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MACHINE LEARNING IN IMPLANT DENTISTRY: FROM TOMOGRAPHIC ANALYSIS TO PERIO-IMPLANTITIS PREDICTION

Ana Luísa de Castro e Silva[1], Jennifer Vera Santos Gumert[2], Lahis Signor Caumo[3], Camila de Souza Nunes[4], Larissa Caroline Cayres Pereira[5], Jéssica Luiza Feitosa Monteiro Alves[6], Nathália Félix de Leiros Ferreira[7], Sabrina Lima Dantas Nóbrega[8], Maiana Vaz Moreira[9], Andreza Calazans Rodrigues[10]

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REVISÃO DE LITERATURA

ABSTRACT

The incorporation of Artificial Intelligence (AI) and Machine Learning (ML) in implant dentistry represents a disruptive advancement in digital dentistry, enabling a more predictable and personalized clinical practice. The present study analyzes the applicability of these technologies throughout the implant treatment workflow, from automated tomographic analysis to long-term biological monitoring. In diagnostic imaging, deep learning models demonstrate high accuracy in the segmentation of critical anatomical structures such as the mandibular canal and maxillary sinuses, as well as the automated identification of implant systems and mitigation of metallic artifacts in cone-beam computed tomography (CBCT) [3,4]. During the surgical phase, AI-assisted dynamic navigation systems optimize the three-dimensional positioning of implants in real time [12]. Recent literature also highlights the role of predictive algorithms in the early detection of marginal bone loss and in multifactorial risk analysis for peri-implantitis [1]. The integration between human clinical judgment and algorithmic precision emerges as a key factor in improving surgical safety, treatment predictability, and long-term implant success.

Keywords: Artificial Intelligence; Implant Dentistry; Cone-Beam Computed Tomography; Peri-implantitis; Machine Learning.

Instituição afiliada – [1] Universidade Salgado de Oliveira, Goiânia – GO, Brasil.
[2] Centro Universitário UniDomBosco, Brasil.
[3] Universidade Regional Integrada do Alto Uruguai e das Missões (URI), Erechim – RS, Brasil.
[4] FEAD – Faculdade de Estudos Administrativos, Brasil.
[5] Universidade Santa Cecília, Santos – SP, Brasil.
[6] Pontifícia Universidade Católica do Rio de Janeiro (PUC-Rio), Rio de Janeiro – RJ, Brasil.
[7] Universidade Federal do Rio Grande do Norte (UFRN), Natal – RN, Brasil.
[8] Universidade Federal de Minas Gerais (UFMG), Belo Horizonte – MG, Brasil.
[9] Centro Universitário Salgado de Oliveira, Goiânia – GO, Brasil.
[10] INCO25, Niterói – RJ, Brasil.

Autorcorrespondente: *Ana Luísa de Castro e Silva* – dra.analuisacastro@gmail.com

1 Introduction and digital paradigm in implant dentistry

Contemporary implant dentistry is undergoing a paradigmatic transition from a predominantly visual and tactile planning model to a data-driven digital ecosystem. The increasing availability of diagnostic information from cone-beam computed tomography (CBCT) and digital intraoral scanning has expanded the possibilities for treatment planning and analysis.

Machine learning has emerged as a key technological component capable of extracting meaningful patterns from large datasets and assisting clinicians in diagnostic interpretation and therapeutic decision-making [11]. Artificial intelligence systems based on convolutional neural networks can identify anatomical structures, dental implants, and pathological changes with levels of accuracy comparable to experienced clinicians.

In implant dentistry, these tools have been applied to diagnostic imaging, surgical planning, prosthetic design, and prediction of treatment outcomes [11].

2 Methodology

This study is a narrative literature review aimed at analyzing the current applications of artificial intelligence (AI) and machine learning (ML) in implant dentistry, with emphasis on tomographic analysis, surgical planning, prosthetic rehabilitation, and prediction of peri-implant diseases.

A comprehensive search of the literature was conducted in the electronic databases PubMed, Scopus, and Web of Science. The search strategy included combinations of the following keywords: *“artificial intelligence”, “machine learning”, “implant dentistry”, “cone-beam computed tomography”, “peri-implantitis”, and “digital dentistry”*.

Articles published between 2020 and 2025 were considered to ensure the inclusion of the most recent technological advancements in the field. Original research articles, systematic reviews, and meta-analyses written in English were included. Studies not directly related to implant dentistry or lacking clinical or radiographic relevance were excluded.

The selection of studies was based on relevance to the topic, methodological quality, and contribution to the understanding of AI applications in implant dentistry. Data from the selected studies were qualitatively analyzed and organized according to the main stages of the implant treatment workflow.

