Artificial intelligence and finite element analysis: applications in implant dentistry

Francesco Valente1,2,*A, Luigi Falconio1,2,A, Cristina Falcinelli1, San-dipan Roy4, Oriana Trubiani1,2, Tonino Traini1,2

1 Department of Innovative Technologies in Medicine & Dentistry, University “G. d’Annunzio” of Chieti-Pescara, Via dei Vestini 31, 66100 Chieti, Italy
2 Electron Microscopy Laboratory, University “G. d’Annunzio” of Chieti-Pescara, Via dei Vestini 31, 66100 Chieti, Italy
3 Department of Engineering and Geology, University “G. d’Annunzio” of Chieti-Pescara, Viale Pindaro 42, Pescara 65127, Italy
4 Department of Mechanical Engineering, SRM Institute of Science and Technology, Kattankulathur, Tamil Nadu 603203, India

*Corresponding author. E-mail: francesco.valente@unich.it
A These authors equally contribute to this work.

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...
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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.
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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BIBLIOGRAPHY


