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# PRECISION IN DENTAL IMPLANTOLOGY: A REVIEW OF FREEHAND AND GUIDED IMPLANT PLACEMENT TECHNIQUES

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## Abstract

Accurate implant placement is essential for long-term success in implant dentistry, with freehand and guided techniques being the two primary approaches. Freehand placement relies on the clinician's expertise and intraoperative judgment, while guided surgery utilizes digital workflows to enhance precision and predictability. This review compares both techniques in terms of accuracy, efficiency, clinical outcomes, and cost-effectiveness. Literature suggests that guided implant placement offers superior precision and reduced complications but requires additional costs and preoperative planning. Conversely, freehand placement remains a flexible and efficient technique in skilled hands. The choice between these approaches depends on factors such as case complexity, clinician experience, and resource availability. Advancements in digital dentistry and artificial intelligence may further refine implant placement techniques, improving overall treatment outcomes.

**Keywords:** Dental implant placement, Freehand surgery, Guided implant surgery, Implant accuracy, Indication in implant placement, Advancements in implant.

## INTRODUCTION

Dental implants are used to replace missing teeth, restoring both function and aesthetics. A key factor contributing to their reliability is successful osseointegration, which depends on minimizing surgical complications such as nerve damage, perforation, and cortical plate perforation. Since modern implantology was introduced in the early 1980s, surgeons have focused on placing implants based on the available bone in the patient's jaw. However, this approach can sometimes result in improper implant positioning, leading to challenges in achieving a well-fitting and aesthetically pleasing prosthesis(1).

In this regard, the use of new technologies and modern software provides the possibility of three-dimensional examination of the location of implants, making the diagnosis and treatment of patients more reliable. Dental implants are performed in two general ways, which are implantation with the normal method and implantation with the surgical guide.

Traditionally, implant placement has been performed using a freehand approach, where clinicians depend on their anatomical knowledge, tactile feedback, and radiographic evaluations. Although this technique offers flexibility and remains widely practiced, its accuracy can vary, potentially resulting in complications such as implant mispositioning, insufficient bone support, and prosthetic misalignment(2).

In dental implant treatment, guided surgery enables clinicians to plan implant placement with a prosthetically driven approach, considering the virtual envelope of the future prosthesis to optimize implant position and depth. This approach is crucial for achieving an aesthetic outcome with a well-contoured and easily maintainable emergence profile. Advances in digital radiography, particularly computed tomography (CT) and cone beam CT (CBCT), have facilitated preoperative assessments by providing detailed information on bone volume, density, and quality, while also aiding in the identification of critical anatomical structures such as blood vessels, nerves, sinuses, and foramina that may impact implant placement(3). As both techniques continue to be widely used, an ongoing debate exists regarding cost-effectiveness, and clinical outcomes. This review aims to explore the differences between freehand and guided implant placement, evaluate their advantages and limitations, and analyse current clinical evidence to provide insights into optimal case selection and best practices in implant surgery.

# FREEHAND IMPLANT PLACEMENT

Freehand implant placement is a conventional surgical technique in which the clinician places dental implants without the aid of a surgical guide or navigation system. The procedure relies on the surgeon's experience, anatomical knowledge, and visual-tactile perception to determine the optimal implant position. It is widely practiced due to its flexibility, lower cost, and reduced preoperative planning time compared to guided techniques. Surgical implant placement may be carried out in one- or two-stage methods.

The one-stage method, also referred to as the non-submerged technique, involves preparing the bone to accommodate the implant, which is then placed into the osteotomy site. In this approach, the coronal portion of the implant remains above the bone crest, extending through the soft tissue and exposed to the oral environment during the healing phase. The restoration can either be attached immediately after implant placement or postponed for a later stage(4).

The one-stage method offers several advantages, including: Eliminating the need for a second surgical procedure, reducing crestal bone resorption by avoiding a micro-gap between the implant and abutment at the alveolar bone crest level, simplifying the prosthetic workflow and minimizing chair time for the patient, allowing flexibility in loading protocols, including non- loaded, immediate, or delayed loading options(4).

A potential drawback of this surgical protocol is the exposure of the implant to the oral environment, which increases the risk of surgical site contamination. Additionally, the implant may be subjected to unintended trauma, potentially compromising the healing process(4).

