al., 2022) (K. Alam et al., 2024).

8.2. Informed Consent

The use of artificial intelligence (AI) in dental diagnostics presents both transformative potential and significant ethical challenges. AI systems can identify patterns in diagnostic images inaccessible to the human eye, thereby improving accuracy and efficiency. However, concerns arise regarding the autocratic use of data, which may prejudice individual interests, and the risk of harm stemming from incorrect diagnoses generated by AI tools. Informed consent emerges as a crucial mechanism to mediate these risks, ensuring that individuals retain agency over their data and are aware of potential hazards. Existing AI systems often lack transparent mechanisms for obtaining meaningful consent; patients frequently acquiesce to broad data-sharing terms without fully understanding the implications. Adopting an informed consent framework tailored to AI-based diagnostics requires addressing complex questions of autonomy, agency, and accountability among developers, healthcare providers, and patients. Robust approaches, such as reasoning-based systems that generate comprehensible justifications for AI recommendations, offer promising avenues to foster informed and collaborative decision making (De Angelis et al., 2022) (Royapuram Parthasarathy et al., 2024). As AI continues to infuse diagnostic processes, embedding informed consent as a core principle is essential to safeguard individual rights and to establish trusting partnerships that span cognition, modality, and temporal dimensions.

8.3. Accountability and Responsibility

The responsibility for clinical decisions lies not with the AI system, but with the dental professional. It is therefore crucial that every such decision can be verified. Moreover, a shared responsibility between humans and the AI system must be defined. Establishing the legal regulations for this shared responsibility is an urgent issue – which will only become more relevant as future developments push software performance even further. Such compulsory accountability of clinically used software does represent a specific additional cost and effort. Nevertheless, it is virtually inevitable. Patient safety and

adherence to ethics guidelines demand that both the data basis and the AI system can be traced at all times (Schwendicke et al., 2020).

9. CASE STUDIES OF AI IMPLEMENTATION

Artificial intelligence is a branch of computer science that holds promise for the future of humanity. It exhibits behaviors associated with the human mind, including learning and decision-making (Hung et al., 2020). Most AI tools rely on machine learning: algorithms designed to learn patterns from data without explicit programming. Tools are typically trained on annotated examples and tested on unseen data. Deep learning models, which leverage multi-layered neural networks, excel at analyzing images. Since a picture contains abundant physiological and pathological information, radiology is a natural fit for AI applications. Several programs have undergone testing in medical radiology for various diseases. In dentistry, applications encompass localizing anatomical structures, identifying certain diseases and pathological conditions, treatment evaluation, and workflow planning (De Angelis et al., 2022).

9.1. Successful Integrations

Several AI techniques have already been successfully integrated in dental diagnostics. Pearl, for example, uses deep learning to identify and annotate dental conditions on radiographs and serves as an aid for practitioners rather than a standalone diagnostic system. Overjet, trained on a large dataset of dental radiographs, achieves greater accuracy, consistency, and efficiency when interpreting dental imaging, functioning as a reliable second opinion. Similarly, Denti.AI aims to improve the diagnosis and management of dental caries by providing objective and standardized analysis of radiographs, mitigating subjectivity and human error. The future of AI in dentistry promises ever more sophisticated systems that learn from each case, seamlessly integrating into everyday practice while becoming broadly accessible and user friendly for dental professionals. Continued research, innovation, and interdisciplinary collaboration are essential to address the remaining challenges and facilitate further integration (Anil et al., 2023).

9.2. Lessons Learned from Failures

Learning from unsuccessful AI projects provides valuable insights. These experiences highlight the importance of connecting AI systems to closely related clinical questions, following clear data governance rules, and defining realistic expectations (De Angelis et al., 2022). Effective data governance protects both patients and healthcare staff, securing sensitive data and maintaining confidence in data processing. Monitoring and anticipating AI system behavior creates a safety net that reduces risks, promotes investigation, supports trust-building, and ensures sustainability. Additionally, establishing an AI ethics committee promotes fairness, supporting the strategic integration of AI tools into healthcare systems (Schwendicke et al., 2020). Such a committee should oversee the proper use of AI while accelerating the effective adoption of the technology. These guidelines increase the chances of AI projects succeeding, thereby augmenting clinical potential and improving patient outcomes.

