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Innovations In Dental Implantology: Transitioning to Dynamic Navigation. -A Review

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***Abstract*— Dynamic navigation systems in implantology have emerged as a significant advancement in improving the precision and success rates of dental implant placements. These systems utilize real-time imaging and tracking technologies to guide the surgeon, offering higher accuracy compared to traditional free-hand methods. Dynamic navigation systems are particularly beneficial in complex cases, where precise positioning is crucial for optimal implant placement. Studies comparing dynamic navigation with static guidance have shown comparable accuracy, although the dynamic system offers more flexibility during the procedure. However, challenges such as high costs and limited evidence regarding aesthetic outcomes remain. Additionally, both dynamic and static navigation techniques result in similar postoperative outcomes in terms of patient satisfaction, swelling, and pain management. Despite these promising results, further research with larger sample sizes is required to fully establish the clinical advantages of dynamic navigation in routine implant surgeries. As the technology continues to evolve, dynamic navigation holds potential for becoming a standard practice in implantology, offering improved surgical precision and patient outcomes. This review provides an overview of the existing literature and evidence on dynamic navigation, exploring its potential applications, benefits, drawbacks, and future prospects.**

***Index Terms*—Static, Dynamic, Navigation,**

I. INTRODUCTION

The field of dental implantology has seen remarkable progress, with implant placement becoming increasingly popular. Key advancements include the adoption of Cone Beam Computed Tomography (CBCT) for treatment planning and the use of static implant guides to enhance precision. This technique, referred to as static navigation, provides pre-determined guidance for implant positioning.

A significant advancement in this domain is the introduction of dynamic navigation technology. This method enables real-time guidance during surgery, allowing clinicians to monitor the drill's position and orientation in relation to the patient's bone structure through preoperative CBCT imaging displayed on a screen. Dynamic navigation has already been utilized successfully in various medical disciplines, such as neurosurgery, orthopedics, and oncology.[1]

In dentistry, this technology plays a role in several oral surgeries, including midface fracture management, jaw reconstruction, orthognathic surgery, and temporomandibular joint treatments. Its primary objective extends beyond precise implant placement to achieving superior clinical outcomes.[2] These outcomes include ideal implant positioning, improved prosthetic functionality, enhanced aesthetics, and sustained peri-implant health.

This article delves into the applications of dynamic navigation in dental implantology, highlighting its potential to improve accuracy, efficiency, and overall patient care.[3]

II. SURGICAL NAVIGATION SYSTEM- A COMPARISON TO GPS ANALOG

A surgical navigation system can be likened to a global positioning system (GPS) in its basic structure and functionality. Similar to GPS, it comprises three key components: a surgical instrument acting as the GPS device, a locator functioning like a satellite, and a visual representation such as a CT, MRI, or CBCT scan displayed on a screen, akin to a map.[4] In GPS, the device receives signals from satellites and integrates them with preloaded maps to determine precise locations. Similarly, in surgical navigation, the locator (satellite) and surgical instrument (GPS device) are connected through mechanical, electromagnetic, ultrasonographic, or optical systems. Dynamic navigation systems in implant surgery predominantly use optical tracking, which can be categorized into active and passive methods. Active tracking involves stereo cameras detecting infrared light emitted by the system, while passive tracking uses reflective spheres that bounce infrared light from the source back to the camera. Passive optical tracking is the most commonly employed technique. Infrared light is emitted from a source above the patient, reflected off tracking arrays attached to the patient and surgical instrument, and captured by stereo cameras positioned above. The patient's preoperative image is synchronized with their real-time position through a process known as registration. [2,4]

III. REGISTRATION IN SURGICAL NAVIGATION

In surgical navigation, registration is the process of aligning the physical coordinate system of the patient with the virtual coordinate system of imaging data. This connection allows the surgeon to work seamlessly between the real clinical environment and the virtual imaging datasets. Registration methods include point-based techniques and surface-matching algorithms. For implant surgery, registration ensures even the drill depths are accurately tracked. This is typically done by linking preoperative CT scans to the patient using fiducial markers—anatomical landmarks that are consistently identifiable in both the physical and virtual spaces.[5]

