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A Narrative Review On Accuracy Of Computer Assisted Implant Surgery In Digital Implantology

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Abstract
Background:
Dental implantology has evolved significantly with the integration of digital technologies. Computer-assisted implant surgery (CAIS), offered in both static and dynamic forms, aims to enhance precision and reduce errors compared with conventional freehand techniques. The degree of accuracy achieved with these systems directly influences surgical safety, prosthetic outcomes, and patient satisfaction.
Aim:
This review consolidates and evaluates the evidence on the accuracy of static and dynamic CAIS compared with freehand methods in implant placement, highlighting their clinical effectiveness, advantages, and limitations.
Methods:
A comprehensive search of Medline (PubMed), Google Scholar, and manual references was performed for studies published between 2015 and March 2025. Eighteen studies were included based on predefined inclusion and exclusion criteria. These comprised randomized controlled trials, prospective clinical studies, and in vivo investigations that assessed parameters such as coronal, apical, depth, and angular deviations in implant placement.
Results:
Across the included studies, CAIS consistently demonstrated superior accuracy compared with freehand surgery. Fully guided static systems achieved the highest trueness and precision, particularly in angular and apical positioning, while pilot-drill or half-guided approaches showed lower accuracy but still outperformed freehand placement. Digital workflows incorporating CAD/CAM, intraoral scanning, and immediate restoration enhanced clinical efficiency, reduced laboratory steps, and improved patient-reported outcomes.
Conclusion:

Both static and dynamic CAIS improve the accuracy of implant placement relative to freehand techniques. Static fully guided systems provide the most predictable outcomes, while dynamic navigation is advantageous in complex anatomical situations requiring intraoperative adjustments. Despite higher costs and longer chairside times, CAIS is increasingly integral to modern implant dentistry, ensuring precision, reduced prosthetic complications, and better overall treatment predictability.

Keywords: *Dental implants; Computer-assisted implant surgery; Static navigation; Dynamic navigation; Guided surgery; Digital workflow; Implant accuracy*

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I. Introduction

Dental implants are artificial devices placed in the jawbone to provide support for crowns, bridges, dentures, or other prosthetic restorations [1]. Since their introduction in the 1960s, implant dentistry has advanced significantly, leading to more predictable outcomes and easier clinical procedures [2,3]. The incorporation of digital technologies has further revolutionized implant planning and placement. Tools such as cone beam computed tomography (CBCT), intraoral and surface scanners, and specialized planning software allow clinicians to accurately assess anatomical structures and design the ideal prosthetic solution before surgery[4].

Computer-assisted implant surgery (CAIS) was developed to enhance precision and accuracy in implant placement. It is generally classified into two main approaches: static and dynamic. Both methods rely on three-dimensional imaging and virtual planning to determine the ideal implant position[5,6]. Then the virtually planned implant position is transferred to the real surgical sites by means of a custom-made guided surgery template in the case of static CAIS or through a real-time tracking and guidance of the surgical drill in dynamic CAIS system [7,8]. In static CAIS, the planned implant location is transferred to the patient's mouth using a custom-made surgical guide, which can be bone-, mucosa-, or tooth-supported. The highest accuracy is usually achieved with fully guided systems, where both the osteotomy and implant placement are directed by the guide [4,9,10]. In contrast, dynamic CAIS uses real-time tracking systems to guide the surgical drill, allowing intraoperative adjustments to the implant position based on clinical findings. While this provides flexibility, the accuracy of dynamic systems still depends on the surgeon's hand–eye coordination and fine motor control under surgical conditions[4,11,12].

The highest degree of precision in static computer-assisted implant surgery (CAIS) is achieved with fully guided systems. These systems employ designated sleeves, drills, and implant drivers with depth-control features, allowing the surgeon to replicate every step of the digital plan—from osteotomy preparation to final implant insertion—with high accuracy[13]. The accuracy of implant placement using static computer- assisted surgery has been investigated in numerous studies, where the deviation between the planned and the actual implant placement was found to be within acceptable ranges [14,15; 16,17].

Accuracy of implanting guide comprises trueness and precision. Trueness refers to the deviation between postoperative placement and preoperative plan of the implant; precision refers to the deviation of repetitive test results. Generally, accuracy discussed in clinical studies refers to trueness and precision.[18] Comparative studies further highlight that both static and dynamic CAIS demonstrate superior accuracy compared with conventional freehand surgery. These improvements are evident in terms of reduced deviations at the implant platform, apex, and angulation. However, most available clinical studies have primarily assessed single implant placements, with fewer investigations focusing on full-arch or complex rehabilitations, where the challenges of accuracy and reproducibility are more pronounced[19,20,21,22].

