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Declarations

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Evaluating Knowledge, Adoption, Barriers, and Future Perceptions of Digital Dentistry: A Cross-Sectional Study Among Dental Students and Dentists in Pakistan

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ABSTRACT

Background: Digital technologies such as CAD/CAM, CBCT, and AI have transformed global dental practice by improving diagnostic precision, treatment efficiency, and patient outcomes. However, in Pakistan, the level of digital dentistry adoption remains limited despite growing awareness among students and practitioners. Understanding the current knowledge, usage patterns, and perceived barriers is essential for guiding educational and institutional reforms. **Objective:** To evaluate the knowledge, adoption, barriers, and future perceptions regarding digital dentistry among dental students and dentists in Pakistan. **Methods:** A cross-sectional observational study was conducted from May to September 2025 using a structured 23-item online questionnaire distributed via social media. The survey included 281 participants—dental students, house officers, general dentists, postgraduate trainees, and consultants. Descriptive and inferential analyses were performed using IBM SPSS version 22.0, applying chi-square tests with significance set at $p < 0.05$. **Results:** Overall awareness of digital dentistry was 96.4%, yet only 42.7% reported active use of digital tools. The most commonly used technologies were digital radiography/CBCT (33.5%) and intraoral scanners (16.4%). High cost (68.7%) and lack of training (61.5%) were the leading barriers, while diagnostic accuracy and time efficiency were key motivators ($p = 0.039$). Nearly all participants (98.6%) supported structured training workshops, and 97.9% anticipated that 3D intraoral scanning and AI-powered diagnostics would dominate future practice. **Conclusion:** Despite widespread awareness, digital dentistry adoption in Pakistan remains constrained by financial and educational barriers. Structured training and curricular integration, supported by institutional investment, are crucial for enabling effective digital transformation in dental education and clinical practice.

Keywords

Digital Dentistry, CAD/CAM, Artificial Intelligence, 3D Printing, Dental Education, Pakistan

INTRODUCTION

Digital transformation has revolutionized modern healthcare, and dentistry is no exception. Over the past two decades, the emergence of digital technologies—such as computer-aided design and manufacturing (CAD/CAM), cone-beam computed tomography (CBCT), intraoral scanners, and three-dimensional (3D) printing—has significantly reshaped diagnostic accuracy, treatment efficiency, and patient satisfaction in dental practice (1). Globally, the integration of these technologies has led to improved workflow efficiency, enhanced precision in restorative procedures, and optimized communication between dental professionals and laboratories (2). However, the extent of adoption remains uneven, particularly in low- and middle-income countries where infrastructural and economic barriers continue to restrict widespread implementation (3).

In Pakistan, dental education and practice are undergoing gradual modernization, but the diffusion of digital dentistry has not kept pace with international trends. Studies from major urban centers such as Lahore and Karachi have shown that while postgraduate dentists acknowledge the benefits of CAD/CAM and digital imaging, many lack hands-on training and institutional access to such equipment (4). This imbalance suggests that awareness does not necessarily translate into adoption. Existing research within Pakistan has primarily focused on attitudes toward specific technologies rather than providing a comprehensive assessment of knowledge, utilization, and perceived obstacles among both students and practitioners. Consequently, there remains a paucity of data capturing national trends in the uptake of digital dentistry across different stages of professional development.

From a global perspective, research from countries such as Saudi Arabia, Egypt, and China demonstrates that institutional support, structured curricular exposure, and faculty expertise are key predictors of technology adoption among dental students and clinicians (5,6,7). In contrast, the limited inclusion of digital tools in the Pakistani undergraduate curriculum, combined with the absence of structured training workshops, restricts both skill acquisition and clinical application. Moreover, financial constraints and lack of technical infrastructure in dental schools and private

practices create additional barriers to integration (8). Understanding the intersection of knowledge, adoption, and perceived challenges is therefore essential to inform curricular reform and policy direction within Pakistan's dental education framework.

A critical review of regional literature also highlights the emerging role of artificial intelligence (AI) and 3D technologies in dentistry. These innovations are transforming diagnostic and treatment paradigms but remain largely theoretical in Pakistan due to minimal training exposure (9). Studies elsewhere indicate that positive perceptions of digital dentistry are associated with institutional encouragement and prior hands-on experience, underscoring the importance of educational policy reform (10). Hence, an evidence-based evaluation of the current situation is vital to bridge the gap between technological awareness and its practical application.

