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Research Article

The Future of Dental Prosthetics: Artificial Intelligence and Machine Learning Applications

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Abstract

Background: Dental prosthetics, such as crowns, bridges, and implants, have traditionally required meticulous craftsmanship and labor-intensive processes. The introduction of Artificial Intelligence (AI) and Machine Learning (ML) promises to revolutionize this field by enhancing precision, efficiency, and personalization in the creation and fitting of prosthetics. These technologies can automate various stages of prosthetic development, from diagnosis to manufacturing, resulting in more accurate, tailored, and cost-effective dental solutions. However, integrating AI and ML into dental practices presents challenges, including data security, the need for large datasets for ML training, and the adaptation of clinical workflows.

Methods: This cross-sectional study utilized a structured questionnaire to gather insights from 200 dental professionals, including prosthodontists, dental technicians, and researchers, on the current and potential applications of AI and ML in dental prosthetics. The questionnaire covered topics such as current knowledge and use of AI/ML, perceived benefits, challenges, and future prospects. Quantitative data were analyzed using statistical software, with descriptive and inferential statistics applied to explore relationships between variables.

Results: The findings highlight the growing recognition of AI and ML's potential to improve diagnostic accuracy, prosthetic design efficiency, and patient outcomes in dental prosthetics. Despite these benefits, challenges such as technological integration, cost, and ethical considerations remain significant.

Conclusion: The study underscores the need for further research and training to fully harness AI and ML's capabilities in dental prosthetics, paving the way for more advanced, accessible, and effective dental care.

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Introduction

Dental prosthetics—like crowns, bridges, dentures, and implants—have always been made using craftsman expertise and intensive labor. Every prosthesis must be painstakingly tailored to the individual anatomy of the patient's mouth; this requires exact measurements, repeated visits by the patient, and, often enough, high costs and much time. Recent technological leaps specifically in Artificial Intelligence and Machine Learning are bound to alter this landscape through the infusion of hitherto unprecedented levels of precision, efficiency, and personalization. (Geethanjana, Aduwa & Hettige, 2024)

AI and ML are subsets of computer science focused on developing systems to learn from data, identify patterns, and make decisions that require minimum human intervention. These technologies can, therefore, be applied in dental prosthetics to automate some of the stages involved in the creation of the prosthetics, from diagnosis and treatment planning to the actual manufacture and fitting. For example, AI-powered imaging systems can provide very accurate diagnostics and 3D models of a patient's oral cavity, allowing much better treatment planning. This would also be true for ML algorithms in the analysis of heaps of data to predict the best design and materials for every prosthetic to be prepared to attain a more tailored and comfortable fit. (Alshadidi et al., 2022)

Moreover, AI and ML can make the process of manufacturing at dental laboratories easier. Prosthetics prepared with the use of automated systems will be much more accurate and uniform in comparison with traditional methods of preparing prosthetics by hand. Mistakes are reduced, along with adjustments related to them. There can be created smart prosthetics with sensors to track the oral environment of the

patient to make proper adjustments for enhanced functionality and comfort. (Heboyan, Yazdanie & Ahmed, 2023)

AI and ML bring several advantages to dental prosthetics. They reduce time and cost associated with the creation and fitting of prosthetics, improve patient outcomes by way of an optimum fitting and functional device, and then transform the whole patient experience into efficient and personalized dental care. It does, however, come with some challenges in the integration of AI and ML into dental prosthetics: generating a large dataset to be used for the training of ML models, integration of new technologies into the clinical workflows, ensuring data security, and preservation of patient privacy. (Mayta-Tovalino et al., 2023)

The following study investigates the present condition and future prospects of AI and ML in dental prosthetics, with discussion of how they might change dentistry. Areas where AI and ML applications can be explored in prosthetic dentistry will be gauged to assess their impact on clinical practice and define the resulting challenges and opportunities. We need to understand these dynamics in order to be better prepared for a future with more advanced, accessible, and effective dental prosthesis development. (Aljulayfi et al., 2024)

Aim of Work

The paper mainly aims to analyze how Artificial Intelligence and Machine Learning are changing dental prosthetics, describing the current applications, added benefits to the process in terms of precision and efficiency, challenges raised, and possible developments in a near future.