Given the rapid development and widespread adoption of these technologies, along with the growing body of literature on CAIS in recent years, it is crucial to consolidate all available data on the accuracy of various sCAIS and dCAIS approaches. Hence, the primary aim of this review is to evaluate and compare the accuracy of different CAIS (Computer assisted Implant Surgery)systems in achieving the Accuracy of Implant placement.

Focused question

Is the use of Computer assisted implant surgery using digital technologies for the implant Placement more efficient and accurate?

Study Design

This narrative review was conducted to evaluate the accuracy of computer-assisted implant surgery (CAIS) systems compared with conventional freehand implant placement. The review adhered to standard methodological approaches for narrative reviews, aiming to synthesize evidence from clinical and experimental studies published within the last decade.

Search Strategy

A comprehensive electronic search was carried out in Medline (PubMed) and Google Scholar, covering the period from January 2015 to March 2025. The search strategy combined keywords and MeSH terms including: "computer-assisted implant surgery,"static navigation,"dynamic navigation, "guided surgery," "implant accuracy," and "digital workflow." The search was restricted to articles published in English. In addition, a manual search of the reference lists of retrieved full-text articles was conducted to identify additional relevant studies not captured in the database search.

Eligibility Criteria

Inclusion criteria:

- Prospective studies, randomized controlled trials (RCTs), in vitro randomized crossover studies, and clinical trials reporting on the accuracy of CAIS.
- Studies evaluating implant placement using static or dynamic navigation systems, with or without comparison to freehand methods.
- Studies reporting quantitative accuracy outcomes such as coronal deviation (mm), apical deviation (mm), depth deviation (mm), and/or angular deviation (°).
- Publications written in English between 2015 and 2025.

Exclusion criteria:

- In vitro and preclinical studies unrelated to CAIS accuracy.
- Studies based solely on questionnaires, interviews, or survey-based methodologies.
- Reports evaluating only conventional freehand techniques without a digital comparison.
- Case reports, narrative reviews, and expert opinions.

Study Selection

Titles and abstracts of all identified records were independently screened by a single reviewer (MK) to determine preliminary eligibility. Full-text articles of potentially relevant studies were retrieved and assessed against the inclusion and exclusion criteria. Final selection was confirmed by two reviewers (MK, AS).

Data Extraction and Analysis

Data from the included studies were systematically extracted and tabulated. Extracted information included: author and year of publication, study design, sample size, type of CAIS evaluated (static or dynamic), control group, virtual planning protocols, and key outcome measures. Accuracy outcomes were synthesized narratively and compared across studies, with particular focus on deviations in implant placement parameters.

