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Major approaches and scientific relevance of virtual surgery in implant dentistry: a systematic review

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Abstract

Introduction: Dental implant procedures have increased worldwide, reaching approximately one million dental implants per year the optimization of faster and more accurate techniques by dentists and postoperative surgeons with better results and quality of life stimulated the development of numerous software and hardware for performing computer-guided surgeries, the so-called Guided Surgeries (GS). **Objective:** The present study carried out a systematic review to highlight the optimization of the safety and effectiveness of digital dental implants. **Methods:** The rules of the Systematic Review-PRISMA Platform were followed. The research was carried out from November 2024 to January 2025 and developed based on Scopus, PubMed, Science Direct, Scielo, and Google Scholar. The quality of the studies was based on the GRADE instrument and the risk of bias was analyzed according to the Cochrane instrument. **Results and Conclusion:** A total of 112 articles were found. A total of 42 articles were fully evaluated and 14 were included in the systematic review. A total of 32 studies were excluded because they did not meet the GRADE criteria, and 20 studies were excluded because they had a high risk of bias. Preoperative virtual planning and reconstruction of the mandible guided by dental implants through preoperative designs provide high success rates for the implant and dental rehabilitation, benefiting also prosthetic restorations supported by fixed implants. Still, the concept of using personalized implants with the help of 3D virtual treatment planning, stereolithographic models, and computer-assisted design greatly improves mandibular restoration and helps to obtain a good facial profile, and aesthetic and dental rehabilitation, avoiding complications with autologous grafts.

Keywords: Digital Surgery. Virtual surgery. Guided Surgery. Dental Implants.

Introduction

Dental implant procedures have increased worldwide, reaching approximately one million dental implants per year [1]. Thus, maxillary atrophy is an increasingly frequent clinical condition and the causes that lead to focal or generalized atrophy are multiple factors [2]. Thus, bone density influences the operative protocol and the choice of the type of implant used to replace missing teeth [2-6].

In this context, the optimization of faster and more accurate techniques by dentists and postoperative surgeons with better results and quality of life stimulated the development of numerous software and hardware (equipment and instruments) for performing computer-guided surgeries, the so-called Guided Surgeries (GS) [7]. In this sense, it is essential to perform Computed Tomography (CT) in the patient, with reference points, such as the prosthesis itself, for capturing images on a computer, with the images processed in programs such as NobelGuide®, Simplant® or DentalSlice® [8].

Thus, these programs allow the placement of implants in the program, as well as the preparation of a high-precision surgical guide, leading to the possibility of performing surgeries without flaps, for placing the implants and prosthesis in immediate load on patients [8]. In this way, some authors have reviewed the literature to find some biases, emphasizing which are the different factors and which are the limitations that influence the accuracy of this type of treatment. Thus, they reported that the accuracy of GS systems for the placement of dental implants depends on some cumulative and interactive factors, which can lead to errors [8-10]. In this sense, as information gaps, we can mention the image acquisition process, the registration process, software navigation, the production of the surgical guide, and human error [11-13]. However, compared to the traditional technique, placing the implant with the aid of a computer requires substantially greater investment and effort, but it seems to provide a good result, in the sense of eliminating errors and systematizing the successful reproduction of treatments [14].

Also, GS allows the protection of critical anatomical structures, as well as aesthetic and functional advantages that come from placing the implant in the location determined by the prosthesis. GS is not indicated in easy cases, with sufficient anatomical orientation and bone volume [15]. However, it can be indicated in cases where a CT is recommended as a diagnostic tool, when the precise placement of the implant is mandatory, and when implants with longer lengths are desired for the optimal use of the available bone [16].

Besides, reconstruction technologies have expanded to include the use of guided surgical planning (GSP) and computer-aided design and manufacturing (CAD-CAM), and three-dimensional printing. The advantages of GSP over traditional techniques can be concerning late reconstruction, maxillary reconstruction, placement of dental implants, and precision-guided oncology [17]. The use of CT and the development of programs for guided planning are directing oral surgery precisely towards a specific target. Thus, the planning of virtual dental implants allows for a prosthetic approach, resulting in the best possible prosthesis design, better aesthetics, optimized occlusion, and loading [18].

