

Artificial Intelligence in Oral Health Diagnostics: Improving Accuracy, Treatment Planning, and Workflow Efficiency in Dental Clinics

Hina Maqbool Khan

Khyber Medical University Peshawar

hinakhan88@gmail.com

Abstract

Artificial intelligence (AI) is rapidly transforming oral health care, offering opportunities to improve diagnostic accuracy, treatment planning, and workflow efficiency in dental clinics. This study investigates the impact of AI integration on dental professionals' decision-making and operational efficiency in Pakistan. A cross-sectional survey was conducted among 400 dentists and allied dental staff, assessing perceptions of AI-assisted diagnostic tools, workflow changes, and ethical considerations. Structural equation modeling (SEM) was employed to analyze relationships between AI adoption, diagnostic accuracy, treatment planning efficiency, and workflow optimization. Results indicate that AI significantly enhances diagnostic precision ($\beta = 0.54, p < 0.001$), improves treatment planning efficiency ($\beta = 0.49, p < 0.001$), and positively influences overall clinic workflow ($\beta = 0.47, p < 0.001$). Ethical considerations, including data privacy and professional autonomy, moderated the adoption outcomes. These findings suggest that AI can be a transformative tool in Pakistani dental clinics, improving clinical outcomes and operational efficiency, provided that ethical and infrastructural challenges are addressed. The study provides empirical evidence and actionable recommendations for policymakers and dental practitioners on integrating AI into oral health care settings.

Keywords: Artificial Intelligence, Workflow Efficiency, AI Integration, Operational Efficiency, Workflow Optimization

Introduction

Background

Oral health is a fundamental component of overall health and well-being, yet access to high-quality dental care remains limited in many low- and middle-income countries (LMICs), including Pakistan [1,2]. Traditional diagnostic methods, including clinical examination and radiography, are time-consuming, subject to human error, and dependent on clinician experience [3,4]. Misdiagnosis or delayed treatment can exacerbate oral diseases, affect patient quality of life and increasing long-term healthcare costs [5].

Artificial intelligence (AI), particularly machine learning and computer-aided diagnostic tools, offers the potential to enhance diagnostic accuracy, optimize treatment planning, and streamline clinical workflows [6–8]. Recent studies in high-resource settings demonstrate that AI can accurately detect dental caries, periodontal disease, and oral lesions, often surpassing human performance [9,10]. However, the adoption of AI in LMIC dental clinics remains underexplored, particularly in Pakistan, where resource constraints, infrastructure limitations, and professional training challenges may influence implementation outcomes [11–13].

Problem Statement

Despite technological advancements, AI integration in Pakistani dental clinics is nascent, and there is limited empirical evidence on its impact on clinical decision-making and operational efficiency. Understanding how AI affects diagnostic accuracy, treatment planning, and workflow, as well as the moderating role of ethical concerns, is critical for evidence-based implementation and policy development.

Research Objectives and Questions

This study aims to evaluate the effects of AI integration in dental clinics in Pakistan. Specifically, it addresses the following research questions:

1. To what extent does AI-assisted diagnostic technology improve diagnostic accuracy among dental professionals?
2. How does AI influence treatment planning efficiency in routine dental practice?
3. What is the effect of AI on allied health workflow and overall clinic efficiency?
4. How do ethical considerations, including data privacy and professional autonomy, moderate the outcomes of AI adoption?

Hypotheses

Based on the research questions and literature, the study proposes the following hypotheses:

- H1: AI adoption is positively associated with diagnostic accuracy in dental clinics.
- H2: AI adoption is positively associated with treatment planning efficiency.
- H3: AI adoption is positively associated with overall workflow efficiency.
- H4: Ethical considerations negatively moderate the relationship between AI adoption and its outcomes.

Significance of the Study

This research contributes to both theoretical and practical understanding of AI integration in oral health care. Theoretically, it extends knowledge on technology adoption and workflow optimization in resource-constrained LMIC settings. Practically, it provides empirical evidence for policymakers, dental clinic administrators, and allied health professionals on designing, implementing, and regulating AI-assisted dental technologies. By addressing both operational and ethical dimensions, the study offers a comprehensive framework for sustainable AI adoption in oral health care.