Fig 1: Flow Chart Of Search Results

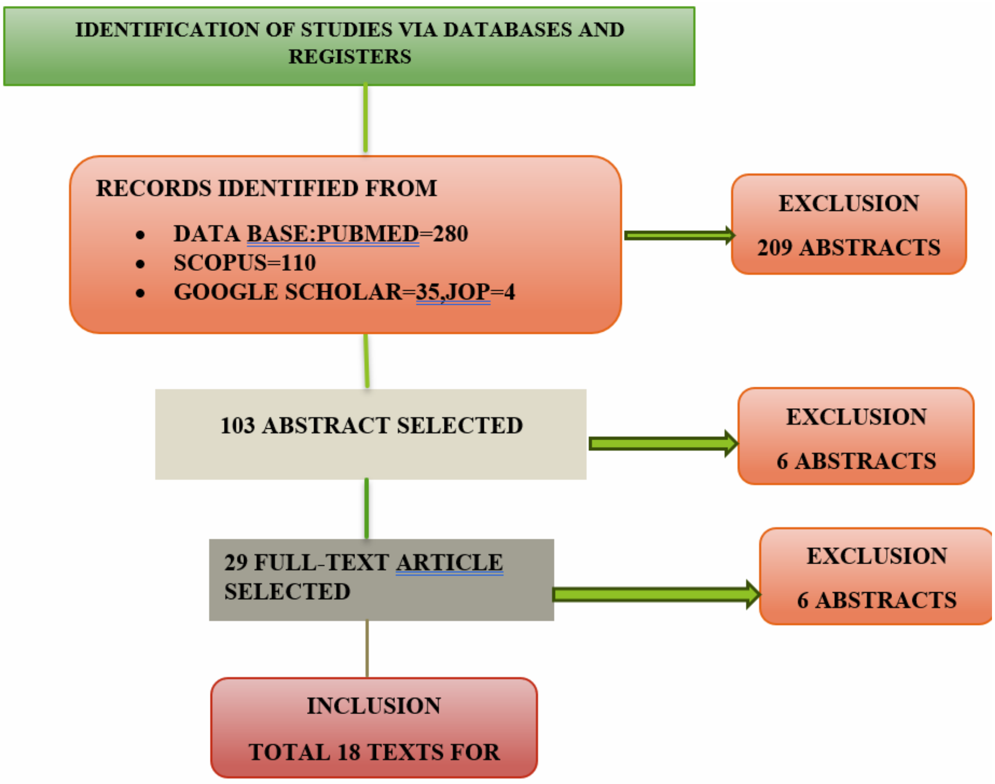

Table 1: The Assesment Of Accuracy Of Implant Placement Using Different Digital Technology

Sl No.	Author & Year	Tittle	Study Design	Sample Size	Test Group	Control Group	Major Key Findings
1	Vercruyssen et al.,(2015)[23]	Depth and lateral deviations in guided implant surgery: an RCT comparing guided surgery with mental navigation or the use of a pilot-drill template.	RCT	60 patients (72 jaws)	Guided surgery (Materialize Universal mucosa/bone, Facilitate mucosa/bone)	Mental navigation , Pilot-drill template	Guided surgery improves accuracy compared to non-guided, particularly in lateral dimensions. However, vertical (depth) deviations remain the main limitation, even with digital workflows.
2	Blockms et al.,(2017)[24]	Implant placement accuracy using dynamic navigation.A Randomized controlled trial	RCT	39males,61 females	Dynamic navigation	freehand	The accuracy of dynamic navigation was superior to that of freehand implant placement
3	Younes et.,al. (2018)[25]	A randomized controlled study on the accuracy of free-handed, pilot-drill guided and fully-guided implant surgery in partially edentulous patients	RCT	32 patients, 71 implants	Pilot-drill guided and fully guided	Freehand	Fully guided surgery demonstrated the highest accuracy, followed by pilot-drill guided. Freehand showed significant deviations, often requiring restoration modifications.
4	Ceyda Aktolun Aydemir, Volkan Arısan. (2019)[26]	Accuracy of dental implant placement via dynamic navigation or the freehand method: A split-mouth randomized controlled clinical trial	A split-mouth randomized controlled clinical trial	Split-mouth, posterior maxilla	Dynamic navigation	Freehand	Dynamic navigation enabled more accurate implant positioning than freehand, confirming its role as a reliable digital alternative.
5	Yuce m.et al(2019)[27]	Clinical benefits and effectiveness of static computer-aided implant surgery compared with	RCT	TOTAL-26 Implant	13 tooth-supported surgical templates	13 using the conventional	Tooth supported surgical templates had no particular effect on the accuracy of

