A REVIEW ON ARTIFICIAL INTELLIGENCE AND DENTISTRY

Dissertation Submitted to

The IIHMR University, Jaipur

for the partial fulfillment for the award of the degree of

Master of Business Administration (MBA)

in

Hospital and Health Management

by

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Under the Supervision and Guidance of

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2025

IIHMR UNIVERSITY

Completion Certificate

This is to certify that Dr. Sakshi Toshniwal in partial fulfillment of the requirements for the award of the degree of MBA (Hospital Management) from the IIHMR University, Jaipur has successfully completed her internship at IIHMR University, Jaipur during March 10 – May 31, 2025.

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CERTIFICATE

This is to certify that dissertation titled "**A Review on Artificial Intelligence and Dentistry**" is a record of the research work undertaken by **Dr. Sakshi Toshniwal** in partial fulfillment of the requirements for the award of the degree of MBA (Hospital Management) from the IIHMR University, Jaipur under my guidance and supervision and her approach to the research study has been sincere, scientific, and analytical.

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DECLARATION BY STUDENT

I hereby declare that this dissertation titled **A Review on Artificial Intelligence and Dentistry** is the bonafide record of my original research work. I declare that it has not been submitted to any other university or institution for the award of any degree or diploma. Information derived from the published or unpublished work of others has been duly acknowledged in the text.

Sakshi 23/06/25

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ABSTRACT

Artificial Intelligence has emerged as a transformative force in modern dentistry, offering significant potential to augment diagnostic accuracy, enhance treatment planning, streamline administrative workflows, and foster personalized patient care. This dissertation presents an integrated review of how AI, including Machine Learning and Deep Learning , is being applied across various dental specialties such as periodontology, endodontics, orthodontics, prosthodontics, and oral pathology.

AI applications discussed include convolutional neural networks (CNNs) for radiographic caries detection, Support Vector Machines (SVMs) for orthodontic diagnostics, and ANN-based Clinical Decision Support Systems (CDSS) for endodontic decision-making. These technologies exhibit diagnostic performance comparable to or better than human experts while reducing time and human error.

However, the review also highlights current limitations such as data imbalance, overfitting, limited generalizability, lack of clinician training, and ethical risks including algorithmic bias and data privacy. The omission of AI ethics and environmental sustainability from mainstream dental literature is especially concerning. The Montreal Declaration and the EU Ethics Guidelines for Trustworthy AI offer essential frameworks that remain underutilized. Notably, this dissertation expands the scope of discussion to include AI's intersection with environmental sustainability and its alignment with the UN Sustainable Development Goals (SDGs). It explores how AI-enabled digital dentistry, teleconsultations, and predictive modeling contribute to waste reduction, energy efficiency, and green dental practices.

The dissertation concludes by calling for the development of regulatory frameworks, curriculum reforms, and clinical validation mechanisms that promote ethical, inclusive, and sustainable integration of AI in dentistry. Future directions should also explore AR/VR integration, robotic automation, and explainable AI (XAI) to bridge the gap between clinical reliability and technological advancement.

ACKNOWLEDGEMENT

I would like to express my heartfelt gratitude to all those who supported me throughout the journey of completing this dissertation titled **"A Review on Artificial Intelligence and Dentistry."**

First and foremost, I am deeply thankful to **Mr. Sarthak Sengupta**, my faculty guide, for his invaluable guidance, mentorship, and constant encouragement. His insightful suggestions and critical feedback helped refine the direction of my research and strengthened the foundation of this work.

I extend my sincere appreciation to **IIHMR University, Jaipur**, for providing an academically enriching environment and access to resources that enabled the successful completion of this study.

I also thank the faculty members, peers, and administrative staff who directly or indirectly contributed their time, knowledge, and cooperation during this research process.

A special note of thanks to my **family and friends** for their unwavering support, patience, and motivation throughout this academic endeavor. Their faith in me has been a pillar of strength.
Finally, I acknowledge all the authors and researchers whose published work contributed to the understanding and development of this dissertation.

With deep gratitude,
Dr. Sakshi Toshniwal

INTRODUCTION

The integration of artificial intelligence into the field of dentistry has accelerated in recent years, bringing forth both promising advancements and pressing ethical concerns. This correspondence emerges in response to two recent publications in the journal that critically evaluated the role of AI in clinical dentistry. These earlier articles identified key ethical challenges associated with AI, specifically regarding data accuracy and security, diminished humanistic care, and the potential erosion of patient autonomy and medical ethics.

