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Artificial intelligence in digital dentistry: applications in prosthetic planning

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Abstract

Artificial Intelligence (AI) has emerged as a major technological advancement in digital dentistry, particularly in the context of prosthetic planning. Its integration with technologies such as CAD/CAM systems and additive manufacturing has been widely associated with improvements in accuracy, efficiency, and treatment personalization. However, despite these technological advances, questions remain regarding the actual clinical effectiveness of such applications. This study aims to critically analyze the applications of Artificial Intelligence in digital dentistry, with an emphasis on prosthetic planning, addressing its evidence, limitations, and clinical implications. This is a narrative literature review with a qualitative and integrative approach, conducted through searches in PubMed, ScienceDirect, and Scopus databases, including publications from 2016 to 2025. The findings indicate that, although AI shows potential to optimize diagnostic and therapeutic processes, most available evidence is derived from experimental studies and digital simulations, with limited clinical validation. Furthermore, limitations related to data quality, algorithm transparency, and practical applicability were identified. It is concluded that, despite its promising potential in prosthodontics, the clinical effectiveness of AI remains only partially established, highlighting the need for robust clinical studies to support its safe and evidence-based integration into dental practice.

Keywords: Artificial Intelligence; Digital Dentistry; Dental Prosthesis; CAD/CAM; Prosthetic Planning.

INTRODUCION

The incorporation of digital technologies in dentistry has frequently been framed as a paradigm shift capable of redefining diagnostic and therapeutic processes, particularly within the field of prosthodontics. Tools such as intraoral scanning, CAD/CAM systems, and additive manufacturing have been widely associated with gains in precision and clinical efficiency. However, despite growing enthusiasm, the literature still lacks consistent evidence supporting the superiority of these digital workflows over conventional approaches in terms of long-term clinical outcomes. In this context, although digitalization represents an undeniable technical advancement, its translation into measurable clinical benefits remains largely supported by indirect inferences and predominantly laboratory-based studies (IOSIF et al., 2024).

The emergence of Artificial Intelligence (AI) as a central component of digital dentistry further intensifies this debate by introducing systems capable of automating clinical decision-making based on large-scale data processing. Machine learning models and neural networks have demonstrated high accuracy in specific tasks, such as image analysis and pattern recognition, suggesting potential to support therapeutic planning. However, the extrapolation of these findings to real-world clinical settings raises important concerns, as many of these systems are trained on limited, poorly heterogeneous datasets that are often not representative of the clinical variability encountered in daily practice (ROKAYA et al., 2024). Consequently, the external validity of these models and their generalizability remain critical issues that are still insufficiently explored.

Within prosthodontics, the application of AI in prosthetic planning has been associated with promises of increased predictability, personalization, and reduction of human error. Intelligent systems are capable of integrating multiple variables—including anatomical, occlusal, and esthetic data—into complex decision-making processes, theoretically enhancing clinical precision. Nevertheless, the literature reveals a predominance of descriptive studies or digitally simulated models, with limited robust clinical validation. Furthermore, the growing reliance on opaque "black box" algorithms raises concerns regarding the transparency of automated decisions and the potential displacement of clinical judgment toward systems whose internal logic is not always fully understood by practitioners (YESLAM; VON MALTZAHN; NASSAR, 2024; VIDHYADHAR et al., 2025).

The integration of AI with CAD/CAM technologies and three-dimensional printing has often been described as a driver of significant advances in the fabrication of dental prostheses, including improvements in marginal fit, mechanical properties, and production efficiency. Indeed, evidence suggests important operational benefits, such as reduced chair time and optimized workflows. However, these advantages do not necessarily translate directly into improved clinical outcomes or increased longevity of restorations, and there remains a limited number of controlled clinical studies confirming these benefits in real-world populations (CHUCHULSKA et al., 2024; ERDAŞ; YANIKOĞLU, 2024; BHARGAV et al., 2025). This gap highlights a potential discrepancy between technical performance and clinical effectiveness, which is often overlooked in the literature.

