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Comparison of Dynamic Navigation and Static Navigation Systems in Implant Surgery: Accuracy and Application Analysis

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Abstract: Due to the high demands for accuracy and precision in complex implant surgeries, navigation technology has gradually been applied in the field of dentistry. Although static navigation provides pre-designed surgical guides, its inability to adjust the implant pathway in real time during surgery may lead to insufficient accuracy. In contrast, the real-time monitoring and adjustment capabilities of dynamic navigation are particularly important in cases with complex anatomical structures and high aesthetic requirements, significantly reducing the risk of damaging critical anatomical structures and improving the success rate of surgeries. Factors affecting the accuracy of dynamic navigation systems include bone density, the choice of calibration method, the experience and skills of the dentists, as well as the characteristics and design of the implants. This review provides guidance for clinicians in selecting navigation systems, especially highlighting the significant advantages of dynamic navigation in the applications of edentulous implant placement and anterior aesthetic zone implantation.

1 Introduction

Compared to fixed bridges that require damage to adjacent teeth to achieve the purpose of repair, implant surgery has become the preferred method for the restoration of missing teeth. However, traditional, unguided free-hand implant surgery is prone to deviation during the implant placement process, and it also risks damaging important anatomical structures in the jawbone, such as the maxillary sinus and the mandibular canal [1]. To improve the success rate of surgery, reduce postoperative complications, and enhance the patient experience, navigation technology that combines computer-aided design/computer-aided manufacturing (CAD/CAM) technology, three-dimensional imaging technology, and real-time tracking technology has emerged. Navigation technology is divided into static navigation and dynamic navigation. Static navigation uses a computer scanning system for three-dimensional reconstruction of oral anatomy and designs and manufactures a surgical guide through digital technology, which guides the entry of instruments during surgery. Dynamic navigation, based on static navigation, integrates cone-beam computed tomography (CBCT) data with an optical tracking system to display the real-time relative position of the instruments during surgery, thereby guiding the entry of the instruments. Compared to static navigation, dynamic navigation has a higher degree of accuracy and is more suitable for special cases such as edentulous implantation and aesthetic implantation in the anterior aesthetic area, thus offering greater advantages. Therefore, this article reviews the application of these two navigation technologies in implant surgery, aiming to provide clinicians with a comprehensive perspective to better select and apply navigation technology.

2 Navigation Technology in implant surgery

2.1 Static Navigation

Static navigation involves the use of a computer scanning system to perform three-dimensional reconstruction of oral anatomical structures, the design and fabrication of a surgical guide through digital technology. During surgery, the static guide is used to direct the entry of implantation instruments. Compared to freehand operation without guide, static navigation tends to be more accurate [2]. Static guides can be categorized into mucosa-supported, bone-supported, and tooth-supported types according to their supporting methods. The guides can also be divided into semi-guided and fully-guided navigation. The former serves only to fix the position, while the latter can also guide drills of various diameters for gradual stage expansion of holes. The advantage of static navigation is that it allows for the visualization of the patient's occlusion and alveolar bone morphology in three dimensions and enables the preoperative design of the implant plan outside the oral cavity, thereby increasing the accuracy of implant placement [3]. Additionally, since the mandible cannot be completely fixed during surgery, the spatial positioning of dynamic navigation may be disrupted, whereas static navigation can more stably guide drilling. However, the use of static guides is greatly affected by the patient's

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mouth opening, and once the guide is placed, it is not possible to change the surgical plan during the operation. Moreover, the precision of static guides is lower compared to dynamic navigation systems [4].

2.2 Dynamic Navigation

As illustrated in Figure 1, the primary distinction between static and dynamic navigation lies in the fact that dynamic navigation does not depend on pre-fabricated surgical guides. Instead, it can track and display the position, orientation, and depth of surgical instruments within the jawbone in real time, and dynamically generate and adjust the surgical path during the procedure. This technology is typically utilized in conjunction with cone-beam computed tomography (CBCT) data and an optical tracking system, enabling surgeons to precisely control the position and angle of the implant during surgery. Dynamic navigation technology is particularly applicable to cases requiring high precision in implant placement, such as those with complex anatomical structures at the edentulous site, continuous loss of multiple adjacent teeth, and patients with specific aesthetic and functional prosthesis needs. This technology provides real-time path information for implant sites, reduces the risk of damaging critical anatomical structures like the inferior alveolar nerve and maxillary sinus, and increases the success rate of implantation. While dynamic navigation can enhance the accuracy and predictability of implant placement, it also has several drawbacks, including high equipment maintenance costs, a longer learning time, and a more complex preoperative calibration process [5]. Furthermore, some studies have indicated that for experienced implantologists, the effectiveness and accuracy of dynamic navigation is similar to those of static navigation, suggesting that dynamic navigation may not always be necessary [6].