AI has been widely utilized in the field of medicine since its conception over 60 years ago.Although its adoption in dentistry has lagged in some subfields, interest has grown significantly with increased accessibility to AI technologies. AI has made substantial progress in various dental disciplines, such as disease diagnosis, localization, classification, estimation, and disease assessment.
AI encompasses systems that can perform tasks typically requiring human intelligence. Machine learning (ML), a subset of AI, uses algorithms to analyze datasets and make predictions without explicit programming.

The rapid advancement of artificial intelligence has significantly influenced healthcare, and dentistry is no exception. This review focuses on the use of AI technologies—including artificial neural networks (ANNs), convolutional neural networks (CNNs), and deep learning—in improving dental care delivery. These models are capable of mimicking human decision-making by identifying patterns and making predictions based on large volumes of clinical data.

The involvement of computer systems in clinical medicine and dentistry has recently become a necessity. These systems support healthcare professionals in all phases of patient care — from scheduling appointments, creating and maintaining digital patient records, gathering patient history, assisting in clinical diagnosis and radiographic analysis, to supporting laboratory analyses and treatment planning.
Artificial intelligence—particularly machine learning and deep learning—offers promising avenues for improving diagnostic accuracy, treatment planning, and efficiency in dental care. LMICs could benefit substantially from AI's capacity to standardize diagnostics and enhance access.

AI is rapidly transforming the landscape of modern healthcare, including the field of dentistry. Over the past decade, dentistry has witnessed a significant shift from conventional clinical approaches to technologically enhanced diagnostics and treatment planning. AI, with its subfields such as machine learning, deep learning, and neural networks, is being increasingly adopted to improve precision, efficiency, and patient care outcomes.

In dental practices, AI-powered tools are now capable of analyzing radiographs, detecting dental caries, planning orthodontic treatments, and even predicting the outcomes of surgical interventions. These systems not only reduce the margin of error but also assist clinicians in making more informed decisions, enhancing both accuracy and speed in diagnosis and care delivery.

The growing integration of AI into dentistry stems from a broader movement toward digital transformation in healthcare. Dentists and oral healthcare professionals are now leveraging AI for various purposes—ranging from automated charting and voice-enabled assistants to advanced image recognition and robotic surgeries. These innovations reflect a shift from reactive to predictive and personalized care models.

Despite the promising potential of AI, its adoption in dentistry also raises important challenges. Issues such as data privacy, ethical usage, algorithmic bias, and regulatory approval are critical to ensuring safe and equitable deployment of AI technologies. Moreover, successful integration depends on collaboration between dental professionals, technologists, researchers, and policymakers.

This dissertation explores how AI is shaping the future of dentistry by evaluating its applications, benefits, limitations, and ethical considerations. Through a comprehensive review of current technologies and literature, the study aims to identify areas where AI is making the most impact and where further development and regulation are necessary. The focus is on understanding AI's role not as a replacement for dentists, but as a supportive tool that augments human expertise and enhances the quality of patient care.

LITERATURE REVIEW

AI has emerged as a powerful tool in transforming healthcare practices, and dentistry is no exception. The convergence of machine learning, computer vision, and neural network models has provided the dental field with novel diagnostic and operational capabilities. This section reviews major contributions in the current body of research and identifies how AI is reshaping key dental domains.

AI in Diagnostic Imaging:
One of the most profound applications of AI in dentistry is in the domain of diagnostic imaging. Radiographs, panoramic x-rays, and cone-beam computed tomography (CBCT) scans have traditionally required expert interpretation, but AI systems now offer automated analysis with exceptional precision. For instance, convolutional neural networks (CNNs) have shown superior performance in detecting dental caries, bone loss, and periapical pathologies. These tools not only reduce diagnostic errors but also enhance early detection, thereby allowing timely intervention.

A significant advancement has been the development of AI models that can identify cephalometric landmarks automatically. These landmarks are critical in orthodontic planning, and AI-based systems reduce manual effort while maintaining high accuracy. Deep learning algorithms trained on thousands of annotated dental images are also being used to classify different tooth types and detect abnormalities such as impacted third molars or root fractures with a high degree of reliability.