2 Artificial intelligence in tomographic analysis

The interpretation of CBCT scans represents one of the most critical stages of implant planning. Although CBCT provides highly detailed three-dimensional images, human interpretation is subject to variability and visual fatigue.

Deep learning models have demonstrated the ability to automatically segment anatomical structures and detect implant components in radiographic images [3]. Automated detection systems are capable of identifying dental implants and their individual parts, including abutments and healing components, improving diagnostic efficiency and treatment planning.

Additionally, artificial intelligence has been successfully applied to identify implant brands and models using panoramic radiographs, facilitating maintenance procedures in patients with unknown implant systems [10].

Another important contribution of AI involves the reduction of metallic artifacts in CBCT images. Algorithms designed for image reconstruction and noise reduction significantly improve visualization of peri-implant bone structures and anatomical landmarks [4].

Recent studies have also demonstrated the feasibility of automated implant detection and classification directly from CBCT datasets, enabling fully automated radiological interpretation workflows [9].

3 Precision planning and AI-assisted surgical navigation

The integration of digital planning and surgical execution has significantly improved the accuracy of implant placement procedures.

Dynamic navigation systems utilize optical tracking technologies that correlate the position of surgical instruments with CBCT datasets in real time. These systems function similarly to a surgical navigation GPS, allowing clinicians to follow the planned implant trajectory during surgery [12].

Systematic reviews and meta-analyses have demonstrated that dynamic navigation systems present greater accuracy compared with freehand techniques, significantly reducing angular and linear deviations during implant placement [12].

In addition to surgical navigation, machine learning models are being developed to evaluate implant stability and osseointegration outcomes. By analyzing radiographic patterns of peri-implant bone density, artificial intelligence algorithms may assist clinicians in predicting implant stability and integration success [13].

Furthermore, machine learning approaches have been used to analyze risk factors associated with implant failure, integrating clinical, biological, and biomechanical variables into predictive models [2].

4 Prediction of peri-implant diseases using machine learning

Peri-implantitis is one of the main biological complications associated with implant therapy. Early detection is essential to prevent progressive bone loss and implant failure.

Artificial intelligence models trained with radiographic datasets have demonstrated high accuracy in detecting marginal bone loss in periapical radiographs. These algorithms can automatically measure the distance between the implant platform and the crestal bone level, enabling early identification of pathological changes [5].

Machine learning models also allow the integration of multiple risk factors, including smoking, systemic conditions, history of periodontitis, and prosthetic design variables. This multifactorial analysis can classify patients into different risk categories for peri-implant disease development [1].

Studies evaluating predictive models for implant complications indicate that machine learning approaches may outperform traditional statistical methods in predicting peri-implantitis and implant failure [1,2].

5 Prosthetic rehabilitation and AI-driven design

Artificial intelligence has also influenced prosthetic rehabilitation through integration with digital CAD/CAM systems.

Generative design algorithms can automatically design implant-supported crowns and prosthetic structures by analyzing occlusal relationships and anatomical characteristics. These systems simulate biomechanical forces and optimize occlusal morphology to reduce stress concentrations in the implant-bone interface [14].

Another emerging concept is the **virtual patient**, which integrates CBCT images, intraoral scans, and facial scans into a single digital model. This model allows clinicians to simulate prosthetic outcomes and improve communication with patients during treatment planning [6].

AI-assisted prosthetic design also enables more precise occlusal adjustments before fabrication, reducing the need for extensive clinical adjustments and improving prosthetic longevity [6].

6 Ethical considerations and future perspectives

Despite its technological advantages, the incorporation of artificial intelligence in implant dentistry raises important ethical and legal concerns.

One of the primary issues relates to the transparency of complex machine learning algorithms, often described as “black-box” systems due to the difficulty in interpreting their internal decision processes.

Ethical discussions in dental artificial intelligence emphasize that clinical responsibility must remain with the dental professional, and AI systems should be considered decision-support tools rather than autonomous decision makers [8].

In addition, the storage and processing of patient imaging data require strict adherence to data protection regulations to ensure patient privacy and confidentiality.

7 Conclusion

Machine learning is transforming implant dentistry by improving diagnostic accuracy, surgical precision, and long-term monitoring of implant health.

From automated CBCT analysis to predictive models for peri-implantitis and implant failure, artificial intelligence expands the clinician’s ability to interpret complex datasets and anticipate biological complications.

However, successful implementation depends on maintaining a balanced integration between technological innovation and clinical expertise. The synergy between human decision-making and algorithmic precision represents a promising pathway toward safer, more predictable, and biologically sustainable implant treatments.

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