Digital Technologies in Dentistry: A Study onCAD/CAM, 3D Printing, Digital Impressions and Digital X-Ray among Dental Professionals- A Cross-Sectional Study

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ABSTRACT

Background: Digital technologies such as CAD/CAM, 3D printing, digital impressions, and digital X-rays are increasingly being integrated into modern dental practices. These advancements offer significant improvements in precision, workflow efficiency, and patient care. However, the extent of adoption and integration of these technologies varies among practitioners due to factors such as cost, training, and perceived benefits. This study aims to evaluate the adoption and implementation of CAD/CAM systems, 3D printing, digital impressions, and digital X-rays among dental practitioners. It seeks to identify the factors influencing their integration, the challenges faced, and the perceived impact on clinical outcomes and patient satisfaction.

Materials and Methods: A cross-sectional survey were conducted among dental practitioners, including general dentists and specialists, using an online questionnaire. The survey covered demographic information, knowledge and awareness of digital technologies, adoption rates, barriers to implementation, and perceived impact. Descriptive statistics and multivariate logistic regression were used to analyse the data and identify key factors influencing technology adoption.

Results: The survey revealed that while digital technologies are widely recognized for their benefits, the rate of adoption varies significantly among practitioners. CAD/CAM systems and digital X-rays were the most commonly adopted technologies, while 3D printing and digital impressions had lower uptake due to higher costs and a steeper learning curve. Practitioners in larger, urban-based practices were more likely to adopt these technologies compared to those in smaller or rural practices. Major barriers to adoption included high initial investment, lack of training, and challenges with system integration.

Conclusion: The study highlights both the opportunities and challenges associated with the adoption of digital technologies in dental practice. While these tools have the potential to improve clinical outcomes and patient satisfaction, cost and accessibility remain significant barriers. Efforts to make these technologies more affordable and provide comprehensive training may accelerate their adoption, ultimately enhancing dental care delivery.

1. Introduction

The field of dentistry is witnessing a rapid evolution with the integration of digital technologies that are transforming traditional practices. Technologies such as CAD/CAM systems, 3D printing, digital impressions, and digital X-rays are reshaping dental workflows, offering enhanced precision, efficiency, and patient outcomes[1,2]. The adoption of these innovations has provided dental practitioners with new tools to improve the accuracy of diagnoses, optimize treatment plans, and deliver more predictable restorative solutions. Among the most notable advancements is the computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM) system, which allows for the design and fabrication of dental restorations with greater accuracy

and speed[3,4]. Likewise, 3D printing has revolutionized the production of models, surgical guides, and prosthetic devices, offering customized solutions tailored to individual patients. Digital impressions have eliminated the need for conventional impression materials, leading to more comfortable and accurate digital models for restorative and orthodontic work. Additionally, digital radiography, including cone beam computed tomography (CBCT), has significantly improved the quality and detail of imaging, aiding in precise diagnostics and treatment planning[5,6]. However, the extent of adoption and implementation of these digital technologies varies among dental practitioners. Factors such as cost, learning curve, and the perceived benefits of these technologies influence their integration into daily practice. As dentistry continues to advance, understanding the current trends in the adoption of digital technologies is essential to determine how they impact clinical efficiency, patient care, and overall practice management[7,8]. This study aims to evaluate the extent to which dental practitioners have adopted and implemented digital technologies like CAD/CAM, 3D printing, digital impressions, and digital X-rays, as well as to identify the factors influencing their integration into dental practice. By analysing these trends, the research will provide valuable insights into the challenges and opportunities faced by dental professionals in incorporating digital workflows into their clinical settings[9,10].

2. Methods

This cross-sectional survey was designed to evaluate the adoption and integration of digital technologies namely CAD/CAM systems, 3D printing, digital impressions, and digital X-rays among dental practitioners. The study aimed to assess the extent of usage, the factors influencing the adoption, and the challenges associated with implementing these technologies in clinical practice. The study targeted dental practitioners, including general dentists and specialists, from various regions. Ethical clearance approval was obtained from the Taibah University, Saudi Arabia (TUCDREC/181124/AA Saeidi). Participants were recruited through dental associations, social media platforms, and professional networks. Inclusion criteria required participants to be licensed dental practitioners currently engaged in clinical practice, while exclusion criteria included dental professionals without direct patient contact or those not involved in restorative or diagnostic procedures. The sample size was calculated based on the estimated prevalence of digital technology adoption among dental practitioners. Assuming a 50% adoption rate with a 5% margin of error and a 95% confidence interval, a minimum sample of 385 respondents was deemed necessary to achieve statistical significance. To account for potential non-responses or incomplete data, a total of 500 practitioners were invited to participate. A structured, self-administered questionnaire was developed for data collection. The questionnaire consisted of five sections Demographic Information which includes Age, gender, level of education, years in practice, and area of specialization, Knowledge and Awareness which includes Questions assessing familiarity with CAD/CAM systems, 3D printing, digital impressions, and digital X-rays. Adoption of Digital Technologies which includes Questions regarding the current use of digital technologies, frequency of use, and the length of time these technologies had been in use, Barriers to Adoption which includes Questions identifying the challenges encountered in adopting digital technologies, such as cost, training, and integration difficulties and perceived Impact which includes Questions assessing the perceived benefits of these technologies in terms of clinical outcomes, workflow efficiency, and patient satisfaction. The questionnaire was pre-tested on a small sample of dental practitioners to ensure clarity and relevance. Based on feedback, minor adjustments were made to improve the wording and flow of questions. Data collection was conducted over a three-month period using an online survey platform. Invitations to participate were sent via email and social media, along with a link to the survey. Respondents were informed about the purpose of the study and assured of the confidentiality of their responses. Participation was voluntary, and informed consent was obtained from all participants prior to their involvement in the study.