Figure 1 summarizes the differences between static and dynamic navigation, as well as their respective advantages and disadvantages.

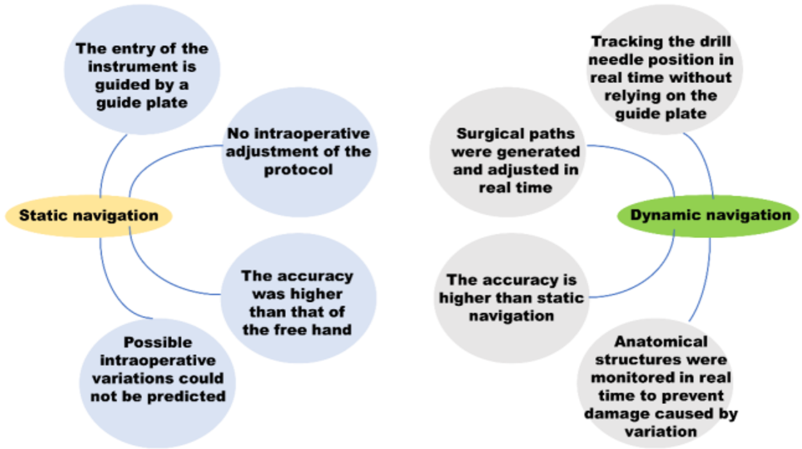

Figure 1. The difference between static and dynamic navigation.

3 Operational Steps of Navigation Systems

3.1 Operating steps of Static Navigation

The operational steps of static navigation primarily involve the acquisition of three-dimensional oral imaging data, surgical plan development, production of CAD/CAM surgical guides, calibration of the surgical guides, guide placement, drilling, and postoperative assessment. Initially, software such as coDiagnostiX (Dental Wings Inc, Montreal, Canada) is used to plan the optimal position, angle, and depth of the implant based on the patient's oral structure and implant requirements. Using Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) technology, a surgical guide that precisely matches the patient's oral anatomy is fabricated according to the design in the planning software. This guide is typically made from transparent resin, facilitating observation and positioning during surgery.

During the design phase, the surgical guide can be first created on patient's plaster model, then transferred to a radiographic stent, and combined with optical scanning and radiographic data to formulate the implant plan. Additionally, the virtual database in the planning software can be utilized to design the prosthesis. Some systems, such as the IST system, offer a virtual jaw stent to analyze static and dynamic occlusions within the CAD software, assisting in the precise placement of the surgical guide [7].

Prior to surgery, the surgical guide is matched with the patient's oral cavity to ensure accurate positioning, a critical step to minimize deviations during the procedure. During surgery, the surgeon follows the guide for positioning, hole preparation, drilling, and implant placement. Post-implantation, a postoperative CBCT scan is conducted to assess the actual position of the implant, ensuring it aligns with the preoperative plan and that the position, angle, and depth of the implant are as expected [8].

While the production process of static navigation technology is more straightforward compared to dynamic navigation, it requires a longer time to fabricate the guide, necessitating multiple clinic visits for the patient. The design and subsequent placement and positioning of the guide demand a high level of expertise from the operators.

3.2 Operating steps of Dynamic Navigation

The operational steps of dynamic navigation are more integrated with computer technology, and the clinical procedures are relatively simpler. The main dynamic navigation systems currently used in clinical practice include X-Guide® (X-Nav Technologies, USA) and Navident® (ClaroNav, Canada) [9]. The steps of dynamic navigation can be divided into five stages:

- Acquisition of three-dimensional scanning data: Initially, the patient's three-dimensional oral structure is captured through cone-beam computed tomography (CBCT) to facilitate subsequent surgical planning.
- Virtual implant planning: Specialized treatment planning software is employed to simulate the optimal position, angle, and depth of the implant in a three-dimensional view based on CBCT data, leading to the formulation of a detailed surgical plan.
- Registration and calibration process: Prior to surgery, the tracking device within the surgical navigation system is calibrated to accurately capture the positions of the surgical tools and the patient's oral structure. Additionally, patient tracking pairing is conducted to align the implant position in the pre-surgical plan with the patient's actual oral anatomy.
- Surgical navigation: During the surgery, the dynamic navigation system provides real-time tracking and display of the surgical tools' positions, allowing comparison with the pre-planned surgical path.
- Real-time adjustment: Dynamic navigation enables clinicians to fine-tune the implant's position, angle, and depth to accommodate any anatomical variations or unexpected situations encountered during the procedure.