This approach also changed the surgical paradigm of using extensive flaps to obtain an adequate view of the surgical area, since implant surgery without a flap, with or without immediate loading, became more predictable [19]. In this sense, computer GS refers to the use of a surgical model supported by tissue. This reproduces the virtual position of the implant directly from the computed tomographic data and this information can be converted into guide models to be used during surgery [20].

Also, dynamic guided surgery, on the other hand, reproduces the virtual position of the implant directly from computed tomographic data and uses motion tracking technology to guide the preparation of the implant osteotomy [21]. Various protocols for GS are available in the literature and are differentiated by different techniques of guide production, support methods, and drilling/placement protocols [22]. In this way, it became possible to plan the position of the optical implant virtually the ideal position of the implant, taking into account the adjacent vital anatomical structures and future prosthetic requirements [23].

Therefore, based on this context, the present study carried out a systematic review to highlight the optimization of the safety and effectiveness of digital dental implants.

Methods

Study Design

This study followed the international systematic review model, following the PRISMA (preferred reporting items for systematic reviews and meta-analysis) rules. Available at: http://www.prisma-statement.org/?AspxAutoDetectCookieSupport=1. It was accessed on: 01/21/2025. The AMSTAR-2 (Assessing the methodological quality of systematic reviews) methodological quality standards were also followed. Available at: https://amstar.ca/. It was accessed on: 01/21/2025.

Data sources and research strategy

The literature search process was carried out from November 2024 to January 2025 and developed based on Web of Science, Scopus, PubMed, Lilacs, Ebsco, Scielo, and Google Scholar, covering scientific articles from various periods to the present day. The descriptors (DeCS / MeSH Terms. Available on: https://decs.bvsalud.org/) were used: "Digital Surgery. Virtual surgery. Guided Surgery. Dental Implants", and using the Boolean "and" between MeSH terms and "or" between historical findings.

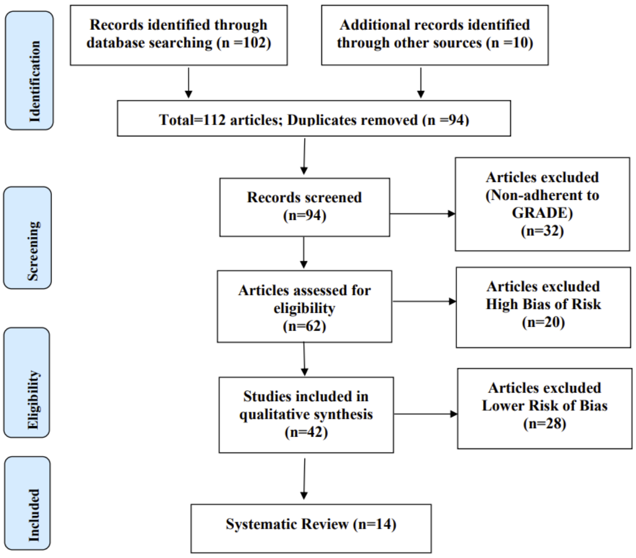
Study Quality and Bias Risk

The quality was classified as high, moderate, low, or very low regarding the risk of bias, clarity of comparisons, precision, and consistency of analyses. The most evident emphasis was on systematic review articles or meta-analysis of randomized clinical trials, followed by randomized clinical trials. Low quality of evidence was attributed to case reports, editorials, and brief communications, according to the GRADE instrument. The risk of bias was analyzed according to the Cochrane instrument by analyzing the Funnel Plot graph (Sample size versus Effect size), using Cohen's d test.

Results and Discussion

A total of 112 articles were found. Initially, duplicate articles were excluded. After this process, the abstracts were evaluated and a new exclusion was performed, removing the articles that did not include the theme of this article, resulting in 62 articles. A total of 42 articles were evaluated in full and included in this study, but only 14 were developed in the systematic review item (Figure 1). Considering the Cochrane tool for risk of bias, the overall evaluation resulted in 20 studies with a high risk of bias and 32 studies that did not meet GRADE. According to the GRADE instrument, the 14 studies that composed the systematic review presented homogeneity in their results, with X^2= 95.1% >50%, with p<0.05.