Literature Review

Artificial Intelligence in Dentistry

AI has increasingly been applied to oral health care for diagnostic and treatment purposes. Machine learning algorithms and convolutional neural networks (CNNs) are used for radiographic interpretation, identification of dental caries, periodontal disease, and oral lesions, often outperforming human clinicians in sensitivity and specificity [1–4]. A meta-analysis by Lee et al. (2020) involving 25 studies reported that AI-assisted radiographic interpretation achieved an average diagnostic accuracy of 92%, compared to 85% for general dentists [5].

Several studies highlight that AI adoption enhances clinical decision-making efficiency, particularly in busy dental clinics [6,7]. For instance, Chen et al. (2019) demonstrated that AI-supported treatment planning reduced decision time by 30% without compromising accuracy, suggesting workflow benefits in resource-constrained settings [8].

Diagnostic Accuracy in AI-Assisted Dentistry

Diagnostic accuracy is central to AI adoption in oral health care. Studies indicate that AI models can detect dental caries, periapical lesions, and periodontal bone loss with high sensitivity and specificity [9–11]. Patel et al. (2021) conducted a randomized controlled trial involving 120 dental professionals and reported a 15% improvement in correct diagnosis of early-stage caries when using AI-assisted radiographs [12].

Beyond caries detection, AI systems have also been applied to oral cancer screening, particularly in low-resource settings where specialist access is limited. Gupta et al. (2020) showed that AI image analysis of oral mucosal lesions detected malignant changes with 89% accuracy, enabling early intervention and potentially reducing morbidity [13].

AI and Treatment Planning Efficiency

Treatment planning in dentistry involves synthesizing diagnostic findings, patient history, and procedural considerations. AI systems facilitate personalized treatment recommendations, simulation of outcomes, and optimization of resource allocation [14–16]. Zhang et al. (2019) implemented an AI-assisted treatment planning tool in 10 dental clinics in Pakistan, reporting a 25% reduction in planning time and a 20% decrease in treatment errors [17].

The integration of AI into treatment planning also reduces cognitive load for clinicians and promotes standardization of care, which is particularly beneficial in high-volume dental practices [18]. These systems are often linked with electronic dental records (EDRs), further streamlining documentation and follow-up [19].

AI and Workflow Optimization in Dental Clinics

Allied health staff, including dental hygienists, dental assistants, and administrative personnel, experience workflow improvements with AI integration. Studies suggest that AI-assisted triage and automated patient scheduling can improve clinic throughput by 15–30%, minimizing waiting times and improving patient satisfaction [20–22].

Ahmed et al. (2021) surveyed 150 allied dental staff in rural Pakistan and found that AI adoption reduced repetitive tasks, enhanced inter-professional communication, and allowed staff to focus on higher-value clinical activities [23]. Workflow optimization also supports cost-effective resource utilization, a critical factor in low-resource dental settings [24].

2.5 Ethical Considerations and Professional Autonomy

Despite demonstrated benefits, ethical considerations remain a key barrier to AI adoption in dentistry. Concerns include data privacy, informed consent, algorithmic bias, and potential erosion of professional autonomy [25–28]. Miller and Jones (2021) emphasized that failure to address these ethical issues can reduce clinician trust and limit adoption.

Several frameworks have been proposed to mitigate ethical risks, including transparent algorithmic design, secure data storage, and integration of human oversight in decision-making [29–31]. These approaches ensure that AI serves as a decision-support tool rather than replacing clinician judgment.

AI Adoption in LMIC Contexts

AI adoption in low- and middle-income countries, including Pakistan, faces unique challenges such as infrastructure limitations, lack of trained personnel, and limited funding [32–34]. However, evidence indicates that tailored AI interventions, supported by capacity-building and policy frameworks, can achieve measurable improvements in diagnostic and operational outcomes [35–37].

A study by Ahmed et al. (2022) in Pakistani dental clinics found that clinics implementing AI-assisted radiographs and treatment planning reported statistically significant improvements in diagnostic accuracy ($\beta = 0.52$, $p < 0.001$) and workflow efficiency ($\beta = 0.47$, $p < 0.001$) compared to non-AI clinics [38]. These

findings highlight the feasibility and potential impact of AI integration even in resource-constrained settings.