Applications in Treatment Planning and Simulation:
Beyond diagnostics, AI is increasingly contributing to treatment planning. In orthodontics, AI-powered systems can simulate treatment outcomes, allowing orthodontists to visualize tooth movement over time. This predictive modeling assists in decision-making and improves patient communication. Similarly, in prosthodontics, AI tools are being used to design dental prostheses with better fit and aesthetics by analyzing 3D scans and occlusion patterns.

AI is also being integrated into robotic systems for implantology, enabling precise navigation and placement of dental implants. These systems use real-time feedback and imaging data to ensure optimal angulation and depth control, which is critical for long-term implant success.

AI in Periodontology and Preventive Dentistry:
In periodontology, AI assists in the evaluation of periodontal pockets and the severity of bone degradation. Some models are trained to interpret intraoral photos or periodontal charts and flag early signs of gingivitis or periodontitis. This has opened the door to preventive care strategies where AI alerts both patients and providers before the disease progresses to advanced stages.
Moreover, AI-driven mobile apps and smart toothbrushes have been developed to track brushing habits, offer real-time feedback, and motivate patients to maintain oral hygiene. These tools serve as a bridge between patients and dental professionals in promoting proactive care and reducing the risk of oral diseases.

Ethical, Legal, and Operational Considerations:
Despite the promise of AI in dentistry, the literature consistently flags important challenges. One concern is data privacy, especially since AI systems rely on large volumes of patient data for training. Inadequate data anonymization can lead to breaches of confidentiality. Another concern involves the transparency of algorithms—often termed the "black box" issue—wherein clinicians may find it difficult to understand how the AI reached a particular decision.

Regulatory oversight for AI applications in dentistry is still evolving. While some systems are approved by entities like the FDA, many operate in grey areas without clear clinical validation. Scholars emphasize the need for ethical frameworks that ensure accountability, informed consent, and equitable access to AI-powered solutions.

Gaps in Research and Future Directions:
Although numerous studies underscore the effectiveness of AI in dental tasks, many lack longitudinal validation or real-world deployment data. There is also a noticeable gap in literature when it comes to AI's role in pediatric dentistry and geriatric dental care—areas that present unique diagnostic and treatment challenges. Furthermore, integration into existing dental practice management systems remains inconsistent, which limits AI's potential impact on overall workflow efficiency.

Looking ahead, interdisciplinary collaboration between dental practitioners, software developers, and ethicists will be essential. Future research must focus on enhancing algorithm interpretability, ensuring diversity in training datasets to prevent bias, and fostering continuous learning systems that adapt to evolving dental practices.

METHODOLOGY

This study rely primarily on secondary data sources. The research aimed to explore the integration of Artificial Intelligence into various domains of dentistry, emphasizing real-world applications, benefits, and challenges.

1. **Research Design**
   A descriptive approach was adopted to collect and interpret information about existing AI technologies in the field of dentistry. The goal was to understand the current landscape, recent developments, and potential areas of improvement.

2. **Data Source**
   Database: Web of Science
   Document Type: Peer-reviewed articles, conference papers, and reviews.

3. **Data Collection**
   Download bibliographic data: Title, Authors, Abstract, Keywords, Year, Journal, Institution, Country, Citation Count, and DOI.

4. **Data Analysis**
   Collected literature was reviewed thematically. Emphasis was placed on identifying recurring patterns, unique innovations, and comparative outcomes across different dental specialties. Key variables analyzed included diagnostic accuracy, patient outcomes, and AI usability in routine dental settings.

5. **Inclusion Criteria**
   Only publications from the past five years were considered to ensure the content reflected recent advancements in AI applications. Articles that specifically discussed dental diagnostics, radiography, treatment planning, or AI-assisted tools in clinical practice were prioritized.

6. **Ethical Considerations**
   As this was a literature-based study, no primary data collection involving human subjects was undertaken.

ADVANTAGES

1. **Enhanced Diagnostic Accuracy**: AI improves the precision of diagnosis, especially in radiographic analysis, by detecting issues like dental caries, bone loss, and lesions more accurately than traditional methods.

2. **Efficiency in Workflow**: By automating repetitive diagnostic tasks and streamlining clinical workflows, AI significantly reduces the time required for procedures and administrative tasks.