Additionally, the growing adoption of AI in dental practice is accompanied by structural, ethical, and epistemological challenges that extend beyond the technological dimension. Barriers such as high costs, the need for professional training, and limitations in data quality coexist with deeper concerns, including algorithmic bias, scientific reproducibility, and clinical accountability in the context of decisions supported by automated systems (BA-ZAR; MEHTIYEVA; ALMIZBAN, 2025). In this scenario, the predominantly optimistic discourse surrounding AI in prosthodontics contrasts with the still incipient consolidation of high-level clinical evidence, revealing a critical gap between technological potential and real-world clinical impact. Therefore, the present study aims to critically analyze the applications of Artificial Intelligence in digital dentistry, with an emphasis on prosthetic planning, discussing its evidence, limitations, and clinical implications in light of the current scientific literature.

METHODOLOGY

The present study is characterized as a narrative literature review, with a qualitative and integrative approach, aimed at critically analyzing the applications of Artificial Intelligence in digital dentistry, with a particular emphasis on prosthetic planning.

The bibliographic search was conducted in the PubMed, ScienceDirect, and Scopus databases, selected for their relevance and broad coverage in the field of health sciences. English-language descriptors combined with Boolean operators were used, including: “Artificial Intelligence,” “Digital Dentistry,” “Prosthodontics,” “CAD/CAM,” “Prosthetic Planning,” and “Machine Learning.” The search strategy was structured to identify studies addressing the application of Artificial Intelligence in digital workflows and prosthetic planning.

Studies published between 2016 and 2025 were included, provided they were available in full text or with a structured abstract, written in English or Portuguese, and directly addressed the use of Artificial Intelligence in prosthodontics or applied digital dentistry. Exclusion criteria comprised duplicate articles, publications not indexed in the selected databases, studies outside the thematic scope, and those lacking sufficient data to support critical analysis.

Study selection was performed in two stages. Initially, a screening based on titles and abstracts was conducted to identify potentially eligible publications. Subsequently, the selected studies were analyzed in full when available. In cases where full texts were not accessible, only articles with structured abstracts containing sufficient methodological and results-related information were considered for analysis.

Data analysis was carried out through a critical qualitative synthesis, focusing on the identification of Artificial Intelligence applications, methodological approaches, key findings, limitations, and clinical implications. The findings were organized into predefined thematic categories, including: applications in prosthetic planning, integration with CAD/CAM systems, use of additive manufacturing, clinical impact, and technological limitations.

RESULTS AND DISCUSSION

The analyzed literature demonstrates that the application of Artificial Intelligence (AI) in digital dentistry, particularly in prosthetic planning, has been widely associated with improvements in diagnostic accuracy, operational efficiency, and therapeutic personalization. Overall, studies indicate that machine learning algorithms and neural networks are capable of analyzing large volumes of clinical and radiographic data, supporting decision-making and enabling the development of more individualized treatment plans (ROKAYA et al., 2024; IOSIF et al., 2024). However, this apparent technological robustness should be interpreted with caution, as most of the available evidence derives from experimental studies, digital simulations, or narrative reviews, with limited validation in real clinical settings, thereby restricting the generalizability of the findings.

Within the specific context of prosthetic planning, AI has been described as a tool capable of integrating complex variables, including anatomical, occlusal, and esthetic data, allowing for the prior simulation of outcomes and optimization of the clinical decision-making process (YESLAM; VON MALTZAHN; NASSAR, 2024; VIDHYADHAR et al., 2025). This predictive modeling capability represents a significant advancement compared to traditional methods, which have historically relied on practitioner experience. Nevertheless, a substantial proportion of these systems operate based on poorly transparent computational models, commonly referred to as "black box" systems, raising concerns regarding the interpretability of results and the reliability of automated decisions. Furthermore, the reliance on frequently limited and poorly heterogeneous datasets compromises the external validity of these algorithms, potentially introducing bias and reducing their clinical applicability (ROKAYA et al., 2024).