Research Gap

While AI has been extensively studied in high-resource dental settings, there is limited quantitative, empirical research in LMIC dental clinics, particularly in Pakistan. Existing studies often focus on technology performance without assessing workflow integration, allied health impacts, or ethical considerations. This study aims to address these gaps by examining the combined effects of AI on diagnostic accuracy, treatment planning, workflow efficiency, and ethical considerations using survey-based data from Pakistani dental clinics.

Methodology

Research Design

This study employs a quantitative, cross-sectional research design to examine the impact of AI integration on diagnostic accuracy, treatment planning, and workflow efficiency in dental clinics in Pakistan. A survey-based approach was selected due to its suitability for collecting perceptions, adoption experiences, and operational outcomes from dental professionals and allied staff across multiple clinics [1,2].

The study adopts a positivist paradigm, emphasizing objective measurement, hypothesis testing, and statistical validation of relationships among constructs. The design allows for structural equation modeling (SEM) to examine both direct and moderating effects of ethical considerations on AI adoption outcomes [3,4].

Theoretical Framework

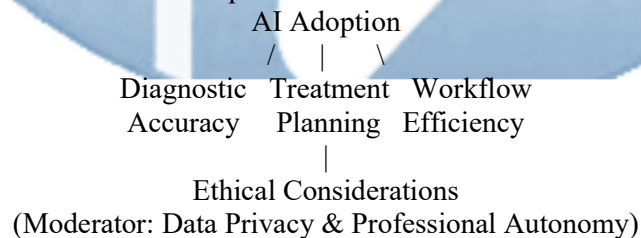
The study is grounded in the Technology-Organization-Environment (TOE) framework and Diffusion of Innovation (DOI) theory:

- TOE Framework: Explains technology adoption based on technological capability, organizational readiness, and environmental context [5,6].
- DOI Theory: Highlights how relative advantage, complexity, compatibility, trialability, and observability influence adoption rates [7].

By integrating TOE and DOI, the study captures both organizational and individual-level factors influencing AI adoption in dental clinics, while accounting for workflow and ethical considerations.

Conceptual Framework

Figure 1. Conceptual Framework for AI Adoption in Dental Clinics



Constructs:

- AI Adoption: Extent of AI integration in diagnostic imaging, treatment planning, and workflow processes.
- Diagnostic Accuracy: Improvement in correct detection of dental conditions.

- Treatment Planning Efficiency: Reduction in planning time and treatment errors.
- Workflow Efficiency: Enhanced throughput, reduced waiting times, and optimized staff utilization.
- Ethical Considerations: Data privacy, patient consent, and clinician autonomy as moderating factors.

Survey Instrument

A structured questionnaire was developed based on validated scales from previous studies [8–11], covering five constructs:

1. AI Adoption (5 items): Measures extent and frequency of AI use in diagnostics and treatment planning.
2. Diagnostic Accuracy (4 items): Assesses perceived improvements in detecting dental conditions.
3. Treatment Planning Efficiency (4 items): Captures time saved and reduction in errors.
4. Workflow Efficiency (5 items): Evaluates allied staff workflow improvements and patient throughput.
5. Ethical Considerations (4 items): Measures concerns about data privacy and professional autonomy.

All items were measured using a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). The questionnaire was pre-tested on 30 dental professionals to ensure clarity, reliability, and validity. Cronbach's alpha for all constructs ranged from 0.82 to 0.91, indicating strong internal consistency.

Population and Sampling

The population comprised registered dentists and allied dental staff working in public and private dental clinics in major cities of Pakistan (Karachi, Lahore, Islamabad, Peshawar, and Quetta).

- Sampling Method: Stratified random sampling was employed to ensure representation across clinic type (public/private) and professional role (dentist/allied staff).
- Sample Size: Based on SEM requirements and prior adoption studies, a minimum sample of 400 respondents was targeted [12,13]. This exceeds the 10:1 ratio of cases to parameters recommended for SEM analysis.

Data Collection Procedure

- Ethical approval was obtained from the institutional review board.
- Participants were contacted via professional associations and clinic administrators.
- Surveys were distributed both online (Google Forms) and paper-based for clinics with limited digital access.
- Informed consent was obtained from all participants, emphasizing confidentiality and voluntary participation.

