UMSHA Press

AJDR
Avicenna Journal of Dental Research

Avicenna J Dent Res. 2025;17(3):x-x. doi:10.34172/ajdr.2212

http://ajdr.umsha.ac.ir

XXX

Advanced Guidelines in Implant Placement Surgery: A Systematic Review Study

Fazilat Khademi[1], Maryam Safari[1*], Ebrahim Yarmohammadi[1], Salman Khazaei[2], Zahra Khamverdi[1]

[1]Department of Restorative Dentistry, School of Dentistry, Hamadan University of Medical Sciences, Hamadan, Iran
[2]Research Center for Health Sciences, Institute of Health Sciences and Technologies, Avicenna Health Research Institute, Hamadan University of Medical Sciences, Hamadan, Iran

Article history:
Received: Xx xx, 2024
Accepted: Xx xx, 2024
ePublished: Xx xx, 2025

***Corresponding author:**
Maryam Safari,
Email: mari.safari147@gmail.com

Abstract

Background: Proper placement of dental implants is essential to prevent damage to vital structures, provide optimal prosthetics, and ensure a successful long-term outcome. While previous studies have sporadically addressed individual advanced surgical guidelines, this systematic review aimed to uniquely synthesize and compare the latest evidence on multiple advanced implant placement techniques from 2019 to 2024, providing clinicians with comprehensive guidance on their relative advantages and accuracy metrics.

Methods: In this systematic review, major international databases, such as PubMed, ISI , Scopus, and the Cochrane Library, were utilized to evaluate published articles related to advanced guidelines in implant placement surgery. The search focused on in vitro studies, randomized controlled clinical trials, and cohort studies published in English from 2019 to March 2024. Two researchers conducted the search using relevant keywords and their combinations.

Results: Overall, 661 articles were identified in the initial search. After eliminating duplicates and reviewing titles, abstracts, and inclusion/exclusion criteria, a total of 13 articles were selected for inclusion in the study. Based on the results of the reviewed studies, the latest advanced guidelines in implant placement surgery include computer-assisted implant surgery (in both static and dynamic methods) and augmented reality-based navigation with cone-beam computed tomography. The success rates of these advanced implant placement guidelines were reported through evaluating their accuracy metrics (assessing hex deviation, angular deviation, crown positioning, and implant angle). In all the mentioned guidelines, the accuracy of implant placement was found to be superior to that of free-hand implant placement guidelines.

Conclusion: According to the results of this review, although the accuracy of the newly introduced advanced guidelines was higher than that of free-hand guidelines, there was no clear evidence indicating which advanced surgical guideline was associated with higher accuracy in implant placements. Given that implant placement surgery can have long-term clinical implications, it is recommended that researchers focus on this type of surgery in the future.

Keywords: Practice guidelines, Surgery, Dental implants, Systematic review

Please cite this article as follows: Khademi F, Safari M, Yarmohammadi E, Khazaei S, Khamverdi Z. Advanced guidelines in implant placement surgery: a systematic review study. Avicenna J Dent Res. 2025;17(3):x-x. doi:10.34172/ajdr.2212

Background

Dental implants have emerged as a widely accepted solution for replacing missing teeth. Essentially, a dental implant consists of a structure made from biocompatible materials that is surgically inserted into oral tissues (beneath the mucosa, within the periosteum, or directly into the bone). The primary purpose of an implant is to provide support and stability for either a fixed or removable dental prosthesis (1). Dental implants offer several advantages over other treatments for lost teeth, including a high success rate (over 97% over 10 years), reduced risk of decay and issues with adjacent teeth roots, improved maintenance of jawbone at the site of the missing tooth, and decreased sensitivity in neighboring teeth (1,2).

Despite advancements in implant technology, potential surgical complications can arise during their placement, including damage to nearby structures, aesthetic issues, inflammation around the implant site, and, in some cases, implant failure (3). Most of these complications arise from improper positioning of the implant (4). Correct placement of the implant provides several benefits, such as excellent aesthetic results and long-term health of soft and hard tissues, ensuring optimal occlusion and placement of the implant (3,5). Additionally, the ideal location for the implant optimizes the design of final restorations and allows for the design and construction of a retaining screw restoration that can also prevent adhesive factors (3).

Generally, implants are placed in areas with a higher amount of jawbone tissue; however, in many cases, the placement of implants is not as precise as it appears. Even a slight deviation in implant placement compared to its ideal position can lead to problems in forming the final structure of implants in the patient's mouth. Therefore, adherence to a precise guideline for placing implants is essential (6). To address this challenge, there are guidelines for the surgical placement of implants that not only assist in diagnosis and treatment planning but also facilitate the selection of appropriate positions for placing implants in the jawbone. This can significantly reduce clinical complications associated with implant placement. Newer and more advanced technologies for surgical procedures have been developed in response to the increasing demand for dental implants and perceived complexities in their placement (7).