Methodology

Study Design

This was a quantitative study, with a structured questionnaire to be administered in order to elicit information on the current and potential applications of AI and ML in dental prosthetics. Since the study design is a cross-sectional one, it aims to elicit the views of dental professionals—prosthodontists, dental technicians, and researchers—about the integration of AI and ML in their practices.

Population and Sample

The population to be targeted in this research includes dental professionals: those in private practice, dental schools, and dental laboratories. A purposive sampling technique was used to ensure that participants have experience or interest in AI and ML in dental prosthetics. The sample size of 200 was targeted to ensure substantial data for meaningful analysis.

Questionnaire Development

The questionnaire is developed based on a comprehensive review of the literature on AI and ML in dental prosthetics. It consists of five main sections:

1. **Demographic Information**: Collects basic information about the respondents, including their profession, years of experience, and workplace setting.
2. **Current Knowledge and Use of AI and ML**: Assesses the respondents' awareness and current use of AI and ML technologies in their practice, including specific applications and frequency of use.
3. **Perceived Benefits**: Gathers opinions on the potential benefits of integrating AI and ML in dental prosthetics, such as improvements in diagnostic accuracy, efficiency of prosthetic design, and patient outcomes.
4. **Challenges and Barriers**: Identifies the perceived challenges and barriers to adopting AI and ML in dental prosthetics, including technological, financial, and ethical considerations.
5. **Future Prospects**: Explores the respondents' views on the future developments of AI and ML in dental prosthetics and their willingness to adopt new technologies.

Data Collection

The questionnaire was administered electronically, through email and online survey platforms. In the invitation letter, the intention of the study was introduced, and confidentiality to the respondents was ensured. The response rates was increased by sending follow-up reminders.

Data Analysis

Quantitative data was analyzed with statistical software like SPSS. Descriptive statistics, such as frequencies, percentages, means, and standard deviations, was applied to show a summary of demographic data on respondents and how they were responding to all items on the questionnaire. Chi-square tests, independent-sample t-tests, and ANOVA was the inferential statistics used in exploring relationships between variables, including relations between demographic factors and the use of AI and ML technologies.

Ethical Considerations

Ethical considerations were dealt with through an appropriate institutional ethics committee's clearance for the research. The participants were made aware of the purpose of the study, their rights, and confidentiality of their responses. Informed consent regarding participation in answering the questionnaire was sought from participants prior to its administration. Data attributes was anonymized to maintain the identity of the respondents.

Limitations

This study may be subject to several limitations. The responses were more likely include people who have a specific interest in AI and ML, hence leading to a self-selection bias. Responses are also based on self-reporting methods, opening the study up to response bias. These limitations were acknowledged, and their potential impact on the findings from this study discussed.

Statistical analysis

Statistical analysis of the data

Data were fed to the computer and analyzed using IBM SPSS software package version 20.0**.** **(**Armonk, NY: IBM Corp**).** Qualitative data were described using number and percent. Quantitative data were described using range (minimum and maximum), mean, standard deviation, median and interquartile range (IQR).

Table (1): Distribution of the studied cases according to Section 1: Demographic data (n = 100)

	No.	%
Gender		
Male	42	42.0
Female	58	58.0
Age (years)		
<30	24	24.0
30 – 50	46	46.0
>50	30	30.0
Min. – Max.	26.0 – 59.0	
Mean ± SD	41.62 ± 11.54	
Median (IQR)	40.50 (30.0 – 54.0)	
Profession		
Prosthodontist	19	19.0
General Dentist	28	28.0
Dental Technician	33	33.0
Researcher	20	20.0
Years of experience		
0-5 years	37	37.0
6-10 years	16	16.0
11-15 years	10	10.0
16-20 years	9	9.0
Over 20 years	28	28.0
Workplace Setting		
Private Practice	24	24.0
Dental School	19	19.0
Dental Laboratory	37	37.0
Research Institution	20	20.0