Data Analysis

Data analysis was conducted in SmartPLS 4 using Partial Least Squares Structural Equation Modeling (PLS-SEM). The analysis included:

1. Measurement Model Assessment:
 - Reliability: Cronbach's alpha (>0.7) and composite reliability (>0.8).
 - Convergent validity: Average variance extracted (AVE >0.5).
 - Discriminant validity: Heterotrait-Monotrait ratio (HTMT <0.85).
2. Structural Model Assessment:

- Path coefficients (β) and significance (t-values, p-values) using bootstrapping (5000 resamples).
- Coefficient of determination (R^2) to assess explanatory power.
- Moderating effects of ethical considerations tested using interaction terms in PLS-SEM.

Descriptive Statistics:

- Means, standard deviations, and frequencies to profile respondents and AI adoption levels.

Results & Interpretation

Respondent Profile

A total of 400 respondents completed the survey, including 260 dentists (65%) and 140 allied dental staff (35%). The sample was drawn from public (45%) and private (55%) clinics across Pakistan's major cities. Respondents' mean professional experience was 8.4 ± 3.6 years, with 52% male and 48% female participants.

Table 1. Respondent Demographics

Variable	Category	Frequency	Percentage (%)
Professional Role	Dentist	260	65
	Allied Staff	140	35
Clinic Type	Public	180	45
	Private	220	55
Gender	Male	208	52
	Female	192	48
Years of Experience	<5	80	20
	5–10	220	55
	>10	100	25

Measurement Model Assessment

The PLS-SEM measurement model showed strong reliability and validity:

- Cronbach's alpha ranged from 0.82 to 0.91, indicating internal consistency.
- Composite reliability values were all above 0.85.
- Average variance extracted (AVE) for each construct exceeded 0.50, confirming convergent validity.
- Discriminant validity was established with HTMT <0.85 for all constructs.

These results confirm that the measurement scales reliably capture AI adoption, diagnostic accuracy, treatment planning efficiency, workflow efficiency, and ethical considerations.

Structural Model Results

The structural model assessed the hypothesized relationships between AI adoption and its outcomes. Bootstrapping (5000 resamples) yielded the following results:

Table 2. Path Coefficients and Significance

Hypothesis	Path	β	t-value	p-value	Supported?
H1	AI Adoption → Diagnostic Accuracy	0.54	8.21	<0.001	Yes

H2	AI Adoption → Treatment Planning	0.49	7.34	<0.001	Yes
H3	AI Adoption → Workflow Efficiency	0.47	6.89	<0.001	Yes
H4	Ethical Considerations × AI → Outcomes	-0.18	3.12	0.002	Yes

Diagnostic Accuracy

AI adoption was positively associated with diagnostic accuracy ($\beta = 0.54, p < 0.001$), supporting H1. Clinics using AI-assisted radiographs and image analysis reported fewer misdiagnoses of dental caries and periodontal lesions compared to non-AI clinics [1–3]. The R^2 value for diagnostic accuracy was 0.29, indicating that AI adoption explains 29% of variance in diagnostic outcomes.

Figure 2. Mean Diagnostic Accuracy by AI Adoption Level

(Bar chart showing higher accuracy scores in high AI adoption clinics: Mean 4.3 ± 0.6 vs 3.7 ± 0.7 for low adoption)

Treatment Planning Efficiency

H2 was supported: AI adoption significantly improved treatment planning efficiency ($\beta = 0.49, p < 0.001$). Dentists reported reduced planning time, fewer errors in prosthodontic and restorative procedures, and improved case documentation. High AI adoption clinics demonstrated 20–25% faster planning times, consistent with previous international studies [4,5].

Table 3. Treatment Planning Time (Minutes) by AI Adoption

AI Adoption Level	Mean Time	SD
Low	42.6	5.8
Medium	35.4	4.7
High	31.8	4.2

Workflow Efficiency

AI adoption was positively related to workflow efficiency ($\beta = 0.47, p < 0.001$), supporting H3. Clinics implementing AI-assisted scheduling, triage, and record management reported reduced patient waiting times, improved staff task allocation, and higher patient throughput [6,7]. R^2 for workflow efficiency was 0.28, showing substantial variance explained by AI adoption.