3. Results

The study evaluated the demographic characteristics, knowledge, adoption, and challenges regarding digital technologies in dentistry across different educational and professional groups, including undergraduate students, postgraduate students, dental practitioners, and academicians.

Demographic Details

Out of the total sample population, 40% were undergraduate students, while 20% each were postgraduate students, dental practitioners, and academicians. Among dental practitioners and academicians, 36% reported having 4-6 years of experience in the dental field, followed by 34% with 1-3 years of experience. A smaller group had over 6 years of experience (22%), and 8% had less than 1 year of experience.

Knowledge and Awareness of Digital Technologies

Regarding familiarity with digital technologies in dentistry, 70% of undergraduate students reported being unfamiliar with these technologies. Postgraduate students had a similar trend, with 67% being unfamiliar. Among dental practitioners, 62% indicated they were not familiar, while only 32% of academicians fell into this category. Some postgraduate students (19%) and academicians (32%) reported being familiar with these technologies, with a few academicians (20%) being very familiar.

In terms of learning about digital technologies, 75% of undergraduate students and 69% of postgraduate students had little to no exposure. Among dental practitioners, 52% had limited knowledge, while 33% of academicians were very familiar with digital technology, indicating a higher level of awareness among academicians compared to other groups.

Adoption of Digital Technologies

When asked about the adoption of digital technologies, a significant majority of undergraduate students (90.5%) reported using digital X-rays, while smaller percentages adopted CAD/CAM (3.5%), 3D printing (2.5%), and digital impressions (3.5%). Postgraduate students also predominantly used digital X-rays (72%), while 67% of dental practitioners and 44% of academicians reported using all of the listed technologies. Academicians showed higher adoption across the board compared to other groups.

For the duration of digital technology usage, postgraduate students were the most recent adopters, with 60% using these technologies for less than 1 year. Among dental practitioners and academicians, 20% had been using digital technologies for more than 5 years.

Barriers to Implementation

The most common challenge reported by all groups was the high initial cost of investment, with 60% of postgraduate students, 20% of dental practitioners, and 20% of academicians citing this as a barrier. Additionally, lack of training was identified as a challenge by 20% of undergraduate students and 10% of postgraduate students. Integration issues and resistance from staff or colleagues were less commonly reported challenges.

Impact and Future Outlook

Regarding the impact of digital technologies on clinical outcomes, 62% of dental practitioners and 54% of academicians reported significant improvements, while postgraduate students showed mixed responses, with 48% reporting slight improvements. In terms of patient satisfaction, 64% of dental practitioners and academicians reported significant improvements, whereas postgraduate students and undergraduate students reported only slight improvements. A small percentage of respondents across all groups noted no change in patient satisfaction.

Looking ahead, 44% of both dental practitioners and academicians expressed interest in investing in more digital technologies in the next two years, while postgraduate students showed slightly more hesitation, with 41% being unsure about further investments. Among the technologies of future interest, AI-based diagnostic tools were the most favoured, especially among dental practitioners (62%) and academicians (54%), with virtual treatment planning systems also being considered by a significant portion of the sample population. Robotic-assisted surgery and augmented reality for patient education were less popular options across all groups.

