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The Role of Artificial Intelligence in Dental Implant Planning

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Abstract

AI technology have transformed implant dentistry. This article focusses on the use of AI in implant dentistry, including its impact on diagnosis, treatment planning, image analysis, and deep learning algorithms. These technologies improve implant placement precision, reduce risks, and optimise aesthetics. AI-driven data analytics enhance patient-specific treatment regimens, leading to higher success rates. AI has the potential to transform implant dentistry and bring in a more personalised and efficient approach to oral healthcare.

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Introduction

Artificial intelligence (AI) has gained prominence across multiple medical domains, transforming healthcare delivery and enhancing patient outcomes. AI technologies have exhibited exceptional ability in augmenting clinical decision-making and improving efficiency, from diagnostic imaging to treatment planning [1]. In dentistry, artificial intelligence is becoming an essential instrument for improving multiple facets of patient care, particularly in implant planning, which is a vital element of dental implantology requiring accuracy and careful preparation. Clinicians can utilise AI algorithms and machine learning approaches to analyse intricate information and enhance treatment strategies for specific patients [2].

Implant planning entails assessing the patient's anatomy, bone density, and additional parameters to ascertain the ideal place, size, and angle of dental implants. This approach has conventionally depended on the proficiency and experience of dental practitioners, frequently using manual measurements and subjective evaluations [3]. The incorporation of AI into implant planning heralds a novel epoch of accuracy and efficacy. A lot of information about a patient, like x-rays, 3D scans, and clinical records, can be looked at by AI algorithms to help doctors make decisions about where to put implants based on evidence [4]. Furthermore, AI can offer predictive modelling and simulation functionalities, enabling doctors to anticipate the expected outcomes of various treatment strategies prior to commencing the operation. This improves treatment planning and facilitates personalised and patient-specific actions [5]. Even though AI could be useful in some situations, using it a lot in implant planning creates a lot of ethical, legal, and practical problems. Challenges such as data privacy, algorithm transparency, and liability must be solved to ensure the acceptable and ethical application of AI technology in dentistry [6].

The objective of this article is to investigate the functions and applications of AI in implant planning by analysing the present state of the art. We will look at the moral and legal effects of using AI in clinical practice. This will help us understand the opportunities and challenges of this rapidly changing field.

Material and Methods

This literature review employs a literature search method, encompassing theories, research, and literature reviews pertinent to dental implants and artificial intelligence. Articles in journals that meet the inclusion criteria are selected and subsequently analysed. This literature review incorporates publications from the past five years, specifically from 2021 to 2025, which are available in full text. We conducted a literature search using

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PubMed and Google Scholar. The criteria under review included English-language research journal articles. The article types utilised comprise research articles, case reports, and epidemiological studies.

Table 1 presents a summary of the search strategy employed. Additionally, studies were excluded in the absence of full text availability. Full-text articles were then assessed for eligibility based on the predetermined inclusion criteria.

Results and Discussion

The systematic search concluded on 1 March 2025. We analysed the summary of the found journals to determine the effectiveness of artificial intelligence (AI) in dental implant placement (Table 2).

Diagnostic procedures are a crucial component of dental practice. The precise diagnosis and identification of anatomical features is the initial step toward effective and individualised treatment [7].

In dental implant rehabilitation, it is crucial to design implant placement away from neurological structures to prevent intraoperative and postoperative problems [8].

Therefore, precise identification of brain structures is crucial. The initial and important stage in planning mandibular implant treatment is determining the location of the inferior alveolar canal. Two academic papers we looked at support the use of AI to locate the mandibular nerve in implant diagnostic testing.

After reading a lot of research, we found two papers that support using AI to find the mandibular nerve in devices that have two uses. All four papers delineate the methodologies employed to construct unique automated procedures using CNNs for segmenting mandibular neural structures. The authors identified the inferior alveolar nerve using two-dimensional panoramic radiographs. The authors used machine learning on 1,366 panoramic photos and found that this method worked better for IAC segmentation in these photos, even when visibility was low or high [9,10]. An AI-driven technology provides precise mandibular canal prevention, even in the presence of anatomical variances such as an anterior loop. Consequently, the now-proven specialist AI tool may assist doctors in automating the segmentation of neurovascular channels and their anatomical variations. It may greatly help in an average of 85.3% of the time, AI and human methods agreed on how to segment the alveolar bone in M. A. Moufti et al.'s study, which was the same as what another study found. Presurgical planning is crucial for dental implant implantation, especially in the intermaxillary area [11].