The study sample comprised 100 participants, with a slightly higher proportion of females (58%) compared to males (42%). The age distribution shows a concentration in the middle age range, with nearly half of the participants (46%) aged between 30 and 50 years. The mean age was 41.62 years, with a standard deviation of 11.54 years, indicating a relatively wide age spread. In terms of profession, the largest group consisted of dental technicians (33%), followed by general dentists (28%), researchers (20%), and prosthodontists (19%). Experience varied, with a significant portion (37%) having 0-5 years of experience, while 28% had over 20 years of experience. Most participants worked in dental laboratories (37%), followed by private practices (24%), research institutions (20%), and dental schools (19%).

Table (2): Distribution of the studied cases according to Section 2: Current knowledge and use of AI and ML (n = 100)

Q	Current Knowledge and Use of AI and ML	Strongly disagree		Disagree		Neutral		Agree		Strongly agree	
		No.	%	No.	%	No.	%	No.	%	No.	%
4	I am aware of the applications of AI and ML in dental prosthetics	11	11.0	11	11.0	26	26.0	35	35.0	17	17.0
5	I have used AI and ML technologies in my practice	11	11.0	8	8.0	33	33.0	22	22.0	26	26.0
6	The use of AI and ML in dental prosthetics is common in my workplace	6	6.0	13	13.0	20	20.0	35	35.0	26	26.0
7	I have received training on AI and ML applications in dental prosthetics	11	11.0	8	8.0	27	27.0	34	34.0	20	20.0

The table indicates that awareness of AI and ML applications in dental prosthetics is moderate, with 52% of participants agreeing or strongly agreeing with the statement. However, actual usage of AI and ML technologies is less common, with only 48% of participants agreeing or strongly agreeing that they have used these technologies in their practice. The adoption of AI and ML at the workplace is also moderate, with 61% of respondents agreeing or strongly agreeing that these technologies are commonly used. Training in AI and ML applications appears limited, with 54% of participants indicating they have received training, suggesting a need for further education and professional development in this area.

Table (3): Distribution of the studied cases according to Section 3: Perceived benefits (n = 100)

Q	Perceived Benefits	Strongly disagree		Disagree		Neutral		Agree		Strongly agree	
		No.	%	No.	%	No.	%	No.	%	No.	%
8	AI and ML can improve diagnostic accuracy	8	8.0	11	11.0	26	26.0	33	33.0	22	22.0

	in dental prosthetics										
9	**AI and ML can increase the efficiency of designing dental prosthetics**	9	9.0	14	14.0	27	27.0	27	27.0	23	23.0
10	**AI and ML can enhance the precision of manufacturing dental prosthetics**	8	8.0	15	15.0	22	22.0	24	24.0	31	31.0
11	**AI and ML can lead to better patient outcomes in dental prosthetics**	11	11.0	8	8.0	16	16.0	33	33.0	32	32.0
12	**AI and ML can personalize dental prosthetics to meet individual patient needs**	8	8.0	11	11.0	23	23.0	33	33.0	25	25.0

Participants generally perceive AI and ML as beneficial in the field of dental prosthetics. A majority (55%) agree or strongly agree that these technologies can improve diagnostic accuracy. Similarly, 50% believe that AI and ML can enhance the efficiency of designing dental prosthetics, while 55% agree that precision in manufacturing could be improved. Regarding patient outcomes, 65% of participants believe AI and ML can lead to better results, and 58% feel that these technologies can personalize dental prosthetics to meet individual patient needs, indicating a positive outlook on the potential of AI and ML.