The two-stage method, also known as the submerged technique, involves two surgical procedures. In the first stage, the implant is placed into the bone, and a cover screw (or sealing screw) is attached to the implant platform. A countersink bone preparation may be performed, allowing the implant platform to be positioned below the bone crest, with the cover screw aligned at the crest level. The raised flap is then repositioned and sutured to fully cover the implant and cover screw. After a healing period of several months, the second-stage surgery is performed, during which the implant site is reopened, the cover screw is removed, and a healing abutment (also referred to as a sulcus former or transmucosal abutment) is placed. This healing abutment is later replaced with either a provisional or final restoration(4).

The primary limitation of freehand implant placement is its lower accuracy and higher variability compared to guided techniques, leading to potential angulation errors, depth misplacement, and proximity to critical structures like the inferior alveolar nerve or maxillary sinus. Since the procedure relies solely on the clinician's experience and visual-tactile judgment, there is an increased risk of mispositioned implants, which can result in prosthetic misfit, biomechanical complications, and peri-implantitis.

Additionally, longer surgical time, higher learning curve, and the need for intraoperative adjustments make freehand placement more challenging, especially for complex cases or less experienced surgeons. Unlike guided techniques, freehand surgery lacks pre-planned precision, increasing the likelihood of additional corrective procedures such as abutment angulation adjustments, bone grafting, or even implant removal in severe cases.

## GUIDED IMPLANT PLACEMENT

A device utilized to guide the surgical shaping of the alveolar process or the positioning of gingival tissues.

A guide designed to aid in the precise surgical placement and angulation of dental implants.

A guide used to facilitate the establishment of the desired occlusion during orthognathic or grafting procedures(5).

There are varying perspectives on the classification of surgical guides. For instance, Balshi and Garver categorize surgical guide stents for implant placement based on the patient's dental condition, identifying three primary types: Completely Edentulous – Provides a general reference for implant positioning and specific guidance on the location and angulation required for each implant. This includes printed surgical guides for full-mouth rehabilitation using four guide pins. Partially Edentulous (Removable Partial Denture Design) – Designed for patients with some remaining teeth, aiding in implant placement alongside a removable prosthesis. Partially Edentulous (Tooth-Supported Design) – Utilizes existing teeth for support and may include a metal sleeve-free surgical guide or a surgical guide with metal sleeves for enhanced precision(1).

Based on the remaining dentition and the required accuracy of the guide, four support options have been proposed: tooth-supported, tissue-supported, a combination of tooth and tissue- supported, and tissue-supported with additional fixation for edentulous patients(1).

Another classification approach for surgical guides is based on a conceptual method that categorizes them according to the degree of restriction they provide during surgery. This classification includes three types: Non-limiting design, Partially limiting design, Completely limiting design(1).

Guided surgery utilizing three-dimensional (3D) computed imaging enhances the evaluation of bone anatomy, improves prosthetic planning, and increases the predictability of treatment outcomes in oral rehabilitation with dental implants. Traditional preclinical assessment methods, such as visualization, palpation, and two-dimensional (2D) radiography, are now being supplemented by advanced computer-based 3D planning technology. Cone beam computed tomography (CBCT) provides more precise imaging while reducing radiation exposure compared to conventional tomography. Once scanned, these images can be processed using specialized software, enabling the creation of 3D anatomical models that accurately replicate the patient’s original anatomy. This allows for more precise pre-surgical planning, considering both prosthetic and anatomical aspects, ultimately enhancing accuracy in implant placement(6).

Despite its advantages, guided implant placement has several limitations, primarily higher cost and increased preoperative preparation time. The need for CBCT imaging, digital planning software, and 3D-printed surgical guides adds to the financial burden, making it less accessible in resource-limited settings. Additionally, static surgical guides lack intraoperative flexibility, meaning unexpected bone quality variations or anatomical challenges cannot be easily adjusted, which may necessitate reverting to freehand placement in some cases.

There is also a learning curve associated with digital workflows, requiring clinicians to be trained in CBCT interpretation, digital treatment planning, and guided surgery protocols. Furthermore, errors in the digital planning phase or guide fabrication can lead to inaccurate implant placement, emphasizing the need for meticulous verification before surgery. Lastly, guided surgery may not always be feasible in emergency cases where immediate implant placement is required without prior digital planning.