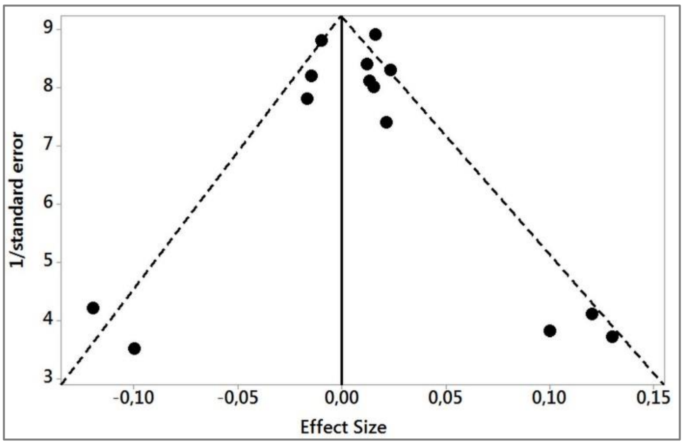
Figure 1. Study Eligibility (Systematic Review).



Source: Own Authorship.

Figure 2 presents the results of the risk of bias in the studies using the Funnel Plot, through the calculation of the Effect Size (Cohen's Test). The sample size was determined indirectly by the inverse of the standard error. The number of studies evaluated was n=14. The graph showed symmetric behavior, not suggesting a significant risk of bias in studies with small sample sizes, which are shown at the bottom of the graph.

Figure 2. The symmetric funnel plot does not suggest a risk of bias between the small sample size studies that are shown at the bottom of the graph. N=14 studies.



Source: Own Authorship.

Major Results

In the scenario of GS in dentistry, advances in technology have contributed to the improvement of models, as there was only the direct impression technique for obtaining patient models, with implant placement not very favorable in aesthetic terms [1,2]. The information that is acquired in 3D reconstructions allows us to determine the quantity and quality of the available bone and also allows the simulation of the implant installation in a virtual environment [1]. This provides the predictability of techniques and difficulties that can be encountered during the surgical intervention, reducing the time and the possibility of errors, allowing the overall reduction in the costs of oral rehabilitation [8].

The development of programs and the creation of bio models using the Additive Fabrication (AF) technique allowed the tactile perception of the anatomy of the region and the pathology under study, allowing other advantages such as communication between the surgical team, help in communicating with patients, simulation and more detailed surgical planning, processing of personalized implants, reduction in the time of surgery, reduction of any complications during the surgical procedure [8]. However, it is possible to notice some information gaps such as high cost, more time for the production of bio motels, little availability of AF equipment [13].

In this sense, the most used image exam in dentistry capable of providing the manufacture of bio models is CT, which allows a three-dimensional assessment of the individual anatomy of patients and more efficient access to the quantity and quality of the areas proposed to receive implants. Thus, many researchers have dedicated themselves to developing specific computer programs for implant dentistry, making it possible to carry out evaluations, image interpretations, and planning, with accurate measurements, based on the knowledge of individualized topographic anatomy, density, quantity and bone quality [13].

A study evaluated the accuracy of a computer-assisted system based on artificial intelligence for detection and identification of dental implant marks using digital periapical radiographs. A total of 1,800 digital periapical radiographs of dental implants from three different manufacturers (f1 = 600, f2 = 600 and f3 = 600) were used, evaluating the precision, sensitivity, specificity, positive and negative predictive values and the Receiver Operating Characteristic curve. System accuracy values of 99.78% were obtained for group training data, 99.36% for group test data, and 85.29% for validation data. Therefore, the effectiveness of artificial intelligence in identifying manufacturers of digital dental implants has been demonstrated, being an accurate method of great clinical significance [24].

In this context, a study used two programs, one for the reconstruction of the 3D bio model (MIMICS®) and another for the CAD project, for the preparation of surgical guides (3-Matic®). MIMICS® is a modeling program and is very fast and intuitive, presenting the ability to separate parts in which there are no interconnections and subtractions, without resorting to the generation of models. The 3-Matic®, on the other hand, has specific design tools, with which it becomes relatively simple to model a prosthesis, as it uses triangular mesh and not curved surfaces that are quite difficult and time-consuming to model. However, 3-Matic® has a disadvantage, it does not show mistakes made during the design phase, impairing the 3D printing phase [18].

