

Original Research Article

Perceptions, benefits, and challenges of smart prosthesis with embedded sensors for monitoring oral health: A survey-based study

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Abstract

Background: Smart prostheses integrated with embedded sensors are emerging as an innovative advancement in prosthodontics, enabling real-time monitoring of intraoral conditions and improving early detection of prosthetic complications.

Objective: To evaluate the awareness, perception, perceived benefits, and challenges associated with the use of smart prostheses among dental professionals.

Materials and Methods: A cross-sectional study was carried out on 100 dentists with the help of a structured questionnaire that included questions about awareness of the use of smart prostheses, perception score of this technology, potential benefits, drawbacks, and willingness to implement smart prostheses in practice. Data were statistically analyzed with regards to comparison of perceptions of those dental professionals who had heard about smart prostheses and those who had not. Furthermore, a connection between awareness and acceptance of smart prostheses was determined.

Results: In general, 60% of respondents were aware of smart prostheses. Participants who knew about this innovation showed significantly higher perception scores (4.05 ± 0.6 versus 3.23 ± 0.8 ; $p < 0.001$) than unaware respondents. Advantages of smart prostheses included enhanced patient monitoring and early complication detection. However, even though 52% of the participants indicated a readiness to adopt the innovation, there is no statistically significant relationship between awareness and readiness ($p = 0.438$).

Conclusion: The dentists had a moderate level of awareness, and their views on smart prostheses were mainly positive. While acknowledging their advantages, fears about costs and data security might hinder their widespread adoption in prosthodontics.

Keywords: Smart prosthesis, Embedded sensors, Oral wearable devices, Digital dentistry, Biosensors, Prosthodontics innovation, Data privacy, Artificial intelligence (AI) in dentistry, Internet of Things (IoT), Intraoral health monitoring.

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1. Introduction

The field of dentistry, especially prosthodontics, has been undergoing a gradual shift from mechanical to digitally assisted and precision-guided treatments. The advent of computer-aided design and computer-aided manufacturing (CAD/CAM), three-dimensional printing, intraoral scanning, and digital workflow integration has brought about a paradigm shift in restorative dentistry.¹ These advancements not only result in an increase in accuracy in fabrication but also impact clinical decision-making and patient follow-up. Thus, prosthodontic treatment can now be defined more in terms of reproducibility, efficiency, and accuracy rather than variability.² In this rapidly evolving digital environment, there has been a gradual shift towards a more dynamic approach to prosthetic rehabilitation. In conventional prosthesis, once inserted, they function in a passive state until a problem occurs. However, with this new approach

to 'smart' prosthesis, there seems to be a prospect of incorporating micro-electromechanical systems and biosensors directly into the prosthetic framework.³ This biosensor would allow for the continuous monitoring of intraoral conditions in real-time, which would include occlusal load, salivary pH, temperature, humidity, and other specific biochemical changes. This would allow for continuous point acquisition, which would change the state from passive to active. The clinical significance of this paradigm shift is considerable. The continuous monitoring of occlusal forces would, in theory, allow for the detection of occlusal overload or parafunctional habits before the actual breakdown of the prosthesis. Likewise, minor changes in temperature or saliva composition would, in theory, provide a warning system for inflammation or peri-implantitis.⁴ Rather than scheduling a patient for clinical visits, the use of a sensor would provide the promise of a proactive approach, blending the art and science of prosthodontics with the principles of preventative healthcare. The use of digital sensing technology would be a paradigm shift.

