MODERN NAVIGATION TECHNOLOGIES IN DENTAL IMPLANTOLOGY: REVIEW AND DEVELOPMENT PROSPECTS IN CLINICAL PRACTICE

Bobamuratova D T., Ashurova M U, Nurmatova N. F

Tashkent State Medical University

Dental implantation is a technically complex surgical procedure that demands high precision and meticulous attention from the clinician to achieve stable and predictable clinical outcomes. With the advent of digital technologies, computer-navigation has become a focal point in contemporary dental practice. This technology has proven highly effective in ensuring the accuracy of dental implant placement and increasing the overall predictability of surgical interventions.

Objective:
This review aims to systematize and analyze current scientific evidence regarding the application of computer navigation in dental implant surgery. Special emphasis is placed on its advantages, existing limitations, and future development prospects of the technology in the context of clinical practice.

Conclusion:
Computer navigation has demonstrated itself as a significant tool in dental implant surgery, substantially improving the accuracy and reliability of implant placement. Despite certain technical and economic limitations, the potential of this technology remains high. It is anticipated that further research, alongside advancements in software and hardware, will expand the capabilities of computer navigation and integrate it into standard implant treatment protocols.

Keywords: computer navigation; dental implantation; digital technologies in dentistry; implant surgery; navigation systems.

Introduction:
The procedure of inserting dental implants is a complex and critical process that requires a high level of expertise and accuracy. In recent years, computer navigation has become an essential aid in performing such interventions, enabling more precise and reliable implant positioning. In this review, we examine existing studies focusing on the use of computer navigation in dental surgery, discuss its merits and demerits, and evaluate the perspectives for further development of this technology.

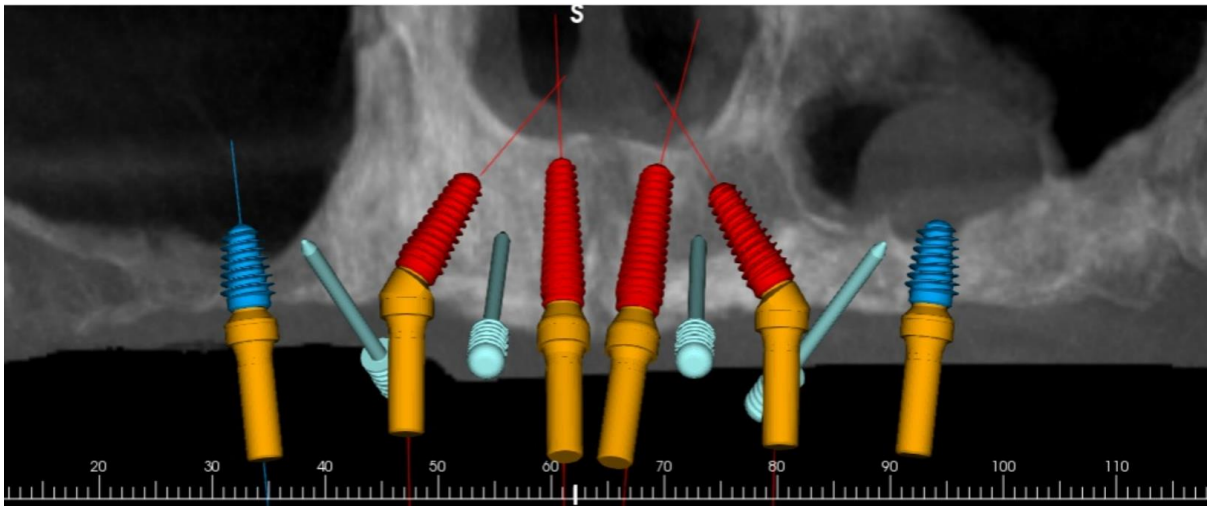

Figure 1. Computer-assisted implant planning.

In the preparation stage for traditional dental implantation, the key factor is the quality of the bone tissue where the implant will be placed. The implantation site is usually determined approximately, based on the results of computed tomography (CT). When it comes time for the surgery, the clinician makes an incision and inserts the implant into the bone, relying largely on tactile sensations and personal experience. This applies not only to the positioning in the left/right coordinate system but also to the depth of implant placement. As a result, there is an increased risk of injury to nerves and major blood vessels, and the final outcome of implantation remains unpredictable.

Navigational surgery involves creating the most optimal treatment strategy for patients with edentulism using an innovative approach based on virtual planning. The digital integration of prosthetic and surgical stages of treatment not only shortens the overall treatment time but also ensures the highest level of quality [9].

Objective:
The purpose of this review study is to analyze the application of computer navigation in dental implant surgery based on the evaluation of available scientific publications.

Materials and Methods:
A systematic search was conducted in the electronic databases **PubMed**, **Scopus**, and **Web of Science** using the keywords *"computer navigation," "dental implant surgery," "guidance system,"* and *"three-dimensional planning."*
Inclusion criteria covered original scientific articles describing the use of computer navigation in dental implant surgery as well as clinical outcomes of implant placement using navigational systems. Publications meeting the following conditions were included:
(1) studies focused on computer-assisted navigation in implantology;
(2) papers reporting clinical outcomes of navigation-assisted procedures;
(3) peer-reviewed articles;
(4) publications written in English.

Results:
The selected publications were analyzed according to the following parameters: study design, sample size, demographic and clinical characteristics of patients, type of implant system used, type of computer-assisted navigation technology, 3D planning method, accuracy of implant placement, duration of surgery, and presence of intra- or postoperative complications.