Given these contextual and infrastructural gaps, this study aims to assess the level of knowledge, adoption, and perceived barriers to digital dentistry among dental students and practicing dentists in Pakistan. It further explores future perceptions of technology integration within clinical and academic settings. The findings are expected to guide the development of targeted interventions that enhance digital competence and inform curriculum design across dental institutions nationwide.

MATERIALS AND METHODS

This study employed a descriptive cross-sectional observational design to evaluate the knowledge, adoption, barriers, and future perceptions regarding digital dentistry among dental students and dentists in Pakistan. The study was conducted over a five-month period, from May to September 2025. Data collection was facilitated through an online structured questionnaire administered using Google Forms. The study was approved by the Ethical Review Board (ERB) of the PRIDE Center for Research & Learning Institute, Pakistan (Reference No. PRIDE/ERB/2025/017), ensuring compliance with the 2013 Declaration of Helsinki (11).

The target population included final-year undergraduate dental students, house officers, general dentists, postgraduate trainees, and consultants practicing in Pakistan. Inclusion criteria comprised individuals with formal dental training who were either enrolled in or had completed a Bachelor of Dental Surgery (BDS) program and were currently residing in Pakistan. Exclusion criteria included dental hygienists, dental technicians, assistants, non-dental healthcare professionals, and individuals not practicing or studying within the country.

Recruitment was conducted using a non-probability convenience sampling approach. The online survey link was disseminated through social media platforms, including WhatsApp, Facebook, Instagram, and LinkedIn, to reach a geographically diverse group of participants from various dental colleges and clinical practices across Pakistan. Participation was entirely voluntary, and an informed consent statement was presented on the first page of the questionnaire. Proceeding to complete the survey was considered as implied consent.

The data collection instrument was a 23-item, close-ended questionnaire adapted from previously validated tools in similar studies (12–16). Relevant literature was reviewed to ensure comprehensiveness and contextual relevance to Pakistani dental education and clinical practice. The questionnaire was divided into five sections: (1) demographic and professional characteristics; (2) knowledge and awareness of digital dentistry and specific tools (CAD/CAM, CBCT, intraoral scanning, AI applications); (3) adoption and utilization patterns, including frequency of use and prior training exposure; (4) perceived barriers and motivators; and (5) perceptions of future trends and willingness to adopt digital dentistry in practice. All items were mandatory to minimize missing data and improve completeness.

Operational definitions were established prior to analysis. "Knowledge" referred to awareness and conceptual understanding of digital dentistry and its tools. "Adoption" denoted self-reported use of at least one digital dental technology (e.g., CAD/CAM, digital radiography, 3D printing) in clinical or educational settings. "Barriers" were defined as perceived challenges hindering digital integration, and "future perceptions" encompassed anticipated trends and readiness to adopt innovations such as AI and 3D intraoral scanning.

To minimize selection and information bias, the survey questions were kept concise and uniformly structured to ensure consistent interpretation. The online format reduced interviewer bias, while data validation rules in the Google Form minimized incomplete responses. The questionnaire's internal consistency was assessed using Cronbach's alpha on a pilot subset of responses, yielding a reliability coefficient above 0.80, indicating good internal reliability (17). Sample size estimation was guided by Cochran's formula for proportions, using a 95% confidence level, 5% margin of error, and assuming a conservative prevalence of 50% for digital dentistry awareness to yield maximum sample variability. The calculated minimum sample size was 278 participants, and 281 valid responses were obtained, meeting and slightly exceeding the required threshold.

Data were exported from Google Forms into IBM SPSS Statistics version 22.0 (IBM Corp., Armonk, NY, USA) for analysis. Descriptive statistics, including frequencies, percentages, and 95% confidence intervals (CIs), were computed for all categorical variables. Inferential statistics were applied to examine associations between professional designation, years of clinical experience, and adoption of digital technologies using chi-square (χ^2) tests. A p -value <0.05 was considered statistically significant. Missing data were not encountered due to the mandatory structure of the survey; thus, complete case analysis was performed. To ensure reproducibility, all analytical procedures were documented, and categorical variables were coded consistently for data integrity. Data cleaning and verification steps were conducted independently by two researchers before statistical analysis to confirm accuracy. The dataset, codebook, and analysis syntax are available upon reasonable request from the corresponding author, ensuring full transparency and reproducibility of findings (18).