The diagnostic potential of the salivary sample provides a fresh outlook to the above clinical scenario. Saliva is recognized for the wide range of biomarkers it possesses, which is a reflection of oral as well as general health. Recent advances in biosensor technology have indicated the potential of analyte detection of glucose, cortisol, and metabolic markers via intraoral devices.⁵ If this technology is harnessed appropriately for prosthetic device development, it may potentially open the doors for the expansion of the scope of the field of prosthodontics from a rehabilitative function to a supportive health monitoring function. Nevertheless, the mere fact of technology being feasible does not automatically translate into clinical acceptability. The history of the adoption of digital dentistry in the past has clearly indicated that clinical acceptability is largely dependent upon the practitioner's perception, workability, financial viability, and confidence in the technology's long-term viability.⁶ Innovations that have demonstrated considerable promise in the laboratory have often failed to achieve clinical acceptability in practice, especially if they have a higher cost implication. However, there are new issues associated with smart prosthesis, such as data transfer, calibration, maintenance strategies, and the use of wireless technology in a confined environment. The issue of economic viability is still a major concern. The use of micro-electronics, biocompatible sensor units, and customized manufacturing techniques, by itself, increases the production costs. On the other hand, the continuous inflow of biological data has already raised significant questions regarding patient confidentiality, data storage,

and regulatory issues under the umbrella of digital health.⁷ In a world where violations of data security are increasingly coming under the spotlight, the handling of sensor data is sure to emerge as a major factor in professional trust.

Furthermore, there are inherent engineering problems associated with the oral environment. The constant exposure to moisture, masticatory forces, temperature fluctuations, and microbial flora can create a scenario that might have a detrimental effect on the longevity of the sensors and stability of their calibration.⁸ The long-term viability of intraoral sensing, therefore, becomes a major issue. Secondly, the ability of the clinician to interpret the data generated and use it meaningfully assumes a working knowledge of digital analytics and technology.⁹

In this regard, the current study aims to investigate the perceptions, expected benefits, and perceived challenges of dental professionals regarding smart prostheses that utilize embedded sensors for intraoral health monitoring. Using a structured survey approach, this study aims to offer an understanding of current awareness levels and shed light on factors that may promote or impede the clinical adoption of sensor-based prosthodontic technologies.

2. Aim and Objectives

2.1. Aim

To assess the perceptions, benefits, and challenges of smart prosthesis with embedded sensors for monitoring oral health among dental professionals.

2.2. Objectives

The aims and objectives of the present study include evaluating the perceptions of dental professionals about the use of smart prostheses, along with the embedded sensors. Additionally, the study aims to identify the potential advantages that could be achieved by the use of the smart prosthetic systems for the monitoring and maintenance of oral health parameters. Moreover, the study aims to identify the challenges and limitations that could be faced during the use of the smart prostheses, along with the embedded sensors.

3. Materials and Methods

The study design of this cross-sectional observational study was carried out over a period of six months at Seema Dental College and Hospital, Rishikesh.

3.1. Study design

The current study was designed as a cross-sectional survey using pre-validated questionnaires to gather contemporary professional views on smart prosthetic systems. The study was conducted at Seema Dental College and Hospital, Rishikesh, over a period of six months

3.2. Study population

The study population consisted of participants from three main groups.

1. Teaching faculty members were included in the study because of their exposure to contemporary research and developments in the curriculum.
2. Postgraduate students pursuing Master of Dental Surgery (MDS) courses were the second group, representing professionals in advanced specialty courses who are likely to have greater exposure to recent technological developments.
3. Private practitioners actively involved in regular clinical practice constituted the third group, whose views would represent practical feasibility and economic viability.

3.3. Sampling strategy

A purposive sampling strategy was used for participant recruitment. The choice of this sampling strategy was deliberate, as the aim of the study was not to generalize the findings but to collect informed views of people directly involved in prosthodontic care and dental education.

1. Sample size: The target sample size was set at 100 participants (n=100).
2. Target population: The target population included Teaching Faculty, Postgraduate Students, and Practitioners.

The data for the study was obtained through the administration of a structured questionnaire. It was designed with the aim of evaluating professional awareness of, and attitudes toward, smart prostheses incorporating embedded sensor technology. The questions were developed following a review of literature on the adoption of digital dentistry technology and technology perception studies.