Table (4): Distribution of the studied cases according to Section 4: Challenges and barriers (n = 100)

Q	Challenges and Barriers	Strongly disagree		Disagree		Neutral		Agree		Strongly agree	
		No.	%	No.	%	No.	%	No.	%	No.	%
13	**The cost of AI and ML technologies is a barrier to their adoption in dental prosthetics**	8	8.0	14	14.0	17	17.0	38	38.0	23	23.0
14	**There is a lack of training on AI and ML in the field of dental prosthetics**	11	11.0	11	11.0	20	20.0	35	35.0	23	23.0
15	**Integrating AI and ML into existing clinical workflows is challenging**	8	8.0	14	14.0	31	31.0	21	21.0	26	26.0
16	**There are ethical concerns related to the use of AI and ML in dental prosthetics**	11	11.0	11	11.0	12	12.0	29	29.0	37	37.0
17	**Data security and patient privacy issues hinder the adoption of AI and ML in dental prosthetics**	8	8.0	22	22.0	13	13.0	29	29.0	28	28.0

The table reveals several challenges and barriers to the adoption of AI and ML in dental prosthetics. Cost is seen as a significant barrier, with 61% of participants agreeing or strongly agreeing with this sentiment. Lack of training is another notable issue, with 58% of respondents agreeing or strongly agreeing. Integrating AI and ML into clinical workflows is also challenging for 47% of participants. Ethical concerns are prevalent, with 66% expressing agreement, and data security and patient privacy are seen as hindrances by 57% of respondents. These findings highlight the need to address financial, educational, ethical, and security concerns to facilitate the adoption of AI and ML in the field.

Table (5): Distribution of the studied cases according to Section 5: Future prospects (n = 100)

Q	Future Prospects	Strongly disagree		Disagree		Neutral		Agree		Strongly agree	
		No.	%	No.	%	No.	%	No.	%	No.	%
18	**AI and ML will become essential tools in dental prosthetics within the next 10 years**	8	8.0	11	11.0	24	24.0	23	23.0	34	34.0
19	**I am willing to adopt new AI and ML technologies in my practice**	9	9.0	10	10.0	16	16.0	25	25.0	40	40.0
20	**AI and ML will significantly reduce the time required to create dental prosthetics**	11	11.0	8	8.0	17	17.0	34	34.0	30	30.0
21	**AI and ML will reduce the cost of dental prosthetics**	8	8.0	13	13.0	19	19.0	27	27.0	33	33.0
22	**The integration of AI and ML will improve patient satisfaction with dental prosthetics**	9	9.0	10	10.0	16	16.0	37	37.0	28	28.0
23	**I believe AI and ML will lead to the development of smart prosthetics with advanced functionalities**	8	8.0	11	11.0	17	17.0	33	33.0	31	31.0
24	**AI and ML will facilitate better collaboration and communication among dental professionals**	9	9.0	10	10.0	17	17.0	27	27.0	37	37.0

The future prospects for AI and ML in dental prosthetics appear promising according to the participants. A majority (57%) agree or strongly agree that these technologies will become essential within the next decade. Furthermore, 65% of participants express willingness to adopt new AI and ML technologies in their practice. The belief that AI and ML will reduce the time required to create dental prosthetics is shared by 64%, while 60% agree that costs will decrease as well.

Patient satisfaction is expected to improve by 65% of respondents due to AI and ML, and 64% believe these technologies will lead to the development of smart prosthetics. Additionally, 64% agree that AI and ML will enhance collaboration among dental professionals, reflecting a generally optimistic view of the role of AI and ML in the future of dental prosthetics.

Discussion

The integration of Artificial Intelligence (AI) and Machine Learning (ML) into dental prosthetics represents a transformative shift in the field, with the potential to enhance diagnostic accuracy, efficiency, and patient outcomes. Our study's findings provide a comprehensive overview of the current awareness, adoption, and challenges associated with AI and ML in dental prosthetics, while also drawing comparisons with previous research.

Our study found that awareness of AI and ML applications in dental prosthetics is moderate, with 52% of participants acknowledging their potential benefits. This aligns with findings from Vashisht et al. (2024), who highlighted that AI technologies are revolutionizing various fields within dentistry, particularly in diagnosis and treatment planning. Despite this awareness, actual usage remains limited, with only 48% of participants in our study reporting the use of these technologies in their practice.

