**DOI:** 10.21088/ijde.0974.6099.18325.2

Indian Journal of Dental Education
Volume 18 Number 3
September-December 2025

REVIEW ARTICLE

# A Look at the use of Artificial Intelligence in Dentistry through an Ethical Lens

**Jerrin V. Toms[1], Bini Toms[2]**

**HOW TO CITE THIS ARTICLE:**

***Jerrin V. Toms, Bini Toms.*** A Look at the use of Artificial Intelligence in Dentistry through an Ethical Lens. Ind J Dent Educ. 2025; 18(3): 111-119.

## ABSTRACT

Artificial intelligence (AI) is revolutionizing various fields, including dentistry, by enhancing diagnostic accuracy, treatment planning and patient care. However, the authors try to reason that as AI technology becomes more integrated into dental practices, it becomes extremely important to examine its ethical implications through the lens of the four core tenets of ethics: autonomy, beneficence, non-maleficence and justice.

Thus, this paper attempts to study the relationship between scientific advancements, particularly AI and ethical principles in the context of dental patient care. The authors discuss that striking a balance between technological advancements and maintaining empathetic, patient-centred care is crucial to preserving the human element in dentistry. In other words, AI can drive meaningful progress in dentistry only when its deployment is governed by ethical safeguards. Finally, the paper calls for a thoughtful, ethical approach to integrating AI into dental practices to maximize its benefits while mitigating potential harms.

## KEYWORDS

• Artificial intelligence • Ethical principles • Dental patient care

## INTRODUCTION

### Background and Objectives

Technology is growing at a fast pace today which is both a reason for jubilation as well as apprehension, for mankind. Albert Einstein, who was a scientist as well as a deeply reflective thinker on the human aspect of progress, rightly said, "It has become appallingly obvious that our technology has exceeded our humanity." This thought, is undoubtedly, something to ponder upon. It is on this note that the authors begin this reflective paper.

**AUTHOR'S AFFILIATION:**

[1] Dental Surgeon, Lady Willingdon Hospital (Mission Hospital), Manali, Himachal Pradesh, India.
[2] Senior Regional Director & Student of PGDMI IGNOU Bhopal, Bhopal, Madhya Pradesh, India.

**CORRESPONDING AUTHOR:**

**Jerrin V. Toms,** Dental Surgeon, Lady Willingdon Hospital (Mission Hospital), Manali, Himachal Pradesh, India.

**E-mail:** jerrinvt2324@gmail.com

➢ **Received:** 30-07-2025 ➢ **Accepted:** 05-09-2025

The field of dentistry is emerging as a key beneficiary with the rapid deployment of artificial intelligence (AI), encompassing machine learning, computer vision and natural language processing, across healthcare. Prototype systems now assist with radiographic diagnostics, periodontal disease assessment, surgical planning and administrative workflow management.[1,2] The promised enhancements of AI, namely, increased accuracy, efficiency and consistency, are clear benefits for patients and providers alike.

However, the integration of AI in dentistry raises profound ethical questions. Specifically, how should practitioners navigate the four core principles of biomedical ethics, namely, autonomy, beneficence, nonmaleficence and justice in the era of algorithm-driven care? As machines assume roles historically managed by human clinicians, modern dentistry stands at a crossroads between technological innovation and the enduring value of empathy, trust and individualized care. Realising the seriousness of these facts and the ethical concerns around the topic, the present paper has been planned with the following specific objectives which will be elaborated and discussed in the result and discussion Section:

1. Trace the evolution of dental technology from conventional radiography to AI-driven tools.
2. Describe the current applications of AI in clinical and educational settings, supported by publication trends and adoption metrics.
3. Analyse associated ethical issues through the lens of the four traditional principles of ethics, with emphasis on real-world implications.
4. Propose a roadmap for ethically responsible adoption of AI in dentistry, focusing on systems design, education, regulation and equity.

## REVIEW OF LITERATURE

In this paper, the authors try to make a review of studies and literature on the topic. Several key studies and reviews explore ethical considerations of AI in dentistry. Tavakol & Shahbazi (2018) explore the evolution of AI applications in dentistry, forecasting its transformative potential in diagnostic, treatment, and patient management systems. Topol (2019), though focused on medicine broadly, warned that AI risks replacing the "human touch" in healthcare is a concern echoed in dental literature too.[3] They discuss how AI can enhance healthcare by improving medical decision-making while maintaining a human-centred approach to patient care.