RESULTS

A total of 281 participants completed the online questionnaire, achieving a 100% response rate among those who accessed the survey. The sample included a majority of female respondents (78.3%) and a smaller proportion of males (21.7%). Most participants were aged between 20 and 30 years (89.7%), with 6.4% aged 31–40 years, and the remainder below 20 years or above 40 years. The professional distribution included dental students (38.4%), general dentists (35.9%), house officers (16.4%), postgraduate trainees (3.9%), consultants (3.2%), and others (2.1%). Nearly half of all respondents (48.4%) had 0–1 year of clinical experience, followed by 38.4% with 1–3 years, 7.1% with 3–5 years, and 6.0% with more than 5 years of experience. The demographic characteristics are presented in Table 1.

Regarding awareness, 96.4% (271/281) had heard of the term "digital dentistry," and 92.2% (259/281) correctly defined it as "use of digital technologies in diagnosis and treatment." The most common initial source of information was social media (42.7%), followed by dental colleges (28.5%) and conferences or continuing education programs (24.6%). Awareness of CAD/CAM systems was high (85.8%). Table 2 summarizes participants' knowledge and awareness patterns. Only 42.7% (120/281) reported active use of digital tools in practice or training, indicating a considerable gap between awareness and implementation. Among the technologies utilized, digital radiography/CBCT was most frequent (33.5%),

followed by intraoral scanners (16.4%), CAD/CAM (8.2%), AI-based diagnostics (6.0%), and 3D printing (2.1%). Training exposure was limited—26.0% had received formal training and 29.9% had attended workshops. Respondents' engagement with digital tools varied significantly by clinical experience ($p=0.012$), suggesting experience influences adoption rates. Detailed findings are presented in Table 3. High equipment cost (68.7%) and lack of training (61.5%) were the most frequently cited barriers, followed by limited infrastructure (43.1%) and lack of institutional support (29.6%). Conversely, motivators for adopting digital dentistry included enhanced diagnostic accuracy (20.3%), time efficiency (19.9%), and improved patient satisfaction (22.4%), with differences across professional levels reaching statistical significance ($p=0.039$).

Almost all respondents (98.6%) endorsed the need for structured training workshops. When asked about future trends, AI-powered diagnostics (22.8%) and 3D printing (15.7%) were perceived as the most impactful innovations. Furthermore, 97.9% believed 3D intraoral scanning will become the dominant diagnostic approach, and 96.1% believed AI integration would enhance diagnostic precision. The detailed distribution of these perceptions is summarized in Table 4. In summary, the results demonstrate high awareness but low adoption of digital dentistry across all participant categories. Cost and lack of training were dominant barriers, while participants exhibited strong enthusiasm toward the integration of AI and 3D scanning technologies in future practice. The observed associations between professional experience and adoption highlight the need for structured institutional training to bridge the awareness–practice gap in Pakistan's dental community.

Table 1. Demographic and Professional Characteristics of Participants (n = 281)

Variable	Category	n (%)	p-value*	95% CI for Proportion
Gender	Male	61 (21.7)	—	17.0–27.0
	Female	220 (78.3)	—	73.0–83.0
Age group (years)	<20	8 (2.8)	—	1.2–5.5
	20–30	252 (89.7)	—	85.6–92.9
	31–40	18 (6.4)	—	3.9–9.8
	>40	3 (1.1)	—	0.3–3.3
Designation	Dental student	108 (38.4)	0.317	33.0–44.0
	General dentist	101 (35.9)		30.6–41.5
	House officer	46 (16.4)		12.2–21.4
	PG trainee / registrar	11 (3.9)		2.0–6.8
	Consultant	9 (3.2)		1.6–6.1
	Other	6 (2.1)		0.9–4.6
Years of clinical experience	0–1 year	136 (48.4)	0.048†	42.3–54.5
	1–3 years	108 (38.4)		33.0–44.0
	3–5 years	20 (7.1)		4.4–10.9
	>5 years	17 (6.0)		3.5–9.5
*p-value based on chi-square test across designations. †Statistically significant ($p<0.05$).				