Depending on the navigation technology employed, all studies were classified into three groups:
(1) use of **static navigation systems** (surgical guides);
(2) use of **dynamic real-time navigation**;
(3) use of **robot-assisted implant placement systems**.

The collected data were subjected to descriptive statistical analysis. For quantitative variables, mean values, standard deviations, and ranges were calculated. The results were summarized and interpreted in the context of current literature, reflecting the present state and future perspectives of computer navigation in dental implant surgery.

Figure 2. Surgical Guide

In navigated implantology, a more extensive and comprehensive diagnostic assessment is performed, allowing the clinician to fully consider the patient's individual anatomical features. During the preparatory stage, a **three-dimensional model of the patient's dentoalveolar system** is created, enabling the identification of the optimal implant placement site and the simulation of the surgical procedure in a virtual environment. To eliminate any potential intraoperative errors, all essential parameters — including the exact positioning of the implant — are transferred onto a **customized surgical guide**, which serves as the navigation reference during the actual surgery. This significantly accelerates the procedure, reduces the risk of complications, and ensures an excellent, predictable clinical outcome [8].

The literature suggests that **computer-assisted navigation** can improve the accuracy of implant placement, reduce surgical time, and enhance overall treatment outcomes. Moreover, it facilitates better communication and collaboration between dental practitioners, enabling improved planning and execution of surgical procedures.
However, this technology also has certain limitations, including the need for **specialized training** and the **high cost of equipment** [1]. Despite these challenges, the use of computer

navigation in dental implant surgery offers numerous advantages and is expected to gain even greater importance in the future. Nevertheless, clinicians must be aware of the limitations and challenges associated with this technology and undergo appropriate training to ensure its safe and effective application [3].

Computer navigation technology continues to evolve, and it is anticipated that emerging developments will further expand its capabilities in dental implant surgery. Promising directions include the integration of **virtual reality (VR)** and **augmented reality (AR)** technologies, which can provide surgeons with a more immersive and intuitive operative experience [2].

Computer-assisted navigation in dental implantology provides significant advantages. It ensures highly accurate **preoperative planning** of implant positioning, taking into account the patient's unique anatomical features and specific treatment objectives. This approach minimizes surgical risks and enhances both the **efficacy and predictability** of clinical outcomes.

In addition, computer navigation offers **real-time dynamic feedback** during surgery, enabling the clinician to adjust instrument positioning as needed [4]. This function is particularly valuable in procedures involving complex anatomical areas that require avoidance of critical structures such as **nerves and major blood vessels**, as well as adaptation to anatomical variations that limit surgical access.

The **increased precision** of implant placement reduces the risk of complications and enhances safety by avoiding critical anatomical zones. Furthermore, improved visualization allows implantation even in cases of partial **bone atrophy**, as the clinician can target areas with sufficient bone density. This precision also decreases the likelihood of implant rejection.

Accurate digital planning minimizes trauma to healthy tissues. Implant placement is typically performed **without large incisions** — instead, implants are inserted through **small punctures** created via openings in the surgical guide (Figure 2). These openings are sufficient for both implant and abutment placement, resulting in a significantly shorter recovery period, reduced swelling, and less postoperative discomfort.

Detailed preoperative planning also reduces **chair time** for the patient. Considering that navigated implantology enables simultaneous placement of implants and temporary crowns within a single visit, the **time efficiency** of this approach is evident.

Finally, **predictability** is the key advantage of the navigated protocol. During the planning stage, the clinician can visualize and present to the patient their **future smile**. The planning software not only allows selection of the implant model but also the type of **crown or bridge restoration**, which is especially important in esthetic zones or full-arch rehabilitations such as **All-on-4** and **All-on-6** protocols with immediate loading [8].

Figure 3. Surgical guides supported by remaining teeth

Limitations

Despite its considerable advantages, the use of computer navigation in dental implantology is accompanied by a number of limitations. First and foremost, the **high cost of equipment and software** can be a significant obstacle to the implementation of this technology in some dental clinics. Furthermore, the **effective use of navigation systems requires specialized training and clinical experience**, which are not always readily available in everyday practice [5].
Another factor to consider is the potential for **technical malfunctions and system errors**, which, although reducing the likelihood of human error, can negatively affect the accuracy and safety of surgical procedures [6].

Nevertheless, the use of computer-assisted navigation in dental implant surgery is expected to expand in the coming years. Technological advancements — including the integration of **artificial intelligence (AI)** and **machine learning** — have the potential to significantly improve the **accuracy, reliability, and affordability** of navigation systems, making them more accessible to a broader range of clinical applications.

Conclusion

Computer navigation has established itself as an important and promising tool in dental implant surgery, providing **high precision and reliability** in implant placement. Despite existing challenges — such as high implementation costs and the need for professional training — its **clinical advantages are evident**, enhancing the safety, predictability, and overall quality of surgical interventions.
It is expected that the role of navigational technologies in dental and maxillofacial surgery will continue to grow in the coming years. For full integration of these systems into

widespread clinical practice, **further research** is needed to optimize methodologies, improve accessibility, and evaluate **long-term clinical outcomes**.

Summary

Computer-assisted navigation represents a **significant advancement** in the field of dental implantology, ensuring precise planning and accurate implant placement tailored to the patient's anatomical and clinical characteristics.
Although certain limitations remain — such as high equipment costs and the need for specialized operator training — the **benefits of this technology make it increasingly valuable** in clinical dentistry. With ongoing technological progress, including the integration of artificial intelligence and automation, its application is expected to expand further.
To fully assess the **efficacy and safety** of computer navigation in the long term, additional large-scale, well-designed **clinical studies** are required.

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