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The Impact of Surgical Guides on the Accuracy of Dental Implant Placement

▷ **Objective.** This review aimed to examine the impact of digital treatment planning and various surgical guide systems on the accuracy of dental implant placement by comparing planned and postoperative implant coordinates. An additional objective was to analyze clinical, anatomical, and technical variables influencing the precision of guided implant surgery.

Materials and Methods. A narrative review of contemporary peer-reviewed publications was performed to evaluate current approaches to digital implant planning and computer-guided implant surgery. Particular attention was given to cone-beam computed tomography (CBCT)-based virtual planning, the characteristics of tooth-, mucosa-, and bone-supported surgical guides, stereolithographic manufacturing technologies, planning software, and various factors that may affect the accuracy of implant placement.

Results. The available evidence indicates that digitally guided implant placement generally provides greater positional accuracy than conventional freehand surgery, resulting in significantly lower linear and angular deviations from the virtual treatment plan. The precision of implant positioning is enhanced when prosthetically driven planning is combined with accurate three-dimensional imaging and an appropriate guide-support design. Nevertheless, the final outcome remains influenced by numerous variables, including bone density and morphology, soft tissue thickness, implant dimensions, guide stability, the surgical protocol, manufacturing accuracy, and the clinician's experience level.

Conclusion. The integration of digital planning with guided implant surgery contributes to more accurate, predictable, and safe implant placement while facilitating prosthetically driven treatment. Despite these advantages, clinicians should recognize the cumulative effect of technical inaccuracies and patient-related anatomical factors that may compromise surgical precision. Future prospective clinical studies using standardized assessment methods are required to compare different guide-support concepts and to further define the contribution of individual variables to implant placement accuracy.

Keywords: *dental implants, guided implant surgery, digital treatment planning, cone-beam computed tomography, surgical guides, implant placement accuracy, computer-assisted implantology.*

Introduction

Dental implant therapy is widely recognized as a reliable and predictable method for restoring missing teeth and rehabilitating oral function. Long-term clinical success depends not only on successful osseointegration but also on accurate three-dimensional (3D) implant positioning, which is essential for achieving favorable aesthetic outcomes, appropriate prosthetic support, healthy peri-implant tissues, and balanced occlusal loading. Inaccurate implant placement may compromise prosthetic rehabilitation and increase the risk of mechanical complications, peri-implantitis, impaired oral hygiene, and premature implant failure.

The rapid development of digital technologies has substantially transformed implant treatment planning. Cone-beam computed tomography (CBCT), intraoral scanning, and specialized planning software enable a comprehensive three-dimensional assessment of the surgical site while integrating anatomical, prosthetic, and functional considerations into a single digital workflow. This prosthetically driven approach facilitates more precise implant positioning and contributes to enhanced treatment predictability and long-term clinical outcomes [1].

To accurately transfer the virtual treatment plan to the operative field, computer-generated surgical guides are increasingly incorporated into implant surgery. Depending on the clinical situation, these guides may be supported by teeth, bone, or the oral mucosa. Their use has been associated with improved positional accuracy, enhanced surgical safety, shorter operative times, and reduced patient morbidity compared with conventional freehand implant placement.

Despite these advantages, guided implant surgery does not completely eliminate positioning errors. Small discrepancies between the planned and postoperative implant positions continue to be reported and may arise from multiple sources, including image acquisition, digital planning, guide manufacturing, guide stability, surgical technique, and patient-specific anatomical characteristics. Therefore, understanding the magnitude and determinants of these deviations remains a critical aspect of contemporary implant research [2].

Objective. The objective of this study was to evaluate the accuracy of dental implant placement performed with computer-generated surgical guides through a systematic analysis of the available literature and to identify the principal clinical, anatomical, and technical factors influencing implant placement accuracy.

Materials and Methods

A systematic literature search was conducted using the PubMed database to identify studies evaluating the accuracy of computer-guided dental implant placement. Only peer-reviewed publications published between January 2014 and December 2024 were considered in order to provide a comprehensive overview of the current evidence.