For patients with teeth, a fiducial clip is attached securely to the dentition, ensuring stability and reproducibility whenever the teeth come together. Thermoplastic material can also serve as a reference clip, created from an impression of the patient's teeth. For patients without teeth, fiducial markers are placed in the alveolar bone using small screws to maintain consistent reference points.[6]

IV. DIFFERENT METHODS FOR PLACING IMPLANTS: FREE HAND APPROACH

The freehand method remains the most widely used technique for implant placement. In this traditional approach, the accuracy of the implant relies solely on the surgeon's expertise and precision.[7] The surgeon uses the opposing and adjacent teeth as reference points and employs calibrated probes to assess whether the available bone height and width are sufficient for the implant.

V. STATIC NAVIGATION

Static navigation involves using surgical templates to guide implant placement. These templates vary based on their material and support type. Materials include clear vacuum-formed stents, which are easy to fabricate but lack precision, and chemical-cure acrylic stents with lead strips, which are diagnostic but unsuitable for surgery. Self-cure acrylic stents with metal sleeves offer the highest accuracy but are more expensive and rigid. Self-cure acrylic stents with gutta-percha-filled channels are less effective than those with metal sleeves.[8]

Support types for templates include tooth-supported, bone-supported, and mucosa-supported designs. These templates maintain the angulation and position of implants in the bone. Some are plaster-based, providing positional guidance but disregarding bone morphology.[9] Advanced computerized templates account for bone structure, using CT-generated designs integrated with coordinated surgical systems to guide implant placement more precisely.

VI. DYNAMIC NAVIGATION

Dynamic navigation is the latest advancement in implant placement, allowing surgeons to guide implants in real-time. This technique uses live X-ray images displayed on a monitor to show the implant's position, depth, and angle during the procedure. It enables precise adjustments and tracking throughout surgery. Dynamic navigation provides a higher degree of accuracy compared to traditional methods, ensuring safer and more reliable outcomes.[10]

VII. FREEHAND VS DYNAMIC NAVIGATION

The freehand method remains the most widely used approach for implant placement, but it lacks 3D-guided treatment planning, which increases the likelihood of inaccuracies. These inaccuracies can lead to complications such as injury to the inferior alveolar nerve, damage to adjacent roots, membrane perforation, hematoma in the floor of the mouth, implant fractures from off-center loading, and more complex prosthetic procedures. Research has shown that dynamic navigation can correct these inaccuracies and offers greater precision compared to the freehand method. Implant accuracy is typically evaluated based on deviations in coronal, apical, and angular directions.[11]

For instance, a randomized split-mouth study by Aydemir and Arisan, which involved 32 patients, found that dynamic navigation provided an additional 0.7 mm in linear accuracy and 5° in angular accuracy compared to the freehand method. A cadaveric study by Chen and Le, focusing on the flapless technique in the anterior maxilla, confirmed that navigation outperformed freehand placement in terms of accuracy. Edelman et al. also concluded that dynamic navigation was more successful than freehand methods in a non-invasive comparative study.[12]

Laboratory studies have further demonstrated the superiority of navigation over freehand placement. In a study by Kramer et al., implant placements in the maxillary region showed less variation in position and angulation when using dynamic navigation ($P < 0.05$). Additionally, the insertion depth was more consistent with navigation.[13] An in vitro study by Hoffman et al. showed that the freehand method was less accurate than dynamic navigation, a finding supported by Chang et al., who observed higher precision with dynamic navigation.[14]

A 2023 randomized controlled trial by Yotpibulwong et al. compared static and dynamic computer-assisted implant surgeries across 120 patients, who were divided into four groups. The study measured implant discrepancies at the platform and apex levels in all directions. It found that the combination of static and dynamic navigation provided the most accurate results, outperforming freehand, static-only, or dynamic-only methods.[15]

These findings collectively support the conclusion that dynamic navigation offers greater accuracy and reduces complications in implant placement.

