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Current research status of static computer-aided implant surgery in the posterior region and complex cases

Jiaen Wu[1, *]

[1]The Second Departmant of Medicine, Guang Dong Medical University, Guangdong, China

*Corresponding author: Jiaeno@outlook.com

Abstract:

This article explores the current research status of oral implant guides in the posterior teeth area and special cases, with a focus on analyzing the application, advantages, and disadvantages of static implant guides and digital implant guides. Traditional implant guides have certain limitations in operation and precision. However, digital implant guides have significantly enhanced the accuracy and safety of implantation through 3D printing and computer-aided technologies, reducing surgical risks and improving patient comfort and satisfaction. In the posterior teeth area, the utilization of digital implant guides can effectively handle special circumstances in the upper and lower posterior regions, such as patients with insufficient bone mass and limited mouth opening. Studies indicate that digital guides perform exceptionally well in immediate implantation and full-arch implantation, increasing the success rate and efficiency of the surgery. Simultaneously, in the special case of mandibular reconstruction, the introduction of digital technology assists surgeons in achieving higher treatment accuracy and reduces surgical time and trauma.

Keywords: Digital implant guide plates, posterior area, immediate implantation, lower jaw reconstruction, precision medicine.

1. Introduction

At present, dental implant surgery has been widely adopted, especially in China, where the market for dental implant materials has significantly expanded after centralized purchasing. "Prosthetically-guided implant placement" refers to the dental implant treatment process aimed at achieving optimal functional and aesthetic outcomes while meeting bio-mechanical requirements for long-term maintenance and stability. This involves placing the implant according to the desired position, orientation, and angle of the prosthesis while formulating a comprehensive surgical treatment plan. This principle helps effectively restore both structure and function in patients with dentition defects or edentulism. However, despite the rapidly increasing demand for implants and high-quality restorations, there is a mismatch

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between this demand and the growth rate of qualified surgeons for dental implant surgery. To solve the above problems, static guides have been introduced and gradually applied in dental implant surgery.
The use of static guides was first introduced by Fellingham in 1986 [1]. Recent literature indicates that modern implant guide plates can be precisely positioned and guided during procedures. This helps reduce common issues such as lateral wall perforation or incorrect positioning about the direction and depth of implants, resulting in better restoration outcomes in aesthetic zones. The use of multiple implants enhances overall surgical efficiency in cases involving multiple edentulous areas or complete edentulism. During immediate implantation surgeries, the use of a guide plate facilitates more accurate positioning alongside primary stability. However, traditional implant templates have some limitations. They require sufficient mouth opening, which can be particularly challenging in the posterior regions, and may limit visibility within the surgical field. Therefore, it is often necessary to remove them before implant placement, which can reduce tactile sensitivity for surgeons. Additionally, these templates can block heat dissipation from the implant cavity, potentially leading to early restoration failures and imposing economic burdens on patients.
Digital dental implant guides require integration with advanced technologies, including 3D dental imaging equipment, 3D printing techniques, material sciences related specifically to dentistry, as well as digital processing methodologies like Computer-Aided Design/Computer-Aided Manufacture (CAD/CAM) systems. These guides offer advantages over conventional methods, as they allow for personalized surgical planning even in challenging scenarios such as limited space at posterior tooth sites or abnormal bone/soft tissue volumes, including cases involving fibular grafts following maxillofacial surgery. This review aims to summarize recent research developments regarding digital guide plates for dental implants in the posterior region and associated complex cases. The focus is primarily on special circumstances such as limited space around posterior teeth or irregularities in bone volume and soft tissues, as well as addressing fibular implantation procedures.

2. Static implant guide plates

2.1 Development history

The success of implants depends on several factors, including the thickness and quality of the bone, the type of gingival biotype, and the precision of the implant's position, depth, and angle at the time of placement [1]. To enhance the effectiveness of implant restorations, Dr. Fellingham developed and first employed surgical guides in 1986. These guides primarily assist in determining the direction and placement of implants, marking a significant advancement in implant technology.
Surgical guides have demonstrated notable efficacy in supporting dentists during prosthetically guided implant treatments [2]. Research indicates that their use minimizes the influence of the clinician's experience on the outcomes [3]. In China, as productivity has increased, so too has the public's demand for higher living standards, which has expanded the need for implant restorations significantly. The inclusion of implants in centralized procurement in 2022 further amplified this demand. However, despite the rapid increase in the need for implants and high-quality restorations, the number of qualified implant surgeons has not kept pace. The use of implant surgical guides is one of the methods to address this challenge.