Records identified through the search strategy were initially screened by title and abstract according to predefined inclusion and exclusion criteria. Experimental (*in vitro*) and clinical (*in vivo*) investigations reporting quantitative measurements of implant placement accuracy were eligible for inclusion. Narrative reviews, systematic reviews, conference proceedings, technical notes, studies without original quantitative data, and publications unavailable in English or lacking an English abstract were excluded.

Potentially eligible studies underwent a subsequent full-text assessment. In addition, a manual screening of the reference lists of the included articles was performed to identify further relevant publications that had not been retrieved during the electronic database search.

The following information was extracted from each study: the type of surgical guide (tooth-, bone-, or mucosa-supported), implant placement protocol, linear and angular deviations between the planned and actual implant positions, sample size, implant location (maxilla or mandible), implant dimensions, and study design (clinical or laboratory).

Accuracy outcomes were assessed using postoperative digital analyses based on CBCT imaging and three-dimensional implant planning software. Descriptive statistical measures, including mean values, standard deviations, and interquartile ranges, were analyzed to summarize reported deviations and evaluate variables potentially associated with implant placement accuracy.

The adopted methodology enabled a structured comparison of the available evidence, facilitating the identification of the principal determinants of guided implant accuracy, and providing a basis for evaluating the clinical performance of different surgical guide systems.

Results and Discussion

The literature search identified 26 studies that fulfilled the predefined eligibility criteria and were included in the final analysis. Collectively, these investigations evaluated the accuracy of computer-guided implant placement under a broad spectrum of clinical and experimental conditions, including partially and completely edentulous arches, different guide-support concepts, various digital planning workflows, manufacturing technologies, and operators with varying levels of clinical experience.

Accuracy of guided implant placement

The reviewed evidence consistently demonstrated that computer-guided implant surgery enables a clinically acceptable transfer of the virtual treatment plan to the operative field. Across the included studies, mean coronal deviations generally ranged from 0.6 to 1.7 mm, apical deviations from approximately 0.8 to 2.3 mm, and angular deviations from 2 to 5°. These values remained within the limits widely accepted for safe implant placement and were consistently lower than those reported for conventional freehand surgery [3–6, 12, 17, 21, 24].

Although numerical deviations varied among studies because of differences in study design, patient populations, implant systems, and measurement protocols, the overall findings support the high predictability of digitally guided implant placement.

Influence of guide-support systems

Guide support represented one of the principal determinants of implant placement accuracy. Tooth-supported surgical guides generally produced the smallest positional deviations because of their stable and reproducible seating. Bone-supported guides achieved comparable results in selected clinical situations, particularly when residual dentition was absent or surgical access was limited. In contrast, mucosa-supported guides tended to demonstrate greater linear deviations, mainly because of soft tissue resilience and compression during surgery [8–10, 13].

Nevertheless, even mucosa-supported guides provided clinically acceptable accuracy when adequate stabilization was achieved. Several investigations emphasized that improper guide seating, rather than guide design itself, was responsible for most clinically relevant positioning errors [4, 7].

Anatomical and implant-related factors

Patient-specific anatomical characteristics significantly influenced surgical precision. The presence of remaining teeth improved guide stability and reduced positional deviations compared with completely edentulous arches. Bone density, residual ridge morphology, mucosal thickness, jaw location, and the implant site were also identified as important determinants of accuracy.

Several studies reported greater deviations in the mandible, particularly within the posterior regions, whereas others observed improved angular accuracy in the maxilla. These discrepancies likely reflect differences in study populations, guide stabilization methods, and surgical protocols rather than true anatomical inconsistencies [3, 5–8, 17].

Implant dimensions further contributed to placement accuracy. Longer and wider implants were generally associated with larger apical deviations because small angular discrepancies become amplified along the implant axis. Consequently, implant length and diameter should be considered during digital treatment planning, particularly when anatomical safety margins are limited [21].