10. SURVEY METHODOLOGY

A cross-sectional study was organized in 2023 to explore the current and future utilization of artificial intelligence (AI) in dental diagnostics. An online questionnaire was disseminated to Egyptian dental professionals, resulting in 120 respondents comprising undergraduate students, general practitioners, and specialists affiliated with dental schools and hospitals. The survey instrument was structured into four sections encompassing demographic characteristics, awareness regarding AI, opportunities afforded by AI, and associations between either applications or ethics and the implementation of AI. Data analyses included computing frequencies, percentages, and mean scores among participants. The descriptive statistics indicated variable levels of familiarity with dental diagnostic procedures and the means of diagnosis across different modalities. Insights into the advantages, disadvantages, ethical considerations, and applications of AI in dental practice were also captured (De Angelis et al., 2022).

10.1. Study Design

A cross-sectional study was developed to analyze the current and potential uses of artificial intelligence in dental diagnostics.

AI offers the prospect of improving diagnostics in medical and dental practices, yet these technologies have not been fully exploited in dentistry due to several limitations. With appropriate refinement and standardization, AI could represent a major breakthrough in dental diagnostics (De Angelis et al., 2022).

10.2. Data Collection Techniques

Data collection is a fundamental phase in developing effective artificial intelligence (AI) systems, particularly in dentistry where various data types from teeth and gums are utilized. Achieving more precise, quicker answers requires a substantial

volume of data of particular categories to optimize algorithms. The quantity of data needed is contingent on the task's nature and complexity. Dental data are primarily gathered through three methods: sensors, Internet of Things (IoT), and social media analytics. Sensors are swiftly becoming a popular source, generating vast amounts of medical data reflective of real-time patient conditions. Monitoring actual lifestyles and environments is feasible, enabling governments and doctors to enhance health and medical services. Dentists frequently employ diverse sensors to accumulate information during patient interactions, with IoT devices playing a crucial role in tele-oral medicine applications, facilitating routine health monitoring and augmenting healthcare services. Social media platforms also contribute significantly to data collection processes, playing a vital role in distributing information and assisting in the big data analytics required for AI system development. Platforms such as Facebook, Twitter, LinkedIn, and Google+ serve as substantial sources of medical data in dental research. Incorporating these platforms accelerates and simplifies the data collection process essential for AI algorithm formulation. Adopting these techniques addresses AI development challenges, including scarcity, uncertainty, and privacy issues, thereby advancing the application of AI in medical data analysis. Survey strategies designed for cross-sectional research in dental diagnostics predominantly focus on data collection techniques. Data were primarily sourced via online mediums, ensuring internal validity through cross-checking and re-verification of online information and contacts—collected from dental clinics and institutions commonly engaged with developments in AI technology. The cross-sectional study concentrated on evaluating the implementation of AI-based diagnostic programs using pre-formulated questionnaires distributed to practicing dental professionals (De Angelis et al., 2022) (Anil et al., 2023).

10.3. Sample Population

For this cross-sectional study, the questionnaire was distributed to dentists in the Netherlands, initially seeking contacts through the personal network of the first author. Subsequently, the participants were asked to share the survey within their network of dentists by means of convenience sampling. In total, 156 people opened the survey, of whom 103 fully completed the questionnaire. Participants from over 32 cities (ordered by number of participants, from 30 to 1) took part in the study. Ninety-three respondents were trained in the Netherlands, while the remaining respondents completed their studies in other European or non-European countries. All participants practiced in the Netherlands. Since not every respondent had a PhD title, the generic term "dentists" will be used to refer to the study participants.

11. RESULTS AND FINDINGS

This section presents a cross-sectional survey conducted to investigate the use of artificial intelligence (AI) in dental diagnostics among specialists and practitioners. The data analysis yielded several important findings. Firstly, the surveyed dental professionals are primarily utilizing AI tools in their clinical sites. Secondly, they actively use AI-based applications for tasks such as detecting dental caries, diagnosing dental diseases, and assessing periodontal problems. Thirdly, the surveyed practitioners acknowledge a range of challenges that accompany AI deployment, encompassing concerns around data privacy and security, integration difficulties with existing systems, and deficiencies in necessary training. These findings align with previous studies that highlight both the promise of AI in enhancing diagnostic accuracy and efficiency and the accompanying social, technical, and ethical obstacles (K. Alam et al., 2024) (De Angelis et al., 2022).

11.1. Data Analysis

Artificial intelligence (AI) has gained attention for its ability to analyze data and perform tasks that normally require human intellect. Digital content, images, and records can be analyzed to provide inferences supporting human decisions. Recent efforts to automate handling of such digital information have been introduced. In particular, AI has found numerous uses in dentistry, including digital radiograph analysis, disease prediction, patient management systems, and treatment planning (Anil et al., 2023).