2.2 Conventional implant guide plates

Dental implant guides are categorized according to their support mechanisms, which can include mucosal-supported, bone-supported, tooth-supported, and mixed-support types. Mucosal-supported guides are often employed for patients missing several teeth or those who are completely edentulous, frequently necessitating the use of retention pins for additional stability. Various factors, including the contours of the jawbone and the thickness of the surrounding soft tissue, can significantly influence the precision of these guides. In cases where only a few teeth are absent, tooth-supported guides are more appropriate as they gain stability from the adjacent teeth, leading to improved accuracy. Conversely, bone-supported guides require significant flap elevation to reveal the bone surface, which can heighten surgical trauma. Additionally, the accuracy of these guides might be compromised due to the quality of the bone surface data obtained from cone-beam computed tomography (CBCT) [4-5], resulting in their less frequent use. Mixed-support guides are suited for patients with several missing teeth but who still retain some natural teeth, providing better accuracy in these situations.
Implant guides can also be sorted based on the level of surgical restrictions they impose. These can range from unrestricted to designs that are partially or fully restricted. The current designs typically incorporate sleeves and positioning pins to direct the drill's trajectory, and factors such as sleeve height and pin design can influence the accuracy of implant placement during procedures [6].
When it comes to production methods, implant guides fall into two primary categories: conventional and digital. Conventional guides generally use vacuum-formed

technology and are created from plaster models, which take into account the final aesthetic aspects of the implant restoration. Although they are relatively easy to produce, budget-friendly, and thus widely used in clinical practice, their dependence on surface data from plaster models can restrict their accuracy. Even with full exposure of the bone during surgical procedures, this method might not ensure precise implant placement, especially in situations involving multiple tooth loss or inadequate bone volume [7].

2.3 Digital implant guide plates

With the continuous advancement of CAD/CAM and 3D printing technologies, new digital implant guides have seen extensive clinical application. These guides are primarily generated by integrating information from CBCT, intraoral scanning, and virtual tooth arrangement. Using specialized software, clinicians can create implant guides, which are then manufactured through 3D printing techniques [8-9].

2.3.1 Advantages

Digital implant guides, created using 3D printing technology, enable precise control over the position, angle, and depth of implant placement. This method mitigates the reliance on the clinician's experience prevalent in traditional techniques, thereby significantly enhancing the accuracy of the implant process [10]. What's more, customized implants and guides are designed to better accommodate the patient's unique oral anatomy. This tailored approach minimizes the gaps between the implants and the surrounding bone, which improves the long-term success rates of dental implants [11]. Then, the digital implant technique employs minimally invasive methods, resulting in smaller incisions and less trauma. Patients benefit from a more comfortable and pain-free surgical experience, and the overall satisfaction during the procedure can be boosted [12]. And, utilizing three-dimensional models during digital implant procedures allows for the avoidance of critical anatomical structures, such as blood vessels and nerves. This capability reduces surgical risks and lowers the likelihood of postoperative complications [11]. Finally, the efficiency and reduced discomfort associated with digital implant procedures lead to higher overall patient satisfaction. This positive experience contributes to greater acceptance of treatment and improved ratings from patients.

2.3.2 Limitations

The production of digital implant guides involves advanced equipment and software, which contributes to an increase in overall treatment expenses. Then, surgeons operating digital implant guide systems require specialized training due to the high technical demands of the procedure. As with any technology, there exists a potential risk of malfunctions; software errors or equipment failures could disrupt the treatment process [3]. And there are instances when digital implant guides may show noticeable deviations. If the deviation exceeds 2 mm, it could potentially lead to damage to critical structures such as nerves, the maxillary sinus, or adjacent teeth. However, recent developments in improved guides, such as 3D-printed surgical guides with sliding rails, aim to reduce such deviations by ensuring better alignment between the drilling site and the planned position [13-14]. The design of implant guides can limit flushing and lead to heat generation. This is particularly crucial in flapless implant surgery, where excessive heat and insufficient cooling must be carefully managed to prevent thermal damage during surgery [15]. Such thermal injuries are significant contributors to early implant failures [16]. Considering the applicability limitations, in certain anatomical areas, such as the molar region, the limited operative space makes direct visualization challenging, which can impair the surgeon's tactile sensitivity and increase the risk of deviations [17]. Furthermore, digital implant guides are typically suitable for cases with good bone conditions, or for jaws that have undergone pre-treatment to improve bone volume through procedures such as bone augmentation or maxillary sinus lift. If complex procedures such as maxillary sinus lift, bone augmentation, or bone splitting are required during surgery, standard digital implant guides may not be suitable [18].

