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Advantages of implant surgery with CAD/CAM surgical guides: An updated review

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Abstract
Introduction: Dental implant surgery has improved dramatically with the use of CAD/CAM surgical guides for precise planning, reduced invasiveness, and better clinical outcomes. This approach optimizes the performance of implant treatments by reducing risks and increasing predictability.
Objective: To analyze the recent evidence on the clinical and technical advantages of CAD/CAM surgical guides in dental implant dentistry.
Methodology: An online search of articles in English from the last five years was carried out in PubMed, Scopus, Science Direct, Embase, and Google Scholar. Terms such as "Dental Implant Surgery," "Surgical Guide," and "CAD/CAM Guide" were used. Clinical studies, systematic reviews, and meta-analyses addressing surgical precision, guide types, support, and protocols were selected.
Results: CAD/CAM-guided surgery showed lower angular (2.2°-3.9°) and linear (<2.3 mm) deviations, especially with fully guided protocols and tooth-supported surgical guides. Clinical benefits such as reduced operative time, less trauma, and the possibility of flapless surgery were reported. Precision depends on the type of support, scanning, and guide stability.
Conclusion: CAD/CAM guides are safe and effective, and their choice should be based on a personalized approach, according to the clinical case.

Keywords: Dental implant surgery, surgical guide, CAD/CAM guide, guided surgery, virtual planning

1. Introduction
Placement of dental implants has evolved significantly by incorporating digital technologies for more precise planning and less invasive procedures. Globally, the need for effective restorative treatments has increased along with the demand for predictable, functional, and esthetic solutions [1]. In this context, computer-guided surgery using surgical guides designed with CAD/CAM (computer-aided design and manufacturing) systems has emerged as a key tool that has changed how practitioners plan and place dental implants [1-3].
This approach is particularly important in contemporary clinical practice because of its multiple benefits. Surgical guides allow precise transfer of the virtual plan to the operative environment, significantly reducing the deviation between the planned and placed implant and improving surgical efficiency. Kim *et al.* [4] reported high precision with the use of R2GATE® software, obtaining average angular deviations of 3.4° and linear deviations of less than 1.2 mm. In their review, Suganna *et al.* [5] confirmed that these guides optimize three-dimensional implant placement for a more conservative surgical approach, especially beneficial in patients with complex medical conditions or compromised anatomical structures. Additionally, Nasti *et al.* [6] emphasize that these technologies improve precision, favor procedural efficiency, reduce radiological exposure, and improve patient experience by facilitating less invasive surgeries. However, despite the advances, the literature still has significant gaps. Unsal *et al.* [1] advise that there are clinical limitations related to mouth opening, guide stability, and cumulative errors in the digital process, which may lead to angular deviations of up to 5° and linear displacements of up to 2.3 mm. Also, although the use of CAD/CAM guides has proven its efficiency, precision is still influenced by factors such as the type of support (bone, mucosal, or dental), the protocol used, image quality, and operator experience. In this regard, Jorba *et al.* [7] reported relevant differences between dynamic techniques, static techniques, and manual procedures, indicating that even with assisted navigation, the deviations can exceed 4° in real

clinical scenarios. For their part, De Almeida *et al.* [8] concluded that even though surgeon experience does not significantly influence precision when guided surgery is used, they emphasize the need for adequate training to prevent complications from inadequate use of the technology.

In light of this situation, there is a clear need for a critical and updated review that not only systematizes the technical and clinical advantages of CAD/CAM surgical guides but also explores their limitations, areas for improvement, and recommendations for their safe implementation in daily practice. This review aims to integrate recent scientific evidence to provide a comprehensive overview of the actual advantages, clinical precision, conditioning factors, and the impact of this technology on dental implant surgery.

Materials and Methods

A literature review of articles published in the academic databases PubMed, Science Direct, Scopus, Embase, and Google Scholar in the last five years was carried out. The articles were selected following the standard guidelines for scientific reviews, including the stages of identification, evaluation, selection, and inclusion of the relevant studies. The methodological quality of the selected articles was assessed according to international guidelines for systematic reviews, prioritizing clinical studies, systematic reviews, and meta-analyses focused on implant surgery assisted by CAD/CAM surgical guides.

The search strategy was structured using Boolean operators (AND, OR, NOT) to combine key terms. The keywords used in English were "Dental Implant Surgery," "Surgical Guide," "CAD/CAM Guide," "Guided Surgery," "Implant Accuracy," "Angular Deviation," and "Virtual Planning". Priority was given to studies with quantitative data on precision (angular and linear deviations), type of surgical guide support (bone, mucosal, or dental), operator experience, and clinical advantages over conventional techniques.