With the growing need for implants, it is expected that the demand for this treatment will increase globally over the next decade. As previously mentioned, despite their acceptance, some issues related to dental implants have been reported, such as surgical complications and prosthetic failures due to the improper diagnosis and positioning of the implants. Accordingly, selecting an advanced surgical guideline for implant placement with minimal complications and consequences is necessary by examining the advantages and disadvantages associated with each surgical guideline. This goal can only be achieved by reviewing the latest advanced guidelines in implant placement surgery. Previous studies have randomly focused on the advantages and disadvantages of advanced surgical guidelines in implant placement; thus, enhancing knowledge regarding the selection of the best advanced surgical guideline requires thorough and systematic investigations. In this way, future treatments for patients eligible for this procedure can be based on these guidelines. Hence, this study seeks to systematically review advanced guidelines in implant placement surgery.

Materials and Methods

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, which involved evaluating all studies related to advanced guidelines in implant placement surgery published in the databases of PubMed, Scopus, ISI , and Cochrane Library. However, there was no clear evidence representing which advanced surgical guideline was related to higher accuracy in implant placements from 2019 to March 2024. The search strategy employed the following English keywords:

((“Surgical Method”) OR (“Guide Surgical”) OR (“Advanced Surgical Guide”) OR (“Advanced Surgical Navigation”) OR (“Online Classes”) OR (“Virtual Education”)) AND ((“Dental Implants”) OR (“Dental Prosthesis Implantation”) OR (“Dental Implantation”) OR (“Dental Prosthesis”) OR (“Prosthesis Implantation”)).

These keywords were utilized in all possible combinations to extract all relevant articles from the aforementioned databases. Additionally, the reference lists of the retrieved articles were examined to identify further studies. Initially, the titles and abstracts of all obtained articles were reviewed, leading to the removal of duplicates and articles that did not meet the inclusion criteria. To minimize bias, all extraction and review processes were conducted independently by two researchers (F. K. and M. S.). Each author independently evaluated all retrieved articles based on their titles, abstracts, and full texts according to the study's inclusion criteria, providing reasons for any exclusions made. Any disagreements between the two researchers were resolved by a third investigator.

On the other hand, the inclusion criteria for this study encompassed studies published in English that were classified as in vitro studies, randomized controlled clinical trials, or cohort studies relevant to the topic of this research. Moreover, these criteria included conference abstracts, case reports, articles without full-text access, review articles, letters to the editor, and publications in languages other than English. In this systematic review, data such as authors' names, year of study, study title, study objectives, research location, study type, and results were separately compiled for each study. The quantitative synthesis of their results was avoided due to the heterogeneity of the searched studies. The obtained data were analyzed through a comprehensive review of articles, qualitative summarization, and final conclusions.

Results

In the conducted review, a total of 661 articles were identified during the initial search. After removing duplicate entries, 494 titles and abstracts were assessed for inclusion and exclusion criteria. Among these, 55 articles met the inclusion criteria. Following the elimination of 42 articles due to including insufficient data, not having access to their full texts, or meeting the exclusion criteria, a final total of 13 articles were deemed eligible for inclusion in the study. Nonetheless, there was no clear evidence demonstrating which advanced surgical guideline was linked to higher accuracy in implant placements (Figure 1).

The results extracted from this systematic review regarding the latest advanced guidelines in implant placement surgery from 2019 to March 2024 included computer-assisted implant surgery (CAIS) and augmented reality (AR)-based navigation with cone-beam computed tomography (CBCT). The most recent scientific studies examined the advantages and superiority of both static and dynamic methods of CAIS or conducted comparative analyses of the aforementioned new guidelines of CAIS and AR navigation against previous free-hand guidelines. In all these investigations, the primary objective was to evaluate and compare hex deviation, angular deviation, crown positioning, and implant angle to select the best guideline (Table 1).

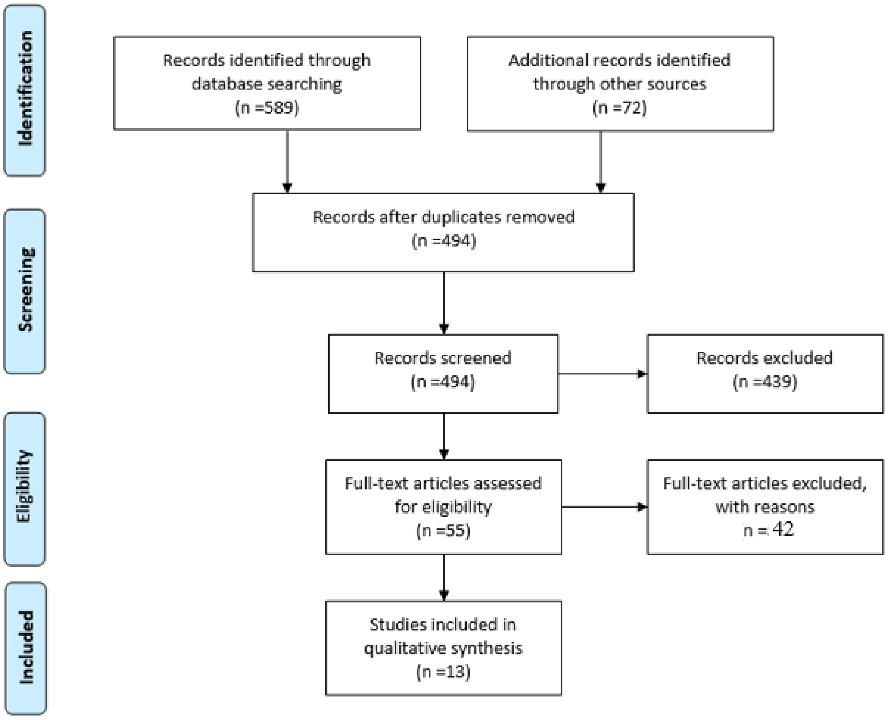

Figure 1. PRISMA Flowchart of Study Selection for the Systematic Review. *Note*. PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses

Computer-Assisted Implant Surgery

CAIS enables dentists to achieve clinically sufficient accuracy in the planned placement position during surgery (21). Guided implant placement is a minimally invasive surgical technique designed to minimize surgical time and reduce postoperative complications. This method helps dentists avoid damaging adjacent tooth roots, major blood vessels, nerves, the nasal cavity, and maxillary sinuses, particularly when compared to traditional free-hand techniques. Optimal aesthetics, functionality, and biomechanics of the implant can be achieved by utilizing this approach while also promoting the long-term stability of the surrounding soft and hard tissues. Guided implant placement can be further categorized into dynamic navigation and static navigation (22).

In static CAIS, the virtual implant site designed using computer assistance is referenced based on CT data, providing precise guidance for implant preparation and placement under a surgical guide template. However, this guide does not allow for the repositioning of the implant during the procedure (23,24). In this type of surgery, a predetermined computer template is used to place a stent with metal tubes. Essentially, the virtual implant position derived from CT data is transferred to the surgical site (6). The advantage of using static computer-assisted surgery (CAS) is knowing the fixture's position before final implant placement, which aids in creating an immediate implant restoration on the same day (25).

Dynamic navigation involves using a surgical navigation system for implant placement that can design the virtual implant location based on CT data (3). This system allows dentists to monitor the preparation of the implant bed during surgery. Image capture from teeth and related information is performed using CT or CBCT, enabling dentists to track the positions of surgical drills in real time with specialized software and tracking methods (26). In other words, dynamic computer-assisted implant systems provide live tracking for implants. This surgical system uses an optimal marker and correlates this information with a three-dimensional virtual program prior to surgery using CBCT (27). This system allows for the real-time tracking of implant drills during the procedure based on tracking technology. If necessary, adjustments to the designed implant location and its size, length, width, and shape can be made during surgery according to the actual intraoral conditions of patients. Overall, dynamic navigation has enhanced the process by providing dentists with navigational tools to improve accuracy in implant placement (3).

The static approach is more commonly used due to its ease of use and lower cost compared to the dynamic approach. Consequently, most major implant brands have their own static computer-assisted surgical systems; however, all are based on a fundamental principle (25).

Augmented Reality-Based Navigation With Cone-Beam Computed Tomography

AR is a technology that overlays computer-generated content onto the real environment to enhance the sensory perception of dentists (28,29). AR includes innovative imaging technology that creates an immersive surgical environment by integrating digital data with real-world surroundings. This technology is incorporated into a dynamic dental implant guiding system to assist operators in visualizing real-time navigation information for improved surgical performance (30,31). AR utilizes a set