The questions in the questionnaire were divided into the following five sections: demographic questions, questions on the level of basic awareness of the technology, questions on the benefits of the technology, questions on the possible problems that may arise from the technology, and questions on the adoption of the

technology. Closed-ended questions were used in the questionnaire for the purpose of facilitating the quantification of the data obtained from the study.

The questionnaire was created in such a manner that it could be filled out electronically via Google Forms. This not only helped the respondents fill out the questionnaire at their own convenience, but it also helped in the automatic recording of the responses. Moreover, the electronic form helped to reduce the chances of errors during the transcription process and provided a live update on the process.

However, prior knowledge about the concept of smart prosthesis technology was not a prerequisite for the respondents. This is because the study aimed to incorporate the difference in the level of awareness about the concept, and the questionnaire was created in a manner that would enable the comparison between the two sets of people.

3.4. Eligibility criteria

Strict eligibility criteria were applied to ensure the quality and relevance of the data:

3.5. Inclusion criteria

1. Dental professionals including teaching faculty, postgraduate (MDS) students, and private practitioners.
2. Individuals actively engaged in clinical practice or academic dental training.
3. Participants willing to provide informed consent.
4. Professionals irrespective of prior awareness or exposure to smart prosthesis technology.

3.6. Exclusion criteria

1. Individuals who declined to provide informed consent.
2. Questionnaires submitted with incomplete or missing essential information.
3. Responses lacking key demographic or evaluative data required for statistical analysis.

3.7. Methodological procedure

The research procedure was conducted in a systematic manner over a period of six months as follows:

3.7.1. Identification of the research participants

The research participants were identified among the dental professionals based on the predetermined criteria set in the research. The research participants included mainly faculty members, postgraduate students, and

private practitioners who could provide informed professional opinion.

3.7.2. Distribution of the survey

The final research questionnaire was converted to an electronic format using Google Forms. The survey was distributed to the potential research participants through electronic communication channels such as emails and WhatsApp messages.

3.7.3. Collection of the research responses

The research participants were free to respond to the questionnaire within the set time. The responses were collected automatically by the online platform.

3.7.4. Screening and validation of the research data

After the expiration of the set time, the forms were screened to ensure completeness. Any incomplete forms were discarded to ensure accuracy in data analysis.

3.7.5. Compilation of the research data

The complete forms were collected from Google Forms and compiled in Microsoft Excel for coding and preparation before statistical analysis.

3.8. Statistical analysis

After the data was cleaned, statistical analysis was done to understand the trends of the responses. The analysis was done for the descriptive trends as well as the comparisons between different subgroups of the study population.

To understand the demographic distribution of the data, descriptive statistics analysis was done. The analysis was done for the categorical data, which included awareness status, challenges, and willingness towards smart prostheses. The data was presented in the form of frequencies as well as percentages, giving a holistic idea of the trends of the data collected from the participants.

To understand the associations between different variables, inferential analysis was done. The chi-square test was done, which helped understand whether awareness status had an impact on the willingness of the participants towards smart prostheses.

To understand the perception of smart prostheses, as well as the benefits, independent t-tests were done between the means of the participants who were aware of smart prostheses and those who were not. To understand if the results are statistically significant, a p-value of less than or equal to 0.05 was considered statistically significant, indicating that the results were not due to chance but had a real difference.

4. Results

A total of 100 dental professionals participated in the survey and fulfilled the criteria for inclusion in the final analysis. Of the surveyed dental professionals, postgraduate students accounted for the largest proportion (44%), followed by private practitioners (30%) and faculty members (26%). In relation to the age distribution of the participants, nearly half of the respondents (45%) were aged 30 years or younger, 35% were between 31 and 45 years, and the remaining 20% were above 45 years. Regarding the awareness of smart prostheses with sensor integration, 60% of the participants were found to have prior knowledge of the idea, while 40% reported that it was the first time they had heard of the concept. This difference in awareness was found to affect the overall perception scores.

Participants who were aware of smart prosthetic systems had higher mean perception scores (4.05 ± 0.6) than those who did not have prior knowledge of the idea (3.23 ± 0.8). The difference was found to be significant using an independent sample t-test ($t = 5.20$, $p < 0.001$), indicating that those with prior knowledge of the idea tended to have a more positive perception.