## COMPARISON OF FREEHAND VERSUS GUIDED IMPLANT PLACEMENT

In freehand surgery, panoramic and periapical radiographs are utilized to evaluate the width and profile of the alveolar bone for implant placement while assessing the surrounding anatomy, with CBCT imaging ultimately providing more detailed insights. Periodontal probes, gauges, or calipers are used during the intraoral examination to sound the bone, offering an estimate of ridge height and thickness. Additionally, adjacent teeth serve as reference points for determining the correct implant position. It is essential to ensure that the implant is placed at least 1.5 mm away from each adjacent tooth and positioned 2 mm apical to the cementoenamel junction(1).

Freehand surgery offers several advantages for dentists, as it allows direct visualization of the clinical condition by reflecting soft tissues and assessing bone anatomy in real time. This approach also facilitates additional treatments, such as bone grafting, platelet-rich fibrin (PRF) application, and guided bone regeneration (GBR), when necessary. Furthermore, surgeons can take measurements using diagnostic casts, and creating a diagnostic replica model provides a clearer understanding of the mesiodistal and apicocoronal dimensions. This helps in accurately determining the implant's position in relation to adjacent teeth and the planned prosthesis(1).

The procedure for guided implant surgery differs from freehand implant placement. In guided surgery, after obtaining CBCT imaging, a DICOM file is generated and combined with either a digital intraoral scan or a precise putty-light body impression to create an accurate model.

This DICOM file, along with the patient's data, is then imported into implant planning software, which processes the information to provide both two-dimensional and three-dimensional visualizations for precise treatment planning(1).

The software enables users to visualize key anatomical landmarks, including the nasopalatine canal, maxillary sinus, inferior alveolar canal, and submandibular fossa. These visualizations serve as essential aids in implant position planning, utilizing various analytical tools for enhanced precision(1).

The surgical guide features round metal sleeves, typically made of titanium or other alloys, positioned at the implant site. These sleeves precisely control the implant's depth, angulation, as well as its mesiodistal and buccolingual positioning. Each surgical guide is customized according to the specifications of the guided implant surgery kit. The drills included in this kit are specifically designed for osteotomy and optimized for accurate performance. Each drill is equipped with a stopper that rests on the occlusal surface of the metal sleeve's outer lip. The length of the metal sleeves determines the offset, which is the distance between the implant neck and the occlusal surface of the sleeve. In edentulous patients, the guide incorporates horizontal sleeves for anchor pins to ensure stability and secure positioning in the mouth(1).

## ACCURACY OF FREEHAND AND GUIDED IMPLANT PLACEMENT

The accuracy of dental implant placement is critical for long-term success, and two primary approaches are used: freehand and guided surgery. Freehand implant placement relies entirely on the clinician's experience and anatomical knowledge, where implants are placed without a physical guide. This method is faster and more adaptable to intraoperative findings but is prone to deviations in angulation, depth, and position. Studies indicate that freehand placement often results in greater deviations (up to 2–4 mm) from the planned position, which may lead to complications such as nerve injury, implant misalignment, or the need for prosthetic adjustments. However, freehand surgery remains a viable option in cases with good bone availability, sufficient visibility, and when cost constraints limit the use of digital guides(7).

Guided surgery, on the other hand, enhances precision by using computer-aided design/computer-aided manufacturing (CAD/CAM) surgical guides or dynamic navigation systems. These guides are based on cone-beam computed tomography (CBCT) scans and digital impressions, allowing for accurate preoperative planning. Studies show that guided implant placement significantly reduces angular and linear deviations, leading to higher prosthetic accuracy and reduced surgical risks(7).

However, it has limitations, including higher costs, longer preoperative preparation, and challenges in cases with limited mouth opening. Additionally, inaccuracies can still arise due to guide instability, errors in CBCT imaging, or variations in bone density. Ultimately, the choice between freehand and guided implant placement depends on the complexity of the case, the surgeon's skill level, and patient-specific factors such as anatomical constraints and financial considerations(7).

## INDICATIONS AND CASE SELECTION OF FREEHAND AND GUIDED IMPLANT PLACEMENT

The choice between freehand and guided implant placement depends on several clinical, anatomical, and patient-related factors. Freehand implant placement is typically indicated in cases with adequate bone volume, clear surgical visibility, and straightforward implant positioning where minor deviations do not compromise function or esthetics. It is also preferred in emergency cases, single implant placements, or when cost and time constraints limit the use of guided techniques. Additionally, skilled surgeons may opt for freehand placement in cases where intraoperative flexibility is needed to adjust for unexpected anatomical variations.