Table 1. A Brief Description of the Discussed Guidelines

Results	Guideline	Purpose	Country	Authors/ Years
"Augmented reality (AR)-based navigation combined with cone-beam computed tomography (CBCT) for dental implant placement showed better results than relying solely on the dentist's experience (mean target error = 1.25 mm vs. 1.63 mm; mean angular error = 4.03 degrees vs. 6.10 degrees)."	The AR-guided implant was placed using three-dimensional (3D) images generated from CBCT.	Clinical evaluation and comparison of implant placement accuracy using AR-based navigation with CBCT versus the dentist's experience	China	Ma et al (8)
The mean deviation at the implant platform and apex in the static computer-assisted implant surgery (CAIS) group was 0.44 ± 0.97 mm and 0.46 ± 1.28 mm, respectively, while in the dynamic CAIS group, it was 1.05 ± 0.44 mm and 1.29 ± 0.50 mm, respectively. The angular deviation in the static and dynamic CAIS groups was 2.84 ± 1.71 degrees and 3.06 ± 1.37 degrees, respectively. The deviation angle, crown, and implant angle were the same and without difference in both static and dynamic groups.	Implants were placed using computer-guided static or dynamic systems.	Comparison of implant placement accuracy between static and dynamic CAIS in single-tooth gaps	Thailand	Kaewsiri et al (9)
The mean coronal deviations were 0.43 ± 0.78 mm for static CAIS and 0.85 ± 0.48 mm for dynamic CAIS. The mean apical deviations were 0.48 ± 1.20 mm and 0.60 ± 1.18 mm for static CAIS and dynamic CAIS, respectively. The angular deviation for static CAIS was 1.48 ± 2.95 degrees and 1.41 ± 4 degrees for dynamic CAIS. The crown position did not differ between the static and dynamic CAIS groups, but the angular deviations were greater in the dynamic group than in the static group.	Implants were placed using computer-guided static or dynamic systems.	Analysis of the accuracy of static and dynamic computer-assisted dental implant	Spain	Mediavilla Guzmán et al (10)
The mean angular deviation was 2.72 ± 1.42 degrees. The mean 3D deviation at the implant entry point was 0.34 ± 0.75 mm, and at the implant apex, the mean was 1.06 ± 0.44 mm. The implant survival rate was 99.3% (only 1 failed implant) at 12 months and 24 months post-placement.	Patients underwent implant placement planning using computer-guided surgery (coDiagnostiX), with the surgical guide fabricated based on the results of tomographic imaging. Three months post-implantation, an intraoral scan of the implant position was obtained to evaluate placement accuracy using the coDiagnostiX treatment evaluation tools.	Analysis of the accuracy of static and dynamic computer-assisted implant placement	Netherlands	Derksen et al (11)
In the static CAIS group, the median (interquartile range) deviations in angles, shoulders, and apices were 2.8 (2.6) degrees, 0.9 (0.8) mm, and 1.2 (0.9) mm, respectively. In the free-hand group, the median deviations in angles, shoulders, and apices were 7.0 (7.0) degrees, 1.3 (0.7) mm, and 2.2 (1.2) mm, respectively. The angular and coronal deviations in the static CAIS group were lower than in the free-hand group.	In both groups, digital implant planning was performed using CBCT data and surface scans. In the static computer-guided system group, a fully guided implant surgical guide was used, while in the free-hand group, implants were placed freehand.	Comparison of the accuracy of dental implant placement using static computer-assisted systems and free-hand surgery in a single tooth gap.	Thailand	Smitkarn et al (12)
The mean 3D deviation in the static and dynamic CAIS groups at the implant platform was 1.04 ± 0.67 mm versus 1.24 ± 0.39 mm, respectively. At the apex, it was 0.79 ± 1.54 mm versus 0.56 ± 1.58 mm, and the angular deviation was 1.69 ± 4.08 degrees versus 1.84 ± 3.78 degrees, respectively. The angular deviation between two placed implants in the static and dynamic CAIS groups was also 2.44 ± 4.32 and 2.29 ± 3.55 degrees, respectively. There was no significant difference in coronal and angular deviations between the two placed (parallel) implants between the two groups. Both static and dynamic CAIS methods provide similar accuracy in 3D implant positioning and parallelism between two implants.	Implants were placed using computer-guided static or dynamic systems.	Comparison of the positional accuracy and parallelism of two implants using static and dynamic computer-assisted systems	Thailand	Yimarj et al (13)
The mean deviation of the implant hex, apex, and angle in the static group was 1.15 ± 0.34 mm, 1.37 ± 0.38 mm, and 2.60 ± 1.11 degrees, respectively. The mean deviation of the implant hex, apex, and angle in the dynamic group was 0.40 ± 0.41 mm, 0.34 ± 0.33 mm, and 1.1 ± 0.97 degrees, respectively. The deviation of the hex, coronal area, and implant angle was lower in the dynamic group compared to the static group.	Implants were placed using computer-guided static or dynamic systems.	Comparison of implant placement accuracy between static and dynamic computer-assisted surgery systems in a model of a partially edentulous mandible	China	Zhou et al (14)
The free-hand technique (mean deviations of 1.10 mm for coronal, 1.88 mm for apical, with an angular deviation of up to 6.3 degrees). The static system (mean deviations of 0.35 mm coronal, 0.43 mm apical, and 0.78 degrees angular, respectively). The angular and coronal deviations in the static computer-assisted system were lower than in the free-hand group.	Patients were divided into two groups for implant surgery planning. One group was planned using CBCT, and the other group was planned using the free-hand technique.	Comparative analysis of implant placement accuracy using static computer systems vs. free-hand surgery	England	Mistry et al (15)

Table 1. Continued.

Results	Guideline	Purpose	Country	Authors/ Years
The 3D angular deviation of the implant in the AR group versus the other group was 1.18 ± 1.68 degrees and 2.17 ± 2.46 degrees, respectively. The mean apical implant deviation in the AR and non-AR groups was 0.36 ± 1.21 mm and 0.52 ± 1.27 mm, respectively. No significant difference was observed between the two groups.	Patients were divided into two groups. A navigation and laboratory guide system with AR was used for one group, and the same system without AR was utilized for the other.	Evaluation of implant deviation between navigation systems and surgical guides with and without AR techniques	Thailand	Yotpibulwong et al (16)
The static method (angular deviation, 4.09 ± 2.79° and 3.21 ± 1.52°; coronal deviation, 0.40 ± 1.27 mm and 0.42 ± 1.31 mm, and apical deviation, 1.31 ± 1.34 mm and 0.1 ± 1.34 mm) AR-based navigation (coronal and apical deviations of 0.79 ± 1.93 mm and 0.74 ± 2.28 mm, respectively). No significant difference was found in the accuracy of dental implant placement using AR-based navigation compared to static computer-assisted implant placement (in terms of angular, coronal, and apical deviations), and the superiority of both methods was confirmed compared to the free-hand technique.	Group 1: AR-based navigation; Group 2: Free-hand implant placement; Group 3: Static computer-guided implant placement.	Comparison of implant placement accuracy in model surgeries performed using three different implant placement methods	Hungary	Kivovics et al (17)
The mean deviations in the static and dynamic CAIS groups were 0.63 ± 0.99 mm and 0.55 ± 1.06 mm, respectively, and the mean apical deviations were 0.75 ± 1.50 mm and 1.18 ± 0.53 mm, respectively. The angular deviation in the static and dynamic CAIS groups was 2.18 ± 3.07 degrees and 1.67 ± 3.23 degrees, respectively. Both static and dynamic methods resulted in accurate implant placement (coronal and apical deviations with no significant difference between the two groups).	Implants were placed using computer-guided static or dynamic systems.	A comparison of full-guidance accuracy between computer-aided implant surgery systems for immediate implant placement in the maxilla	China	Feng et al (18)
The mean coronal and apical deviations for static CAIS were 0.88 ± 0.31 mm and 1.45 ± 0.37 mm, respectively, and for dynamic CAIS, the mean coronal and apical deviations were 0.97 ± 0.32 mm and 1.58 ± 0.56 mm, respectively. Both static and dynamic methods resulted in accurate implant placement (coronal and apical deviations with no significant difference between the two groups). However, the dynamic method showed higher deviations in a laboratory setting.	Implants were placed using computer-guided static or dynamic systems.	Comparison between two different implant sites regarding implant placement accuracy using static versus dynamic computer-guided implant surgery.	Switzerland	Taheri Otaghsara et al (19)
The mean coronal deviation was 0.87 mm and 0.91 mm for the AR and free-hand groups. The mean angular deviation for these two groups was 1.84 degrees and 4.93 degrees, respectively. The AR method demonstrated less angular deviation compared to the free-hand method.	Two groups of patients received implants using the free-hand method and an AR navigation system, respectively.	Developing and evaluating an AR-based implant navigation system for dental implants, and assessing implant accuracy using the free-hand technique	China	Liu et al (20)