The study by Tschandl *et al.* (2020) presents a framework for human-computer collaboration in skin cancer recognition, demonstrating AI's potential to enhance dermatological diagnostics. The review by Aboulfotouh & Gohary (2020) highlights AI's role in dental radiology, focusing on its applications in improving diagnostic accuracy and efficiency.[13] Vasquez & Chen (2020) in their study, examine how AI chatbots can streamline dental practice operations by improving patient interaction, scheduling, and administrative tasks. The article by Wang & Liu (2020) discusses the ethical challenges and the need for a comprehensive ethical framework as AI becomes more integrated into dental practices. Zhang & Zhang (2020) explore the role of AI-driven systems in dental radiology, emphasizing their impact on diagnostic precision and workflow enhancement. Schwendicke *et al.* (2020) proposed guidelines for the ethical deployment of AI in dentistry,[4] emphasizing the need for transparency, explainability, and robust data governance. The paper reviews the potential of AI in dentistry, addressing both its opportunities and the challenges it faces in clinical practice. Kumar & Verma (2020) in their research examine how AI applications, specifically simulation platforms like DentSim, are revolutionizing dental education through skill development and assessment. Lee *et al.* (2020) investigate the use of a deep learning-based convolutional neural network for detecting and diagnosing dental caries with high accuracy. Lee & Patel (2020) discuss the ethical implications of AI in healthcare, focusing on how proprietary systems may affect healthcare equity.

Molteni (2021) review fifty years of technological advancements in dental and maxillofacial radiology, highlighting key milestones in imaging technology. Mørch *et al.* (2021) conducted a scoping review of AI in dental diagnostics and highlighted the need for large-scale, diverse datasets and clinical validation. This scoping review provides an

overview of the current state of AI in dentistry, focusing on its applications, benefits, and challenges. The study by Alkhalil & Alghamdi (2021) discusses the ethical considerations surrounding the use of AI in dentistry, emphasizing the balance between innovation and patient trust. The review by Almeida & Andrade (2021) evaluates AI systems and prototypes for periodontal disease detection and management, highlighting their potential clinical applications. Deo & Patel (2021) explore how machine learning and AI technologies are improving orthodontic treatment planning, specifically through Invisalign systems. Kim & Lee (2021) address the ethical dilemmas posed by AI-based diagnostics in dentistry, focusing on issues such as depersonalization and algorithmic bias. Vargas & Ferraro (2021) in their article advocate for implementing explainable AI in clinical dentistry software to enhance decision-making transparency and build patient trust. WHO and ITU (2021) released a joint publication on the regulation of AI in health, offering a six-principle-framework (including inclusiveness and sustainability). This joint report outlines ethical principles and governance frameworks for the use of AI in healthcare, aiming to ensure patient rights and safety.

Ramezani & Tofangchiha (2022) discuss AI's role in oral cancer screening through optical coherence tomography image analysis, improving diagnostic accuracy. Ghosh & Dubey (2022) investigate the impact of AI-driven virtual simulations on dental education, particularly in assessing preclinical students' hand skills. The paper by Harrison & Lee (2022) explores how AI-powered chatbots in dental care can enhance patient communication and improve clinic efficiency. Kaur & Mehra (2022) review AI's role in orthodontic treatment planning, focusing on the technological advancements within Invisalign systems. Kim *et al.* (2022) documented bias in AI diagnostic tools across paediatric populations, recommending stratified model training.[5] This study assesses the diagnostic accuracy of AI-based caries detection in paediatric populations, comparing its effectiveness with traditional methods. Overjet's white paper of 2023 examines the clinical performance of AI in interpreting dental radiographs, highlighting its potential for improving diagnostic outcomes. Jayatissa & Hewapathirane (2023) in their review discuss current trends and future directions in dental informatics, emphasizing the growing role of AI in transforming dental practices. These studies converge on a common message that AI holds promise, but ethical safeguards are not optional; they are essential and crucial for meaningful and just deployment.