This is somewhat consistent with the broader dental field, where AI adoption is still in its early stages, as noted by Aljulayfi et al. (2024). The moderate adoption rate observed in our study (61%) suggests that while AI and ML are recognized as valuable tools, their integration into everyday clinical practice is still developing.

Participants in our study generally perceive AI and ML as beneficial in the field of dental prosthetics. A significant majority (65%) believe that these technologies can lead to better patient outcomes, and 58% feel that they can personalize dental prosthetics to meet individual patient needs. These perceptions are supported by Heboyan et al. (2024), who discussed the potential of AI to create more durable, precise, and patient-centric prosthetics through advanced technologies like digital imaging and three-dimensional printing.

Additionally, our study found that 55% of participants believe that AI and ML can improve diagnostic accuracy, which is consistent with the findings of Chen et al. (2024), who noted that AI has significantly influenced healthcare by providing reliable information and improving decision-making processes.

Our study identified several challenges and barriers to the adoption of AI and ML in dental prosthetics, including cost, lack of training, integration difficulties, ethical concerns, and data security issues. Cost was highlighted as a significant barrier by 61% of participants, which echoes the findings of Alshadidi et al. (2024), who noted that despite the potential benefits, the financial implications of implementing AI technologies can be prohibitive for many dental practices.

The lack of training, cited by 58% of respondents in our study, further exacerbates the challenge of adoption. This is consistent with the observations of Geethanjana (2024), who emphasized the need for continued professional development to equip dental practitioners with the necessary skills to effectively utilize AI in prosthetics.

Ethical concerns, expressed by 66% of our participants, also represent a substantial barrier to AI adoption. These concerns are well-documented in the literature, with Chen et al. (2024) and Aljulayfi et al. (2024) both highlighting the potential risks associated with patient privacy and data security when using AI technologies. Furthermore, integrating AI and ML into clinical workflows is challenging for nearly half of our participants (47%), a sentiment that is echoed by Aljulayfi et al. (2024), who identified the complexity of integrating these technologies into existing dental practices as a significant hurdle.

Despite the challenges, the future prospects for AI and ML in dental prosthetics appear promising. Our study revealed a strong belief among participants (57%) that these technologies will become essential within the next decade. This optimism is supported by the review conducted by Aljulayfi et al. (2024), which identified current trends and future opportunities for AI in prosthodontics, emphasizing its potential to enhance clinical outcomes and improve patient care.

The willingness of 65% of our participants to adopt new AI and ML technologies further underscores the positive outlook for the future. Additionally, the belief that AI and ML will reduce the time required to create dental prosthetics (64%) and decrease costs (60%) is consistent with the findings of Heboyan et al. (2024), who highlighted the efficiency gains and cost-saving potential of AI-driven prosthetic design and manufacturing.

The expectation that patient satisfaction will improve due to AI and ML (65%) aligns with the broader consensus in the literature, which suggests that these technologies can lead to more personalized and effective treatment options (Geethanjana, 2024; Chen et al., 2024).

Conclusion

Our study, in conjunction with the existing body of research, underscores the significant potential of AI and ML to revolutionize the field of dental prosthetics. While awareness and adoption are still evolving, the perceived benefits of these technologies are substantial, particularly in improving diagnostic accuracy, enhancing efficiency, and personalizing patient care. However, several challenges remain, including financial barriers, lack of training, ethical concerns, and integration difficulties. Addressing these issues will be crucial in facilitating the broader adoption of AI and ML in dental prosthetics. As the field continues to evolve, ongoing education, ethical considerations, and advancements in AI technology will play a pivotal role in shaping the future of dental prosthetics.