of technologies to merge the digital world with reality. The main components of this system include a display, tracking technology, and specialized software. The display allows users to simultaneously perceive both the real environment and presented digital information, while tracking technology ensures that digital information accurately corresponds to real objects in real time (32).

Free-Hand Method

In free-hand surgical techniques, panoramic and periapical radiographs are employed to evaluate the width and characteristics of the available alveolar bone for implant placement and to examine the surrounding anatomy prior to utilizing CBCT imaging. During this process, instruments such as probes, gauges, or periodontal calipers are used in intraoral examinations to assess the bone quality. This approach provides a practical representation of ridge height and thickness, aiding in the planning of the implant procedure (12). Surrounding teeth can also serve as guides for determining the correct position of the implant. The free-hand method offers numerous advantages for dentists as it allows them to visualize diagnostic data in relation to soft tissues and assess bone anatomy relevant to actual clinical conditions (33).

Discussion

This systematic review presented integrated evidence of the latest and most advanced guidelines in implant placement surgery from 2019 to March 2024. Since the introduction of modern implantology to the medical community in the early 1980s, dentists have consistently sought to place implants based on the amount of remaining bone in the patient's jaw (34). This issue is compounded by challenges such as misplacing implants within the jaw, which often makes achieving suitable prosthetics difficult or impossible, both aesthetically and functionally (35). It is essential to understand that dentists typically prefer to place implants in areas with the greatest volume of remaining bone; however, this approach can lead to excessive buccal or lingual positioning of the implant, resulting in complications (36).

Based on the findings of this study, the latest published guidelines for implant placement include CAIS using both static and dynamic methods, as well as AR-based navigation with CBCT. In most studies evaluating the outcomes and implications of CAIS between static and dynamic methods, no significant differences were found regarding accurate positioning for implant placement. However, the results of the study by Zhou et al indicated that hex, crown, and angular deviations were lower in the dynamic group compared to the static group (14). Additionally, another study reported that using dynamic CAS achieved an average crown deviation of less than 1 mm and an angular deviation of less than 5 degrees (37). The higher accuracy of implant placement in these studies can be attributed to their laboratory settings, where implants are placed in models that allow for better surgical visibility without patient movement, thus reducing operator error (38). Another reason for the lower angular deviation in dynamic methods compared to static methods is operator experience, which has become a measured variable influencing accuracy in clinical practice (39). Therefore, an experienced operator can significantly minimize implantation errors.

The accuracy of CAS is affected by all individual errors throughout the treatment process. Considering that CAS approaches are image-based, image acquisition and processing inevitably introduce errors. Although CBCT is currently one of the most reliable tools for preoperative assessment for dental implant placement, measuring the mandible with CBCT can result in an average systematic error of up to 1.4%. Another major source of error in CAS application is related to inputting CT data and surface scan data into planning software (14). Several factors can affect the accuracy of implant positioning when utilizing both static and dynamic CAIS. In static CAIS, common limitations and potential sources of error include the breakage or improper fit of surgical guides, as well as challenges presented by patients with limited mouth opening. On the other hand, dynamic CAIS may encounter limitations and errors related to the learning curve associated with navigation systems, particularly among novice dentists who are still becoming familiar with the technology (13).

The current systematic review indicates that CAIS significantly influences implant placement accuracy. Both static and dynamic CAIS methods are successful for implant placement; however, it appears that dynamic CAS may achieve higher accuracy than static CAS in specific clinical environments (e.g., laboratory settings). The results of this systematic review suggest that utilizing new technologies and modern software is associated with higher success rates for accurate placements with minimal damage and optimal aesthetics for dental implants.

According to this study's findings, the results of Smitkarn et al (12) and Mistry et al (15) revealed that angular and crown deviations were lower in static computer systems compared to free-hand groups. These results confirm that the novel CAIS is more successful than previous guidelines for implant placements. Although a body of evidence suggests greater accuracy for implants placed via static CAIS, the limitations of this technique include higher costs and requirements for favorable anatomical conditions regarding mouth opening (36,40).