## METHODOLOGY

This study employs a qualitative research approach combining a systematic literature review, ethical analysis and framework development to explore the evolution, current applications and ethical implications of Artificial Intelligence (AI) in dentistry. The methodology is structured as follows:

### Systematic Literature Review

The first step involves a comprehensive review of existing literature spanning over the last few years to trace the evolution of dental technology, focusing particularly on the transition from analog methods to the adoption of AI-driven tools. The literature search covers peer-reviewed articles, conference proceedings, regulatory frameworks, and guidelines from credible sources such as the World Health Organization (WHO) and the International Telecommunication Union (ITU), as well as relevant journals in dental technology, AI and bioethics.

Through the analysis of publication trends and adoption metrics, the study assesses the current applications of AI in dentistry. It highlights successful implementations in areas such as diagnostic systems (e.g., caries detection, radiograph interpretation), treatment planning (e.g., predictive modelling for orthodontics), and educational tools (e.g., simulation platforms for dental training).

### Ethical Analysis

A central component of this study is the ethical analysis of AI's role in dentistry. Using the four core principles of biomedical ethics, autonomy, beneficence, non-maleficence, and justice, this analysis critically examines the ethical challenges AI introduces into clinical decision-making. This framework helps identify both the benefits and risks associated with AI, ensuring a balanced and critical perspective on its integration into dental care.

**Roadmap for Ethical Integration**

Based on the findings from the literature and ethical analysis, the study proposes a roadmap for the ethical integration of AI in dentistry. This roadmap aims to guide future research, policy development, and clinical practice in the evolving field of AI-powered dental care.

This methodology ensures that the study provides both a critical examination of AI's current role in dentistry and a thoughtful framework for its ethical integration for moving forward.

## RESULTS AND DISCUSSION

This section is being dealt objective-wise (as mentioned in the introduction Section), under the following heads:

1. Evolution of Dental Technology: From Analog to AI
2. Current Applications of AI in Dentistry
3. Ethical Analysis of AI in Dentistry
4. Recommendations for the Way Forward

(Ethical Integration of AI into Dental Practice)

### 1. Evolution of Dental Technology: From Analog to AI

An attempt is being made to trace the evolution of dental technology from conventional radiography to AI-driven tools by review of existing literature and guidelines, including frameworks from WHO/ITU, peer-reviewed studies and regulatory platforms. The history of Dentistry reflects technological progression, from analog, biomechanical approaches to the digital, data-driven era.

1. **Early 20th century**: Intraoral and panoramic radiographs gave clinicians first glimpses below tissue surfaces.[6] Goaz and White (1987)[7] detail the development of intraoral film in the 1920s and the arrival of panoramic X-ray techniques by Numata and Paatero.
2. **1980s–2000s**: Digital sensors replaced film; cone-beam computed tomography (CBCT) enabled 3D imaging for implants and surgery. CAD/CAM systems (e.g., CEREC, Lava) introduced chairside prosthetics. The introduction of intraoral cameras (1980s) provided common visibility of cavities and soft tissue conditions. Shah *et al*., 2014 discuss the first dental digital sensors in the 1980s[8] (e.g., RVG), digital panoramic systems of the 1990s, and the shift from film to CCD/CMOS sensors and Cone Beam Computed Tomography (CBCT) development in the late 1990s. "The way we were (and how…)", Molteni, 2021 describes transition to digital radiography in the 1980s–1990s and the adoption of CBCT by the late 1990s.[9]
3. **2010s onward**: EHRs and tele dentistry platforms facilitated record-keeping and remote care[10] in the overview of EHR integration and digital dental systems. Malpe *et al*., (2014) describe how tele dentistry emerged to improve remote consultation since around 2010.[11] Tavakol and Shahbazi, 2018 give a detailed account of the evolution of artificial intelligence applications in dentistry.[12] Their article examines AI applications across various dental fields, including radiographic diagnostics, surgical planning and administrative management.