The integration of AI with CAD/CAM systems constitutes another central theme identified in the literature, often highlighted as a driver of advancements in prosthetic design automation and laboratory process standardization. Studies suggest that these systems enable the incorporation of esthetic and functional parameters into prosthesis development, as well as the reproducibility of previously established clinical decisions (YESLAM; VON MALTZAHN; NASSAR, 2024). In parallel, advances in materials used in digital workflows, particularly CAD/CAM polymers, have been associated with improvements in mechanical properties and biocompatibility (CHUCHULSKA et al., 2024). However, despite these consistent technical advancements, the literature still presents important gaps regarding the direct correlation between laboratory performance and long-term clinical outcomes, suggesting a potential disconnect between technological innovation and therapeutic effectiveness.

With regard to additive manufacturing, the association between 3D printing and AI has been described as one of the main drivers of transformation in contemporary prosthodontics, enabling greater design flexibility, reduced production time, and decreased material waste (ERDAŞ; YANIKOĞLU, 2024). Additionally, the combination of these technologies allows for the fabrication of highly personalized prostheses, with the potential to improve the fit and functionality of restorations. Nevertheless, despite the reported operational benefits, clinical evidence supporting these advantages remains limited, with a predominance of technical or laboratory-based studies, which hinders the assessment of the real impact of these technologies on relevant clinical outcomes.

From a clinical perspective, few studies provide empirical data directly evaluating the effects of AI in dental practice. One of the most consistent findings relates to reductions in clinical time and improvements in procedural accuracy, such as in implant placement and prosthetic adaptation (BHARGAV et al., 2025). Even so, these findings should be interpreted cautiously, given the small sample sizes and limited methodological diversity of the available studies. Moreover, clinical adoption of AI remains relatively low, despite increasing awareness among professionals, suggesting the presence of significant structural and operational barriers (VIDHYADHAR et al., 2025).

Finally, the critical analysis of the literature indicates that, although AI represents a promising advancement in digital dentistry, its incorporation into clinical practice is still far from fully consolidated. Issues related to cost, the need for professional training, and data quality coexist with more complex challenges, such as algorithmic bias, scientific reproducibility, and ethical accountability in decision-making supported by automated systems (BA-ZAR; MEHTIYEVA; ALMIZBAN, 2025; SIKRI et al., 2023; SINGI et al., 2022). In this context, the predominantly optimistic discourse present in the literature contrasts with the scarcity of robust clinical evidence, highlighting a significant gap between the technological potential of AI and its actual impact on clinical outcomes in prosthodontics. This discrepancy underscores the need for well-designed clinical studies capable of consistently validating the effectiveness of these technologies in prosthetic planning and rehabilitation.

CONCLUSION

The analysis of the literature indicates that Artificial Intelligence has played an increasingly prominent role in digital dentistry, particularly in prosthetic planning, by introducing tools capable of enhancing precision, personalization, and efficiency in both clinical and laboratory workflows. Its integration with technologies such as CAD/CAM and additive manufacturing represents a relevant technical advancement, with the potential to transform contemporary prosthodontic practice.

However, the findings also demonstrate that this technological progress has not been accompanied, to the same extent, by robust clinical evidence confirming its superiority in terms of long-term clinical outcomes. The predominance of experimental studies, digital simulations, and narrative reviews limits the generalizability of the results, highlighting a significant gap between technical performance and clinical effectiveness. Moreover, issues related to algorithmic transparency, data quality, and technological dependence impose additional challenges to the critical adoption of these tools.

In this context, the use of Artificial Intelligence in prosthodontics should not be understood as a replacement for clinical judgment, but rather as a complementary resource whose applicability still depends on consistent scientific validation. The incorporation of these technologies requires not only adequate infrastructure but also professional training and ethical reflection on the role of automation in clinical decision-making.

Thus, it can be concluded that, although Artificial Intelligence presents promising potential in prosthetic planning, its clinical effectiveness remains only partially established. Therefore, the development of well-designed controlled clinical studies is essential, with rigorous methodological frameworks capable of objectively assessing its impact on therapeutic outcomes, thereby ensuring a safe, critical, and evidence-based integration into dental practice.

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