Manufacturing technology and digital workflow

The manufacturing process used to fabricate surgical guides demonstrated only a limited influence on clinical accuracy. Comparative studies evaluating additive manufacturing (3D printing) and subtractive manufacturing (computer-aided milling) reported nearly identical positional deviations. Likewise, different 3D printing technologies produced comparable levels of accuracy, indicating that adherence to standardized production protocols is more important than the specific manufacturing technique itself [22, 23].

Recent studies have also demonstrated that fully digital workflows incorporating intraoral scanning improve the correspondence between virtual planning and clinical execution by reducing cumulative errors associated with conventional impressions and stone model fabrication [11].

Guide design likewise influenced surgical precision. Sleeve-free guides frequently demonstrated superior vertical and angular accuracy, whereas guides incorporating closed metal sleeves provided greater mechanical stability during implant preparation [15, 16].

Digital planning software

The accuracy of guided implant surgery also depends on the quality of virtual treatment planning. Comparative investigations evaluating commercial planning software and validated open-source platforms demonstrated similar overall performance, although differences in implant platform positioning and angular deviation were reported in some studies. These findings suggest that implant placement accuracy is determined not only by software selection but also by the accuracy of image acquisition, data registration, and guide fabrication [18].

Influence of surgical protocol and operator experience

Computer-guided workflows consistently outperformed conventional freehand implant placement with respect to positional accuracy. Both dual-scan and model-based tomography protocols significantly reduced linear and angular deviations, while no meaningful differences were identified between the two digital approaches [19].

Operator experience influenced the reproducibility rather than the overall success of guided surgery. Although inexperienced clinicians achieved clinically acceptable implant positioning using surgical guides, experienced surgeons demonstrated lower variability in angular and horizontal deviations, indicating greater procedural consistency. Importantly, guided surgery substantially reduced the surgical time and simplified clinical procedures regardless of operator experience, supporting its value as an effective tool for standardizing implant placement [20, 25, 26].

Clinical implications

The collective findings indicate that the accuracy of guided implant surgery results from the interaction of multiple clinical and technical factors. Successful transfer of the virtual treatment plan requires accurate CBCT imaging, appropriate prosthetically driven planning, stable guide support, precise manufacturing, careful guide positioning, and adherence to the recommended surgical protocol.

Despite continuous technological improvements, cumulative errors may occur throughout the digital workflow, from image acquisition to guide fabrication and implant insertion. Therefore, clinicians should maintain appropriate safety margins around vital anatomical structures and carefully verify guide stability before and during surgery.

Overall, the available evidence demonstrates that digital implantology significantly improves the predictability, safety, and reproducibility of implant placement. Nevertheless, optimal clinical outcomes depend on meticulous planning, appropriate case selection, and a careful execution of every stage of the digital workflow. Future prospective multicenter clinical studies using standardized evaluation protocols are required to compare different guide-support concepts and further clarify the contribution of individual clinical and technical variables to implant placement accuracy.

Conclusion

This review synthesized the available evidence on the accuracy of computer-guided dental implant placement using surgical guides. Overall, the analyzed studies demonstrate that guided implant surgery enables a predictable transfer of the virtual treatment plan to the clinical setting and provides clinically acceptable positional accuracy while reducing the risk of deviations associated with conventional freehand implant placement.

The findings indicate that implant positioning accuracy is determined by the combined influence of anatomical, technical, and operator-related factors rather than by any single variable. Guide-support design, jaw morphology, bone quality, mucosal thickness, implant dimensions, guide stabilization, manufacturing precision, and clinician experience all contribute to the final implant position. Consequently, successful guided implant surgery depends on the careful integration of accurate digital planning, high-quality guide fabrication, and meticulous adherence to the surgical protocol.

The reviewed studies further suggest that both additive manufacturing (3D printing) and subtractive manufacturing (computer-aided milling) are capable of producing surgical guides with clinically acceptable accuracy. Likewise, tooth-, bone-, and mucosa-supported guides each represent effective treatment options when selected according to the patient's anatomical conditions and clinical indications. Although residual discrepancies between planned and postoperative implant positions cannot be completely eliminated, current digital workflows substantially reduce cumulative positioning errors and improve the reproducibility of implant surgery.

