World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(REVIEW ARTICLE)

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Application of Artificial Intelligence (AI) on improving accuracy of dental implant placement using Computer-Assisted Implant Surgery (CAIS)

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World Journal of Advanced Research and Reviews, 2023, 19(03), 127–131

Publication history: Received on 18 July 2023; revised on 30 August 2023; accepted on 01 September 2023

Article DOI: https://doi.org/10.30574/wjarr.2023.19.3.1775

Abstract

Tooth loss is one of the most common oral health problems, and may affect mastication, phonetics, aesthetics, and quality of life. Dental implant placement is an effective procedure to replace tooth loss. Dental implant placement techniques using freehand surgery procedures increase potential failure related to position, angle, and depth of insertion with 6.42% failure prevalence. The accuracy of installing dental implants through freehand protocol depends on the ability and experience of the doctor. New innovations such as using Artificial Intelligence (AI) in Computer-Assisted Implant Surgery (CAIS) have been developed to improve the accuracy of dental implant placement. This article review uses a method finding theories from research journals and case reports with keywords "dental implant", "artificial intelligence", "computer-assisted surgery" on Google Scholar and Pubmed, five (5) research journals and one (1) case reports met requirements to be discussed. Application Artificial Intelligence (AI) in CAIS, through 3D Standard Tessellation Language (STL) planning on Cone Beam Computed Tomography (CBCT) segmentation and alignment with Intra-Oral Scanner (IOS). 3D planning is a holographic environment. CAIS are divided into static and dynamic. The static procedure performed by printing stereolithographic guide from the dental implant placement for the operator, the dynamic procedure when the operator sees in real-time the position, angulation, and drilling depth on a screen. The results showed that there was a slight deviation between the position, angulation, and depth of the implant during planning and post-surgery. Artificial Intelligence (AI) applications using Computer-Assisted Implant Surgery (CAIS) can improve the accuracy of dental implant placement.

Keywords: Dental implant; Artificial intelligence; Computer-assisted implant surgery

1. Introduction

Maintaining functional teeth, at least 20 teeth, is the most important aspect of oral health according to the World Health Organization (WHO). Tooth loss is a problem in the oral cavity which is mostly caused by caries and periodontal disease. Loss of teeth can interfere with mastication, phonetics, aesthetics, as well as a person's quality of life [1]. Several treatments can be performed to treat lost teeth, one of which is through the installation of dental implants which are a reliable option in replacing lost teeth. This is because the choice of treatment through dental implants has the advantage of having good aesthetics, no need to remove the attachment, so it doesn't sacrifice the antagonist teeth or neighboring teeth that are used as abutments [2]. Several techniques in installing dental implants today still use conventional methods or freehand dental implant surgery which can allow potential failures related to position, angle to depth of insertion with a failure prevalence of 6.42%. The successful placement of dental implants is marked by the success of osseointegration, which requires a method that minimizes surgical complications [3]. If the installation of the dental implant fails due to inaccurate planning, surgical complications, and previous failed installation sites, it can result in an increased risk of failure. higher for future implant placement [4]. Artificial Intelligence (AI) in dental implant placement is currently demonstrating the potential for dynamic real-time clinical guidance during implant placement, and dental

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implant placement with visual navigation that offers guidance for treatment planning and implant placement in real-time [2]. Installation leverages Artificial Intelligence through Computer-Assisted Implant Surgery (CAIS) can be an option to reduce the risk of failure in the placement of dental implants [5]. CAIS guides the position and angulation of dental implants assisted by the results of Cone Beam Computed Tomography (CBCT) images which are inputs to the implant planning software. There are two types of real-time guides for dental implant placement using CAIS, namely static and dynamic. Placement of dental implants using dynamic CAIS is more accurate than static CAIS, but not significantly different [6]. Based on the potential for failure of conventional dental implant placement and the potential for reducing the risk of failure of dental implant placement using CAIS, further studies are needed regarding the effectiveness of using AI through CAIS in increasing the level of accuracy in dental implant placement.

2. Material and methods

This literature review is written using the literature search method in the form of theories, research as well as literature reviews related to the keywords dental implant, artificial intelligence, and computer-assisted implant surgery. The data used are secondary data. Articles or journals that match the inclusion criteria are taken, then analyzed. This literature review uses literature published in the last five (5) years, namely, 2019-2023 which can be accessed in full text. Literature search was carried out using Pubmed and Google Scholar. The criteria for the journals reviewed were research journal articles in Indonesian and English. The types of articles used include research articles, case reports, and epidemiological studies. Research journals that match the inclusion criteria are then collected and summarized according to the format.

