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Systematic Review

Accuracy of Implant Placement Using Digital Prosthetically-Derived Surgical Guides: A Systematic Review

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Abstract: Dental implant placement is crucial in oral rehabilitation, requiring precision for successful outcomes. Digital technologies, including surgical guides, enhance predictability and efficiency in implant procedures. However, their impact on implant positioning accuracy is still under investigation. This systematic review aimed to evaluate the literature on implant accuracy using digital prosthetically-derived surgical guides. Registered in PROSPERO (CRD 42023483194), the review employed a PICO strategy and searched PubMed for English-language, in vivo studies from 2013 to 2023 on restrictive digital prosthetically-derived surgical guides. Two reviewers independently assessed records, with a third verifying the decisions. PRISMA guidelines were followed, yielding 24 results after excluding nine duplicates. Ten studies met the criteria after title, abstract, and keyword review, with three included after verification. These studies showed coronal deviations of 0.44 mm to 0.56 mm, apical deviations of 0.64 mm to 1.03 mm, angular deviations of 2.03° to 2.42°, and vertical deviations of 0.19 mm to 0.45 mm. Superior accuracy was noted with static guided techniques, while bilateral guides offered stability and printed guides were cost-effective. A surgical guide that comes from a planning with a primary wax-up of the prosthesis leads to the placement of a dental implant that can be functionally and esthetically rehabilitated. Further research is needed to standardize outcomes and improve implant protocols and patient outcomes.

Keywords: dental implants; flapless implant surgery; template-guided surgery; digital prosthetically-derived surgical guides; accuracy

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1. Introduction

Osseointegrated implants have been used to replace missing teeth for approximately 60 years, which has been fundamental in the evolution of oral rehabilitation. The structure, design, and composition of implants have changed over time, constantly improving their overall performance in terms of osseointegration with the recipient tissue [1].

The classic implant placement protocol was first introduced in 1965 and involved delayed implant placement and delayed loading via a submerged approach. Masticatory function was restored by replacing the missing teeth with implant-supported restorations. This approach resulted in a 95% implant success at 5 years and 89% success at 10 years. Since then, the placement procedure has also evolved from delayed to immediate implant placement after tooth extraction, whether or not in conjunction with immediate loading [2].

More recently, a trend has been observed whereby freehand implant placement is increasingly being replaced by static computer-assisted implant surgery. The introduction of three-dimensional (3D) imaging tools, such as cone beam computed tomography

(CBCT) and intraoral scanning, has made it possible to virtually plan implant treatments in advance [3]. These tools allow a more accurate analysis of adjacent anatomical structures, facilitate prosthetic-guided surgical procedures, and optimize the materialization of surgical guides with improved accuracy [4–6].

The prosthetically guided implant protocol involves the virtual planning of a dental implant using 3D planning software (Figure 1). This process requires a wax-up file of the teeth to be replaced, along with a Cone Beam Computed Tomography (CBCT) scan, considering the aesthetic, functional, and anatomical criteria of the prosthesis to achieve correct three-dimensional implant positioning. In contrast to surgical guides not designed from prosthetically guided planning, this approach offers several significant advantages. For instance, it allows for better prediction and control over the final aesthetic outcome by taking into account the position and shape of adjacent teeth and occlusion. Furthermore, integrating prosthesis design into implant planning can help prevent later complications related to aesthetic and functional aspects of the prosthesis. Other advantages of digital prosthetically-derived surgical guides include a shorter surgical time and higher accuracy in placing the implants. In terms of applications, the use of prosthetically guided surgical guides is particularly beneficial in complex cases requiring precise integration with existing dental structures or when optimizing the aesthetic outcome. This can be crucial in complete or partial rehabilitations where precision and predictability are critical for treatment success [7].

Compared to conventional surgical guides that do not incorporate prosthetic planning, the main difference lies in the level of detail and precision achieved. While conventional guides may primarily focus on implant placement relative to bone structures, prosthetically guided guides enable a more comprehensive planning approach that incorporates functional and aesthetic aspects from the outset of the planning process. This can lead to more predictable and satisfactory outcomes for both the professional and the patient. However, any prosthetic-guided implant treatment will depend on the protocol followed and the correct execution by the operator. Therefore, deviations between virtual planning and the real position of the implant have been reported, which might be caused by factors related to the patient and others dependent on the surgical act. In addition, this approach depends on the surgical learning curve and the correct protocol performed through the digital workflow [8–10]. It should be noted that the margin of error of a prosthetically guided implant treatment is minimal if it is carried out correctly [11]. For these reasons, static computer-assisted implant surgery must follow an organized sequence from the planning stage to avoid any discrepancies [12].

The aim of this systematic review was to evaluate the clinical outcomes published in the literature on the accuracy of implant placement using digital prosthetically-derived surgical guides. The question addressed was whether there is a discrepancy in the accuracy between digital planning and the final outcome of prosthetically guided implant placement.