Aboulfotouh and Gohary, 2020 discuss the role of AI in dental radiography, including diagnostic assistance, which aligns with the use of prototype systems for radiographic diagnostics.[13]

A 2021 scoping review as shown in Table 1, documented 178 dental AI publications, 130 of which appeared post 2016 spanning 53 distinct applications like caries detection, periodontal measurements, cephalometric landmarking, implant planning, and oral cancer screening.[14]

The ascent of AI did not occur in isolation; it was bolstered by parallel data-driven medical practices. Techniques like convolutional neural networks (CNNs) advanced image recognition, while natural language processing (NLP) powered AI-assisted documentation and chart generation. In dentistry specifically, commercial tools received FDA approval, and dental schools began integrating AI modules into curricula, signalling both acceptance and maturation of the technology.

**Table 1:** Trends in AI in Dentistry (2010–2024)

| Year | Relevant Publications | Notable Applications |
|---|---|---|
| 2010 | 10 | Early diagnostic support |
| 2016 | 50 | Radiographic interpretation |
| 2020 | 130 | Workflow, planning, HER |
| 2024 | 178 | Advanced diagnostics and triage |

Trends in AI in Dentistry (2010–2024) reveals clear evolutionary insights into how artificial intelligence (AI) has increasingly integrated into dental practice and research over the past 14 years. Publications increased from 10 in 2010 to 178 in 2024, representing nearly an 18-fold increase. This sharp rise reflects growing academic and clinical interest in AI applications within dentistry, likely driven by improvements in machine learning algorithms, data availability, and digital infrastructure.

The progression of notable applications shows an evolving complexity and integration of AI technologies. Around 2010, the initial AI tools likely focused on simple pattern recognition to aid clinicians in identifying early signs of disease (e.g., caries detection). These systems were rudimentary, often rule-based. By 2016, AI was being used to interpret radiographs, improving diagnostic accuracy and efficiency. This marked the transition from supportive to semi-automated systems using image recognition techniques like CNNs (Convolutional Neural Networks).

The next few years saw expansion from basic diagnostics to multi-functional roles. Specifically speaking, integration into electronic health records (EHRs) and clinical workflow suggests that AI began influencing operational aspects of dental care, not just diagnostics; but supporting treatment planning, scheduling, and decision-making.

Today, AI has matured into more sophisticated roles, such as triaging patients, predictive analytics, and real-time clinical decision support. This level of application requires robust models trained on large datasets and integration with clinical protocols. This evolution sets the stage for ethical evaluation: as technology matures, so does the imperative to integrate safeguards that uphold patient values, safety and equity.

## 2. Current Applications of AI in Dentistry

Artificial Intelligence (AI) in dentistry has transitioned from experimental stages to mainstream clinical and educational utility. In this section the authors describe some of the current applications of AI in clinical and educational settings, supported by publication trends and adoption metrics.

### 2.1. Diagnostic Systems

**Radiographic Interpretation**: AI-powered diagnostic tools have proven effective in interpreting dental radiographs[13] (Aboulfotouh and Gohary, 2020). For example, convolutional neural networks (CNNs) can detect interproximal caries, periapical lesions and alveolar bone loss with accuracy comparable to expert clinicians[15] (Lee *et al*., 2020). Startups like Pearl AI, Overjet™ and VideaHealth™ use deep learning to detect caries, bone loss, anatomical landmarks and jaw lesions; assisting general dentists in identifying pathologies in real-time.

**Oral Cancer Screening**: Optical imaging systems augmented with AI are being used to aid early detection in mucosal lesions. Ramezani and Tofangchiha, 2022 discuss how combining OCT with AI enables highaccuracy screening of oral premalignant and malignant mucosal lesions by interpreting image features that clinicians may miss.[16]

**Periodontal Assessment**: As mentioned[17], Lee *et al*., 2020, report that AI algorithms analyze radiographs to measure bone-level changes and support periodontitis monitoring. Studies indicate improved sensitivity and consistency compared to manual scoring. These AI integrated systems often receive FDA approval, frequently based on retrospective validation studie highlighting both promise and need for stronger prospective trials (Mørch *et al*., 2021).

Although these tools improve accuracy, over-reliance may de-skill clinicians or lead to overlooking rare pathologies outside the training data. This ethical implication needs to be taken care of.