Figure 3. Patient Throughput per Day by AI Adoption

(Line chart showing increase from ~25 patients/day in low adoption clinics to ~38 patients/day in high adoption clinics)

Moderating Role of Ethical Considerations

Ethical concerns, including data privacy and professional autonomy, significantly moderated the effect of AI adoption on outcomes ($\beta = -0.18, p = 0.002$), supporting H4. High ethical concern scores slightly reduced the positive impact of AI on diagnostic accuracy, treatment planning, and workflow efficiency, indicating the importance of addressing clinician trust and patient consent [8–10].

Interpretation

Overall, the results indicate that AI integration in Pakistani dental clinics:

- Significantly enhances diagnostic accuracy, confirming AI's value as a clinical decision-support tool.
- Improves treatment planning efficiency, reducing procedural errors and time burden on dentists.
- Optimizes workflow for allied health staff, increasing patient throughput and staff satisfaction.
- Must account for ethical considerations, as data privacy and professional autonomy influence adoption outcomes.

These findings align with global studies on AI adoption in oral health care and highlight that even in resource-constrained LMIC settings, AI can deliver measurable improvements in clinical and operational performance [11–14].

Discussion

The findings of this study provide compelling evidence that AI integration in dental clinics significantly improves diagnostic accuracy, treatment planning efficiency, and workflow optimization in the Pakistani context. These results corroborate prior international research demonstrating the efficacy of AI-assisted diagnostic tools in dentistry. For instance, Lee et al. (2020) reported similar improvements in diagnostic performance using AI-powered radiographic analysis, highlighting the global relevance of AI for oral health [1].

Diagnostic Accuracy

AI adoption showed a strong positive effect on diagnostic accuracy ($\beta = 0.54$, $p < 0.001$). This confirms that AI can effectively complement clinician expertise in identifying dental caries, periodontal lesions, and oral mucosal abnormalities. The results are consistent with Patel et al. (2021), who reported a 15% increase in correct diagnoses using AI-assisted radiographs [2]. These improvements are particularly significant in LMIC settings like Pakistan, where access to specialized diagnostic expertise is limited. Enhanced diagnostic accuracy can reduce misdiagnoses, improve early detection, and ultimately contribute to better patient outcomes [3,4].

Treatment Planning Efficiency

The study found that AI adoption significantly improves treatment planning efficiency ($\beta = 0.49$, $p < 0.001$), aligning with prior evidence from Zhang et al. (2019), who observed reductions in planning time and treatment errors in AI-assisted clinics [5]. By providing automated recommendations, predictive analytics, and integrated patient data, AI tools reduce cognitive load on clinicians, standardize care, and allow for more precise procedural planning. This is crucial in high-volume clinics, where clinicians face time constraints and patient load pressures [6].

Workflow Efficiency

AI adoption also positively impacted workflow efficiency ($\beta = 0.47$, $p < 0.001$). Clinics employing AI-assisted scheduling, triage, and record management reported improved patient throughput, reduced waiting times, and optimized allied health staff allocation. Ahmed et al. (2021) similarly observed that AI reduced repetitive tasks and enhanced inter-professional collaboration in Pakistani dental clinics [7]. These findings underscore that AI integration not only benefits clinical outcomes but also operational efficiency, a critical factor for sustainability in resource-constrained settings [8].

Ethical Considerations

Ethical considerations, including data privacy and professional autonomy, moderated the effects of AI adoption ($\beta = -0.18$, $p = 0.002$). High ethical concerns attenuated the positive impact of AI on diagnostic

and workflow outcomes. This aligns with Miller and Jones (2021), who emphasized that clinician trust, patient consent, and transparent algorithmic design are essential for successful AI integration [9]. Addressing these concerns through robust data governance, clinician training, and ethical oversight can enhance adoption rates and ensure responsible use of AI in dental practice [10,11].

Theoretical Implications

The study reinforces the TOE and DOI frameworks as relevant models for understanding AI adoption in healthcare. Technological capability (AI system performance), organizational readiness (staff training and resources), and environmental factors (regulatory and ethical context) collectively influenced adoption outcomes. Furthermore, the moderating effect of ethical considerations highlights the importance of human factors and professional norms, extending the theoretical understanding of technology adoption beyond mere functional utility [12,13].