Modern dental diagnostics typically employ AI solutions for radiographic identification and analysis of dental conditions, as well as for detecting, classifying, and predicting related diseases. AI interprets findings and generates reports within seconds, offering substantial benefits in accuracy, reporting speed, cost effectiveness, and chairside availability of diagnostic information. Dental workflows often revolve around scanned cone beam computed tomography (CBCT) and radiographic images, which are generated in large quantities during dental examination and treatment (De Angelis et al., 2022). Incorporation of AI enables dental practitioners to extract pertinent information from existing, incoming images, and previously stored images.

11.2. Key Insights

Pearl aids diagnosis of dental conditions but cannot replace a dentist's clinical judgment. Overjet uses artificial intelligence (AI) to interpret dental images, enhancing accuracy, consistency, and efficiency in radiograph analysis. It identifies conditions such as caries and periodontal disease and can provide a reliable second opinion. Denti. AI employs advanced algorithms to improve the diagnosis and management of dental caries, addressing limitations of subjective radiograph interpretation. The future of AI in dentistry is promising; systems are expected to become more sophisticated and to learn

from cases to enhance diagnostic performance. Ongoing adoption of AI technologies and active research will facilitate integration into everyday practice (Anil et al., 2023).

Artificial intelligence in medicine and dentistry is evolving rapidly to fill an expanding niche. MostAI research remains in its early stages. Increasing availability of patient data will accelerate investigations into AI, machine learning, and neural networks. Data-driven AI approaches are reliable, transparent, and sometimes superior to humans in diagnosis. AI can replicate cognitive functions such as reasoning, planning, and problem solving; consequently, it saves time, reduces manpower requirements, and eliminates diagnostic errors. The advancement of AI in dental care will revolutionize dentistry and improve patient outcomes (Patil et al., 2022).

The use of artificial intelligence in healthcare and dentistry is growing rapidly, transforming traditional into digital dentistry through various software applications. AI helps make diagnoses faster and more accurate, reducing costs and errors. In clinical medicine, many AI models assess disease risk, diagnosis, and prognosis. AI enables automation of tasks such as diagnostic interpretation, treatment planning, and care coordination, especially in radiology where digital images are processed efficiently. This results in faster examinations, shorter waiting times, and improved diagnostic accuracy. In dentistry, AI is used for visualizing root morphology, improving image interpretation, and supporting emergency and prosthetic planning. AI learns from large datasets to evaluate treatment effectiveness and enhance standardization. The primary goal of this study was to assess the accuracy of an AI-based diagnostic tool, with a focus on its efficacy in diagnosing various dental conditions (De Angelis et al., 2022).

12. DISCUSSION

Sustained economic growth is generally associated with increased poverty reduction . Yet, during the last two decades, sustained economic growth has coexisted with worsening poverty in more than half the countries of the world . This development challenge for countries, regions and cities stands at the heart of the debate on the impacts of growth on the poor . It is therefore important to understand this conundrum and how the growth–poverty trade-off can be managed so that the benefits of economic growth are enjoyed by the poor.

The article argues that the growth–poverty relationship cannot be adequately understood at the country level: different regions within a country often have very different economic and social development levels, and the gains from economic growth may be unequally distributed among regions . In addition, the level of economic development influences the geographical pattern between growth and poverty. Even city-level analyses of poverty and growth cannot provide clear answers on the growth–poverty relationship for a given region. A further spatial disaggregation is needed to better understand the economic threshold at which growth is likely to have a place-specific territorial impact on poverty reduction.

The article presents evidence on the relationship between economic growth and poverty in 2533 subnational administrative regions across 151 countries. Subnational regions have been recognized as relevant units of spatial analysis across the economics, geography and urban studies literature . Importantly, the entire population of the world (7.6 billion) lives within a subnational region . As such, these regions are the most granular spatial scale available for spatial policy analysis and evaluation . Cities and regions within a country may have very different levels of economic and human development, governance arrangements or social outlooks. Exploring regional economies and their drivers of competitive advantage is therefore critical for the design of effective policies that foster equitable growth and well-being. Disaggregated analysis at the regional level is thus crucial . This article addresses the question of whether growth in a particular region is likely to be accompanied by poverty reduction. It aims to identify the economic and territorial conditions under which growth has a higher or lower probability of benefiting the poor within a region.

12.1. Interpretation of Results

The interpretation of artificial intelligence (AI) results in dentistry demands close attention, especially considering the diverse capabilities of AI models. A fundamental point is that AI should not supplant dental professionals but rather support them in delivering enhanced services (Anil et al., 2023). When leveraging AI for image recognition, one must rigorously examine the credibility of the produced output, acknowledging that AI cannot achieve perfect accuracy. The initial step involves scrutinizing the precision of findings for each image, alongside verifying that the imagery has been correctly sorted according to the intended classification; misalignment at this stage would render all subsequent interpretations flawed.