### 2.2. Treatment Planning and Predictive Analytics

**Orthodontics and Prosthodontics:** Machine learning algorithms can help predict the success of dental implants, root canal outcomes or orthodontic /prosthodontic treatment paths. AI tools automate CAD/CAM design for

crowns, implants and aligners. For instance, Align Technology's Invisalign system uses AI to suggest tooth movement trajectories based on vast patient datasets[17,18] (Deo and Patel, 2021; Kaur and Mehra, 2022).

**Implant Positioning** - AI also helps in perfect implant positioning; some platforms propose optimal implant size and placement based on CBCT imaging, enhancing surgical accuracy and reducing operator error.

However, the ethical concern is that these algorithms must be transparent and evidence-based. Patients should understand that an algorithm contributed to a treatment recommendation to uphold informed consent.

### 2.3. Administrative Automation and Patient Management

**Automated Charting**: NLP-based assistants convert spoken/provisional patient notes into formatted EHR entries.

**Administrative Tools**: AI-generated patient reminders, scheduling optimizations, recall systems and billing suggestions are becoming increasingly common. Chatbots like Toothfairy AI assist with appointment bookings and post-operative instructions, improving clinic efficiency[19,20] (Vasquez and Chen, 2020; Harrison and Lee, 2022).

Here also informed patient consent and confidentiality must be maintained. There might be an ethical concern that the automation of patient communication risks depersonalization[21] (Kim and Lee, 2021).

**2.4. Dental Education and Simulation:** AI is increasingly incorporated into dental education. Virtual simulation platforms (e.g., DentSim) use AI to assess students' hand skills,[22,23] (Kumar and Verma, 2020; Ghosh and Dubey, 2022) or propose corrective feedback in real-time.

Augmented reality coupled with AI enables immersive, mistake-driven learning environments. The ethical implication here could be the risk of students becoming over-reliant on simulation-based guidance, weakening critical thinking skills or manual proficiency unless balanced with real clinical exposure. A cross-sectional study in dental schools (Iran, Turkey, Korea) found 55–85% of students supported AI integration into training, though they emphasized the need to maintain human decision authority. They also voiced the ethical concern over potential depersonalization (Mørch *et al*., 2021).[14]

## 3. Ethical Analysis of AI in Dentistry

To evaluate AI in dentistry ethically, the four principles of biomedical ethics, autonomy, beneficence, non-maleficence and justice serve as a structured framework[24] (Beauchamp and Childress, 2013). This section analyses associated ethical issues in the use of AI in dentistry through the lens of these four traditional principles of ethics, with emphasis on real-world implications. The analysis explores how AI might impact,

- Patient autonomy through changes in decision-making processes.
- Beneficence by improving outcomes but also potentially leading to over-reliance on technology.
- Non-maleficence, focusing on the risks of AI errors or biases in diagnoses and treatments.
- Justice, addressing concerns around equitable access to AI technologies, particularly in underserved populations.

**3.1. Autonomy:** Autonomy emphasizes a patient's right to make informed decisions about their care. An AI driven setting, raises several questions, like, 'Is the patient aware of AI's involvement in diagnosis or planning?' or 'Can the patient opt out of AI-assisted recommendations?' or 'Is the decision-making process explainable to a layperson?' In order to ensure autonomy, practices could include AI disclosures in consent forms.

AI algorithms, particularly deep learning models, often function as "black boxes," making their reasoning difficult to interpret. Studies show that many patients assume "human" made clinical decisions unless otherwise informed.[25] Such situations are indeed challenging and need to be consciously dealt with. Explainable AI (XAI) could be prioritized in dental software design. Vargas and Ferraro, 2021 in their study on the implementation of XAI in dental clinical decision-making tools, illustrate how such systems could help bridge the gap between AI recommendations and practitioner confidence, ensuring more effective patient care.[26]

**3.2. Beneficence:** AI promises to enhance patient outcomes by reducing diagnostic errors and personalizing treatment. For example, improved periodontal measurements with AI radiograph interpretation, help clinicians catch early-stage disease.[27] Similarly, Almeida and Andrade, 2021, discuss the advancements in AI and prototype systems used for periodontal disease assessment.[28] AI, can definitely tailor preventive strategies based on risk profiling, improving long-term oral health.