Furthermore, based on the results of this systematic review, the examined studies demonstrated a higher success rate for AR-based navigation with CBCT compared to traditional free-hand methods. According to Kivovics et al, the lowest crown or apical deviations between implant positions were reported using AR navigation systems compared to free-hand methods (17), highlighting the superiority of this new guideline in successful implant placements.

AR navigation allows dentists to visualize surgical plans overlaid on the actual surgical field, providing complete visual control over both the surgical plan and the field simultaneously. In this method, surgeons do not need to shift their focus between a monitor and the surgical area, which may be a significant advantage over dynamic navigation in clinical settings and could help prevent iatrogenic complications during implant placement. Additionally, a noted advantage of AR navigation over static CAIS is that it does not require template fabrication; instead, immediate loading of surgical plans into computer systems is possible (17,32,41). In the study by Kivovics et al, crown and apical angular deviations following AR navigation were reported as 0.40 ± 1.27 mm and 0.41 ± 1.34 mm, respectively (17), similar to previous laboratory studies' results (8,31,42,43). The developed AR navigation guideline can provide a scene from the surgical site and enhance depth perception for dentists. This therapeutic approach can resolve hand-eye coordination issues present in some commercially developed navigation systems for dental implant surgery because older guiding systems always display navigational information on a screen away from the surgical site. Considering that dental implant placement methods must meet biomechanical, functional, and aesthetic needs, precise location and orientation are essential (8). This novel guideline is capable of fulfilling these requirements for dental implant placements.

To the best of our knowledge, this was the first study to examine advanced guidelines in implant placement surgery over the past five years (2019-2024), which is a strength of this research. However, limitations included a limited number of studies focusing on advanced guidelines for dental implant surgery and concentrating on only one surgical guideline; additionally, methodological diversity among studies and heterogeneity in published results posed challenges for conducting meta-analyses.

Conclusion

Based on the findings from studies reviewed in this research, each of the static and dynamic CAIS guidelines, along with AR-based navigation with CBCT, was successfully performed compared to older free-hand guidelines in dental implant placement surgery. Each of these new guidelines offers advantages regarding accuracy during dental implantation; however, limitations and challenges still exist within each novel CAIS guideline (static or dynamic), as well as AR-based navigation with CBCT, thereby requiring further investigation through laboratory and clinical studies. Evidence-based studies should provide solutions aimed at addressing these limitations and challenges associated with novel CAIS guidelines (both static and dynamic) and AR-based navigation with CBCT.

Acknowledgments

We gratefully acknowledge the Research Deputy of Hamadan University of Medical Sciences for the approval and support of this study.

Authors' Contribution

Conceptualization: Fazilat Khademi, Maryam Safari.
Data curation: Ebrahim Yarmohammadi, Zahra Khamverdi.
Formal analysis: Salman Khazaei, Maryam Safari.
Funding acquisition: Ebrahim Yarmohammadi.
Investigation: Salman Khazaei, Maryam Safari, Fazilat Khademi.
Methodology: Ebrahim Yarmohammadi, Zahra Khamverdi, Fazilat Khademi.
Project administration: Maryam Safari, Fazilat Khademi.
Resources: Ebrahim Yarmohammadi.
Software: Salman Khazaei.
Supervision: Ebrahim Yarmohammadi, Zahra Khamverdi.
Validation: Ebrahim Yarmohammadi, Zahra Khamverdi.
Visualization: Ebrahim Yarmohammadi, Zahra Khamverdi.
Writing-original draft: Maryam Safari, Salman Khazaei, Zahra Khamverdi, Fazilat Khademi.
Writing–review and editing: Maryam Safari, Salman Khazaei, Zahra Khamverdi, Fazilat Khademi, Ebrahim Yarmohammadi.

Competing Interests

The authors declare that they have no competing financial or non-financial interests related to this work.

Ethical Approval

This study was conducted in accordance with ethical standards and received approval from Hamadan University of Medical Sciences (approval code IR.UMSHA.REC.1404.094).

Funding

This study was self-funded by the authors and received no external financial support from any funding organization.