Figure 2 summarizes the key steps of static and dynamic navigation.

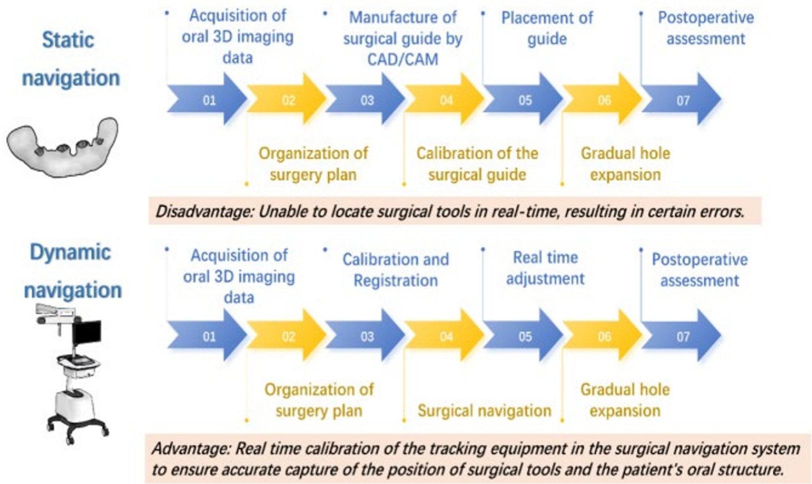

Figure 2. The operation procedure of static and dynamic navigation.

4 Factors Affecting the Accuracy of Dynamic Navigation Systems

Although the static guide can provide relatively accurate positioning, there may be variations in intraoperative anatomical structures. For beginners, it can still be challenging to clearly see the implant device's path within the bone. In cases of severe alveolar ridge resorption, there is a significant risk of damaging the maxillary sinus and the mandibular canal. Consequently, the dynamic navigation system is currently the preferred auxiliary method for implantation. However, the accuracy of the dynamic navigation system is influenced by various factors. To achieve optimal surgical results, it is essential to consider these factors comprehensively and select the most appropriate surgical plan based on the specific situation.

4.1 Bone Density

Bone density is a crucial factor affecting the accuracy of dental implant surgery. In Computer-Guided Surgery (CGS), parameters such as bone density, bone width, and cortical bone thickness significantly impact accuracy. Studies have shown that low bone density or a narrow buccal-lingual width may be risk factors affecting the accuracy of CGS implantation. A retrospective study demonstrated that low bone density and narrow bone width could lead to deviations of the initial drilling point from the planned area during the drilling process, thereby reducing the accuracy of implant placement [10]. In vitro models, López used Mguide software to plan the placement of four implants on a mandibular model made of acrylic resin and calibrated each model, reaching the same conclusion [11]. However, an in vitro study by Chen showed that when using artificial intelligence (AI)-assisted implant planning software to evaluate the clinical reliability of the implant template, an increase in bone density could lead to greater implant deviation, particularly in the apex deviation and angular deviation of the implant [12]. This result may be related to the hardness of the bone cortex.

4.2 Choice of Calibration Method

Errors during the calibration process will directly affect the accuracy of the navigation system, so when Errors during the calibration process can directly affect the accuracy of the navigation system. Therefore, when choosing a calibration method, its potential impact on surgical accuracy should be considered [13]. Common calibration methods include bone landmark calibration, occlusal splint, U-shaped tube calibration, facial frame calibration, and anatomical landmark calibration. Among these, bone landmark calibration is the most accurate, while facial frame calibration is the most error-prone [14]. Additionally, the commonly used U-shaped tube calibration can be affected by facial stability, whereas anatomical landmark calibration relies on the precise identification and matching of landmarks such as teeth, alveolar bone, jawbone, implants, and other bony structures.

4.3 Experience and Skills of the Surgical Operator

The experience and skills of the dentists are key factors in determining the accuracy of the navigation system. Research by Block showed that as dentists become more familiar with the dynamic navigation system, surgical accuracy improves. Experienced doctors are better able to utilize the navigation system effectively, thereby reducing operational errors [15].

4.4. Characteristics and Design of the Implant

The characteristics and design of the implant affect the accuracy of dynamic navigation by influencing its contact area with the surrounding bone tissue and its ability to integrate with the bone. Longer implants can provide better stability, but excessively long implants may risk damaging nerves or blood vessels. Implants with a larger diameter offer better initial stability and facilitate the even distribution of loads. The tilt of the implant is related to the design of the upper prosthetic structure, as well as its relationship with adjacent and opposing teeth [16].