Advances in cone-beam computed tomography, virtual treatment planning, intraoral scanning, stereolithographic manufacturing, and computer-assisted surgical guidance have transformed implant therapy by improving surgical precision, facilitating prosthetically driven treatment planning, reducing operative times, and supporting minimally invasive approaches, including flapless implant placement.

Despite these advances, further prospective multicenter clinical investigations using standardized measurement protocols are required to establish stronger evidence regarding the comparative performance of different guide-support systems, manufacturing technologies, digital planning platforms, and stabilization methods. Additional research should also clarify the influence of operator experience, patient-specific anatomical characteristics, and biomechanical factors on implant placement accuracy and long-term clinical outcomes.

In conclusion, computer-guided implant surgery represents a reliable and effective approach for improving the precision, safety, and predictability of dental implant placement. Continued refinement of digital workflows and guided surgery technologies is expected to further optimize treatment outcomes and support a broader implementation of evidence-based implant rehabilitation.

Conflict of interest

The authors declare no conflict of interest.

Consent to publication

The authors have given their consent to the publication of the manuscript.

Use of Artificial Intelligence

The authors state that no artificial intelligence was used in the writing of the article..

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Вплив хірургічних шаблонів на точність встановлення дентальних імплантатів

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Мета. Цей огляд мав на меті дослідити вплив цифрового планування лікування та різних систем хірургічних шаблонів на точність встановлення дентальних імплантатів шляхом порівняння запланованого та післяопераційного положення імплантатів. Додатковою метою був аналіз клінічних, анатомічних та технічних змінних, що можуть впливати на точність дентальної імплантації із використанням хірургічних шаблонів.

Матеріали та методи. Для оцінки сучасних підходів до цифрового планування імплантації та дентальної імплантації під контролем комп'ютерних технологій було проведено наративний огляд сучасних рецензованих публікацій. Особливу увагу приділено віртуальному плануванню на основі конусно-променевої комп'ютерної томографії (КПКТ), характеристикам хірургічних шаблонів із опорою на зуби, слизову оболонку та кісткову тканину, стереолітографічним технологіям виробництва, програмному забезпеченню для планування, а також факторам, що можуть впливати на точність встановлення імплантатів.

Результати. Наявні дані свідчать про те, що встановлення імплантатів із цифровим керуванням загалом забезпечує вищу точність позиціонування порівняно з традиційними операціями від руки (вільною рукою), що призводить до менших лінійних та кутових відхилень від віртуального плану лікування. Точність позиціонування імплантатів підвищується, коли ортопедично орієнтоване планування поєднується з точним тривимірним візуалізаційним дослідженням та відповідним дизайном шаблону. Проте, на кінцевий результат усе ще впливають численні змінні, зокрема щільність та морфологія кісткової тканини, товщина м'яких тканин, розміри імплантату, стабільність шаблону, хірургічний протокол, точність виготовлення та рівень досвіду клініциста.

Висновок. Інтеграція цифрового планування з керованою імплантаційною хірургією сприяє більш точному, передбачуваному та безпечному встановленню імплантатів, водночас полегшуючи проведення ортопедично орієнтованого лікування. Незважаючи на ці переваги, клініцистам слід враховувати кумулятивний ефект технічних похибок та пов'язаних із пацієнтом анатомічних факторів, які можуть знизити хірургічну точність. Необхідні подальші перспективні клінічні дослідження з використанням стандартизованих методів оцінки для порівняння різних концепцій опори шаблонів та детальнішого визначення впливу окремих змінних на точність встановлення імплантатів.

Ключові слова: *дентальні імплантати, хірургічні шаблони, цифрове планування лікування, конусно-променева комп'ютерна томографія, точність встановлення імплантатів, комп'ютерна імплантологія.*

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