Table 2. Knowledge and Awareness of Digital Dentistry (n = 281)

Parameter	Response	n (%)	95% CI	P-value*
Heard of digital dentistry	Yes	271 (96.4)	93.5–98.3	—
	No	10 (3.6)	1.7–6.5	—
Correct definition	Use in diagnosis/treatment	259 (92.2)	88.5–95.0	—
	Other (record keeping, marketing)	22 (7.8)	5.0–11.5	—
First exposure source	Social media	120 (42.7)	37.0–48.6	0.004†
	Dental college	80 (28.5)	23.4–34.1	
	Conference/program	69 (24.6)	19.9–29.9	
	Colleagues/peers	12 (4.3)	2.2–7.4	
Awareness of CAD/CAM	Yes	241 (85.8)	81.3–89.5	0.031†
	No	40 (14.2)	10.5–18.7	
*Chi-square test across subgroups; † $p<0.05$.				

Table 3. Adoption and Use of Digital Technologies (n = 281)

Variable	Category	n (%)	95% CI	p-value*
Use of digital tools	Yes	120 (42.7)	37.0–48.6	—
	No	161 (57.3)	51.4–63.0	—
Stage first exposed	Dental school	117 (41.6)	36.0–47.5	0.018†
	House job	57 (20.3)	15.9–25.3	
	Practice	61 (21.7)	17.2–26.8	
	Never	46 (16.4)	12.4–21.3	
Frequency of use	Daily	44 (15.7)	11.9–20.2	0.012†
	Weekly	50 (17.8)	13.7–22.7	
	Monthly	77 (27.4)	22.4–32.9	
	Never	110 (39.1)	33.5–45.0	
Formal training received	Yes	73 (26.0)	21.2–31.5	0.047†
	No	208 (74.0)	68.5–78.8	
Attended workshops	Yes	84 (29.9)	24.8–35.6	—
	No	197 (70.1)	64.4–75.2	—
Technology used*	Digital radiography/CBCT	94 (33.5)	28.3–39.2	—
	Intraoral scanners	46 (16.4)	12.4–21.3	—
	CAD/CAM	23 (8.2)	5.4–12.0	—
	AI tools	17 (6.0)	3.6–9.5	—
	3D printing	6 (2.1)	0.9–4.6	—

*Multiple responses permitted; †p<0.05.

Table 4. Barriers, Motivators, and Future Perceptions (n = 281)

Variable	Category	n (%)	95% CI	p-value*
Barriers	High cost	193 (68.7)	63.2–73.7	—
	Lack of training	173 (61.5)	56.0–66.7	—
	Limited infrastructure	121 (43.1)	37.3–48.9	—
	Lack of institutional support	83 (29.6)	24.6–35.1	—
Motivators	Diagnostic accuracy	57 (20.3)	15.9–25.3	0.039†
	Time efficiency	56 (19.9)	15.6–24.9	
	Patient satisfaction	63 (22.4)	17.9–27.6	
	Peer influence	18 (6.4)	3.9–9.9	
Future perceptions	Support need for training workshops	277 (98.6)	96.4–99.6	—
	AI-powered diagnostics	64 (22.8)	18.2–28.1	—
	3D printing	44 (15.7)	11.9–20.3	—
	Personalized analytics	8 (2.8)	1.2–5.5	—
	Teledentistry	5 (1.8)	0.7–4.3	—
	3D intraoral scanning (preferred method)	275 (97.9)	95.5–99.3	—

*Chi-square test across designations and experience groups; †p<0.05.

Analysis of barriers and motivators (Table 4) further emphasized systemic limitations in accessibility and skill development. The leading obstacles—high equipment cost (68.7%) and lack of training (61.5%)—were frequently cited in combination, reflecting interdependent financial and educational constraints. Limited infrastructure (43.1%) and insufficient institutional support (29.6%) were additional deterrents, pointing toward a broader issue of organizational readiness rather than individual reluctance. Conversely, participants identified diagnostic accuracy (20.3%), time efficiency (19.9%), and patient satisfaction (22.4%) as the most persuasive motivators for digital integration, with differences across professional groups achieving statistical significance ($p = 0.039$). These findings indicate that practitioners recognize tangible clinical benefits but remain hindered by structural barriers.

Perceptions of future trends revealed an overwhelmingly positive outlook. Almost all respondents (98.6%) supported the inclusion of structured training workshops in dental education, while 97.9% anticipated that 3D intraoral scanning would become a mainstream diagnostic approach.