One study evaluated the linear and angular deviations of the implants installed by the GS technique using CT [19]. Eighteen patients participated. Of these, ten patients had a completely toothless jaw and eight had a completely toothless jaw. The patients received a total of 115 implants, of which 81 implants were installed in the maxilla, and 34 were installed in the mandible. Tomographic guides were made for tomographic examination in the upper and lower jaws. Afterimage acquisition, guided planning of implant placement was performed in relation to the previously made prosthesis.

The measurement of linear and angular deviations between the guided planning and the final position of the implants was performed with the overlapping of the planning and postoperative tomography. There were no differences in the linear and angular deviations of the implants installed in the maxilla and mandible. In comparison with the coronal region, there was a trend for greater linear deviations in the apical regions of the implants and a greater tendency for deviations in the posterior regions than in the anterior regions of both arches. Therefore, GS by CT promoted the installation of implants with high precision and allowed the installation of straight abutments in all cases evaluated. The linear deviations were not different in the different regions of the month and in the different portions of the implants [19].

Another study analyzed the improvement in mandibular function, facial aesthetics, and quality of life after the reconstruction of complex mandibular defects using the patient-specific three-dimensional titanium implant, with a total of seven patients [20]. The planning of three-dimensional virtual treatment was carried out using its CT data. The unaffected contralateral side of the mandible was superimposed on the side of the defect and a custom implant was designed in the desired size and shape in the virtual model using computer-aided design and ground in titanium using selective laser fusion, for precise mandibular anatomical reconstruction. There was a significant improvement in its aesthetics, function, and quality of life. The symmetry of the face and occlusion was restored with adequate opening of the mouth, closing, and lateral movements of the mandible, without deviation of the mandible during the movements. Patient-specific implants appear to be very useful for accurate jaw reconstruction.

In this sense, the concept of using personalized implants with the help of 3D virtual treatment planning, stereolithographic models and computer-aided design greatly improves mandibular restoration and helps to obtain a good facial profile, aesthetics and dental rehabilitation preventing serious complications related to grafts autologous [20].

Also, regarding GS, it is considered accurate, precise, and reliable in comparison to free implant surgery. However, the deviation between guided implant planning and the actual implant position can occur due to the surgical learning curve and the accumulated errors that can occur over the various stages of the digital workflow. The reliability of computer GS does not justify blind execution. The learning curve is undeniable and a clinician with basic surgical skills, including conventional implant dentistry, will be in a better position to deal with any complications [21].

Still in this context, in GS the implants can be planned based on information from the radiographic guide according to a restored treatment plan. However, the palatal or lingual surface of the teeth cannot be easily identified. Thus, a study described the use of a prosthetic shell digitally designed to improve the precision of planning the guided-welded approach for immediate restorations supported by abutments. As a result, importing the virtual shell into the planning program provided an effective protocol for using the definitive information from the prosthetic space to plan the shape and position of the structure in a predictable manner, increasing the accuracy of guided planning and reducing the time required for realigning the prosthetic shell [22].

One study compared the precision of guided planning of new computer-assisted implant placement techniques, based on models that use stereolithographic CAD/CAM surgical models with or without metal sleeves. Patients were randomized according to a parallel group design in two groups: surgical mold with or without metal sleeves. Three deviation parameters (angular, horizontal, vertical) were defined to assess the discrepancy between the planned and placed positions of the implants. No implant failed and there were no complications. Forty-one implants were placed using surgical models with metal sleeves, while 49 implants were placed with a surgical template without metal sleeves. Of these, 16 implants were placed through open sleeves and 33 through closed sleeves. There was a statistically significant difference in the angle ($p = 0.0212$) and in the vertical plane ($p = 0.0073$), with lower values for implants placed with surgical mold without metal sleeves. In the test group, closed sleeves were more accurate compared to open sleeves in the angle ($p = 0.0268$) and in the horizontal plane ($p = 0.0477$). Therefore, surgical models without metallic sleeves were more accurate in the vertical plane and in the angle in relation to the conventional model. Open sleeves should be used with caution in the molar region only in the case of reduced space between squares [23].