		conventional freehand method for single-tooth implant placement				freehand method	single implant placement. Nevertheless, this procedure allows flappless surgery with minimal invasive approach, reduce operation time and post-op pain levels
6	Smitkarn, P.,(2019)[28]	The accuracy of single-tooth implants placed using fully digital-guided surgery and freehand implant surgery	RCT	52 patients 6o implants	Static CAIS group	Freehand	Static CAIS provided more accuracy in implant positions than freehand placement in a single edentulous space.
7	Yimarj Et Al., (2020) [29]	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.	RCT	30 patients, 60 implants	Static CAIS, Dynamic CAIS	—	Both static and dynamic CAIS systems produced similar levels of accuracy and implant parallelism, suggesting either can be used effectively.
8	Sønderga ard et al., (2021)[30]	Fully versus conventionally guided implant placement by dental students: A randomized controlled trial	RCT	25 patients, 26 implants	Fully guided by students	Conventio nally guided by students	Implants placed by students using fully guided or conventionally guided methods showed similar overall accuracy; however, FG reduced angular and apical deviations.
9	chalermch ai ngampr asertkit·, weerapan aunmeun gthong, pathawee khongkhu nthian, (2021)[31]	The implant position accuracy between using only surgical drill guide and surgical drill guide with implant guide in fully digital workflow: a randomized clinical trial	RCT	30 IMPLAN TS	Surgical drill + implant guide (SDIG)	Drill guide only (SDG)	Using an implant guide in addition to a drill guide (SDIG) resulted in significantly fewer deviations than drill guide alone (SDG), supporting more comprehensive digital workflows.
10	Orban et al., (2022)[32]	Accuracy of halfguided implant placement with machinedriven or manual insertion: a prospective, randomized clinical study	Rando mized clinica l study	Posterior maxilla	Half-guided with surgical motor	Half-guided with manual torque wrench	Machine-driven half-guided placement was faster than manual insertion, with no accuracy differences. Both techniques achieved clinically acceptable precision.
11	Feng et al. (2022)[33]	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	A prospe ctive study	40 patients (esthetic zone)	Dynamic CAIS	Static CAIS	Static and dynamic CAIS were both accurate for immediate implants in the esthetic zone, with no significant differences between the systems.
12	Li et al.(2 023)[34]	Accuracy assessment of implant placement with versus without a CAD/CAM surgical guide by novices versus specialists via the digital registration method: an in vitro randomized crossover study	An in vitro rando mized crosso ver study	60 students, 10 instructor s	CAD/CAM surgical guide	Freehand	CAD/CAM surgical guides significantly improved accuracy for novice students compared to freehand. For experienced operators, both approaches yielded similar results.
13	JORBA-GARCÍA et al.(2023)[35]	Accuracy of dental implant placement with or without the use of a dynamic navigation assisted system: A	RCT	60 patients, 44 implants	Dynamic navigation	Freehand	Dynamic navigation significantly improved accuracy over freehand, particularly in angular deviations. However,

		randomized clinical trial					surgical time was longer and patient satisfaction was similar.
14	Elashry et al.(2024)[36]	Evaluation of the accuracy of conventional and digital implant impression techniques in bilateral distal extension cases: a randomized clinical trial	RCT	8 patients, 32 implants	Digital impressions (TRIOS)	Conventional impressions	Digital impressions using intraoral scanners and conventional splinted impressions showed comparable accuracy. Both methods were reliable for clinical use.
15	Younis et al.(2024)[37]	Accuracy of dynamic navigation compared to static surgical guides and the freehand approach in implant placement: a prospective clinical study	A prospective clinical study	65 patients, 94 implants	Dynamic navigation	Freehand	Dynamic navigation and static guides outperformed freehand in accuracy. Dynamic navigation offered flexibility but required more operative time.
16	Waltenberger et al. (2024)[38]	Effect of immediate all-digital Restoration of single posterior implants: The Safety Crown concept on patient-reported outcome measures,accuracy,and treatment time—A randomized clinical trial	RCT	39 patients, 45 implants	Digital workflow + immediate restoration	Conventional delayed restoration	Immediate loading with digital workflows was successful and improved patient satisfaction. Accuracy was high, but treatment time was longer than conventional delayed restoration.
17	Ren et al.(2024)[39]	Auxiliary occlusal devices for IO scanning in a complete digital workflow of implant supported crowns: a randomized controlled trial	RCT	24 patients, 48 implants	Digital workflow + occlusal device.	Conventional impressions + stone cast crowns	Digital workflow with an occlusal device improved occlusal accuracy and reduced lab time compared to conventional impressions, enhancing efficiency without loss of precision.
18	Mahmoud , N.R, et al(2024)[40]	Computer guided versus freehand dental implant surgery: Randomized controlled clinical trial	RCT	20 Patients 20 implants	Group I =ten patients who received computer-guided dental implant place ment,	Group II =ten patients who received manual placements	surgical guides enhance the accuracy of implant placement, particularly in a deficient alveolar ridge

