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Artificial intelligence and finite element analysis: applications in implant dentistry

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Abstract. Artificial intelligence (AI) has shown great potential across scientific disciplines, including implant dentistry. This review investigates the applications of AI in Finite Element Analysis (FEA) of dental implants, examining implications, limitations, and future directions. By following Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, relevant articles were obtained from PubMed, Scopus, Web of Science, and Google Scholar databases. Six articles were included, covering topics such as osseointegration assessment, implant design optimization, and bone healing prediction. Integrating AI and FEA can improve parameter optimization, computational efficiency, and analysis time. FEA simulations were consistently used to train AI models, which were then validated against FEA-calculated data. While AI in dental implantology is still in its early stages, opportunities for innovation and refinement are apparent. Challenges, such as algorithmic misconduct and interpretation of AI outputs, need to be addressed through collaborative efforts between clinicians and computer engineers. Future research should explore incorporating factors like bone homeostasis and multiscale analysis to enhance understanding of peri-implant bone response. Long-term clinical studies are necessary to validate AI model predictions in real-world scenarios.

Keywords: artificial intelligence, machine learning, deep learning, finite element analysis, dental implants.

INTRODUCTION

Artificial intelligence (AI) is an interdisciplinary field of computer science that focuses on the development of intelligent systems and algorithms capable of emulating human cognitive abilities. Its fundamental goal is to design and create computational models and algorithms that can acquire, process, analyze, and interpret vast amounts of data, enabling machines to perform complex tasks that traditionally require human intelligence (Aiken and Epstein 2000). In recent years, the integration of artificial intelligence in the field of implant dentistry has witnessed significant advancements (Revilla-León et al. 2021). Finite Element Analysis (FEA) plays a crucial role in evaluating the biomechanical behavior of dental implants and supporting bone, aiding in the design and optimization of implant-supported restorations. However, traditional FEA approaches rely on manual inputs and assumptions, which may introduce limitations, potential inaccuracies, and long testing times (Falcinelli et al. 2023). By incorporating AI techniques, such as machine learning and deep learning algorithms, FEA can leverage large datasets and complex models to enhance its predictive capabilities and overcome these limitations.

This mini-review aims to explore the applications of AI in FEA within the field of implant dentistry, highlighting its implications for scientific research, the current limitations, and the possible paths for future development.

MATERIALS AND METHODS

Reporting of this review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al. 2010). The search included articles about AI and FEA in implant dentistry: all study types excluding reviews, only English-language articles, and articles published until June 2023 were included. The literature search was performed on electronic databases via PubMed, Scopus, Web of Science, and Google Scholar. The search strategy used a combination of MeSH terms: (artificial intelligence OR machine learning OR deep learning) AND finite element analysis AND dental implant. The articles were selected based on their title and abstract, and then the full text was evaluated by two different reviewers (F.V., L.F.). Cohen's K test was used to assess the agreement between the two reviewers. Disagreements were resolved by consensus with a third examiner (C.F.) to identify studies that passed the selection criteria.

RESULTS

The results of the literature search are shown in Figure 1. Six articles were included in the review. One article was published in 2009 and five articles from 2018. There was substantial agreement between the two investigators for the articles that were selected, both for the title/abstract and the full-text screening (Cohen's K value=0.90 and 1, respectively). The articles and their main findings are summarized in Table 1.

DISCUSSION

Upon initial observation, it can be observed, except for the publication by Zaw and coworkers (Zaw et al. 2009), all the articles analyzed in this review were published in very recent years. This confirms the recent significant growth in interest regarding AI technologies. Consequently, there has been a notable rise in research endeavors focused on incorporating this captivating technology into various scientific domains. The articles surveyed in relation to the integration of AI into FEA exhibit a common approach, irrespective of subject matter, analyzed variables, or AI methodologies employed. The general method entails the use of FEA for initial simulations, employing predetermined parameters and variables. Subsequently, the obtained FEA data are extrapolated and employed to train the AI model. The output generated by the AI is then validated and compared against the FEA-calculated data. Consequently, the overarching objective of these studies primarily revolves around substituting FEA calculations with AI computations, with a view to enhancing parameter optimization, computational efficiency, and overall time required for analysis. The exception was the study performed by Kwak et al. (Kwak et al. 2021). In the context of their study, advanced image recognition techniques were adopted, and ultrasonic signals were inverted using a Convolutional Neural Network (CNN) to assess the osseointegration phenomena. The main topics investigated by the different studies were: osseointegration assessment (Kwak et al. 2021), implant design optimization (Zaw et al. 2009; Roy et al. 2018; Li et al. 2019; Choudhury et al. 2022), and prediction of bone healing around dental implants (Kung et al. 2023).