3. **Personalized Treatment Planning**: AI enables tailored treatment recommendations based on patient data, improving outcomes in orthodontics, prosthodontics, and endodontics.

4. **Real-Time Data Analysis**: Advanced AI systems can process vast amounts of patient data instantaneously, facilitating better clinical decisions and risk assessments.

5. **Improved Patient Experience**: AI-driven tools, such as virtual reality for anxiety reduction and behavior assessment in pediatric patients, help improve comfort and cooperation during treatment.

6. **Remote Accessibility**: Teledentistry powered by AI allows for consultations and follow-ups without requiring physical visits, making care more accessible.

7. **Support in Education**: AI technologies have enabled virtual simulations and case generation, ensuring continuity in dental education, particularly during crises like the COVID-19 pandemic.

8. **Surgical Precision**: In implantology and orthognathic surgeries, AI enhances accuracy in implant placement and procedural simulations.

9. **Reduction in Human Error**: Automated data analysis and treatment recommendations reduce clinical errors and support less-experienced practitioners.

DISADVANTAGES

1. **Data Quality and Bias**: AI models require large, diverse, and well-annotated datasets. Inadequate or skewed data can lead to biased or inaccurate outcomes.

2. **Lack of Generalization**: Models trained in specific environments may not perform reliably in different clinical settings due to variations in demographics and equipment.

3. **Ethical and Legal Concerns**: Issues related to patient privacy, informed consent, and the ambiguous liability of AI-generated recommendations remain major concerns.

4. **Technological Barriers**: High initial investment, expensive hardware, and infrastructure requirements limit AI adoption in smaller or resource-constrained dental clinics.

5. **Training and Adoption Challenges**: Many dental practitioners lack formal training in using AI tools and may resist integrating new technologies into their practice.

6. **Cybersecurity Risks**: The increasing reliance on digital platforms for AI-based diagnostics introduces potential vulnerabilities related to data breaches and system hacking.

7. **Standardization Gaps**: The absence of universal clinical guidelines and interoperability protocols hampers consistent AI integration across dental practices.

8. **Digital Divide**: Not all patients or practitioners have equal access to technology, which can exacerbate inequalities in oral healthcare delivery.

CHALLENGES AND LIMITATIONS

While this dissertation presents a comprehensive analysis of the role of Artificial Intelligence in dentistry, certain limitations were encountered during the study:

1. **Dependence on Secondary Data**: The research is primarily based on existing literature and publicly available sources, which may not fully capture the most recent advancements of AI in dental practices.

2. **Lack of Primary Clinical Validation**: Due to constraints in time and access, no direct clinical trials or hands-on experiments with AI-based dental tools could be conducted to validate theoretical findings.

3. **Rapid Technological Advancements**: The field of AI is evolving at a fast pace, some information or tools discussed in this study may become outdated as newer innovations and models emerge.

4. **Limited Scope in Specific Dental Domains**: While the dissertation touches upon multiple specialties like radiology, orthodontics, and prosthodontics, it does not explore all subfields of dentistry in depth, such as pediatric or geriatric dentistry.

5. **Geographical and Institutional Bias**: Much of the data referenced originates from studies conducted in technologically advanced regions.

6. **Ethical and Legal Uncertainties**: The study acknowledges the presence of ethical and legal issues in AI adoption but does not perform an in-depth legal analysis due to its academic and managerial focus.
7. **Environmental and Sustainability Challenges:** Although AI can contribute to more efficient workflows, the computational resources required for training and running large models are energy-intensive especially in the context of green healthcare practices.

RESULTS

The study found that artificial intelligence has significantly improved the precision and speed of various dental procedures. In diagnostic imaging, AI tools demonstrated over 90% accuracy in identifying dental caries and other oral health conditions when compared to traditional examination methods. AI-powered radiographic analysis, particularly with deep learning models, enabled the detection of issues such as periodontal bone loss with higher reliability.

In orthodontics, the use of AI allowed for real-time treatment planning and simulation, enhancing both clinical decision-making and patient experience. AI also facilitated cephalometric landmark identification, which is essential for effective orthodontic diagnosis and planning.

Despite these advancements, the research identified that the integration of AI into daily dental practice is not uniform. Factors such as financial investment, limited training in AI systems, and regulatory uncertainties have created barriers to widespread adoption. Moreover, access to high-quality datasets remains a limitation for developing and testing AI models, particularly in developing regions.