Results

Angular and linear precision in CAD/CAM-guided surgery

Several studies have reported that CAD/CAM-guided surgery allows implant placement with high angular and linear precision. In the study by Massuda *et al.* [9], mean angular deviation of 2.68°, coronal deviation of 0.82 mm, and apical deviation of 1.14 mm were observed. Similarly, Putra *et al.* [10] evidenced that the deviations were significantly lower in fully guided protocols, with mean values of 2.83° in angle, 0.29 mm in neck, and 0.19 mm in apex. Unsal *et al.* [1] analyzed nine clinical studies and reported angular deviations of up to 5.01° and linear deviations of up to 2.3 mm. These results were consistent with the findings of Jorba *et al.* [7], Htay *et al.* [11], and Eftekhar *et al.* [12], *w*ho also confirmed that the guided technique improves precision compared to conventional surgery.

Type of surgical guide support

The type of guide support (dental, mucosal, or bone) is critical in surgical precision. Putra *et al.* [10] identified greater precision in tooth-supported compared to mucosa-supported and bone-supported surgical guides. Massuda *et al.* [9] used guides with mixed support and pin fixation for better stability. The findings of Cunha *et al.* [13], De Almeida *et al.* [8], and Herschdorfer *et al.* [14] support these observations, pointing out that stabilization using fixation screws is determinant to minimize deviations.

Factors influencing precision

Factors associated with precision include arch type (maxillary vs. mandibular), type of edentulous space, surgical protocol (fully guided or partial), scanning method (IOS vs. EOS), and operator experience. Kim *et al.* [4], Turkyilmaz *et al.* [3], and Suganna *et al.* [5] agree that operator experience has less impact when fully guided protocols are followed. Putra *et al.* [10] demonstrated that the use of CAD/CAM-made guides outperforms conventional laboratory-made guides in terms of precision. Chai *et al.* [15], Ochandiano *et al.* [16], and Saini *et al.* [17] also highlighted the effect of the type of scanning and support on the results.

Comparison with conventional surgery

Comparative studies such as Afshari *et al.* [18], Kernen *et al.* [19], and Vinnakota *et al.* [20] showed that guided surgery significantly reduces deviations compared to the manual technique. Li *et al.* [21] and Gelpi *et al.* [22] reported that the guided technique not only improves precision but also reduces surgical time and invasiveness. The possibility of digital planning allows for superior three-dimensional control, as also confirmed by the findings of Nasti *et al.* [6].

Clinical advantages observed

Among the most outstanding clinical advantages are shorter operative time, less postoperative morbidity, pain reduction, possibility of flapless surgery, and better prosthetic positioning. The studies of De Almeida *et al.* [8], Massuda *et al.* [9], and Suganna *et al.* [5] report that patients showed good tolerance, minimal use of analgesics, and few complications. Gelpi *et al.* [22] emphasize that the precision achieved favors immediate loading in selected cases, contributing to better functional and esthetic results

Table 1: Clinical evidence of CAD/CAM-guided implant surgery

Study	Study design	Population	Intervention	Conclusions
Putra *et al.* (2022) [10]	Systematic review and meta-analysis	642 partially edentulous patients (1317 implants)	Guided surgery with fully guided protocol vs. pilot drill	Fully CAD/CAM-guided surgery was more precise, with less angular and linear deviations.
Jorba *et al.* (2021) [7]	Systematic review	Studies with different guided protocols	Evaluation of precision of dynamic vs. static surgery	Both techniques were effective, but dynamic surgery had greater variability in terms of precision.
Massuda *et al.* (2024) [9]	Clinical study	11 partially edentulous participants	Static CAD-CAM-guided surgery + intraoral scanning	Mean angular deviation of 2.68° and linear deviation of <1.5 mm. Clinically acceptable precision and rapid recovery.
Kim *et al.* (2023) [4]	Retrospective clinical study	Patients with R2GATE type guides	Precision evaluation with static guided surgery	High precision with angular deviations of <4°. Flapless surgeries with good clinical predictability.

Conclusion

Implant surgery assisted by CAD/CAM surgical guides has demonstrated significant clinical and technical advantages compared to conventional approaches. The studies reviewed show that this technology allows for more precise implant placement with less angular and linear deviations, especially when fully guided protocols and 3D-printed guides are used. The use of tooth-supported surgical guides, intraoral scans, and prosthetically directed planning are associated with better clinical outcomes, favoring less invasive surgeries, reduced operative time, and more favorable postoperative recovery.

However, the evidence also highlights that this technique has limitations. Factors such as the type of guide support, operator experience, mouth opening, and surgical protocol can influence the final precision. In addition, the existence of methodological variability among the studies reviewed reinforces the need for standardization of clinical protocols and adequate training of practitioners. Overall, this review confirms that CAD/CAM guided surgery is an effective and predictable tool in modern dental implant surgery, but its success depends on careful planning, correct clinical indication, and mastery of the digital flow by the treating team.

Conflict of Interest

Not available

Financial Support

Not available

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