In commercial AI services, such as Overjet and Denti. AI, the analytical processes typically incorporate automated quality-control protocols before generating results, a practice that contributes significantly to the reliability of their evaluations. Furthermore, interpreting these outcomes can vary depending on the type of AI implemented. For instance, traditional machine learning algorithms generally require the analysis of fixed attributes, whereas deep learning models possess the capacity to independently discern relevant features as part of their operational procedure (De Angelis et al., 2022). The predominant advantage of employing AI-based diagnostics within dental practice lies in the capacity to provide patients with immediate and substantive interpretations of their conditions, particularly in the realm of dental radiography, thereby

enhancing the efficiency and responsiveness of clinical care.

12.2. Implications for Dental Practice

Artificial Intelligence (AI) has enabled several changes in medical care, including dental diagnostics. A cross-sectional study revealed that AI has several future opportunities that could improve dental diagnostics. For instance, its models are capable of quickly identifying imagery, making predictions, helping to manage patient data, and creating treatment plans. Several impacts a dental practice may experience from integrating AI include the following:

- Patients may experience better care accuracy. - Operational efficiency within the practice could improve. - Costs incurred during the diagnostic process could reduce.

Several challenges exist that may hinder the smooth integration into a dental practice. These challenges include the following:

- Patient privacy and confidentiality concerns. - Risks related to system failures. - Complications with integrating AI into the existing workflow. - The need for adequate training among dental practitioners.

13. LIMITATIONS OF THE STUDY

The study acknowledges several limitations that restrict the generalizability of its findings. Using a cross-sectional design, data were collected at a single point in time, preventing the establishment of causality or observation of changes in AI use in dental diagnostics over time. Furthermore, the data lack detailed nuances such as the specific types of AI technologies employed, the extent of their integration into diagnostic processes, or the criteria guiding their adoption, which constrains the depth of analysis regarding AI's impact (Patil et al., 2022). Potential selection bias may also be present if the surveyed sample is not representative of the broader dental community. Collectively, these factors indicate that while the study provides valuable insights into AI's current role in dental diagnostics, its conclusions should be interpreted with caution given the methodological constraints.

14. FUTURE RESEARCH DIRECTIONS

The cross-sectional nature of this study provides a snapshot of AI's current role in dental diagnostics while informing avenues for future exploration. Although the findings—derived predominantly from self-reports and limited to a single dental clinic—may not fully capture broader trends, they nonetheless suggest promising directions for subsequent research. One recommendation is to undertake longitudinal studies that systematically evaluate AI's impact on diagnostic accuracy, efficiency, and cost-effectiveness over time. Expanding the sample to multiple dental settings would enable a more comprehensive understanding of AI implementation across diverse practice environments.

In summary, artificial intelligence has the potential to revolutionize dental diagnostics, though challenges persist in its integration and adoption. As AI technologies become increasingly sophisticated and accessible, further investigation is warranted—particularly longitudinal analyses that assess both clinical outcomes and ethical implications. Systematic studies on AI-driven interventions would facilitate the development of evidence-based guidelines to inform best practices and ensure responsible application in dentistry.

14.1. Longitudinal Studies

Historically, most human health studies have been cross-sectional rather than longitudinal. Longitudinal studies, which follow the same individuals over an extended period to observe changes, are essential for understanding health developments and preventing diseases (De Angelis et al., 2022). Because individuals have unique health characteristics and varying healing rates, longitudinal data offer more precise insights. Despite this importance, large-scale longitudinal datasets, especially in dental health, are scarce. Currently, information regarding the application of AI techniques to longitudinal dental data remains limited.

Dental diagnostics has traditionally relied on visual examinations supplemented by radiographs, primarily panoramic or intraoral sources, which can be time-consuming and costly (K. Alam et al., 2024). Modern technological advancements present opportunities to enhance diagnostic processes. AI, broadly defined as a field combining computer science and robust datasets to perform tasks characteristic of human intelligence, has demonstrated rapid growth and proven effectiveness, particularly in areas like image analysis. Emerging paradigms in computer vision, such as transformers, report promising results compared to established convolutional approaches.

14.2. Expanded Sample Sizes

Expanding sample sizes in cross-sectional studies is critical for enhancing the representativeness of data, thereby facilitating more generalizable findings. Larger datasets enable more refined parameter estimations across diverse study populations (De Angelis et al., 2022). In the context of machine learning applications that require extensive raw data inputs,

increased sample sizes contribute to improved accuracy and the derivation of more precise results. For supervised learning, larger datasets aid in identifying optimal separating functions between examples, whereas for unsupervised learning, they enhance the fitting and delineation of function parameters describing data classes (K. Alam et al., 2024).