VIII. STATIC GUIDED SURGERY VS DYNAMIC NAVIGATION

Static navigation, as the term suggests, uses fixed templates to determine the exact location and angle for implant placement. This means that once the stent is in place, the implant's position cannot be adjusted unless the stent is removed. If the stent doesn't fit properly, the entire procedure needs to be restarted. Static navigation limits the surgeon to using only the same implant system.[16] In contrast to the freehand method, static navigation involves computer-assisted planning, making it more precise. While static navigation is a potential alternative to freehand surgery and has improved success rates, it also comes with some drawbacks.[16,17] Various factors influence implant surgery, including the precision of CBCT, the alignment of the model with the CBCT data, the accuracy of template fabrication, the tolerance of the template sleeve, the stability of the template during surgery, the exact fit of the template, and the surgeon's experience in designing the guide. Additionally, once a stent is made, it cannot be modified. The patient's mouth opening and other factors also play a role.[18] Though dynamic navigation offers several advantages; studies have not shown a statistically significant difference in accuracy between static and dynamic navigation. The implant site is also crucial to the success of both techniques.[19]

A randomized control trial by Kaewsiri et al. comparing static and dynamic navigation found that both methods demonstrated comparable accuracy.[20] Similarly, Yimarj et al. compared the two systems and found both techniques had similar accuracy and implant alignment.[21] Wu et al. observed that static navigation's accuracy was comparable to dynamic navigation, and the surgeon's experience did not significantly impact static navigation's effectiveness.[22] Guzman et al. also concluded that both methods were equally accurate. Block et al. found that static guidance's accuracy was on par with dynamic navigation.[2]

Surgeons with more experience generally achieve better implant placement accuracy, but dynamic navigation can help less experienced surgeons place implants with precision, as it provides real-time feedback. Clinical experience does not significantly affect implant accuracy with dynamic navigation, as demonstrated by Sun et al., who found that dynamic navigation enabled precise implant placement regardless of the surgeon's experience.[23] Other studies have supported this conclusion. Furthermore, dynamic navigation can be useful in training dental students, as it allows for real-time correlation with the image on the screen, helping them better understand anatomy and implant placement. Zhan et al. studied the role of dynamic navigation in training dental students and found it significantly improved their ability to correct implant deviations. [24] Pellegrino et al. observed that while dynamic navigation did not influence accuracy for experienced surgeons, the operating time was longer for less experienced surgeons compared to those with more experience.[25]

IX. ADVANTAGES

Dynamic navigation in implantology offers significant benefits over both static guided implants and the freehand approach. Numerous recent clinical studies have demonstrated its advantages compared to other implant placement techniques. One of the main benefits of dynamic navigation is the ability to verify implant placement throughout the procedure, which is not possible with freehand or static guided methods. In static guidance, if there is an error with the splint, the entire process is compromised. [26,27] Additionally, dynamic navigation allows most of the procedure to be carried out while the patient is monitored on the screen, ensuring precision. This is particularly useful in aesthetic areas, such as the maxillary anterior region, where the correct positioning of the implant can be ensured in terms of bucco-lingual, mesio-distal, and apico-coronal dimensions, leading to favorable clinical and aesthetic outcomes.[28]

Another advantage of dynamic navigation is its ability to prevent interference with critical anatomical spaces, such as the functional tongue space, which is essential for speech and preventing sleep apnea.[29] Freehand or poorly executed static guided surgery can encroach on this space, potentially causing tongue thrusting, open bite, or tongue trauma. Dynamic navigation reduces this risk by allowing adjustments to the implant's position during surgery.[30]

Additionally, dynamic navigation can help prevent back pain, a common issue for dentists during procedures, and allows implants to be placed even in cases of restricted mouth opening, making the process easier for both the surgeon and patient. The procedure can be scheduled and completed on the same day, without delays for creating static splints. With dynamic navigation, flapless surgery is also possible, as the drill's exact position in the bone is always visible. Several studies have reported that this technique leads to a noticeable reduction in surgical time. [31,32]