Abbreviation: Randomized control trail

II. Results

This review included 18 studies that looked at the accuracy of computer-assisted implant surgery (CAIS) compared with freehand techniques. Overall, both static and dynamic CAIS showed better accuracy than freehand placement.**Static CAIS** most studies found that fully guided static systems gave the highest accuracy. These guides reduced errors in implant depth, angulation, and final position (Vercruyssen et al., 2015; Younes et al., 2018; Smitkarn, 2019)[23,25,28] .Half-guided or pilot-drill methods were not as precise but were still more accurate than freehand techniques (Ngamprasertkit et al., 2021; Orban et al., 2022)[31,32]. Using both drill and implant guides together further reduced deviations compared to using a drill-only guide. Static systems also worked well in immediate implant placement, even in the esthetic zone (Feng et al., 2022)[33]. **Dynamic CAIS** also performed better than freehand placement. It reduced deviations in coronal, apical, and angular measurements across multiple studies (Block et al., 2017; Aydemir & Arısan, 2019; Jorba-García et al., 2023; Younis et al., 2024) [24,26,34,37]. In some cases, dynamic navigation showed results similar to static guides (Yimarj et al., 2020; Feng et al., 2022) [29,32]. Its main advantage was the ability to adjust implant positioning in real time, which is useful in more complex surgeries. However, this flexibility often required more surgical time and depended on the surgeon's experience.Studies on dental education showed that students performed better with guided systems. Fully guided and CAD/CAM-based guides helped beginners place implants more accurately, while experienced clinicians showed smaller differences between freehand and guided methods (Søndergaard et al., 2021; Li et al., 2023) [30,34].

Other digital approaches, such as intraoral scanning, CAD/CAM protocols, and immediate restoration, were also effective. These methods saved laboratory time and improved efficiency without reducing accuracy (Waltenberger et al., 2024; Ren et al., 2024; Elashry et al., 2024) [36,38,39]. Patients were generally more satisfied with digital workflows, although treatment times could sometimes be longer.Across all 18 studies, static and dynamic CAIS both showed better precision than freehand placement. Static fully guided systems provided the most predictable results, while dynamic systems allowed flexibility in complex cases. Digital workflows and guided techniques not only improved clinical accuracy but also enhanced training and patient satisfaction.

III. Discussion

Dental implants are inert, alloplastic materials embedded in the maxilla and/or mandible for the management of tooth loss and to aid replacement of lost orofacial structures as a result of trauma, neoplasia and congenital defects. The most common type is the endosseous implant, usually screw or cylinder shaped, placed directly into bone. Titanium and its alloys are widely used, while ceramics and other metals are less common.[41]

The concept of **osseointegration** was introduced by P.-I. Brånemark in 1969 after noticing that titanium placed in rabbit bone became firmly fixed and could not be removed. After a year of observation, the surrounding bone showed no signs of inflammation, while both bone and soft tissue established stable contact with the titanium surface.[42]

In conventional implantology, the most commonly used technique is flap implant insertion, which involves detaching a muco-periosteal flap to expose the alveolar bone and allow a direct visualization of the surgical field. However, the flapless technique can be, less invasive, which involves perforating the gingiva with a surgical guide or special drill, reducing the operative time and postoperative discomfort, but requiring extremely precise preoperative planning.Conventional implant placement has several disadvantages, including reliance on the clinician's experience, reduced accuracy in angulation and depth, higher risk of damaging vital structures, and difficulty in achieving ideal prosthetic positioning. It often requires larger flaps, making the surgery more invasive, which may increase postoperative pain, swelling, and healing time. Additionally, outcomes are less predictable and less reproducible, and documentation for future reference is limited.[43-45]

As the demand for implant treatments has increased, so needs to standardize procedures, optimize materials, and adapt techniques to a variety of clinical situations. Therefore introduction of digital technologies in planning, such as cone beam computed tomography (CBCT) and 3D planning software, has allowed for increased accuracy in implant positioning and greater predictability of results. Personalized surgical guides, made using CAD/CAM technology, contribute to reducing surgical errors and shortening the intervention time.[46-48]

By integrating images obtained by cone beam computed tomography (CBCT) and digital intraoral scans, personalized surgical guides can be created that allow precise positioning of the implants in relation to the anatomical structures and the final prosthetic plane. The guides can be static – made in the laboratory and fixed during the intervention or dynamic, in the case of using real-time computerized systems. These technologies contribute to reducing risks, optimizing the position of implants and shortening the operative time. [43-45,49]Thus, the correct management of dental inclusions, combined with advanced implantology techniques, optimizes clinical outcomes, ensuring implant stability, preventing postoperative complications and improving long-term patient comfort and satisfaction.[49-59]