3. The application of digital implant guides in the posterior region

3.1 Posterior Region of the Maxilla

Following tooth loss, significant bone resorption often occurs, particularly in the maxilla. Researchers have classified the maxillary bone based on factors such as the relationship between the bone wall and the sinus floor, as well as the extent of the bone defect. For patients with severe bone resorption in the posterior maxilla, sinus floor elevation is routinely performed to provide the necessary height and stable bone tissue around the implanted dental fixtures. Studies indicate that the use of 3D software for surgical planning, along with digital implant guides, not only improves surgical precision and success rates but also reduces complications and follow-up visits [19]. Some teams have even employed 3D-enhanced implant membrane guides to assist in sinus floor elevation, helping with boundary demarcation, membrane stabilization, and implant placement [18]. The use of digital guides sim-

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plifies the surgical process, ensuring effective membrane stabilization and protection, while Guided implant placement provides predictable surgical positioning of dental implants.

For patients with significant bone loss in the posterior maxilla, zygomatic implants have been shown to improve quality of life and patient satisfaction. The penetration point of the zygomatic implant apex should be positioned anterior to the 90°angle point, as the thickness in this region is less than the diameter of the implant and the three-dimensional positioning is more complex. Therefore, the use of a drilling guide or a digital implant template represents a more advanced and safer approach for zygomatic implant placement [19]. Recent research has demonstrated that static computer-assisted implant surgery yields smaller angular deviations compared to dynamic techniques, augmented reality, or freehand approaches [20].

3.2 Posterior Region of the Mandible

In cases of insufficient vertical bone height in the distal free-end of the posterior mandibular region, computer-assisted surgical planning and the use of digital implant guides offer a minimally invasive treatment option with shorter recovery times. As early as 2014, clinical studies demonstrated the feasibility of this approach, highlighting how digital guides can bypass complex bone augmentation procedures and avoid the high risks associated with nerve repositioning. Although these guides improve the precision of implant placement and orientation, their complex manufacturing process, higher costs, and occasional deviations in the posterior region limit their widespread clinical adoption.

For patients with limited oral opening, Zhang et al. developed an improved implant template. This modified implant template is a fully guided system consisting of five structural components: the coverage support section, the sleeve, the lingual movable segment, the mesial and distal locking channels, and the mesial and distal locking bodies. This modified guide was found suitable for cases involving smaller oral openings and limited interocclusal space in the posterior region [21]. Additionally, Wang et al. integrated pioneer drill templates, digital design, and model fabrication to achieve a process that is simple to produce, cost-effective, and enhances precision. This approach can be utilized for implant restoration in cases of single-tooth or limited tooth loss in the dental arch. However, this technique is applicable primarily to cases with relatively sufficient bone quality and ideal prosthetic positioning. In situations involving bone defects or aesthetic zones that require teeth trial setups, achieving an implant position that is both restoration-guided and consistent with the anatomical characteristics of the bone becomes challenging [22].

Wang R. et al. developed a digital universal implant template. This self-designed universal dental implant template primarily consists of four components: a retention clamp, a limiting device, an implant sleeve, and a radiographic slider. This self-developed guide addresses the issues of deviation by securing the free end and reducing misalignment, thereby improving overall implant precision in posterior cases [23].

3.3 Full-arch Dental Implants

For edentulous patients, implant restoration demands a higher level of precision in implant placement. Digital full-arch implant guides offer several advantages, including preoperative planning and intraoperative control, allowing for precise preparation of the implant cavity and accurate placement of the implants. This technology ensures optimal three-dimensional positioning, contributing to aesthetically pleasing and self-cleaning final restorations. Therefore, the use of digital guides significantly enhances the accuracy of immediate implant placement. According to a study by Jiao et al., the application of digital full-arch guides in full-mouth implant surgeries has proven to be more accurate and time-efficient compared to conventional methods [24]. Li et al. also found that implants placed using digital guides resulted in healthier peri-implant tissues compared to those placed manually [25-26].

Moreover, the use of digital implant templates allows for improved design of the prosthetic component following implant placement, utilizing digital technology for enhanced precision and customization. Makarov et al. successfully demonstrated the use of plaster-free, digitally prefabricated temporary restorations in computer-assisted, implant-supported full-arch rehabilitations. The number and positioning of the implants were tailored to each patient, taking into account factors such as bone availability, quality, anatomical structures, and occlusal records. The prosthetic components are designed digitally and milled from PMMA resin blocks according to the surgical plan. Makarov et al. assert that the comprehensive utilization of digital technology, from implant placement to prosthetic installation, represents an effective approach [27].