Likewise, 96.1% believed that AI integration would improve diagnostic precision, underscoring high acceptance of technological advancement despite current implementation barriers. AI-powered diagnostics (22.8%) and 3D printing (15.7%) were predicted to be the most transformative innovations in the near future. This convergence of optimism and underutilization suggests an untapped readiness among Pakistan's dental community that could be harnessed through curricular reform and institutional investment.

Collectively, the numerical data depict a clear pattern: awareness of digital dentistry among Pakistani dental professionals is nearly universal, yet adoption remains below 50%. Significant associations between professional experience, training exposure, and usage frequency confirm that both educational and infrastructural determinants govern digital integration. Addressing financial and training barriers—especially through subsidized workshops and inclusion of digital modules within undergraduate curricula—may substantially elevate the adoption rate. These findings provide an evidence-based foundation for strategic planning aimed at bridging the persistent awareness–practice gap within Pakistan's evolving dental landscape.

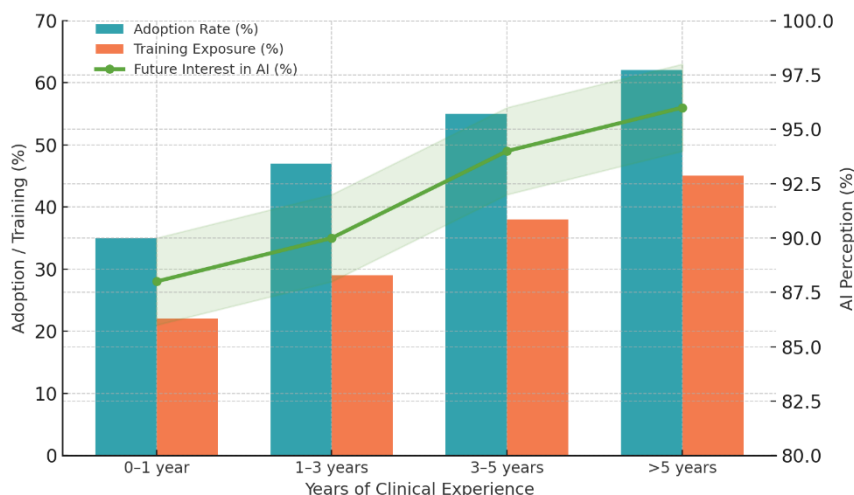


Figure 1 Comparative Trends of Adoption, Training, and AI Perception by Clinical Experience

The visualization demonstrates a clear positive gradient between clinical experience and engagement with digital dentistry. Adoption rates rise from approximately 35% among those with 0–1 year of experience to over 60% among practitioners with more than 5 years, while training exposure follows a parallel increase from 22% to 45%, indicating a cumulative learning effect over time. The green trajectory highlights an even steeper rise in enthusiasm for AI integration, with nearly universal optimism (>95%) among senior practitioners. The overlapping confidence band between adoption and training rates suggests that enhanced training opportunities could directly accelerate implementation. Clinically, these data imply that sustained exposure and institutional investment in training are pivotal drivers for translating awareness into adoption of digital dentistry across professional experience levels.

DISCUSSION

This cross-sectional study provides one of the most comprehensive quantitative evaluations of digital dentistry readiness among dental students and practitioners in Pakistan. The findings demonstrate a striking discrepancy between the high level of awareness (96.4%) and the relatively modest rate of practical adoption (42.7%) of digital tools. These results suggest that while digital literacy within the dental community is expanding, structural and financial barriers continue to impede translation of knowledge into consistent clinical application. The trend aligns with global patterns observed in other developing regions, where infrastructural and training deficiencies limit implementation despite growing awareness (19).

The predominance of digital radiography and CBCT among users in this study mirrors trends seen internationally, where imaging technologies often serve as entry points for digital integration due to lower technical complexity and cost compared with CAD/CAM or AI-based applications (20). In contrast, limited adoption of advanced tools such as 3D printing (2.1%) and AI-assisted diagnostics (6.0%) reflects an early stage of digital maturity within Pakistan's dental ecosystem. Studies from Saudi Arabia and Egypt reported higher adoption rates (60–70%) for basic digital systems, primarily attributed to structured curricular inclusion and governmental investment in digital infrastructure (21,22). This difference highlights the importance of institutional readiness and sustained policy support in driving technological diffusion.