In contrast, guided implant placement is recommended for complex cases requiring high precision, such as full-arch rehabilitations, multiple implant placements, or cases with minimal bone volume where angulation is critical. It is particularly beneficial in aesthetic zones, immediate implant placement, or when proximity to vital structures like the inferior alveolar nerve or maxillary sinus demands accuracy. Guided surgery is also ideal for minimally invasive flapless techniques, reducing trauma and post-operative discomfort. However, its use is limited in patients with restricted mouth opening, significant bone defects, or situations where guide stability cannot be ensured. Ultimately, the choice should be based on the surgeon's expertise, case complexity, and patient-specific needs to achieve optimal outcomes.

Young Patients - Implant placement should be deferred until jaw growth is complete, as implants do not adapt to the eruption of natural teeth. Placing implants in a developing jaw may lead to occlusal and gingival discrepancies (Testori et al., 2018)(8).

Patients with Periodontal Instability Requiring Extensive Treatment - For periodontally compromised patients, successful long-term outcomes depend on eliminating periodontal lesions, maintaining strict infection control, and adhering to a structured maintenance regimen (Roccuzzo et al., 2022)(8).

Expected Delay in Implant Treatment - When implant placement is postponed due to personal or medical reasons, alveolar ridge preservation can be considered to minimize alveolar ridge resorption and maintain bone volume for future implant placement(8).

Survival Rates - Survival rates range from 97.7% to 98.3%, with follow-up periods of up to 2.5 years, depending on the loading protocol used (Gallucci et al., 2018)(8).

## CLINICAL EVIDENCE AND STUDIES

"Accuracy of Dynamic Navigation Compared to Static Surgical Guides and Freehand Implant Placement: A Clinical Study" (2024) Youssef et al. This clinical study assessed the accuracy of implant placement using dynamic navigation, static surgical guides, and freehand techniques. The results highlighted the superior accuracy of dynamic navigation and static guides over the freehand approach(9).

"Evaluation of the Accuracy of Implant Placement by Using Implant Positional Guide Versus Freehand: A Prospective Clinical Study" (2023) by Huang et al. The implant positional guide serves as a viable tool for dental implant surgery, offering a cost-effective solution with high precision. However, given the limited clinical evidence available, further research involving larger population studies, extended follow-up periods, and standardized experimental methodologies is necessary to validate its effectiveness(10).

"Examining the Influence of Freehand, Pilot-Guided, and Fully Guided Techniques on the Accuracy of Immediately Placed Implants: An In Vitro Study" (2023) Mohamed et al. This in vitro study evaluated the accuracy of immediately placed implants using freehand, pilot- guided, and fully guided techniques. The findings indicated that fully guided techniques resulted in significantly lower global and mesial–distal deviations compared to pilot-guided and freehand methods(11).

"Fully Guided Versus Half-Guided and Freehand Implant Placement: A Systematic Review and Meta-Analysis" (2020) by Gargallo-Albiol et al. Static fully guided implant navigation surgery offers the highest accuracy in transferring presurgical positioning plans to the patient, followed by static half-guided surgery, whereas freehand implant placement is the least precise(12).

"Comparison Between Computer-Guided and Freehand Dental Implant Placement Surgery: A Systematic Review" (2020) by Vercruyssen et al. This systematic review compared computer- guided (fully guided) and freehand implant placement surgeries concerning marginal bone loss, complications, and implant survival.

The analysis revealed that computer-guided implant placement resulted in less marginal bone loss and fewer complications compared to the freehand approach(13).

## FUTURE TRENDS AND INNOVATIONS

Finite Element Analysis (FEA) - Implant failure remains a relatively common issue, necessitating the analysis of abutments for improved outcomes. Finite Element Analysis (FEA) is increasingly utilized in implant dentistry, enabling engineers and researchers to study jawbone and implant properties, as well as the bone-implant interface. This method aids in optimizing implant design to ensure functionality within physiologically acceptable limits. FEA involves the creation of a computerized three-dimensional model that has been extensively used to predict stress distribution in the bone surrounding implants. These stress patterns are influenced by factors such as implant dimensions and the biomechanical bond formed between the bone and the implant(14).

Artificial Intelligence (AI) and Machine Learning - AI-powered software can predict implant success, optimize treatment planning, and provide real-time guidance during surgery. Machine learning models are being developed to analyze CBCT scans and recommend ideal implant positions based on bone density and anatomical structures.