X. DISADVANTAGES

One of the main drawbacks of dynamic navigation is the high cost of the system and its components. Even experienced implant surgeons need time to become proficient with the technique, which involves a learning curve. Additionally, edentulous patients require extra surgical exposure for placing fiducials. A frequent complication observed with this technique is the loss of communication between the sensor and the camera. As a result, the decision to use dynamic navigation over static navigation should be well-justified. [32,33]

XI. IMPORTANCE

Imaging technologies, both 2D and 3D, are essential in implant dentistry. Commonly used imaging methods include Radiovisiography (RVG), Orthopantomography (OPG), and Cone Beam Computed Tomography (CBCT). While intraoral radiographs and panoramic images are commonly used, they are less accurate than CBCT, which provides 3D imaging. Panoramic imaging, in particular, can show magnification variations between different OPG machines, making it less reliable.[34] According to the International Commission on Radiological Protection (ICRP), intraoral and panoramic techniques expose patients to lower radiation compared to CBCT, though CBCT still has less exposure than traditional CT scans. The ICRP recommends two strategies to minimize radiation exposure: justification and optimization.

Justification means radiographs should only be taken, when necessary, based on a proper clinical examination and patient history, ensuring that the benefits outweigh the risks. Optimization means that once the decision to take radiographs is made, the exposure should be kept as low as possible. [35,36]

Radiographs are crucial for implant placement, providing vital information about bone quality (measured by Hounsfield units), bone quantity in all dimensions, and the distance from the implant site to nearby structures like the inferior alveolar nerve, mental foramen, adjacent teeth, incisive canal, and other potential pathologies in the mandible, nasal cavity, maxillary sinus, and septa.[37] Advanced implant placement techniques, such as static and dynamic navigation systems, rely heavily on CBCT data. In static navigation, CBCT data is used to create a 3D-printed template that guides the implant's depth, position, and angle. In dynamic navigation, a template with implant reference markers is worn by the patient during imaging, and these markers provide real-time information to ensure precise implant placement during surgery. In freehand methods, achieving accurate implant placement is essential for the long-term success and survival of the implant.[38]

XII. FUTURE PERSPECTIVES IN IMPLANTOLOGY

The dynamic navigation system uses CBCT or other radiographic imaging to position implants, but errors cannot be completely ruled out, including potential positioning mistakes and malfunctions in the device that marks the location. Recent research by Yang et al. demonstrated the high accuracy of robotic implant placement for single-tooth replacements in a case series of 10 patients, with no postoperative complications or adverse events. This study helped confirm the potential of robotic surgery as an alternative to dynamic navigation systems.[39] Bolding et al. highlighted the accuracy of haptic robotic guidance in implant placement for completely edentulous arches, especially for implant-supported prostheses. When compared to non-robotic methods, robotic guidance showed great accuracy, even in complex cases like highly resorbed ridges in the posterior maxilla.[40] Preliminary research by Li et al. also explored the use of robotic systems for placing zygomatic implants, achieving minimal deviation and ensuring proper accuracy without compromising the lateral wall of the maxillary sinus.[41] A study by Chen J et al. using a phantom model revealed that robotic systems had superior angular deviation compared to dynamic navigation systems, suggesting that robotic technology holds significant potential in future dental implantology, though more clinical trials are still needed.[42]

XIII. CONCLUSION

Dynamic navigation in implant surgery offers improved accuracy and higher success rates. It is significantly more precise than the free-hand method. The static guided or static navigation approach is also more accurate than the free-hand technique. However, several factors influence the reliability of static navigation. Research indicates that the accuracy of dynamic and static navigation systems is statistically similar across different studies. One downside of dynamic navigation is the higher cost of the system and its accessories. There is limited evidence supporting superior aesthetic outcomes with dynamic navigation. The use of conventional or dynamic navigation methods for implant placement results in similar postoperative outcomes in terms of patient satisfaction, swelling, and pain medication use.[10] Therefore, further studies with larger sample sizes are needed to validate the clinical use of dynamic navigation for routine dental implant procedures.[43]

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