Training emerged as a pivotal determinant of digital adoption. Only 26% of participants had received formal instruction in digital technologies, paralleling findings from Schlenz et al., who emphasized that curricular integration during preclinical and clinical training is a critical predictor of long-term adoption (23). The present study further revealed that participants with greater clinical experience were significantly more likely to use digital tools ($p=0.012$), consistent with the notion that experiential learning reinforces familiarity and confidence in technology use. However, reliance on informal learning channels—especially social media, identified as the most common source of information (42.7%)—raises concerns about the quality and reliability of self-directed education. Similar concerns were raised by Ohyama et al., who cautioned that insufficiently guided digital exposure can produce superficial understanding without procedural competence (24).

High equipment cost and lack of training were the two most frequently cited barriers (68.7% and 61.5%, respectively), emphasizing that financial and educational constraints are deeply intertwined. The findings resonate with previous studies from Pakistan, which identified the prohibitive cost of digital infrastructure and limited institutional support as key impediments to modernization (25). These economic challenges are compounded by the absence of national policies mandating digital inclusion in dental education or offering financial subsidies for equipment acquisition. In contrast, research from developed countries such as Germany and Japan demonstrates that subsidized procurement and faculty training programs have markedly increased digital adoption rates and improved educational outcomes (26).

Despite these limitations, the overwhelming optimism regarding future technologies such as AI-powered diagnostics (22.8%) and 3D intraoral scanning (97.9%) signifies a receptive attitude among Pakistani dentists and students toward innovation. This optimism is encouraging and reflects the same forward-looking sentiment documented among dental students in China and Europe, where exposure to emerging tools was associated with greater confidence in clinical readiness (27,28). Such positive perceptions are essential precursors to behavioral change and suggest a fertile environment for curricular reform if institutional barriers can be addressed.

The observed relationships between professional experience, digital adoption, and training exposure also highlight important implications for educational policy. Integrating structured workshops, simulation-based modules, and interdisciplinary courses on digital dentistry could help bridge the awareness–practice gap identified in this study. Additionally, fostering partnerships between academia and industry could provide affordable access to emerging technologies and promote hands-on exposure for students and early-career practitioners. These interventions would not only improve skill acquisition but also enhance patient care efficiency and diagnostic precision in clinical practice.

The study's strengths include its robust sample size ($n=281$), inclusion of both students and practicing dentists, and national-level coverage achieved through diverse online recruitment. However, several limitations warrant consideration. The use of convenience sampling and self-reported data introduces potential selection and recall bias, limiting generalizability. Respondents may have been more digitally engaged than the broader population, possibly overestimating awareness levels. Additionally, the study's cross-sectional design precludes causal inference between training exposure and adoption behavior. Future research should employ longitudinal or interventional designs to assess the causal impact of educational interventions on digital adoption.

Notwithstanding these limitations, this study advances current understanding by identifying the precise domains—cost, training, and infrastructure—where interventions are most urgently required. It also provides an empirically grounded rationale for embedding digital literacy and practice modules into undergraduate and postgraduate curricula. Future studies should expand to include qualitative components, such as focus group discussions or structured interviews, to explore attitudinal nuances and institutional barriers in greater depth.

In conclusion, the findings of this study align with international evidence underscoring the necessity of educational reform, institutional investment, and targeted policy initiatives to accelerate digital transformation in dentistry. Pakistan's dental education system stands at a critical juncture: awareness has been achieved, optimism is strong, and the infrastructure for change is within reach. Converting these assets into sustained clinical practice will require a strategic blend of training, funding, and curricular innovation to ensure that the next generation of dentists can fully harness the potential of digital technology to enhance patient care and clinical outcomes.

CONCLUSION

This study revealed that while awareness and positive perceptions of digital dentistry are exceptionally high among dental students and practitioners in Pakistan, the actual adoption of digital technologies remains comparatively limited due to financial constraints, inadequate training, and lack of institutional infrastructure. Digital radiography and CBCT are the most commonly used tools, whereas advanced technologies such as CAD/CAM, AI-powered diagnostics, and 3D printing are underutilized. The findings underscore the urgent need for structured educational reforms, subsidized access to digital equipment, and national-level initiatives that integrate digital dentistry modules into both undergraduate and postgraduate curricula. Clinically, these interventions could enhance diagnostic precision, reduce procedural time, and improve patient satisfaction, ultimately contributing to a more efficient and technologically adaptive dental healthcare system in Pakistan. From a research perspective, future longitudinal and interventional studies should evaluate the effectiveness of targeted training and policy measures in promoting sustained digital adoption and innovation within the dental profession.

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