A similar trend was also found when the analysis of perceived benefits was considered. Respondents with prior awareness showed a higher mean benefit score (7.7 ± 1.2), whereas those without awareness showed a comparatively lower mean benefit score (6.2 ± 1.5). This trend shows that awareness of the technology may have a positive effect on the recognition of its potential clinical benefit.

Despite these encouraging findings, some practical issues also arose. The most common issue was the high cost, which was identified by 65% of the respondents. Concerns about data privacy and security were identified by 48%, whereas 41% had reservations about the long-term reliability and technical longevity of the technology in the oral environment. Other concerns included usability and the need for professional training.

Regarding the intention to adopt, 52% of the respondents stated that they would be willing to adopt smart prostheses in their clinical practice if they were available. Postgraduate students seemed to be comparatively more receptive to the idea of adoption. However, the chi-square test showed that the intention to adopt was not significantly related to prior awareness ($\chi^2 = 0.602$, $p = 0.438$).

The graphical representations (**Figure 1-Figure 4**) illustrate these trends, including distribution of

awareness levels, variation in perception scores, comparison of benefit scores based on awareness status, and willingness to adopt across professional categories.

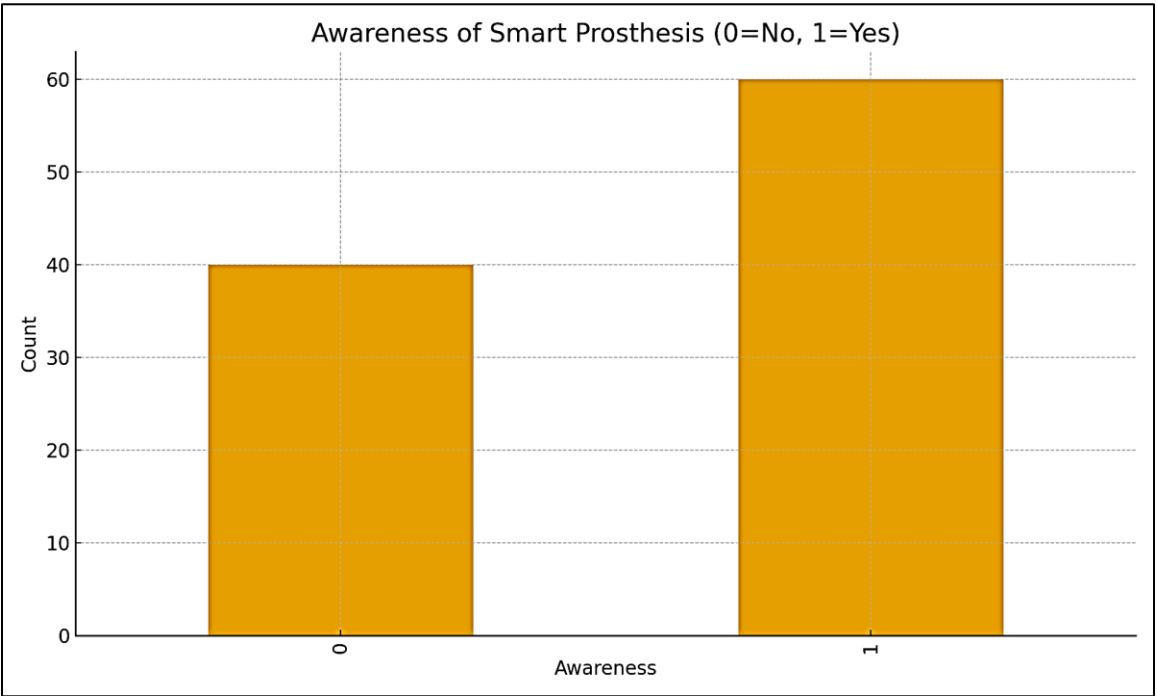


Figure 1: Awareness of smart prostheses among participants

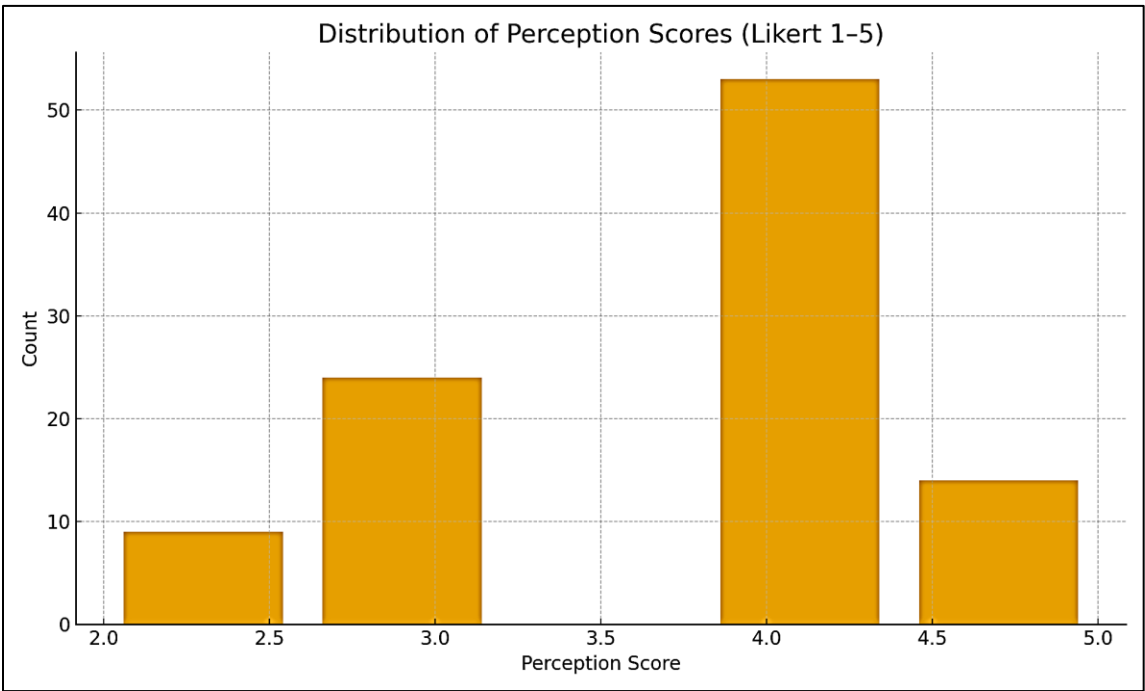


Figure 2: Distribution of perception scores (Likert scale 1–5)