In terms of implant placement site design, dynamic navigation systems offer greater advantages over traditional methods in specific situations, such as when the mesiodistal space of the implant site is less than 7 mm, or the distance from the center point of the implant to the natural tooth is less than 4 mm. They are also advantageous for multiple continuous implants with implant spacing less than 7 mm, patients with a smaller mouth opening, second molar implantation, trans-alveolar implantation, and immediate implantation [17].

5 Application of Dynamic Navigation

5.1 Application in the Anterior Aesthetic Region

The maxillary anterior tooth has a certain angle with the long axis of the maxilla which is relatively thin. Traditional implantation in this area is prone to cause implant tilt and penetration of the buccal bone wall. The dynamic navigation system can reduce the probability of postoperative complications. Research by Romandini showed that in completely flapless implantation, commonly used in the anterior aesthetic region, dynamic navigation can achieve higher implant accuracy. This improves the survival rate and repair accuracy of the implant, while reducing the number of postoperative complications, pain incidence, the amount of anti-inflammatory medication needed, and the bleeding rate. Even in the long-term prognosis, the reduction in alveolar bone height is alleviated. However, Romandini suggested that in clinical design, a safety margin of at least 2 mm should be retained for implant depth errors, 3 mm for coronal and radicular errors, and 4° for angular errors [18].

5.2 Application in Edentulous Patients

In edentulous patients, the absence of natural alveolar bone landmarks makes traditional implant surgery methods challenging for precise positioning. In contrast, dynamic navigation systems can accurately guide implant placement, ensuring that the implant aligns with the anatomical structure of the jawbone [19].

6 Conclusion and Prospects

Compared to traditional and static navigation methods, dynamic navigation systems offer exceptional real-time performance and flexibility. Unlike prefabricated static guide, dynamic navigation systems track the positions of surgical tools in real time, allowing doctors to adjust their strategies instantaneously during the procedure. This capability is particularly valuable for managing complex anatomical structures and high aesthetic demands, as it significantly reduces the risk of damage to crucial anatomical features and enhances the success rate of the surgery [20]. Another significant advantage of dynamic navigation is its high-precision control. By integrating CBCT data with optical tracking systems, dynamic navigation ensures precise control over the positions and angles of implants, further increasing the success rate of surgeries. Additionally, this technology supports individualized treatment, allowing for intraoperative adjustments based on the patient's specific anatomical structure [21]. The application prospects of dynamic navigation technology in education and training are also promising. By simulating the surgical process and providing real-time feedback, this technology can help dentists enhance their surgical skills. It is particularly beneficial for complex implant restorations and surgical operations, offering real-time guidance and evaluation to accelerate skill development [22]. However, the high cost of dynamic navigation equipment, the demanding skill requirements for operators, and the need to modify existing workflows may limit its widespread adoption in some medical institutions [23]. Future researches are expected to more focus on reducing costs and streamlining the operational process.

References

1. FENG Y, YAO Y, YANG X. Effect of a dynamic navigation device on the accuracy of implant

placement in the completely edentulous mandible: An in vitro study [J]. J Prosthet Dent, 2022, S0022-3913(21): 702－722