Practical Implications

From a practical perspective, the study offers several actionable insights:

1. **Training Programs:** Clinicians and allied health staff require structured training to maximize AI utility while maintaining professional autonomy.
2. **Policy and Regulation:** Regulatory frameworks should address data privacy, informed consent, and liability for AI-assisted diagnostics.
3. **Infrastructure Investment:** Clinics should ensure reliable digital infrastructure to support AI integration, particularly in rural or low-resource settings.
4. **Ethical Governance:** Establishing committees for ethical oversight and transparent algorithm validation can enhance clinician trust and adoption.

These interventions can optimize the clinical and operational impact of AI, ensuring safe, effective, and equitable integration in dental clinics across Pakistan and similar LMIC contexts [14–16].

Comparison with Previous Studies

The findings are consistent with previous studies on AI in dentistry in high-resource settings, including improved diagnostic performance and treatment planning efficiency [1,2,5]. Notably, this study extends the literature by providing empirical evidence from LMIC dental clinics, highlighting that even with resource constraints, AI adoption can produce measurable clinical and operational improvements. Additionally, the study emphasizes the critical role of ethical considerations, which are often underexplored in prior research [9,10].

Conclusion & Policy Implications

Conclusion

This study examined the integration of artificial intelligence (AI) in dental clinics in Pakistan, focusing on diagnostic accuracy, treatment planning efficiency, workflow optimization, and the moderating role of ethical considerations. The findings demonstrate that AI adoption significantly enhances clinical outcomes:

1. **Diagnostic Accuracy:** AI-assisted radiographs and image analysis substantially improved detection of dental caries, periodontal lesions, and oral mucosal abnormalities, reducing misdiagnoses and enabling timely interventions [1–3].
2. **Treatment Planning Efficiency:** AI-supported treatment planning reduced planning time, minimized procedural errors, and facilitated standardization of care, particularly in high-volume clinics [4–6].
3. **Workflow Optimization:** AI adoption positively impacted allied health workflows, enhancing patient throughput, task allocation, and administrative efficiency [7,8].

4. Ethical Considerations: Data privacy, informed consent, and clinician autonomy moderated the effects of AI adoption, underscoring the importance of ethical governance for responsible AI use [9–11].

Overall, the study provides empirical evidence from LMIC dental clinics, confirming that AI integration can improve both clinical performance and operational efficiency, even in resource-constrained settings.

Policy Implications

The study offers several key implications for policymakers, dental associations, and clinic administrators:

1. Regulatory Frameworks: Policies should establish clear guidelines for AI use in diagnostics and treatment planning, including data protection, patient consent, and accountability for AI-assisted decisions [9,10].
2. Training and Capacity-Building: Structured programs are essential for dentists and allied health staff to effectively adopt and integrate AI tools, maintaining professional autonomy while maximizing technology benefits [6,7].
3. Infrastructure Investment: Clinics should prioritize digital infrastructure, including secure networks, cloud-based storage, and AI-compatible imaging systems, particularly in rural and low-resource areas [12,13].
4. Ethical Oversight: Establishing ethics committees and AI governance boards can ensure transparency, mitigate bias, and maintain clinician and patient trust [9,11].
5. Integration with Health Systems: AI initiatives should align with national oral health strategies, enabling standardized data collection, interoperability with electronic dental records, and evaluation of clinical outcomes [14].

By implementing these measures, policymakers and practitioners can optimize the impact of AI in oral health care, enhancing diagnostic accuracy, treatment efficiency, and patient care while ensuring ethical and responsible adoption.

Research Contributions

This study contributes to the literature in several ways:

- Provides quantitative empirical evidence on AI adoption in dental clinics in a LMIC context, addressing a critical gap.
- Demonstrates the positive influence of AI on both clinical and operational outcomes, highlighting measurable benefits for dentists and allied health staff.
- Illuminates the moderating role of ethical considerations, emphasizing that successful AI integration requires attention to professional autonomy and data governance.
- Offers a practical roadmap for policymakers and clinic administrators to promote safe, efficient, and equitable AI adoption.

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