From this review it can be noticed that AI applied to in silico studies in in dental implantology is still in the early stages, but its potential is very promising. AI's main limitation is its inability to provide direct interpretation, making misinterpretations possible due to algorithmic misconduct and training method. To mitigate risks, collaboration between experienced clinicians and expert computer engineers is essential in the development of AI programs. Further evaluations should encompass the actual knowledge on bone homeostasis (Valente et al. 2022) and the recent recognition of the need for a multiscale analysis to predict peri-implant

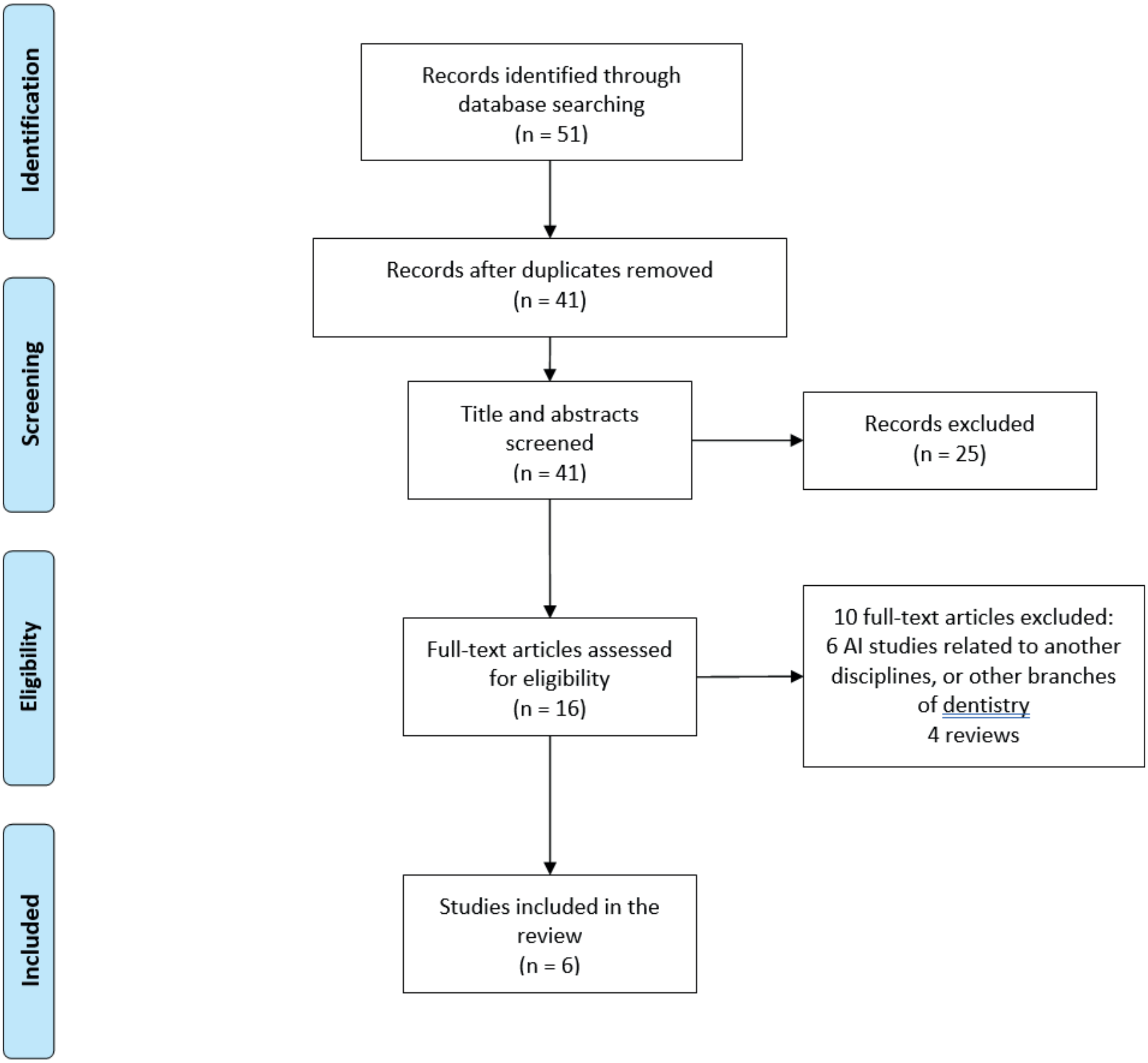

Figure 1. PRISMA flow diagram with information through phases of study selection (Moher et al. 2010).

bone response (Falcinelli et al. 2023). The incorporation of such aspects could help obtain information about the relation among implant design, distribution of stress applied to the bone, bone growth and histological arrangement. The integration of AI will allow for continuous observation of these parameters and their interrelated development, which is difficult to achieve through traditional clinical experiments, and can provide predictions prior to the insertion surgery, reducing the need for costly trial and error procedures. This can potentially save time and resources for both patients and healthcare providers.

CONCLUSIONS

The conclusion of this mini-review can be summarized as follows:

1. AI integration with FEA in dental implantology is still in its early stages.
2. FEA is mainly used to extrapolate data for AI training.
3. The main topics covered by the studies include osseointegration assessment, implant design optimization, and prediction of bone healing around dental implants.

Table 1. Overview of the studies included in the review and their main features.

Reference	AI models used	Study's purposes	Main outcomes
Zaw et al. 2009	- Neural Network (NN)	To validate a rapid inverse analysis approach based on the Reduced-Basis Method (RBM) and Neural Network to identify the elastic modulus (Young's modulus) of the interfacial tissue between a dental implant and the surrounding bones	Results identified by trained NN are very accurate, reliable, and the computational saving is very significant