Moreover, a study evaluated the effects of guided preoperative planning and mandibular reconstruction guided by the rehabilitation of the dental implant in the rehabilitation of the dental prosthesis after the reconstruction of the mandible. The virtual design was created according to the preoperative CT. The implant surgery was performed 6 months after the reconstruction surgery. After the completion of treatment, factors such as implant survival rate, reconstruction site, graft type, and prosthesis type were compared. As a result, a total of 29 patients were included in the study, with 16 patients in the group without navigation and 13 in the navigation group. A total of 101 implants were inserted, and the implant success rate was 98.02%. All patients received prosthetic treatment. Of the 13 patients in the navigation group, 9 received implant-supported fixed prostheses, while the other 4 received removable prostheses. Of the 16 patients in the non-navigation group, 9 eventually received implanted fixed prostheses and 7 received removable prostheses. There were no significant intergroup differences in terms of prosthesis type ($p = 0.702$). However, the proportion of implant-supported fixed prostheses in the navigation group was higher compared to the group without navigation. Therefore, guided preoperative planning and reconstruction of the mandible guided by dental implants through preoperative designs can provide a good opportunity to achieve high rates of implant success and dental rehabilitation. This method can also benefit prosthetic restorations supported by fixed implants. In addition, the use of navigation after guided planning has no effect on the type of prosthetic reconstruction [25].

Based on the literary findings presented above, it is possible to develop a method of preoperative planning, associated with the area of implant dentistry, using digital images. This group of digital images includes all the potential of the great diversity of CAD programs and image editing in three dimensions. It highlights the great utility of diagnostic imaging methods such as CT, being essential to develop all methods. The use of AF technologies in the dental field is also notorious, and it can be used in several types of surgical interventions [26].

In addition, the MIMICS® program made it possible to easily obtain a CAD file in STL from the DICOM files obtained through the CT, through its own database, distinguishing in the DICOM file the part to be reproduced in STL formats, such as veins or bone tissue and visualize the location and fixation of the implant. The 3-Matic® program, on the other hand, presented an excellent modeling capacity in STL files, making it very versatile, fast, and capable of designing mesh forming tools due to its ability to model surfaces. However, errors are not easily detected, impairing the 3D printing phase [27].

In this way, some programs are able to correct these errors like MeshFix, MeshWorks, and Autodesk Netfabb. The highlight for Autodesk Netfabb which was able to correct the open contours and other problems that the model contained. However, when these defects were corrected, this program assumed that the holes made in the model, for later surgical guidance, were open contours, which were automatically closed. Another problem that arose when using this program was that the model failed to achieve a fit for the patient's mouth [26].

Thus, the surgical guide produced by AF is able to transfer the virtual planning to the surgical field with excellence, since it manages to reduce the surgical time, decreased post-surgical morbidity, provides less discomfort and pain and decreased the failure rate, in addition to significantly reducing the patient's psychological trauma. It is a perfectly viable option for the use of anatomically complex cases or due to the need for a specific prosthetic solution [26].

Still, in relation to the conventional surgical guide, it presented some advantages as being cheaper, simple, and easy to perform, however, it leads to a higher operative risk for the patient. However, the accuracy of the location to be implanted is not the best and this guide is more likely to be worn, due to the contact of the drills with it [27].

In general, the preparation of a surgical guide ensures that during surgery the implants are positioned and tilted according to the pre-established location, considering the bone quantity, positioning, inclination, and three-dimensional relationships of the implants. In addition, poorly positioned implants can compromise the functionality and aesthetics of the final prosthetic work, and the AF is an important resource combined with implant dentistry [27].

Conclusion

It was concluded that preoperative guided planning and mandibular reconstruction guided by dental implants through preoperative designs provide high implant success rates and dental rehabilitation, also benefiting prosthetic restorations supported by fixed implants. Still, the concept of using personalized implants with the help of 3D virtual treatment planning, stereolithographic models and computer-aided design greatly improves mandibular restoration and helps to obtain a good facial profile, aesthetics, and dental rehabilitation, avoiding complications with the grafts autologous.

CRediT

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Conflict of Interest

The authors declare no conflict of interest.

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