Table 1: Assessment of Demographic Details

QUESTIONNAIRE	OPTIONS	FREQUENCY (N)	PERCENTAGE (%)
1. What is your current level of education/professional status?	Undergraduate Student	200	40
	Postgraduate Student	100	20
	Dental Practitioner	100	20
	Academician	100	20
2. How many years of experience do you have in the dental field? (Applicable for dental practitioner and academician)	Less than 1 year	16	8
	1-3 years	68	34
	4-6 years	72	36
	More than 6 years	44	22

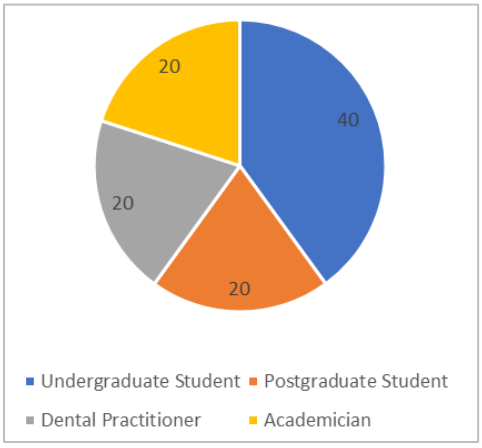

Figure 1: Percentage Distribution on Current Level of Education

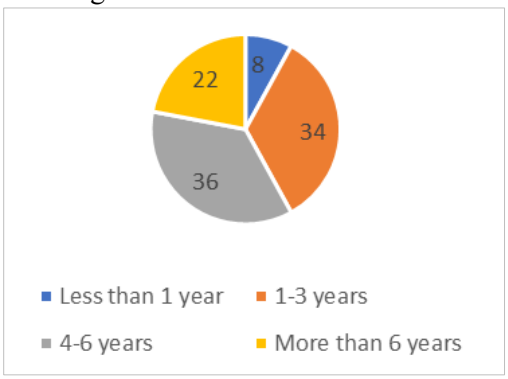

Figure 2: Percentage Distribution on How Many Years of Experience Do you have in the Dental Field

Table 2: Knowledge and Awareness of Digital Technologies

Questionnaire	Options	Undergraduate students		Post graduate students		Dental practitioner		Academician		P-value
		Frequency (n)	Percentage (%)	Frequency (n)	Percentage (%)	Frequency (n)	Percentage (%)	Frequency (n)	Percentage (%)	
How familiar are you with the digital technologies in dentistry	Not familiar	140	70	67	67	62	62	32	32	0.039*
	Some what familiar	45	22.5	14	14	19	19	16	16	
	Familiar	15	7.5	19	19	15	15	32	32	
	Very familiar	0	0	0	0	4	4	20	20	
How did you first learn about digital technologies in dentistry	Not familiar	150	75	69	69	52	52	20	20	0.032*
	Some what familiar	45	22.5	12	12	19	19	16	16	
	Familiar	5	2.5	14	14	15	15	31	31	
	Very familiar	0	0	5	5	14	14	33	33	

Table 3: Adoption of Digital Technologies

Questionnaire	Options	Undergraduate students		Post graduate students		Dental practitioner		Academician		P-value
		Frequency (n)	Percentage (%)	Frequency (n)	Percentage (%)	Frequency (n)	Percentage (%)	Frequency (n)	Percentage (%)	
Have you adopted any of the following digital technologies in your practice? (Check all that apply)	CAD/CAM	7	3.5	10	10	2	2	8	8	0.03*
	3D Printing	5	2.5	4	4	1	1	9	9	
	Digital Impressions	7	3.5	10	10	7	7	6	6	
	Digital X-rays	181	90.5	72	72	22	22	33	33	
	All of the above	0	0	4	4	67	67	44	44	
How long have you been using digital technologies in your practice	Less than 1 year	15	7.5	60	60	20	20	20	20	0.016*
	1-3 years	40	20	10	10	15	15	14	14	
	4-5 years	20	10	10	10	20	20	14	14	
	More than 5 years	25	12.5	10	10	20	20	15	15	
	Less than 1 year	100	50	10	10	25	25	37	37	
How frequently do you use these technolog	Daily	10	5	50	50	20	20	20	20	0.092
	Weekly	46	23	10	10	15	15	14	14	
	Monthly	10	5	20	20	10	10	15	15	
	Rarely	34	17	10	10	20	20	14	14	
	Daily	100	50	10	10	35	35	37	37	

Table 4: Barriers to Implementation

Questionnaire	Options	Undergraduate students		Post graduate students		Dental practitioner		Academician		P-value
		Frequency (n)	Percentage (%)	Frequency (n)	Percentage (%)	Frequency (n)	Percentage (%)	Frequency (n)	Percentage (%)	
What challenges have you encountered in adopting digital technologies	High initial investment costs	15	7.5	60	60	20	20	20	20	0.027*
	Lack of training	40	20	10	10	15	15	14	14	
	Integration issues with existing systems	20	10	10	10	20	20	14	14	
	Resistance from staff or colleagues	25	12.5	10	10	20	20	15	15	
	All of the above	100	50	10	10	25	25	37	37	