References

1. Gupta R, Gupta N, Weber KK. Dental implants. In: StatPearls [Internet]. Treasure Island, FL: StatPearls Publishing; 2023.
2. Block MS. Dental implants: the last 100 years. J Oral Maxillofac Surg. 2018;76(1):11-26. doi: 10.1016/j.joms.2017.08.045.
3. Wu D, Zhou L, Yang J, Zhang B, Lin Y, Chen J, et al. Accuracy of dynamic navigation compared to static surgical guide for dental implant placement. Int J Implant Dent. 2020;6(1):78. doi: 10.1186/s40729-020-00272-0.
4. Panchal N, Mahmood L, Retana A, Emery R 3rd. Dynamic navigation for dental implant surgery. Oral Maxillofac Surg Clin North Am. 2019;31(4):539-47. doi: 10.1016/j.coms.2019.08.001.
5. Marcantonio C, Nicoli LG, Marcantonio Junior E, Zandim-Barcelos DL. Prevalence and possible risk factors of peri-implantitis: a concept review. J Contemp Dent Pract. 2015;16(9):750-7. doi: 10.5005/jp-journals-10024-1752.
6. Yeshwante B, Baig N, Tambake SS, Tambake R, Patil V, Rathod R. Mastering dental implant placement: a review. J Appl Dent Med Sci. 2017;3(2):220-7.
7. Pyo SW, Lim YJ, Koo KT, Lee J. Methods used to assess the 3D accuracy of dental implant positions in computer-guided implant placement: a review. J Clin Med. 2019;8(1):54. doi: 10.3390/jcm8010054.
8. Ma L, Jiang W, Zhang B, Qu X, Ning G, Zhang X, et al. Augmented reality surgical navigation with accurate CBCT-patient registration for dental implant placement. Med Biol Eng Comput. 2019;57(1):47-57. doi: 10.1007/s11517-018-1861-9.
9. Kaewsiri D, Panmekiate S, Subbalekha K, Mattheos N, Pimkhaokham A. The accuracy of static vs. dynamic computer-assisted implant surgery in single tooth space: a randomized controlled trial. Clin Oral Implants Res. 2019;30(6):505-14. doi: 10.1111/clr.13435.
10. Mediavilla Guzmán A, Riad Deglow E, Zubizarreta-Macho Á, Agustín-Panadero R, Hernández Montero S. Accuracy of computer-aided dynamic navigation compared to computer-aided static navigation for dental implant placement: an in vitro study. J Clin Med. 2019;8(12):2123. doi: 10.3390/jcm8122123.
11. Derksen W, Wismeijer D, Flügge T, Hassan B, Tahmaseb A. The accuracy of computer-guided implant surgery with tooth-supported, digitally designed drill guides based on CBCT and intraoral scanning. A prospective cohort study. Clin Oral Implants Res. 2019;30(10):1005-15. doi: 10.1111/clr.13514.
12. Smitkarn P, Subbalekha K, Mattheos N, Pimkhaokham A. The accuracy of single-tooth implants placed using fully digital-guided surgery and freehand implant surgery. J Clin Periodontol. 2019;46(9):949-57. doi: 10.1111/jcpe.13160.
13. Yimarj P, Subbalekha K, Dhanesuan K, Siriwatana K, Mattheos N, Pimkhaokham A. Comparison of the accuracy of implant position for two-implants supported fixed dental prosthesis using static and dynamic computer-assisted implant surgery: a randomized controlled clinical trial. Clin Implant Dent Relat Res. 2020;22(6):672-8. doi: 10.1111/cid.12949.
14. Zhou M, Zhou H, Li SY, Zhu YB, Geng YM. Comparison of the accuracy of dental implant placement using static and dynamic computer-assisted systems: an in vitro study. J Stomatol Oral Maxillofac Surg. 2021;122(4):343-8. doi: 10.1016/j.jormas.2020.11.008.
15. Mistry A, Ucer C, Thompson JD, Khan RS, Karahmet E, Sher F. 3D guided dental implant placement: impact on surgical accuracy and collateral damage to the inferior alveolar nerve. Dent J (Basel). 2021;9(9):99. doi: 10.3390/dj9090099.
16. Yotpibulwong T, Arunjaroensuk S, Pimkhaokham A. Application of Augmented Reality with Navigation System and Laboratory Guide Affected on the Deviation of Dental Implant-A Pilot Clinical Study. RSU International Research Conference; 2022. p. 193-201.
17. Kivovics M, Takács A, Pénzes D, Németh O, Mijiritsky E. Accuracy of dental implant placement using augmented reality-based navigation, static computer assisted implant surgery, and the free-hand method: an in vitro study. J Dent. 2022;119:104070. doi: 10.1016/j.jdent.2022.104070.
18. Feng Y, Su Z, Mo A, Yang X. Comparison of the accuracy of immediate implant placement using static and dynamic computer-assisted implant system in the esthetic zone of the maxilla: a prospective study. Int J Implant Dent. 2022;8(1):65. doi: 10.1186/s40729-022-00464-w.
19. Taheri Otaghsara SS, Joda T, Thieringer FM. Accuracy of dental implant placement using static versus dynamic computer-assisted implant surgery: An in vitro study. J Dent. 2023;132:104487. doi: 10.1016/j.jdent.2023.104487.
20. Liu L, Wang X, Guan M, Fan Y, Yang Z, Li D, et al. A mixed reality-based navigation method for dental implant navigation method: a pilot study. Comput Biol Med. 2023;154:106568.