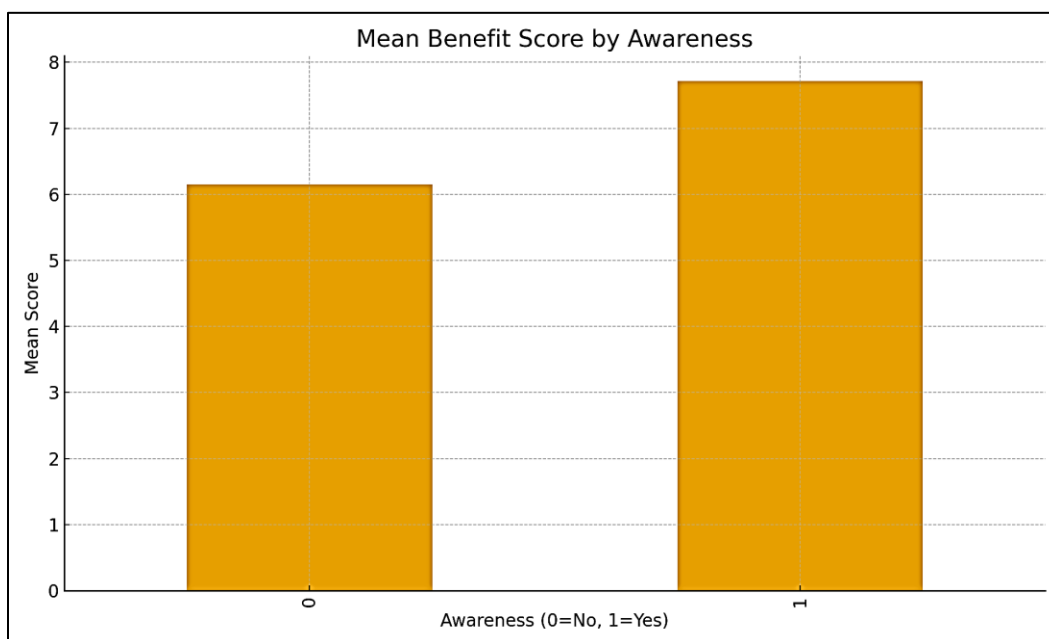


Figure 3: Mean perceived benefit score by awareness status

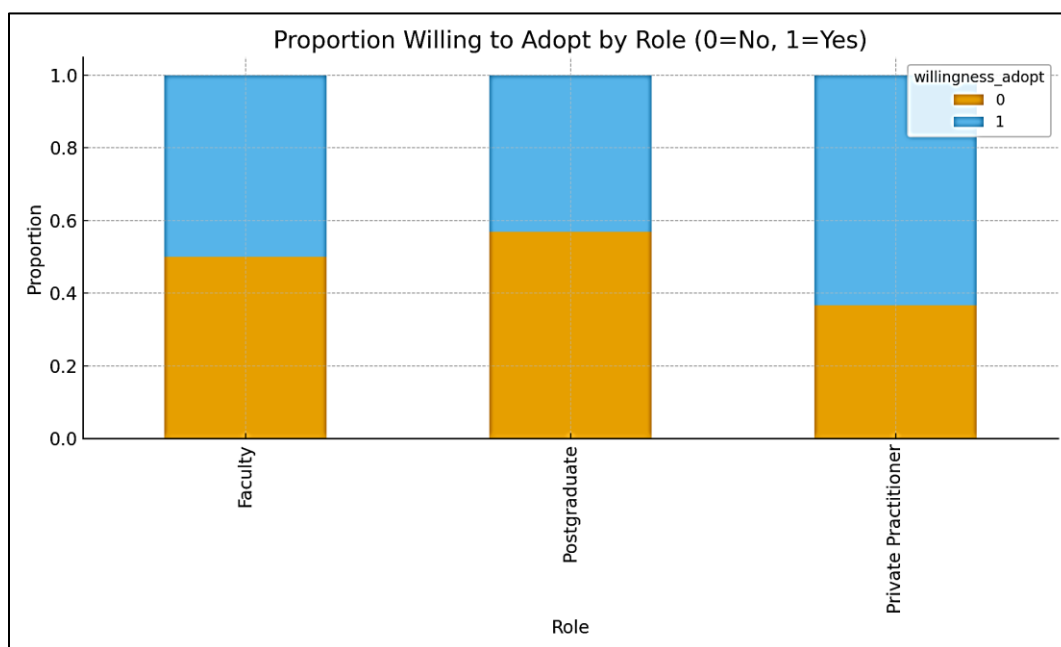


Figure 4: Proportion of participants willing to adopt by professional role

5. Discussion

The current investigation showed how dental professionals view smart prostheses with built-in sensing systems. While this technology is still in development, many in the clinical field are already aware of this. What was also noticed was that the level of familiarity with the concept appeared to influence the level of positive assessment. Those who were already familiar with the concept scored well in their perceptions and benefits. This is understandable. Many studies on digital health and the adoption of technology in healthcare have shown