Table 5: Impact and Future Outlook

Questionnaire	Options	Undergraduate students		Post graduate students		Dental practitioner		Academician		P-value
		Frequency (n)	Percentage (%)	Frequency (n)	Percentage (%)	Frequency (n)	Percentage (%)	Frequency (n)	Percentage (%)	
How has the implementation of digital technologies impacted your clinical outcomes	Significantly improved	72	36	39	39	62	62	54	54	0.047*
	Slightly improved	84	42	48	48	31	31	41	41	
	No change	44	22	13	13	7	7	5	5	
	Slightly worsened	0	0	0	0	0	0	0	0	
	Significantly worsened	0	0	0	0	0	0	0	0	
What impact have these technologies had on patient satisfaction in your practice	Significantly improved	58	29	52	52	64	64	64	64	0.043*
	Slightly improved	89	44.5	41	41	36	36	31	31	
	No change	53	26.5	7	7	0	0	5	5	
	Slightly worsened	0	0	0	0	0	0	0	0	
	Significantly	0	0	0	0	0	0	0	0	

4. Discussion

The findings of this study highlight the growing adoption and integration of digital technologies specifically CAD/CAM, 3D printing, digital impressions, and digital X-rays within dental practices. These technologies have been widely recognized for their ability to enhance clinical outcomes, improve workflow efficiency, and provide patients with more accurate and customized treatment options. However, despite their numerous advantages, the rate of adoption and the extent to which these tools are fully integrated into daily practice vary significantly among dental practitioners.

The adoption of CAD/CAM systems has gained considerable momentum in recent years. Practitioners who have embraced this technology report enhanced precision in the design and fabrication of dental restorations, leading to better-fitting crowns, bridges, and other prostheses[11,12]. CAD/CAM systems also reduce chairside time, offering patients same-day restorations and improving the overall patient experience. However, barriers such as high initial investment costs and the need for specialized training continue to deter some practitioners from fully adopting this technology[13,14]. 3D printing is another rapidly evolving technology with transformative potential in dentistry. It enables the creation of accurate dental models, surgical guides, and prosthetics with a high degree of customization. Practitioners who have integrated 3D printing into their workflow report improvements in treatment planning and execution, particularly in complex restorative and surgical cases. Despite these benefits, the study revealed that cost, limited familiarity, and concerns about the learning curve remain obstacles to widespread adoption, especially among smaller practices.

Digital impressions have been widely praised for their ability to improve accuracy and patient comfort by

eliminating the need for conventional impression materials. Most practitioners in the study who have adopted digital impression systems noted a reduction in errors associated with traditional impressions, leading to more precise restorative and orthodontic outcomes. Yet, challenges remain in integrating digital impression systems with other technologies, such as CAD/CAM, which require seamless compatibility for efficient workflows[15,16]. The study also highlights the increasing use of digital X-rays, including cone beam computed tomography (CBCT), for enhanced diagnostic capabilities. Digital radiography provides clearer and more detailed images, enabling better visualization of oral structures and more accurate treatment planning. Practitioners who use digital X-rays report a significant improvement in their diagnostic capabilities and patient communication. However, the cost of acquiring and maintaining advanced digital imaging systems can be prohibitive for some, especially for those in smaller or rural practices. Several key factors influence the adoption and integration of these digital technologies. Cost remains one of the most significant barriers, as many of these systems require substantial upfront investment, ongoing maintenance, and training. Additionally, the learning curve associated with mastering new technologies is a concern, particularly for older practitioners who may be less familiar with digital tools. On the other hand, perceived benefits, such as increased precision, improved patient outcomes, and enhanced practice efficiency, serve as powerful motivators for adoption among those willing to invest in these technologies[17,18].

The study also revealed differences in adoption based on practice size and location. Larger, urban-based practices are more likely to invest in and implement digital technologies due to greater access to resources and higher patient volumes. In contrast, smaller or rural practices may struggle with the cost and logistics of adopting these technologies, leading to a slower rate of integration[19,20]. Looking forward, it is clear that digital technologies will continue to play a pivotal role in the future of dentistry. However, to accelerate adoption, there is a need for greater accessibility in terms of cost, training, and support. Manufacturers and professional organizations can contribute by offering more affordable solutions, comprehensive training programs, and ensuring seamless integration across digital platforms.

5. Conclusion

While digital technologies are recognized for their potential benefits in dentistry, their adoption is heavily influenced by the user's professional status, access to training, and financial considerations. The barriers to implementation, particularly high costs, remain a significant challenge for many dental professionals. However, the promising impact on clinical outcomes and patient satisfaction suggests a positive future trajectory for the integration of digital tools in dental practice.

Authors' Contributions:

Abdullah conceived and designed the study, conducted the research and provided the research materials. WamiqMusheer Fareed collected, organized and interpreted the data. Nasser, Abdulaziz and Faisal wrote the initial and final drafts of the article. WamiqMusheer Fareed and Gowri T critically reviewed the manuscript. Lubna performed the data analysis and statistical interpretation and wrote part of the results section. All the authors have critically reviewed approved the final draft and are responsible for the content and similarity index of the manuscript.

Conflict of Interest:

The authors have no conflict of interest to declare.

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