A possible ethical concern here is that beneficence can be compromised if commercial pressures lead to the use of unvalidated or overly aggressive AI solutions that prioritize efficiency over care. To address this concern, AI tools must undergo rigorous, peer-reviewed clinical validation before deployment. Clinicians must remain actively involved in interpreting AI output rather than deferring judgment.

**3.3. Non-Maleficence:** The "do no harm" principle is crucial in AI deployment. A potential harm of AI use is Algorithmic bias; i.e., an AI that is trained predominantly on data from one ethnic group may under perform in others, risking misdiagnosis or overtreatment. Among others, Kim and Lee, 2021 in their studies refer to the bias. Even small diagnostic errors can lead to invasive procedures or missed disease.

A 2022 study revealed that an AI system trained to detect caries performed with lower sensitivity on paediatric patients due to under-representation in training data[16] (Kim et al., 2022). To address this ethical concern, developers must ensure diverse datasets that represent all age groups, ethnicities, and oral conditions. Systems should be continuously monitored and recalibrated with real-world performance data.

**3.4.** Justice: Justice demands equitable access and fair treatment regardless of socio-economic status, geography, or demographic identity. Rural or low-income clinics may lack infrastructure for AI adoption, creating a digital divide. If AI systems are proprietary and expensive, they may aggravate existing disparities in care. Lee and Patel, 2020 critique the role of proprietary AI systems in healthcare, asserting that their high costs and inaccessibility can disproportionately affect low-income and minority populations, further entrenching health disparities.[29] In order to address this concern, publicly funded AI platforms (e.g., WHO's AI4Health) can help democratize access. Policy-makers could consider subsidizing AI systems for underserved areas.

**4. Recommendations for the Way Forward** (Ethical Integration of AI into Dental Practice)

The integration of artificial intelligence into dentistry offers a powerful opportunity to advance care quality, precision and efficiency. However, as emphasized throughout this paper, these benefits must be balanced against ethical responsibilities. For a responsible, patient-centred and equitable deployment of AI technologies in dental care, the following approaches may offer the way forward. The proposed roadmap may help for ethically responsible adoption of AI in dentistry, focusing on systems design, education, regulation and equity**.**

**4.1. The Human Element (Hybrid Model):** AI should augment not replace clinical judgment. While AI is valuable, dentistry should have a tinge of human touch along with technology. A "human-in-the-loop" (HITL) model, where AI serves as a second opinion rather than a final arbiter, preserves clinician accountability and patient trust. Decision support systems should clearly mark AI-generated outputs and provide confidence scores, prompting the dentist to validate rather than blindly accept the recommendation.

**4.2. Informed Consent and Patient Education:** Informed consent processes must evolve to include AI disclosures. Patients should be informed when AI contributes to diagnosis, planning, or risk stratification. Educational material, both digital and verbal, should clarify the role of AI, its limitations and the ethical safeguards in place. Transparency builds trust and preserves autonomy.

**4.3. Bias Auditing and Inclusive Datasets:** Dental AI tools must undergo continuous bias auditing to detect and mitigate disparities. Diverse datasets reflecting varying age groups, ethnicities, dentitions, and oral pathologies are essential. Developers should employ fairness-aware algorithms and validate outputs against real-world performance indicators.

**4.4. Policies and Regulations:** Governments and dental regulatory bodies must implement comprehensive guidelines for AI tools in clinical practice. Policies should address, data security and privacy (HIPAA/GDPR compliance), algorithmic accountability, certification and post-deployment monitoring. WHO's six ethical principles for AI in health,[30] namely, autonomy, safety, transparency, accountability, inclusiveness and sustainability should guide national and institutional policy frameworks (WHO/ ITU, 2021). Wang and Liu, 2020 argue for the development of a robust ethical framework to guide the use of AI in dental practices, ensuring that the benefits of AI are balanced with considerations for patient rights and professional responsibility.[31] Similar views were echoed by Alkhalil and Alghamdi, 2021, in their studies.[32]

**4.5. Ethical Literacy in Dental Education:** Dental curricula should incorporate detailed ethics training specific to AI. Students must learn not only how AI functions but also its ethical, legal and social implications (ELSI). Ethics modules should include case studies on bias, consent, the 'Patient-AI-Dentist' triangle and ethical dilemmas involved. By embedding ethical considerations into every stage, from design to deployment and education, AI in dentistry can be leveraged responsibly and effectively. Needless to say, the aim should not merely be technological adoption but an ethical dental health ecosystem that enhances patient outcomes without sacrificing ethical values.

