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APPLICATION OF COMPUTER TECHNOLOGIES IN DENTAL IMPLANTATION PLANNING (LITERATURE REVIEW)

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Abstract

Modern dental implantology actively integrates digital technologies to improve the precision and predictability of surgical interventions. The use of navigational surgical templates, created using cone-beam computed tomography data and digital jaw modeling, ensures prosthetic-oriented implant positioning with minimal deviations from the virtual plan (no more than 0.5 mm). This approach significantly reduces the risk of damage to anatomically significant structures, reduces surgical trauma, shortens its duration, and facilitates postoperative care. Computerized planning ensures uniform distribution of masticatory loads, highly aesthetic results, and the possibility of immediate or early orthopedic loading. Navigational implantation is particularly effective in complex clinical situations—multiple defects, complete edentulism, bone deficiency, and areas with high aesthetic demands. Thus, the use of computer technologies and navigation templates in dental implantology allows for the optimization of patient examination and treatment algorithms, increasing the safety and long-term effectiveness of rehabilitation.

Keywords: Dental implantation, computer planning, navigational surgical templates, digital technologies, 3D printing.

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Introduction

Modern dental implantology increasingly incorporates digital technologies and guided surgery techniques to enhance the accuracy and predictability of treatment outcomes. Surgical navigation templates, which represent patient-specific guides with drilling sleeves, have become an essential component of the surgical protocol for implant placement. The use of computer-assisted planning and surgical guides enables the implementation of virtually designed treatment with high precision, minimizing deviations of the implant from the planned position. At present, implant positioning under the guidance of templates typically deviates by no more than 0.5 mm from the preoperative plan. This significantly reduces the risk of intraoperative complications and lowers the likelihood of damage to the inferior alveolar nerve, perforation of the maxillary sinus, or injury to adjacent tooth roots [24,12]. Computer-assisted implant planning provides several clinical advantages. First and foremost, it allows for less invasive surgical interventions. Accurate guidance of implant placement often eliminates the need for extensive flap elevation and makes flapless surgery feasible. Consequently, intraoperative blood loss and tissue trauma are minimized, postoperative recovery is facilitated, and patients experience less pain and swelling, resulting in faster rehabilitation. In addition, the guided approach shortens the duration of the surgical procedure, as all aspects of implant positioning are predetermined, reducing the surgeon's reliance on intraoperative adjustments. The high accuracy of implant placement achieved through navigation contributes to even distribution of occlusal loads and optimal alignment with the prosthetic design, thereby potentially improving both the functional and esthetic outcomes of treatment. The use of surgical guides is particularly valuable in complex clinical scenarios, such as multiple defects, complete edentulism, limited bone volume, or esthetically demanding regions, where achieving optimal implant positioning is especially challenging [20,18]. In such cases, digital planning with the fabrication of surgical guides enables the avoidance of additional traumatic procedures. For example, sinus lifting during implant placement in the maxilla may be circumvented by selecting sites with sufficient bone volume, thereby allowing for the placement of multiple implants in optimal positions during a single surgical intervention. It should be emphasized

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that cone-beam computed tomography (CBCT) is currently recognized as the gold standard for preoperative assessment prior to dental implant placement. Unlike two-dimensional panoramic radiography, CBCT provides a three-dimensional representation of the jaws, allowing for detailed evaluation of all critical anatomical structures in the implant site. This information is essential for determining the optimal implant length and diameter, angulation, and for deciding whether bone augmentation or sinus lifting is required [27]. CBCT also visualizes the roots of adjacent teeth, facilitating implant positioning in a way that preserves their integrity and maintains safe inter-radicular distances. The CBCT dataset is subsequently integrated into specialized computer software for virtual surgical planning. Within the same platform, the design of a navigation stent or surgical guide with drilling sleeves is carried out, which serves as an intraoperative tool for guiding instruments. Thus, comprehensive patient-specific anatomical data (bone, nerves, sinuses, adjacent teeth) are utilized for precise three-dimensional implant planning and the fabrication of customized surgical templates, ensuring implementation of the plan with minimal deviation [23,13]. At this stage, indications for implant therapy are determined, and the optimal surgical protocol—whether immediate or delayed implant placement—is selected according to the clinical situation. Preoperative oral sanitation and preparation are also critical. Prior to the planning phase, all infectious foci in the oral cavity must be eliminated to reduce the risk of peri-implantitis and other inflammatory complications. This includes professional dental hygiene procedures such as removal of plaque and calculus, antiseptic treatment of gingival tissues, restorative treatment of caries and its complications, management of gingivitis or periodontitis, and extraction of non-restorable teeth [16]. The subsequent step involves performing CBCT of the jaws. Acquisition of a three-dimensional tomographic dataset enables detailed evaluation of anatomical conditions for implant placement, as described above. To ensure the highest accuracy of CBCT imaging, patient preparation is essential. First, all removable prostheses and metallic objects must be removed from the oral cavity, as they may cause artifacts in the CT images. Second, to prevent occlusal contact between the maxilla and mandible, a special wax bite block with a thickness of approximately 5 mm is