that one of the factors influencing the adoption of digital health is the level of awareness. Li et al.¹⁰ reported that clinicians who were aware of the oral wearable sensor system were more confident in their use. This study's results also show this to be true. What was also mentioned by the respondents was the potential benefits to patients. Monitoring in the mouth was seen to be beneficial. This would help in identifying occlusal overload, habits such as grinding, and any biological issues. Unlike traditional prosthetics that must be checked periodically in the dentist's office, sensors in these systems would continually monitor. This capability

is consistent with the preventive approach that modern healthcare has taken. Past studies have proven that technologies for real-time monitoring have been effective in providing earlier interventions as well as longer-lasting prostheses. Timpel et al. another notable feature is the potential that this technology has for diagnostic purposes.¹¹ As a medium, saliva has been noted to be effective for diagnosing various conditions. Zheng et al. noted that there is potential for integrating smart biosensors for saliva analysis. This means that prostheses have potential uses beyond providing support.¹² Smart prostheses could be useful not only for dental care but also for healthcare integration.

However, enthusiasm about this technology was also accompanied by more tangible concerns. The cost was the most frequently mentioned barrier, especially among dental practitioners. Financial factors have historically been significant in the adoption of digital technologies in dentistry.¹³ Financial factors often impede the adoption of new fabrication technologies, especially when the benefits are obvious. This was also evident in the present results. Simply knowing the benefits does not equate to wanting to invest.

Another concern was related to data privacy and security. Collecting biological and behavioral data also evoked other ethical concerns compared to traditional prosthodontics.¹⁴ With the development of digital health technologies, factors such as consent and data ownership become crucial to ensure the adoption of prosthetic devices equipped with sensors, strong regulations in these fields would also be essential. Questions about durability and reliability would also be crucial. The oral cavity is a harsh environment in which to operate. There are moisture, temperature fluctuations, masticatory forces, and bacteria. Ensuring the reliable performance of sensors in these conditions would also be a significant challenge. Further improvement in waterproofing, calibration stability, and biocompatibility is required for these sensing systems to function effectively over the long term.¹⁵ The participants in this study seemed to understand these technical challenges. It was interesting to note that while awareness was a strong influencer in perception scores, it was not a strong influencer in willingness to adopt. This is an important point. It suggests that acceptance and practice are driven by different factors. Alhallak K et al. while acceptance can be driven by theory, practice can be driven by practicality, cost-benefit considerations, and evidence. A similar pattern has been noted in previous shifts to digital technologies in prosthodontics.¹⁶ The initial adoption of CAD/CAM systems and guided implant surgery was slow, often limited by perceived learning curves and required

investments. Smart prostheses may take a similar route if clinical validation studies confirm their reliability and cost-effectiveness. Aeran H et al. applications such as nanomaterials, nanodiagnostics, and nanorobotics are expected to transform clinical practice by improving biocompatibility, strength, and effectiveness of dental treatments.¹⁷

Professionals seem open to innovation but are practically focused on cost, training, and protecting patient data. Closing this gap will likely need collaboration among prosthodontists, biomedical engineers, data scientists, and regulatory bodies. Educational programs that improve digital literacy may also help lessen uncertainty and build confidence in interpreting data the results of the current study emphasize the increased interest of dental professionals in smart prostheses with sensors. The potential of smart prostheses to improve the monitoring of oral health conditions in real time has been a topic of interest.

6. Conclusion

The results of this survey indicate that dental professionals have positive perceptions about smart prosthetics and sensor-embedded technology. More awareness is related to perception and benefit, but this is not necessarily linked to implementation. While more than half of the sample were willing to implement this type of technology into practice, more than half also had concerns about cost, data privacy, and reliability.

High financial costs were found to be the most important barrier, especially for dental professionals in private practice, and concerns about ongoing monitoring of data and information management. Moreover, lack of knowledge about how long this sensor will last in the oral environment is another area that needs further development in this type of technology. Future development in this area will be important for successful implementation in prosthodontic practice.

Ethical Approval

This questionnaire-based study did not require formal ethical approval. Participation was voluntary with informed consent, and confidentiality was maintained.

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None.

Conflict of Interest

None.

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