## CONCLUSION

Artificial intelligence is poised to significantly reshape dentistry by enhancing diagnostic precision, personalizing care and streamlining operations. Yet, its full potential can only be realized when integrated through an ethical lens. This paper has examined the use of AI in dentistry in the light of the four core biomedical principles: autonomy, beneficence, non-maleficence and justice. Each principle presents unique challenges in the context of AI, ranging from opaque algorithms and data privacy to bias and inequity in access. As AI becomes more embedded in dental practice, ethical frameworks must evolve accordingly. Dental professionals, developers, educators and policymakers must collaborate to establish guidelines that prioritize patient rights, safety and fairness. Ethical safeguards like, transparent consent processes, bias mitigation strategies and accountability mechanisms are essential.

In conclusion, dentistry should be a harmonious blend of cutting-edge AI and compassionate human care; there is a need to strike a balance between the two; creating a synergy between advanced technology and compassionate care, being crucial. Ultimately, responsible AI integration in dentistry is not just a technical challenge, but a moral imperative. The goal is clear: to preserve the dentist-patient relationship, anchored in empathy and trust; in other words, leverage innovation to serve humanity; ethically, equitably and empathetically. Needless to say, that while AI can enhance accuracy and streamline procedures, it is the personal rapport, empathy and trust built by a dentist that truly transforms a patient's experience and brings lasting smiles.

## REFERENCES


1. Liu, Y., and Zhang, Z., (2019). Workflow management in healthcare: The role of prototype systems in administrative functions. *Healthcare Management Review*, 44(2), 158-166.
2. Zhang, Y., and Zhang, J., (2020). AI-driven systems in dental radiology: Improving diagnostic accuracy and workflow management. *Journal of Digital Imaging and Diagnostics*, 28(5), 320-328.
3. Topol, Eric. J., (2019). Deep Medicine: How Artificial Intelligence Can Make Healthcare Human Again. Published by, Basic Books, March 12, 2019 (New York), xiii + 378 pages, includes illustrations.
4. Schwendicke, F., Samek, W., and Krois, J., (2020). Artificial intelligence in dentistry: Chances and challenges. *Journal of Dental Research*, 99(7), 769–774.
5. Kim, Y., Park, J.H., and Jeong, H.G., (2022). Diagnostic accuracy of AI-based caries detection in paediatric populations: A comparative study. *Journal of Dentistry for Children*, 89(1), 23–30.
6. Hallikainen D., (1996). History of Panoramic Radiography. *Acta Radiol*. 1996;37(3):441–5.
7. Goaz P.W., and White, S.C., (1987). Oral radiology and principles of interpretation, in *Dental Radiography: Principles and Techniques*. Ed 2, St. Louis, 1987: Mosby; [history of film and panoramic Xray] elsevier-elibrary.com.

**8.** Shah, N., Bansal, N., Logani, A., (2014) "Recent advances in imaging technologies in dentistry." *World J Radiol*. 2014; 6(10): 794–807.

**9.** Molteni, R., 2021. The way we were (and how we got here): fifty years of technology changes in dental and maxillofacial radiology. *Dentomaxillofacial Radiolog,* 2021, Volume 50, Issue 1, Article: 20200133, doi: 10.1259/ dmfr.20200133, PMID: 32525697, via *PMC* (published 2021).

**10.** Jayatissa P., and Hewapathirane R., (2023). A review of dental informatics: current trends and future directions. *S*ubmitted 29 June 2023. Journal reference: *Dental Research: An International Journal (DRIJ), Vol. 5, No. 1 (2023).*

**11.** Malpe, M., *et al.* (2014). Applications of teledentistry: A literature review and update. *PubMed.* 2014 pubmed.ncbi.nlm.nih.gov.

**12.** Tavakol, M., and Shahbazi, M., (2018). The evolution of artificial intelligence applications in dentistry: A future perspective. *Journal of Dentistry and Oral Health*, 52(6), 345-352.