2. CHEN C K, YUH D Y, HUANG R Y, et al. Accuracy of implant placement with a navigation system, a laboratoryguide, and freehand drilling [J]. Int J Oral Maxillofac Implants, 2018, 33(6): 1213-1218
3. Hama DR, Mahmood BJ. Comparison of accuracy between free-hand and surgical guide implant placement among experienced and non-experienced dental implant practitioners: an in vitro study. J Periodontal Implant Sci. 2023 Oct; 53(5): 388-401. doi: 10.5051/jpis.2204700235. Epub 2023 Apr 24. PMID: 37154109; PMCID: PMC10627737.
4. Hinckfuss S, Conrad HJ, Lin L, Lunos S, Seong WJ. Effect of surgical guide design and surgeon's experience on the accuracy of implant placement. J Oral Implantol. 2012; 38:311–323.
5. Block MS, Emery RW, Lank K, Ryan J. Implant Placement Accuracy Using Dynamic Navigation. Int J Oral Maxillofac Implants. 2017 Jan/Feb;32(1):92-99. doi: 10.11607/jomi.5004. Epub 2016 Sep 19. PMID: 27643585.
6. Block MS, Emery RW. Static or Dynamic Navigation for Implant Placement-Choosing the Method of Guidance. J Oral Maxillofac Surg. 2016 Feb;74(2):269-77. doi: 10.1016/j.joms.2015.09.022. Epub 2015 Sep 30. PMID: 26452429.
7. Flügge, Tabea, et al."Digital implantology—a review of virtual planning software for guided implant surgery. Part II: Prosthetic set-up and virtual implant planning". BMC Oral Health, vol.22, 2022, https://doi.org/10.1186/s12903-022-02057-w.
8. Somogyi-Ganss E, Holmes HI, Jokstad A. Accuracy of a novel prototype dynamic computer-assisted surgery system. Clin Oral Implants Res. 2015 Aug;26(8):882-890. doi: 10.1111/clr.12414. Epub 2014 May 19. PMID: 24837492.
9. Raabe, Clemens, et al. "Accuracy of keyless vs drill-key implant systems for static computer-assisted implant surgery using two guide-hole designs compared to freehand implant placement: an in vitro study." International journal of implant dentistry 9.1 (2023): 4.
10. Putra RH, Yoda N, Iikubo M, Kataoka Y, Yamauchi K, Koyama S, Cooray U, Astuti ER, Takahashi T, Sasaki K. Influence of bone condition on implant placement accuracy with computer-guided surgery. Int J Implant Dent. 2020 Sep 20;6(1):62. doi: 10.1186/s40729-020-00249-z. PMID: 32951152; PMCID: PMC7502099.
11. Quispe-López N, Flores-Fraile J, Pardal-Peláez B, Delgado-Martínez J, Montero J. Factors Influencing the Accuracy of Guided Surgery: An In Vitro Trial. Int J Oral Maxillofac Implants. 2023 Jan-Feb;38(1):120-129. doi: 10.11607/jomi.9794. PMID: 37099581.
12. Chen Z, Liu Y, Xie X, Deng F. Influence of bone density on the accuracy of artificial intelligence-guided implant surgery: An in vitro study. J Prosthet Dent. 2024 Feb;131(2):254-261. doi: 10.1016/j.prosdent.2021.07.019. Epub 2022 Apr 22. PMID: 35469649.
13. Jorba-García A, González-Barnadas A, Camps-Font O, et al. Accuracy assessment of dynamic computer-aided implant placement: a systematic review and meta-analysis. Clin Oral Investig, 2021, 25(5): 2479-2494.
14. Tian Tian, Zhang Zhihong, Liu Honghong. Effects of different registration methods on the accuracy of navigation registration in dental implants [J]. International Journal of Stomatology. 2020, 47(02): 196-201.
15. Block MS, Emery RW, Lank K, et al. Implant placement accuracy using dynamic navigation. Int J Oral Maxillofac Implants, 2017, 32(1): 92-99.
16. Ozan O, Orhan K, Turkyilmaz I. Correlation between bone density and angular deviation of implants placed using CT-generated surgical guides. J Craniofac Surg, 2011, 22(5): 1755-1761.
17. Yanjun Ge, Xiaoqiang Liu, Yong Wang. Clinical Application and Prospects of Dynamic Navigation System in Oral Implantology J. Chinese Journal of Practical Stomatology, 2020, 13(8): 449- AccessDate. DOI: 10.19538/j.kq.2020.08.001.
18. Romandini, Mario, et al." Minimal invasiveness at dental implant placement: A systematic review with meta-analyses on flapless fully guided surgery". Periodontology 2000, vol.91, 2022, pp.89-112, https://doi.org/10.1111/prd.12440.
19. Bhalerao, Ashwini, et al. "Flapless placement of zygomatic implants using dynamic navigation: an innovative technical note". British Journal of Oral and Maxillofacial Surgery, vol.61, 2023, pp.136-140, https://doi.org/10.1016/j.bjoms.2022.11.282.
20. Panchal, Neeraj, et al." Dynamic Navigation for Dental Implant Surgery". Oral and Maxillofacial Surgery Clinics of North America, vol.31, 2019, pp.539-547, https://doi.org/10.1016/j.coms.2019.08.001.
21. Zhan, Yalin, et al. "Evaluation of a dynamic navigation system for training students in dental implant placement". Journal of Dental Education, vol.85,2020, pp.120-127, https://doi.org/10.1002/jdd.12399.
22. Ayoub, Ashraf, and Pulijala Yeshwanth. "The application of virtual reality and augmented reality in Oral & Maxillofacial Surgery". BMC Oral Health, vol.19, 2019, https://doi.org/10.1186/s12903-019-0937-8.
23. Wu, Bin-Zhang, and Sun Feng. "A registration-and-fixation approach with handpiece adjustment for dynamic navigation in dental implant surgery". Heliyon, v ol.8, 2022, pp. e10565, https://doi.org/10.1016/j.heliyon.2022.e10565.