In M. A. Moufti et al.'s study, they said that the results were like those of another study that found a slightly higher overlap in alveolar bone segmentation between AI and manual methods, with an average DSC of 85.3%. However, the previous study mostly looked at segmenting the front part of the jaw.This simplifies the model by eliminating the need to deal with curved structures, a topic we will discuss later.. Additionally, that stuuutiliseded ultrasonography, which restricts its applicability and usefulness in broader clinical settings [12]. Furthermore, Kurt Bayrakdar et More than that, Kurt Bayrakdar et al. discovered that there were no statistically significant differences in bone height measurements between AI and manual methods in the premolar area of the mandible and the premolar and molar area. AI-powered software can accurately find the best place for an implant by learning on its own. Ness measurements between AI and manual measurements ($p < 0.001$). The detection accuracy was 72.2% for canals, 66.4% fThey also looked at bone density and found that higher bone density led to bigger implant deviations. This shows how important it is to consider bone density when planning implants [13].

AI-powered software can accurately find the best place for an implant by learning on its own. They also looked at bone density and found that higher bone density led to bigger implant deviations. This shows how important it is to consider bone density when planning implants. We selected one article that discussed conducting an amnestic assessment on the patient before implant surgery [14]. The research conducted by Takahiko S. et al. involved the acquisition of anonymous CBCT pictures from 60 patients. After implant insertion, Takahiko S. et al. obtained pictures of the osseous areas at the implant site from 20 slices of CBCT images. The established drilling protocols classified the photos into three categories: A, B, and C. We allocated a total of 1,200 photos into training and validation datasets (n = 960, 80%) and a test dataset (n = 240, 20%). We took a total of 240 photos (80 per protocol) from the 60 cases to use as test data. We constructed an AI model using LeNet-5 and these datasets. The accuracy, sensitivity, precision, F-value, area under the curve (AUC), and receiver operating characteristic curve were computed. The trained model achieved an accuracy of 93.8%. The sensitivities for drilling methods A, B, and C were 97.5%, 95.0%, and 85.0%, respectively. The precision results for the same protocols were 86.7%, 92.7%, and 100%, respectively, whereas the F values were 91.8%, 93.8%, and 91.9%, respectively. The AUC values for protocols A, B, and C were 98.6%, 98.6%, and 99.4%, respectively [15]. Implantologists frequently employ peri-implant site preparation when dealing with extremely soft bone. A clinician's level of expertise usually determines the extent to which they are unprepared [16]. In implantology, the use of radiographic stents as reference points ensures accurate surgical planning [17]. The radiographic stent incorporates identifiable reference locations, known as radiographic landmarks, in the panoramic radiograph or CBCT scan. A radiographic stent is used before a panoramic x-ray or CBCT scan of the patient, or during surgery, to ensure that the landmarks align correctly with the patient's anatomy. Bless the surgeon for precisely determining the location and angulation of dental implants according to preoperative planning [18].

The initial and most critical step in planning an implant in the maxillary region involves identifying anatomical structures and evaluating bone quality and quantity, as well as any adjacent vital structures such as the maxillary sstructures,l cavity, and infraorbital nerve [19]. Consequently, our review proposed one study utilising CNN for the detection of critical anatomical structures in the maxillary region, employing AI in implant diagnostic assessment. Nermin Morgan's study introduced and validated a novel automated CNN-based methodology for segmenting the maxillary sinus utilising CBCT images. We obtained a dataset of 264 sinuses from two CBCT devices and randomly partitioned it into three subsets: training, validation, and testing. A 3D U-NWe developed a 3D U-Net architecture CNN model and evaluated it against semi-automatic segmentation in terms of time, accuracy, and consistency.rage duration for automatic segmentation was markedly decreased (p-value < $2.2e-16$), with automaThe inter-observer reliability for minor refinement of the automatic segmentation showed a DSC of 99.6%, which means it worked very well.entification of the segmented region, achieving a Dice Similarity Coefficient (DSC) of 98.4%. The inter-observer reliability for minor refinement of the automatic segmentation exhibited a DSC of 99.6%, indicating excellent performance [20].
In the upcoming years, we expect a substantial expansion in the demand for AI-driven oral implantology. As technology progresses, expenses diminish, and regulatory structures evolve, AI is anticipated to become a more prevalent instrument in dental practice. The future possesses significant promise for AI to transform oral implantology, resulting in enhanced precision, personalisation, and,

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eventually, greater effectiveness in implant treatments for patients.