doi: 10.1016/j.compbiomed.2023.106568.
21. Gargallo-Albiol J, Barootchi S, Salomó-Coll O, Wang HL. Advantages and disadvantages of implant navigation surgery. A systematic review. Ann Anat. 2019;225:1-10. doi: 10.1016/j.aanat.2019.04.005.
22. Joda T, Zarone F, Ferrari M. The complete digital workflow in fixed prosthodontics: a systematic review. BMC Oral Health. 2017;17(1):124. doi: 10.1186/s12903-017-0415-0.
23. Colombo M, Mangano C, Mijiritsky E, Krebs M, Hauschild U, Fortin T. Clinical applications and effectiveness of guided implant surgery: a critical review based on randomized controlled trials. BMC Oral Health. 2017;17(1):150. doi: 10.1186/s12903-017-0441-y.
24. Wismeijer D, Joda T, Flügge T, Fokas G, Tahmaseb A, Bechelli D, et al. Group 5 ITI consensus report: digital technologies. Clin Oral Implants Res. 2018;29 Suppl 16:436-42. doi: 10.1111/clr.13309.
25. Thangwarawut P, Amornvit P, Rokaya D, Kiattavorncharoen S. Comparison of different types of static computer-guided implant surgery in varying bone inclinations. Materials (Basel). 2022;15(9):3004. doi: 10.3390/ma15093004.
26. Wei SM, Zhu Y, Wei JX, Zhang CN, Shi JY, Lai HC. Accuracy of dynamic navigation in implant surgery: a systematic review and meta-analysis. Clin Oral Implants Res. 2021;32(4):383-93. doi: 10.1111/clr.13719.
27. Pellegrino G, Lizio G, Basile F, Stefanelli LV, Marchetti C, Felice P. Dynamic navigation for zygomatic implants: a case report about a protocol with intraoral anchored reference tool and an up-to-date review of the available protocols. Methods Protoc. 2020;3(4):75. doi: 10.3390/mps3040075.
28. Ayoub A, Pulijala Y. The application of virtual reality and augmented reality in oral & maxillofacial surgery. BMC Oral Health. 2019;19(1):238. doi: 10.1186/s12903-019-0937-8.
29. Durham M, Engel B, Ferrill T, Halford J, Singh TP, Gladwell M. Digitally augmented learning in implant dentistry. Oral Maxillofac Surg Clin North Am. 2019;31(3):387-98. doi: 10.1016/j.coms.2019.03.003.
30. Kwon HB, Park YS, Han JS. Augmented reality in dentistry: a current perspective. Acta Odontol Scand. 2018;76(7):497-503. doi: 10.1080/00016357.2018.1441437.
31. Yao J, Zeng W, Zhou S, Cheng J, Huang C, Tang W. Augmented reality technology could be an alternative method to treat craniomaxillofacial foreign bodies: a comparative study between augmented reality technology and navigation technology. J Oral Maxillofac Surg. 2020;78(4):578-87. doi: 10.1016/j.joms.2019.11.019.
32. Wang J, Shen Y, Yang S. A practical marker-less image registration method for augmented reality oral and maxillofacial surgery. Int J Comput Assist Radiol Surg. 2019;14(5):763-73. doi: 10.1007/s11548-019-01921-5.
33. Yogui FC, Verri FR, de Luna Gomes JM, Lemos CA, Cruz RS, Pellizzer EP. Comparison between computer-guided and freehand dental implant placement surgery: a systematic review and meta-analysis. Int J Oral Maxillofac Surg. 2021;50(2):242-50. doi: 10.1016/j.ijom.2020.08.004.
34. Nair R. Implant surgical guides are they useful? J Prosthet Implant Dent. 2018;1(2):107-15.
35. Spielau T, Hauschild U, Katsoulis J. Computer-assisted, template-guided immediate implant placement and loading in the mandible: a case report. BMC Oral Health. 2019;19(1):55. doi: 10.1186/s12903-019-0746-0.
36. Choi W, Nguyen BC, Doan A, Girod S, Gaudilliere B, Gaudilliere D. Freehand versus guided surgery: factors influencing accuracy of dental implant placement. Implant Dent. 2017;26(4):500-9. doi: 10.1097/id.0000000000000620.
37. Emery RW, Merritt SA, Lank K, Gibbs JD. Accuracy of dynamic navigation for dental implant placement-model-based evaluation. J Oral Implantol. 2016;42(5):399-405. doi: 10.1563/aaid-joi-D-16-00025.
38. Chang RJ, Chen HL, Huang LG, Wong YK. Accuracy of implant placement with a computer-aided fabricated surgical template with guided parallel pins: a pilot study. J Chin Med Assoc. 2018;81(11):970-6. doi: 10.1016/j.jcma.2018.04.004.
39. Rungcharassaeng K, Caruso JM, Kan JY, Schutyser F, Boumans T. Accuracy of computer-guided surgery: a comparison of operator experience. J Prosthet Dent. 2015;114(3):407-13. doi: 10.1016/j.prosdent.2015.04.004.
40. Pozzi A, Polizzi G, Moy PK. Guided surgery with tooth-supported templates for single missing teeth: a critical review. Eur J Oral Implantol. 2016;9 Suppl 1:S135-53.
41. Jiang W, Ma L, Zhang B, Fan Y, Qu X, Zhang X, et al. Evaluation of the 3D augmented reality-guided intraoperative positioning of dental implants in edentulous mandibular models. Int J Oral Maxillofac Implants. 2018;33(6):1219-28. doi: 10.11607/jomi.6638.
42. Katić D, Spengler P, Bodenstedt S, Castrillon-Oberndorfer G, Seeberger R, Hoffmann J, et al. A system for context-aware intraoperative augmented reality in dental implant surgery. Int J Comput Assist Radiol Surg. 2015;10(1):101-8. doi: 10.1007/s11548-014-1005-0.
43. Lin YK, Yau HT, Wang IC, Zheng C, Chung KH. A novel dental implant guided surgery based on integration of surgical template and augmented reality. Clin Implant Dent Relat Res. 2015;17(3):543-53. doi: 10.1111/cid.12119.