The evidence from this review confirms that static computer-assisted implant surgery (CAIS) offers the highest level of precision, particularly when fully guided systems are employed. Vercruyssen et al. (2015)[23]and Younes et al. (2018)[25] demonstrated that fully guided templates markedly improved accuracy compared to freehand and pilot-drill methods, particularly in terms of angular and apical deviations. Smitkarn (2019)[28] reinforced these findings by showing superior outcomes in single-tooth implant placements when fully guided protocols were used. In contrast, studies on half-guided or drill-only approaches, such as those by Ngamprasertkit et al. (2021)[31]and Orban et al. (2022)[32], indicated that while they were less precise than fully guided systems, they still outperformed conventional methods. Yüce et al. (2019) [27], however, found no significant accuracy advantage in single-tooth placements, suggesting that in straightforward cases the benefits may be more related to minimally invasive, flapless surgery and reduced patient discomfort rather than accuracy alone. Collectively, these studies establish static CAIS as the most predictable option, especially in partially edentulous and esthetic zone cases, as also demonstrated by Feng et al. (2022) [33].

Dynamic navigation systems were also shown to provide clinically reliable accuracy and a valuable alternative to static guides. Block et al. (2017) [24] and Aydemir and Arısan (2019)[26]highlighted that dynamic navigation consistently outperformed freehand techniques, significantly reducing coronal and angular deviations. Yimarj et al. (2020) [29] and Feng et al. (2022) [32] further emphasized that dynamic systems can achieve results comparable to static methods, suggesting their suitability in diverse clinical settings. More recent studies, such as those by Jorba-García et al. (2023) [35]and Younis et al. (2024) [37], reinforced the accuracy benefits of dynamic navigation, particularly in compromised anatomical conditions. Mahmoud et al. (2024) [40] also highlighted their clinical value in challenging cases with deficient alveolar ridges, where guided systems enhanced both safety and predictability. However, despite their flexibility, dynamic systems are associated with longer surgical times, higher technique sensitivity, and greater dependence on operator training. Their reliance on real-time calibration and costly equipment can also make them less practical in resource-limited clinical settings.

In addition to clinical accuracy, several studies addressed the role of CAIS in education and workflow efficiency. Søndergaard et al. (2021) [30] and Li et al. (2023) found that dental students achieved better accuracy with guided systems than with freehand placement, confirming the role of CAIS in improving training outcomes for novice operators. Beyond training, digital workflows have demonstrated broad clinical utility. Waltenberger et al. (2024) [38] and Ren et al. (2024) [39] showed that digital workflows incorporating intraoral scanning, CAD/CAM technology, and immediate restoration protocols improved patient satisfaction and reduced laboratory steps, even if treatment times were sometimes extended. Similarly, Elashry et al. (2024) [36] confirmed the reliability of digital impression techniques, while Younis et al. (2024)[37] underscored that both static and dynamic systems enhanced clinical flexibility compared to freehand methods. Still, it is important to recognize that the complexity of digital workflows and the need for specialized equipment can increase treatment costs and introduce logistical challenges.

Overall, the body of evidence indicates that CAIS—whether static or dynamic—consistently improves the accuracy of implant placement compared to conventional freehand surgery. Static fully guided systems remain the most predictable, particularly for single-tooth and esthetic zone placements, while dynamic navigation provides critical intraoperative adaptability in complex or anatomically compromised situations. Educational and digital workflow studies further support the integration of CAIS into modern implant dentistry, highlighting its impact on training efficiency, laboratory processes, and patient satisfaction. On the other hand, the limitations of increased costs, extended procedure times, and reliance on operator skill remain barriers to universal adoption. Looking ahead, developments such as artificial intelligence–based planning, simplified navigation interfaces, and cost-effective digital solutions are expected to enhance the accessibility and precision of CAIS, reinforcing its role as a cornerstone of contemporary implantology.

IV. Conclusion

Computer-assisted implant surgery, whether static or dynamic, has been shown to be more accurate than freehand methods, helping to place implants in the correct position and improving treatment results. Static fully guided systems are the most reliable, while dynamic navigation allows adjustments during surgery, which is useful in complex cases. Digital workflows also improve efficiency and patient satisfaction, and guided systems give students and young clinicians better training experiences. The main drawbacks are higher costs, longer procedure times, and the need for experienced operators. In the future, improvements such as artificial intelligence–based planning, simpler navigation systems, and more affordable digital tools are expected to make these techniques even more precise and accessible, strengthening their role in modern implant dentistry.

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