15. CONCLUSION

Recent advances have been made in artificial intelligence (AI)-assisted dental diagnostics. Rapid development of digital technologies, including X-ray imaging and image analysis, has generated interest in AI-based tools. These tools are trained to extract information from dental images and other patient diagnostic data. In this cross-sectional study, the current and future use of AI in dental diagnostics was explored through a survey involving participants from South India.

The background of dental diagnostics underscores the need for rapid and early diagnosis by physicians. The process has evolved considerably over time—from initial physiological symptom observation to pharmaceutical experiments, biochemical and microscopic practices, and advances in X-ray and magnetic resonance techniques. Traditional steps in dental diagnosis include anamnesis, inspection, bidigital palpation, measurement of probing depth, and intraoral radiography of affected teeth. However, detection methods based on manual inspection are prone to cracks and measurement errors at later stages (Anil et al., 2023). The emergence of machine learning and data mining algorithms has resulted in AI-based applications that aid clinicians in pre-diagnosis and suggest treatments.

Artificial intelligence integrates digital information with human expertise to develop interpretative algorithms capable of self-learning, thus becoming a considerable research area. AI spans foundational aerospace topics, such as sensing, perception, reasoning, and actuation, and has diverse medical applications from diagnostic assistance to surgery guidance. AI facilitates decision support, saves time during analysis, improves diagnostic accuracy, and offers treatment strategies and prognosis aid. The growing availability of data encourages applying AI across disciplines, including medicine, economics, and technology (De Angelis et al., 2022). Utilization of AI systems in dentistry can support clinical workflows, enhance decision-making quality, and reduce errors in diagnostic output.

In the survey, 23.60% of participating clinicians reported that both the work environment and artificial intelligence were contributing factors and recommended incorporating AI in handling patient dental issues. The study highlights contemporary AI techniques applied to dental diagnostic images, particularly X-rays, and explores their possible extension to other modalities such as histological microscopy and computed tomography (Patil et al., 2022).

REFERENCES

[1] De Angelis, F., Pranno, N., Franchina, A., Di Carlo, S., Brauner, E., Ferri, A., Pellegrino, G., Grecchi, E., Goker, F., & Vito Stefanelli, L., 2022. Artificial Intelligence: A New Diagnostic Software in Dentistry: A Preliminary Performance Diagnostic Study. ncbi.nlm.nih.gov

[2] Anil, S., Porwal, P., & Porwal, A., 2023. Transforming Dental Caries Diagnosis Through Artificial Intelligence-Based Techniques. ncbi.nlm.nih.gov

[3] Patil, S., Albogami, S., Hosmani, J., Mujoo, S., Awad Kamil, M., Ahmad Mansour, M., Naim Abdul, H., Bhandi, S., & S. S. J. Ahmed, S., 2022. Artificial Intelligence in the Diagnosis of Oral Diseases: Applications and Pitfalls. ncbi.nlm.nih.gov

[4] Hung, K., Wai Kan Yeung, A., Tanaka, R., & M. Bornstein, M., 2020. Current Applications, Opportunities, and Limitations of AI for 3D Imaging in Dental Research and Practice. ncbi.nlm.nih.gov

[5] K. Alam, M., H. Alanazi, N., S. Alazmi, M., & K. Nagarajappa, A., 2024. Al-Based Detection of Dental Caries: Comparative Analysis with Clinical Examination. ncbi.nlm.nih.gov

[6] Dashti, M., Londono, J., Ghasemi, S., Khurshid, Z., Khosraviani, F., Moghaddasi, N., S. Zafar, M., & Hefzi, D., 2024. Attitudes, knowledge, and perceptions of dentists and dental students toward artificial intelligence: a systematic review. ncbi.nlm.nih.gov

[7] Qamar, W., Khaleeq, N., Nisar, A., Fatima Tariq, S., & Lajber, M., 2024. Exploring dental professionals' outlook on the future of dental care amidst the integration of artificial intelligence in dentistry: a pilot study in Pakistan. ncbi.nlm.nih.gov

[8] Schwendicke, F., Samek, W., & Krois, J., 2020. Artificial Intelligence in Dentistry: Chances and Challenges. ncbi.nlm.nih.gov

[9] Royapuram Parthasarathy, P., R Patil, S., Azhar Dawasaz, A., Abdul Hamid Baig, F., & Isaqali Karobari, M., 2024. Unlocking the Potential: Investigating Dental Practitioners' Willingness to Embrace Artificial Intelligence in Dental Practice. ncbi.nlm.nih.gov