3. Results and discussion

The summary of the journals found are analyzed, discussing the effectiveness of Artificial Intelligence (AI) using Computer-Assisted Implant Surgery (CAIS) in increasing the level of accuracy of dental implant placement (Table 1). Artificial Intelligence (AI) in Computer-Assisted Implant Surgery (CAIS) is used to determine the best implant position from patient data provided in the form of Cone Beam Computed Tomography (CBCT) images. AI usage begins with entering data in the form of a patient's CBCT photo after dental implant placement by showing the bone margins on the LeNet-5-based model and then becomes the training dataset passed through the algorithm. AI is implemented in software for good implant planning on static and dynamic CAIS and also creation of Standard Tessellation Language (STL) files from CBCT segmentation used for static CAIS guidance [8,9]. In 2019, Kaewsri et al. conducted a clinical controlled trial on the accuracy between static and dynamic CAIS with 60 patients over the age of 20 who required implant placement and had adequate bone for implant placement. Pre-operative CBCT was taken and then entered the software to determine the optimal implant position. Implant placement was carried out post-operatively using a stereolithographic guide template (static CAIS) and implant navigation system (dynamic CAIS), then post-surgery CBCT was taken. Deviations in the implant platform and implant apex in the static CAIS group (0.97 ± 0.44 mm and 1.28 ± 0.46 mm) and the dynamic CAIS group (1.05 ± 0.44 mm and 1.29 ± 0.46 mm) have no significant difference. This is also seen in the angle deviation of static CAIS (2.84 ± 1.71 degrees) and dynamic CAIS (3.06 ± 1.37 degrees), indicating that the accuracy of implant placement in single teeth using dynamic CAIS is the same as static CAIS [6]. In 2020, Yimarj et al. also conducted research on static and dynamic CAIS accuracy with the placement of two implants. From this study it was found that static and dynamic CAIS systems have similar clinical outcomes in terms of deviation from the optimal implant position and implant parallelism [7]. In 2022, Sakai et al. conducted research related to the development of Artificial Intelligence (AI) which is used as a drilling protocol in dental implant placement. This study used 60 patients who were divided into three groups, using conventional drilling with tapping drills, without tapping drills, and undersized drilling. The results obtained in this study are the learning model accuracy rate of 93.7%, protocol sensitivity of 97.5% in conventional tapping drills, 95% without tapping drills, and 85% undersized drilling. The conclusion obtained in this study is that the Artificial Intelligence (AI) model is effective in predicting the drilling protocol before surgery, so that this treatment can be used as a decision-making support [9]. In 2022, Kivovics et al. conducted an in vitro test comparing the accuracy of implant placement with Augmented Reality (AR)-based navigation, implant surgery with static CAIS, and the freehand method. This study used 3D models in 12 patients using Standard Tessellation Language (STL) files which were randomly divided into three groups. The first group implant placement was assisted by AR-based navigation, the second group used freehand techniques, and the third group used static CAIS. Measurement of the accuracy of implant placement for each group was obtained through preoperative and postoperative CBCT examinations. The results of this study showed that the accuracy of implant placement using AR-based navigation did not show a significant difference compared to static CAIS [5]. In 2023, Pomare-puig, et al. conducted a proof-of-concept regarding the use of static and dynamic CAIS in patients with complete loss of teeth. In this study, static and dynamic CAIS were combined to overcome deficiencies of dynamic CAIS in tooth loss. This method is a new approach to the use of CAIS and is referred to as the "double factor" technique. Ten patients required implant-supported full denture

rehabilitation in October 2021 and March 2022 for a total of 48 implants. Eight patients required a single full denture and the other two patients required a full denture of both jaws. Implant placement was performed using a flapless approach and guided by static and dynamic CAIS. The results showed that the mean angle deviation was 3.74 with a linear 3D deviation of the platform and the implant apex of 1.25 mm (SD: 0.55) and 1.42 mm (SD: 0.64). Implant placement in the maxilla was slightly more accurate than the mandibular, but not statistically different. The difference in position of the implant is not detectable from axial (mesial) and oblique (distal). Based on the results of this study, the "double factor" technique with a combination of static and dynamic CAIS approaches can be a valid and accurate approach to the treatment of full edentulous. In addition, the "double factor" technique was reported associated with high satisfaction and increased quality of life [10]. In 2023, Mangano et al. conducted research related to the relationship between Artificial Intelligence (AI) and treatment plans in dental implant placement. In this study using the installation of 3 implants on the left mandible, two implants on teeth 36 and 37, and one implant on tooth 46 which will later be carried out using an AI system. The results obtained in this study were that dental implants were clinically acceptable with little deviation [8]. Based on the results of several studies above, it shows that the use of static and dynamic CAIS can reduce the deviation between the planning and the results of dental implant placement in terms of position, angulation, and depth. The use of AI is also capable of assisting decision-making in terms of selecting drilling protocols and planning implant placement in bone, so that AI through CAIS can improve the accuracy of dental implant placement.