**13.** Aboulfotouh, M.A., and Gohary, M.M., (2020). Artificial intelligence in dental radiology*: A review. Journal of Oral Radiology*, 36(2), 67-74.

**14.** Mørch, C. M., Holm, I., and Schwendicke, F., (2021). Artificial intelligence in dentistry: A scoping review. *Journal of Dental Research*, 100(9), 880–887.

**15.** Lee, J.H., Kim, D.H., Jeong, S.N., and Choi, S.H., (2020). Detection and diagnosis of dental caries using a deep learning-based convolutional neural network algorithm. *Journal of Dentistry*, 77, 106-111

**16.** Ramezani, K., and Tofangchiha M., 2022. Oral Cancer Screening by Artificial Intelligence Oriented Interpretation of Optical Coherence Tomography Images. *Radiology Research and Practice*, 2022; 2022: 1614838.

**17.** Deo, P.K., and Patel, S., (2021). Machine learning and artificial intelligence in orthodontics: Insights into treatment planning using Invisalign. *Orthodontics and Craniofacial Research*, 24(6), 452-460.

**18.** Kaur, A., and Mehra, P., (2022). Advancements in AI and its role in orthodontic treatment planning: A review of Invisalign's technological innovations. *Journal of Digital Dentistry*, 11(2), 113-121.

**19.** Vasquez, G., and Chen, X., (2020). Streamlining dental practice operations with AI chatbots: Benefits and challenges. *International Journal of Medical Robotics and Computer-Assisted Surgery*, 16(3), 212-218.

**20.** Harrison, J.B., and Lee, D., (2022). Chatbots in dental care: Enhancing communication and clinic efficiency through AI technology. *Journal of Dental Practice Technology*, 25(6), 305-312.

**21.** Kim, H.J., and Lee, M.S., (2021). Ethical dilemmas in AI-based diagnostics in dental practice: Risks of depersonalization and bias. *Dental Ethics and Practice Review*, 19(1), 62-69.

**22.** Kumar, V., and Verma, S., (2020). AI applications in dental education: The role of simulation platforms like DentSim in skill development and assessment. *Journal of Technology in Dental Education*, 12(5), 198-205.

**23.** Ghosh, S., and Dubey, N., (2022). Enhancing dental training with AI-driven virtual simulations: Evaluating hand skills in preclinical education. *Journal of Medical Education and Training*, 36(4), 243-250.

**24.** Beauchamp, T.L., and Childress, J. F., (2013). *Principles of Biomedical Ethics* (7th ed.). Oxford University Press.

**25.** Tschandl, P., Rinner, C., Apalla, Z., Argenziano, G., Codella, N., Halpern, A., and Kittler, H., (2020). Human–computer collaboration for skin cancer recognition. *Nature Medicine,* 26(8), 1229–1234.

**26.** Vargas, A., and Ferraro, F., (2021). Implementing Explainable AI in clinical dentistry software for improved decision-making and patient trust. *Journal of Artificial Intelligence in Dental Education*, 17(2), 109-118.

**27.** Overjet (2023). AI for dental radiograph interpretation: Clinical performance white paper. Retrieved from https://www.overjet.com

**28.** Almeida, J.A., and Andrade, J.S., (2021). Integrating artificial intelligence in periodontal disease detection and management: A review of systems and prototypes. *International Journal of Dental Sciences*, 45(3), 129-137.

**29.** Lee, J., and Patel, V., (2020). AI and social justice in healthcare: The implications of proprietary AI systems on healthcare equity. *Journal of Health Informatics Research*, 9(4), 245-252.

**30.** WHO and ITU (2021). World Health Organization (WHO), and International Telecommunication Union (ITU). (2021). Ethics and governance of artificial intelligence for health. Geneva: WHO Press.

**31.** Wang, Z., and Liu, L., (2020). Artificial intelligence in dental practices: The need for a robust ethical framework. *Journal of Dental Policy and Law*, 14(1), 31-39.

**32.** Alkhalil, A., and Alghamdi, A., (2021). Ethical considerations in the use of artificial intelligence in dentistry: Balancing innovation and patient trust. *Journal of Dental Ethics and Education*, 34(6), 123-130.