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fabricated. The combination of interarch separation and removal of metallic structures minimizes imaging artifacts and distortions associated with the cone-beam geometry of CBCT [19,14]. In parallel with radiological diagnostics, patients undergo a comprehensive medical evaluation, including a series of laboratory tests. The standard pre-implantation panel typically includes a complete blood count to exclude acute inflammatory conditions and assess immune status, biochemical blood tests to evaluate organ function and mineral metabolism, as well as serological tests for hepatitis B and C, HIV/AIDS, and the Wassermann reaction. These infections constitute relative or absolute contraindications for elective surgical procedures. Coagulation studies (coagulogram) are performed to assess hemostatic function and bleeding risk, and fasting blood glucose levels are determined to exclude uncontrolled diabetes mellitus. In patients with severe comorbidities, additional examinations may be prescribed. The primary goal of this stage is to ensure that the patient is in satisfactory general health and that no hidden contraindications to implant surgery exist. If abnormalities are detected, appropriate medical management is initiated, or the surgical procedure is postponed until stabilization of the patient's condition [11,5]. Once baseline data have been collected and local oral problems resolved, the multidisciplinary team proceeds to definitive treatment planning. It is crucial that implant therapy be prosthetically driven, meaning that planning must begin with the anticipated final restorative outcome. At this stage, the implant surgeon, prosthodontist, and dental technician work collaboratively, analyzing the number of teeth to be restored, the type of prosthesis to be used, and the anatomical and functional limitations influencing implant positioning (bone volume, occlusal scheme, smile esthetics). Fabrication of a surgical guide requires not only radiographic imaging but also precise models of the dentition and soft tissues on which the guide will rest. Therefore, the next step involves acquisition of a digital impression of the dental arches. Two main approaches are employed. The direct method involves intraoral scanning with a specialized intraoral scanner, while the indirect method relies on conventional impression-taking followed by laboratory scanning of the impressions or plaster casts [3,1]. The direct approach is convenient, provides rapid results, and offers very high

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accuracy in cases of limited edentulous spaces, with deviations of approximately 10 microns when one or two teeth are missing. However, in cases of extensive edentulism or long-span free-end saddles, intraoral scanning may accumulate error as the scanning distance increases. In such situations, the indirect laboratory method is preferred: conventional impressions are poured into models, which are subsequently scanned with a stationary optical or CT scanner. The cumulative accuracy of this method remains within 10–50 µm, even for larger edentulous spans. Regardless of the chosen method, it is essential to obtain digital models of both jaws, even when implant placement is planned for only one arch [17,22,25]. Once CBCT data and digital jaw models are available, the clinician proceeds to computer-assisted surgical planning using dedicated software (e.g., Exoplan, coDiagnostiX, Nobel Clinician, RealGuide, among others). The first step involves aligning the three-dimensional model of the jaws with the CT dataset. Registration is typically performed based on hard-tissue landmarks, either semi-automatically or manually, by matching corresponding anatomical points on the digital model and the CT scan. The accuracy of this alignment is verified visually: the contours of the digital tooth surfaces must coincide precisely with those of the radiographic images in all three planes [7,8,9,4]. Subsequently, virtual implant placement is carried out according to the pre-established prosthetic plan. Using the software library, the clinician selects 3D models of implants of the desired system and dimensions. Each implant is positioned within the digital 3D jaw model, with specification of its exact location, angulation, and depth of insertion within the bone [1,6]. Adjustments are made as necessary until the optimal compromise is achieved between prosthetic requirements and anatomical constraints. The outcome of this stage is a virtual surgical plan, where the procedure has effectively been “performed” in advance on the computer, allowing potential complications to be anticipated and addressed prior to surgery. The final stage of digital planning involves designing the surgical guide itself. Based on the virtual implant positions, the software generates a model of the template in the form of a volumetric stent that precisely conforms to the supporting oral surfaces and contains guide sleeves for each implant. Several types of guides exist depending on their support method. Clinical evidence indicates that tooth-

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supported guides offer the highest precision due to their stable fixation on rigid, immobile structures [2]. However, even in fully edentulous cases, surgical guides significantly improve the accuracy of implant placement compared to conventional freehand techniques. Template modeling within the software includes defining wall thickness, the position and diameter of guide sleeves, and—where necessary—designing fixation elements such as anchor pins for stabilization in edentulous protocols. After virtual design, the guide model undergoes final verification to ensure the absence of structural defects. The completed digital 3D model is exported in STL format, after which the physical guide is fabricated either by additive manufacturing (3D printing) or by milling from a high-strength polymer block. Guide sleeves are inserted into the template if they are not incorporated during the printing process. The finished device undergoes post-processing and mandatory sterilization prior to clinical use, typically by autoclaving (15 minutes at 121 °C or 3 minutes at 134–138 °C) [15,21,26]. The entire process from 3D planning to obtaining a sterile surgical guide may take from several hours to several days, depending on the technological capabilities of the clinic and laboratory. Immediately prior to surgery, the fabricated guide must be trial-fitted intraorally to verify its accuracy of seating and stability in the working position. For tooth-supported guides, a precise and gap-free fit is confirmed; for mucosa-supported designs, stability of retention is carefully evaluated. Following administration of local anesthesia, the surgeon places the guide and proceeds with osteotomy preparation directly through the guiding sleeves. Once the osteotomy is prepared, the implant is inserted into the bone via the guide, ensuring that it is positioned exactly as virtually planned. Final radiographic control, either through periapical imaging or CBCT, typically confirms only minimal deviations when the guide is correctly utilized. Subsequent prosthetic procedures may then be performed as required. The integration of computer-assisted planning with guided surgical templates significantly elevates the quality and predictability of implant therapy.

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Conclusion

Computer-based planning and navigational surgical templates are effective tools in modern dental implantology, enabling prosthetically driven treatment, high accuracy of implant placement, and improved functional and esthetic outcomes.

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