Table 1 Summary of articles matching inclusion criteria

No	Article focus	Results	Reference
1.	Comparison of static and dynamic CAIS accuracy on single tooth implants	Mean deviation on the static CAIS group at the implant platform and implant apex are 0.97 ± 0.44 mm and 1.28 ± 0.46 mm respectively, while on the dynamic CAIS group the mean deviation at the implant platform and implant apex are 1.05 ± 0.44 mm and 1.29 ± 0.50 mm. The angular deviation on static and dynamic CAIS groups are 2.84 ± 1.71 degrees and 3.06 ± 1.37 degrees respectively. Implant deviation towards mesial on dynamic CAIS group is higher significantly than static CAIS (p = 0,032). The accuracy of implant placement on single tooth space using dynamic CAIS is the same as static CAIS.	[6]
2.	Comparison of static and dynamic CAIS accuracy on implant-supported fixed dental prosthesis	The mean 3D deviation on static and dynamic CAIS on the implant platform are 1.04 ± 0.67 and 1.24 ± 0.39 mm respectively, on implant apex are 1.54 ± 0.79 and 1.58 ± 0.56 mm and angulation for each methods are 4.08 ± 1.69 and 3.78 ± 1.84. Angular deviation between the two implants placed in static and dynamic CAIS groups are 4.32 ± 2.44 and 3.55 ± 2.29 respectively. There are no significant differences between all perimeters on each groups.	[7]
3.	Static CAIS using AR and AI	This method is effective and efficient when used to plan simple cases with static guided implant surgery on partially edentulous teeth. Doctors can plan implants in a 3D environment without the need for a radiological guided surgery program. The precision of implant placement was clinically acceptable, with minor deviations.	[8]
4.	AI to help determine the dental implant drilling protocol	Accuracy of the learning model: 93.7%. Sensitivity, precision, and F-value for protocol A with conventional drilling protocol with tapping drill are (97.5%), (86.7%), and (91.8%) respectively. Sensitivity, precision, and F-value for protocol B with conventional drilling protocol without tapping drill are (95.0%), (92.7%), and (93.8%) respectively. Sensitivity, precision, and F-value for protocol C with undersized drilling protocol are (85.0%), (100%), and (91.9%) respectively	[9]

		The AI model developed in this study is effective in predicting the drilling protocol from CBCT images before surgery, indicating the possibility of making a decision-making program to improve the stability of the primary implant.	
5.	Static and dynamic CAIS in fully edentulous patient	The main outcome was accuracy of implant placement, measured by preoperative and postoperative CBCT overlapping with implant planning. Mean angular deviation are 3.74° (SD: 2). Total linear deviation on the implant apex and platform respectively are 1.25 mm (SD: 0.55) and 1.42 mm (SD: 0.64). There are no statistically significant differences found between implants in the tilted and axial, maxillary and mandibular, or right and left-sided conditions.	[10]
6.	Comparison of implant placement with augmented reality-based navigation, static CAIS, and freehand methods	The accuracy of implant placement using AR-based dynamic navigation did not show any significant differences compared to static CAIS The level of implant positioning accuracy of AR-based dynamic navigation was comparable to that of static CAIS and superior to that obtained with freehand implant placement.	[5]

4. Conclusion

The results obtained in the use of Artificial Intelligence (AI) and Computer-Assisted Implant Surgery (CAIS) are effective in predicting the position in dental implant placement as indicated by the slight deviation between position, angulation, and implant depth between planning and post-surgery results rather than placing dental implants using a freehand protocol. Further clinical studies regarding the use of AI and CAIS are needed in the future.

Compliance with ethical standards

Acknowledgements

The Authors acknowledge the contributions of well-wishers without whose support this publication would not have been possible.

Disclosure of Conflict of interest

No conflict of interest to be disclosed.

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