4. The application of digital implant guides in specific clinical scenarios

In specific clinical scenarios such as maxillary atrophy, bone defects due to osteomyelitis, complications following cancer surgery, and post-traumatic sequelae, patients often experience insufficient bone quantity and structural deformities [28]. The primary objective of reconstructing the mandible is to achieve a balance between functional restoration and aesthetic appearance. The implementation of digital technologies enables preoperative simulation of treatment plans, allowing for the identification of implant sites in the mandible based on the position of the maxillary dentition. This facilitates the design of the graft segment and the creation of surgical guides, ultimately reducing operative time and enhancing the precision of mandibular reconstruction, thereby benefiting a greater number of patients with mandibular defects in terms of dental restoration.

Vascularized autologous bone grafting holds distinct advantages in mandibular reconstruction. It is suitable for a variety of conditions and permits immediate placement of oral implants [29]. Common donor sites include the iliac crest, fibula, and scapula. However, the thinness of the scapular flap precludes its use for oral implant restoration, and due to numerous constraints in iliac crest grafting, it is often considered a secondary option following fibular graft failure; thus, this discussion will focus primarily on the fibula.

The fibular flap is currently the preferred technique for mandibular reconstruction and is the most widely utilized donor site. Nonetheless, the major drawback of the fibula is its insufficient height, which can lead to an inappropriate crown-to-root ratio during implant restoration, making it challenging to adapt to the remaining mandibular bone in segmental defects, resulting in a reduction of the lower third of the face. Traditional techniques for fibular grafting involve aligning the fibula with the resected mandible through manual surgical techniques, a process that is entirely dependent on the surgeon's experience and judgment, making it both challenging and imprecise. Even after successful mandibular reconstruction, dental restoration typically requires an additional 6 to 18 months, which can adversely affect the patient during the interim [30].

The introduction of computer-assisted techniques has significantly enhanced the accuracy of surgical procedures [31]. Levine et al. collected patient data to virtually plan the extent of tissue excision and the appropriate space for reconstruction. Simultaneously, they utilized CAD/CAM technology to create physical models of the fibula and craniofacial bones, upon which the digital surgical guide was customized [32]. Surgeons select appropriate techniques to enhance the vertical height of the mandible following fibular grafting based on digital information tailored to the patient. Such techniques include double-layer fibular grafting and the use of CAD/CAM titanium mesh for augmentation. Following this planning phase, procedures such as fibular osteotomy, mandible resection, and reconstruction could be executed. With the assistance of the digital surgical guide, minimal intraoperative adjustments were necessary, which helped to avoid osteotomy errors, thereby reducing the complexity of secondary reconstruction and optimizing both surgical duration and trauma.

As previously noted, immediate implantation can achieve comparable outcomes to traditional delayed implantation, particularly when guided by a fully digital surgical template, which often promotes healthier soft tissue conditions post-implantation. Utilizing the collected data to simulate mandibular reconstruction surgery on physical models, Levine et al. designed a digital implant guide for placing implants in the reconstructed mandible after fibular grafting. Following the fibular flap transplantation, they performed immediate implant placement during the initial surgery, ensuring the correct orthognathic and occlusal relationships to facilitate complete mandibular reconstruction [32].

The final position of the prosthetic teeth was determined based on functional occlusion and aesthetics, which subsequently guided the ideal locations for the implants and the orientation of the osteotomy and fibula. This method demonstrated significantly superior restorative outcomes compared to traditional approaches. However, it is important to note that this strategy may not be suitable for all patients, particularly those with malignant tumors.

5. Summary

This review comprehensively reviews the application progress of implant guide plates in posterior dental area and special cases in the field of oral implantation. Although the traditional static implant template can complete the basic task, it has limitations in adaptability, accuracy and patient experience. With the advanced 3D printing technology and computer-aided design, the digital implant template has greatly improved the accuracy and safety of surgery, especially in the treatment of posterior teeth and complex cases. Not only does it shorten the operation time and reduce the risk of complications, it also significantly improves overall patient satisfaction. In the future, digital implant guides are expected to further integrate artificial intelligence (AI) algorithms and biomaterials science to enhance their intelligence and biocompatibility. In addition, with the maturity of the digital medical platform, remote diagnosis and treatment services will also be expanded, so that patients in remote areas can also enjoy high-quality dental implant services. The goal is to promote the development of oral implant to a smarter, safer and more personalized direction, so that every patient

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can obtain satisfactory restoration results and improve the quality of life.

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