Overall, the results point to a positive trend in AI adoption in dentistry, with substantial benefits in efficiency, accuracy, and patient satisfaction. However, these benefits are contingent upon addressing existing infrastructural and educational challenges.

DISCUSSION

The adoption of Artificial Intelligence in dentistry is reshaping the contours of clinical practice by introducing new paradigms for diagnosis, planning, and patient engagement. Synthesizing the discussions from various studies, it is evident that AI technologies are no longer peripheral innovations—they are central to the modernization of oral healthcare.

A recurring theme across the literature is the enhanced diagnostic accuracy that AI systems provide, especially in radiographic analysis. Tools like Convolutional Neural Networks (CNNs) have been shown to surpass human accuracy in identifying dental caries, root fractures, and periodontal diseases. For example, AI systems trained on annotated panoramic and periapical images can now highlight lesions and anomalies with pixel-level precision, assisting practitioners in early and accurate detection.

Another critical dimension of AI's integration lies in orthodontics and prosthodontics, where machine learning algorithms aid in treatment planning, cephalometric landmark identification, and virtual simulations. This not only reduces manual effort but also improves patient satisfaction by visualizing end results and customizing interventions. Several studies emphasize the potential of AI in predicting treatment outcomes based on past patient data and procedural success rates, making interventions more evidence-driven.

Despite these advancements, the discussions also reflect substantial challenges. Key among them is the ethical and regulatory ambiguity surrounding AI usage. Concerns regarding data privacy, informed consent, and algorithmic bias are prominent. If datasets used for training AI models lack diversity, they may yield skewed or unreliable outcomes, which is particularly critical in healthcare where patient variability is high.

Implementation barriers were also frequently discussed. While AI offers promising outcomes in controlled environments or pilot projects, its translation into everyday clinical settings is often hampered by high infrastructure costs, lack of standardized protocols, and resistance from practitioners unfamiliar with digital tools. Furthermore, the absence of regulatory clarity on liability in AI-assisted errors presents a legal grey area.

Another important observation is the need for interdisciplinary training. Dentists and dental technicians require structured programs to build confidence in using AI applications. Without adequate training and change management strategies, even the most sophisticated systems risk underutilization or misuse.

In summary, while AI in dentistry offers undeniable benefits, its success depends on thoughtful integration that addresses clinical needs, ethical standards, and user readiness. The consensus across discussions points toward a collaborative model—where AI acts as an assistant rather than a replacement—thus reinforcing human judgment rather than attempting to override it. Going forward, policy frameworks, stakeholder engagement, and evidence-based validations will play a pivotal role in steering AI toward meaningful and equitable adoption in dental practice.

CONCLUSION

Artificial Intelligence has become an indispensable force shaping the future of dentistry. Its applications have transcended traditional diagnostic limitations, enabling dental professionals to deliver faster, more precise, and patient-centric care. Through advancements in machine learning, deep learning, and computer vision, AI systems are now capable of detecting dental anomalies, analyzing radiographic data, predicting treatment outcomes, and automating routine processes with remarkable efficiency.

The integration of AI in various dental domains—such as oral radiology, prosthodontics, orthodontics, and periodontology—has demonstrated measurable improvements in diagnostic accuracy and clinical workflow optimization. From detecting carious lesions and identifying cephalometric landmarks to planning orthodontic interventions and designing prostheses, AI enhances both clinical outcomes and operational efficiency.

However, successful adoption of AI in dentistry is not without its challenges. Issues concerning data privacy, ethical implications, lack of regulatory clarity, and limited technical expertise in dental settings continue to hinder widespread implementation. Additionally, while AI augments clinical decision-making, it cannot—and should not—replace the professional judgment and human touch of dental practitioners.

As dental technologies evolve, it is imperative that the dental community embraces AI as a collaborative tool rather than a replacement. Education and training programs must evolve in parallel to equip future professionals with the necessary skills to harness AI effectively. Regulatory frameworks should also mature to ensure responsible development and deployment of AI tools in clinical practice.

In conclusion, AI holds transformative potential in dentistry, but its future success relies on ethical integration, interdisciplinary collaboration, and an unwavering focus on improving patient care. With continued research and responsible innovation, AI can become a cornerstone of modern dental practice, bridging the gap between clinical expertise and technological advancement.

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