Dynamic Navigation Systems (Computer-Guided Surgery 2.0) - Unlike traditional static surgical guides, dynamic navigation systems provide real-time 3D tracking of the implant drill in relation to the patient’s anatomy. These systems improve accuracy while maintaining intraoperative flexibility, allowing surgeons to make adjustments without needing a prefabricated guide.

Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM) Technology - The fabrication of implants and abutments has undergone significant advancements, with continuous improvements in design and manufacturing processes. Given the increasing use of complex-shaped implants and abutments, CAD/CAM technology has become an essential tool in modern dentistry. This technique offers notable advantages, including enhanced precision and reduced manufacturing time, making it a highly efficient solution for implant production(14).

Fully Robotic-Assisted Implant Placement - Robotic systems can perform fully automated implant surgeries with sub-millimeter accuracy, reducing the risk of human error. Haptic feedback and AI integration enable the robotic arm to respond dynamically to real-time conditions during surgery.

Augmented Reality (AR) and Virtual Reality (VR) in Implant Surgery -AR overlays provide real-time visualization of implant positioning, superimposing digital plans onto the patient’s anatomy during surgery. VR simulation is being used for training and preoperative planning, allowing clinicians to practice implant placement in a virtual 3D environment.

Micro Casting - Micro casting involves the use of molten metal, which is poured into a microstructured mold to produce small-scale structures with intricate geometrical details in the micrometer range. This technique offers several advantages, including cost efficiency and scalability, allowing for the production of both single units and large quantities of identical components(14).

3D Printing and Custom Implant Solutions - Patient-specific 3D-printed surgical guides are improving accuracy while reducing costs and production time. Custom 3D-printed implants allow for better fit, faster osseointegration, and improved esthetics in cases with severe bone loss.

Biologics and Regenerative Technologies - Growth factors (BMPs, PRF, PRP) and stem cell therapy are being studied to enhance bone regeneration and accelerate healing.

Electron Microscopy - Analyzing the phase composition of the surface oxide layer is crucial in some cases. However, due to the thin nature of the oxide layer and the limitations of many techniques designed for flat surfaces, studying complex implant geometries with increased surface roughness presents a challenge. High-resolution transmission electron microscopy (HR-TEM) enables precise measurement of lattice parameters, as well as detailed analysis of the microstructure and grain sizes of the surface layer. Additionally, electron diffraction can be utilized for phase identification at the nanoscale. Electron backscatter diffraction (EBSD) using scanning electron microscopy (SEM) further facilitates electron diffraction analysis of surface films without requiring extensive sample preparation(14).

Smart and Digital Implants -Smart implants with built-in sensors can monitor loading forces, osseointegration, and infection risks, sending real-time data to the clinician. Bluetooth-enabled implants can provide patient-specific feedback to improve long-term success rates.

Minimally Invasive and Needle-Guided Implant Techniques -Piezosurgery and laser-assisted implant placement are reducing tissue trauma and improving healing. Needle-guided implant insertion is being researched as a potential alternative to traditional drills, offering greater precision with minimal discomfort.

Nanotechnology-Based Implants - Nanotechnology involves innovative methods for manipulating matter at the atomic scale. Currently, extensive research is being conducted to develop nanotechnology-based dental implants. These advancements focus on modifying surface roughness at the nanoscale to enhance protein adsorption and cell adhesion, applying biomimetic calcium phosphate coatings, and incorporating growth factors to accelerate the bone healing process(14).

# CONCLUSION

Since the 1980s, dental implants have been a dependable treatment option, offering long-term stability, minimal impact on adjacent teeth, and enhanced aesthetics. With advancements in computer-aided design (CAD) and rapid prototyping, guided implant surgery has gained popularity, enabling precise preoperative planning and reduced surgical invasiveness. However, certain challenges remain, including tomographic image misinterpretation, slight deviations in surgical guide fabrication, and fixation inaccuracies, all of which can affect placement precision. Additionally, factors such as the number of adjacent implants, tooth positioning, timing of extraction, clinician expertise, and the width of the edentulous space play a crucial role in determining implant accuracy(1).

In general, freehand implant placement is suitable for patients with adjacent teeth and single implant cases, particularly in narrow spaces where angle deviations are less critical. However, guided surgery is preferred for fully edentulous patients, multiple implant placements, and cases with incomplete bone regeneration, where precise positioning is essential. Despite the higher accuracy of guided surgery, some clinicians still favor freehand placement due to a lack of comprehensive knowledge on both techniques. Therefore, further research and education are encouraged to enhance understanding and optimize outcomes based on case-specific requirements.

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