Roy et al. 2018	- Genetic Algorithm (GA) - Artificial Neural Network (ANN)	To present a novel approach for designing patient-specific dental implants using FEA and computational intelligence techniques	Genetic algorithm is successfully used for designing dental implant to achieve the desired microstrain and implant stress
Li et al. 2019	- Support Vector Regression (SVR) - GA	To propose an uncertainty optimization approach for dental implants to reduce stress at the implant-bone interface	SVR model optimizes the implant design variables to minimize the stress at the implant-bone interface. There is a reduction of 36.6% of the stress at the implant-bone interface compared with the FEA model
Kwak et al. 2021	- Convolutional Neural Network (CNN)	To present a method to assess the soft tissue thickness at the bone-implant interface (BII) based on the analysis of its ultrasonic response using a simulation-based CNN	The linear correlation between actual and estimated soft tissue thickness shows correlation values equal to 99.52% and 99.65% for microscopic and macroscopic roughness, supporting the reliability of the proposed assessment of osseointegration phenomena
Choudhury et al. 2022	- ANN - GA	To present a methodology for designing patient-specific basal dental implants using FEA and ANN	The ANN metamodel developed from the FE simulation data is found to be able to formulate the fitness function for the optimization using GA to achieve desired microstrain in the peri-implant bone for a better osseointegration
Kung et al. 2023	- Deep Learning Network (DLN)	To present a DLN model that can predict tissue differentiation around dental implants in patients with different ages, genders, and occlusal forces	The network successfully surrogated the finite element (FE) calculation and mechano-regulation algorithm and significantly increased the calculation efficiency with an accuracy of 97.23%

4. All studies demonstrated the accuracy and efficiency of AI output compared to FEA.
5. Incorporating additional factors such as multiscale analysis can provide a more comprehensive understanding of the peri-implant bone response.
6. Long-term clinical studies are needed to validate the predictions made by AI models and assess their reliability in real-world scenarios.
7. The cooperation among researchers, clinicians, and AI developers is crucial for addressing technical obstacles and successfully implementing AI technology in the field of dental implantology.

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