[6]

Conclusions

When Artificial Intelligence (AI) is used in dental implant planning, the results show that it is good at predicting where the implants will go. [7] This is shown by the small differences in position, angulation, and implant depth between the preoperative planning and postoperative results, compared to when dental implants are [8] placed by hand. Additional clinical research on the application of AI in implant planning is necessary in the future.

[9]

Conflict of Interest

The authors report no conflicts of interest.

[10]

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Table 1. Search strategy.

Component	Details
Databases Searched	- PubMed - Web of Science - Google Scholar
Search Terms	"Artificial Intelligence" [Mesh] OR (AI) OR (machine learning) OR (deep learning) - "Implant Planning" [Mesh] OR (implantology) OR (implant treatment plan)
Inclusion Criteria	- Clinical trials, case reports, case series, and in vitro studies - Human radiological images from dental clinics - Published in English - Articles published from 2021 to 2025
Exclusion Criteria	- Expert opinions, review articles, and letters to the editor
Study Selection Process	1. Screening of titles and abstracts 2. Full-text assessment based on inclusion/exclusion criteria

Article focus	Results	Reference
Development of artificial intelligence model for supporting implant drilling protocol decision making	The trained model's accuracy is 93.8%. The sensitivity outcomes for drilling protocols A, B, and C were 97.5%, 95.0%, and 85.0%, respectively, while the specificity results for the same protocols were 86.7%, 92.7%, and 100%, respectively. The F values for protocols A, B, and C were 91.8%, 93.8%, and 91.9%, respectively. The AUC values for protocols A, B, and C are 98.6%, 98.6%, and 99.4%, respectively.	[15]
Convolutional neural network for automatic maxillary sinus segmentation on cone-beam computed tomographic images	The study showed that automatic segmentation was significantly faster than semi-automatic segmentation, reducing the time from 60.8 minutes (3649.8 seconds) to just 24.4 seconds (p-value < 2.2e−16). Approximately 30% of the testing set required refinements, taking an average of 7.1 minutes. Automatic and refined segmentations were 149 and 9 times faster than semi-automatic segmentation, respectively. In terms of accuracy, the automatic segmentation achieved a Dice Similarity Coefficient (DSC) of 98.4% and a Root Mean Square (RMS) error of 0.21 mm, indicating a high level of precision and close matching to the ground truth.	[20]
Automatic segmentation of inferior alveolar canal with ambiguity classification in panoramic images using deep learning	Automatic segmentation attained a Dice Similarity Coefficient (DSC) of 85.7% (95% confidence interval [CI] 75.4%–90.3%), precision of 84.1% (95% CI 78.4%–89.3%), and recall of 87.7% (95% CI 77.7%–93.4%). In contrast to manual annotation (5.9 seconds each image), automated segmentation markedly enhanced the effectiveness of IAC segmentation (33 milliseconds per image). The DSC and accuracy metrics of group 4 (most visible) were markedly superior to those of group 1 (least visible). The memory values for groups 3 and 4 were markedly superior to those of group 1.	[10]
Deep learning-based approach for 3D bone segmentation and prediction of missing tooth region for dental implant planning	The experimental results demonstrated outstanding performance in terms of dice, precision, and recall for bone segmentation (0.93, 0.94, and 0.93, respectively) with a low volume error (0.01). The proposed models offer promising automated dental implant planning for dental implantologists.	[21]
Automated segmentation of the mandibular canal and its anterior loop by deep learning	The AI-driven tool provided accurate segmentation of the mandibular canal, even in the presence of anatomical variation such as an anterior loop. Thus, the presently validated dedicated AI tool may aid clinicians in automating the segmentation of neurovascular canals and their anatomical variations. It may significantly contribute to presurgical planning for dental implant placement, especially in the interforaminal region.	[11]

Developing an Artificial Intelligence Solution to Autosegment the Edentulous Mandibular Bone for Implant Planning	The sample consisted mainly of lower molars and premolars. DSC yielded an average value of 0.89 for training and 0.78 for testing. Unilateral edentulous areas, comprising 75% of the sample, resulted in a better DSC (0.91) than bilateral cases (0.73).	[12]
A deep learning approach for dental implant planning in cone-beam computed tomography images	In the bone height measurements, there were no statistically significant differences between AI and manual measurements in the premolar region of mandible and the premolar and molar regions of the maxilla ($p > 0.05$). In the bone thickness measurements, there were statistically significant differences between AI and manual measurements in all regions of maxilla and mandible ($p < 0.001$). Also, the percentage of right detection was 72.2% for canals, 66.4% for sinuses/fossae and 95.3% for missing tooth regions.	[13]