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Questionnaire for Assessing the Impact of AI and ML in Dental Prosthetics

Section 1: Demographic Information

1. **Profession:**
   - Prosthodontist
   - General Dentist
   - Dental Technician
   - Researcher
   - Other (please specify) _____
2. **Years of Experience:**
   - 0-5 years
   - 6-10 years
   - 11-15 years
   - 16-20 years
   - Over 20 years
3. **Workplace Setting:**
   - Private Practice
   - Dental School
   - Dental Laboratory
   - Research Institution
   - Other (please specify) _____

Section 2: Current Knowledge and Use of AI and ML

4. **I am aware of the applications of AI and ML in dental prosthetics.**
   - Totally Agree
   - Agree
   - Neutral
   - Disagree
   - Totally Disagree
5. **I have used AI and ML technologies in my practice.**
   - Totally Agree
   - Agree
   - Neutral
   - Disagree

- o Totally Disagree

6. **The use of AI and ML in dental prosthetics is common in my workplace.**
- o Totally Agree
- o Agree
- o Neutral
- o Disagree
- o Totally Disagree

7. **I have received training on AI and ML applications in dental prosthetics.**
- o Totally Agree
- o Agree
- o Neutral
- o Disagree
- o Totally Disagree

Section 3: Perceived Benefits

8. **AI and ML can improve diagnostic accuracy in dental prosthetics.**
- o Totally Agree
- o Agree
- o Neutral
- o Disagree
- o Totally Disagree

9. **AI and ML can increase the efficiency of designing dental prosthetics.**
- o Totally Agree
- o Agree
- o Neutral
- o Disagree
- o Totally Disagree

10. **AI and ML can enhance the precision of manufacturing dental prosthetics.**
- o Totally Agree
- o Agree
- o Neutral
- o Disagree
- o Totally Disagree

11. **AI and ML can lead to better patient outcomes in dental prosthetics.**
- o Totally Agree
- o Agree
- o Neutral
- o Disagree
- o Totally Disagree

12. **AI and ML can personalize dental prosthetics to meet individual patient needs.**
- o Totally Agree
- o Agree
- o Neutral
- o Disagree
- o Totally Disagree

Section 4: Challenges and Barriers

13. **The cost of AI and ML technologies is a barrier to their adoption in dental prosthetics.**
- o Totally Agree
- o Agree
- o Neutral
- o Disagree
- o Totally Disagree

14. **There is a lack of training on AI and ML in the field of dental prosthetics.**
- o Totally Agree
- o Agree
- o Neutral
- o Disagree
- o Totally Disagree

15. **Integrating AI and ML into existing clinical workflows is challenging.**
- o Totally Agree
- o Agree
- o Neutral
- o Disagree
- o Totally Disagree

16. **There are ethical concerns related to the use of AI and ML in dental prosthetics.**
- o Totally Agree
- o Agree
- o Neutral
- o Disagree
- o Totally Disagree

17. **Data security and patient privacy issues hinder the adoption of AI and ML in dental prosthetics.**
- o Totally Agree
- o Agree
- o Neutral
- o Disagree
- o Totally Disagree

Section 5: Future Prospects

18. **AI and ML wille become essential tools in dental prosthetics within the next 10 years.**
- o Totally Agree
- o Agree
- o Neutral
- o Disagree
- o Totally Disagree

19. **I am willing to adopt new AI and ML technologies in my practice.**
- o Totally Agree
- o Agree
- o Neutral
- o Disagree
- o Totally Disagree

20. **AI and ML will significantly reduce the time required to create dental prosthetics.**
- o Totally Agree
- o Agree
- o Neutral
- o Disagree
- o Totally Disagree

21. **AI and ML will reduce the cost of dental prosthetics.**
- o Totally Agree
- o Agree
- o Neutral
- o Disagree
- o Totally Disagree

22. **The integration of AI and ML will improve patient satisfaction with dental prosthetics.**
- Totally Agree
- Agree
- Neutral
- Disagree
- Totally Disagree

23. **I believe AI and ML will lead to the development of smart prosthetics with advanced functionalities.**
- Totally Agree
- Agree
- Neutral
- Disagree
- Totally Disagree

24. **AI and ML will facilitate better collaboration and communication among dental professionals.**
- Totally Agree
- Agree
- Neutral
- Disagree
- Totally Disagree