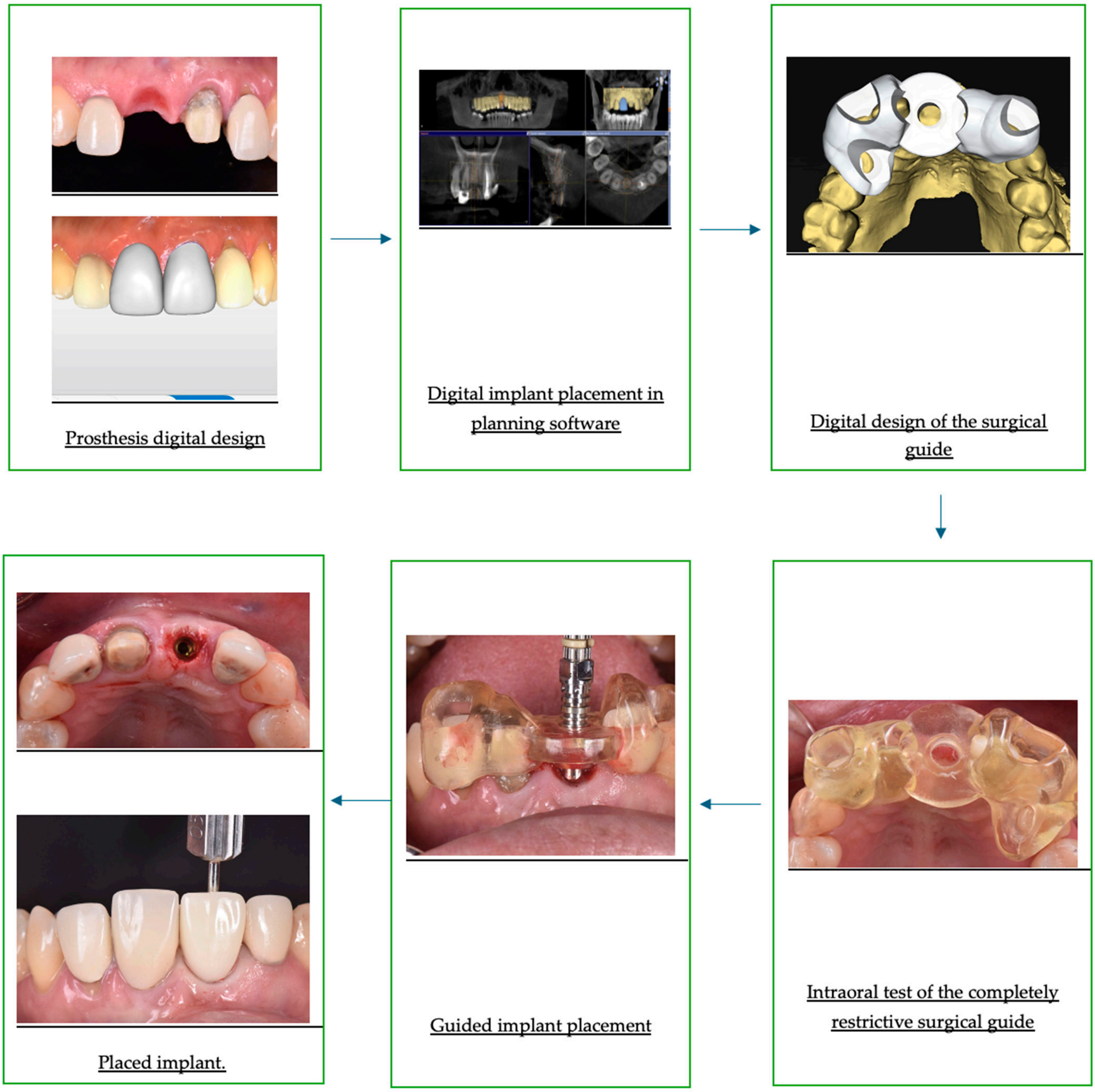

Figure 1. Workflow chart of implant placement using digital prosthetically-derived surgical guides.

2. Materials and Methods

This review has been registered in PROSPERO (number CRD42023483194).

The search was performed using keywords based on the following PICO question: Population (P) = Patients with dental implants placed using a prosthetically guided protocol. Intervention (I) = Patients who had implants placed in a prosthetically guided manner based on digital planning. Comparison/control (C) = Existence of a control group in each study. Outcome/Result (O) = Accuracy. Differences and discrepancies in millimeters/microns were evaluated between the final position of the dental implants placed virtually as planned with respect to the prosthesis with a digital workflow. Coronal deviation (mm), apical deviation (mm), depth deviation (mm), and angular deviation (°) were also evaluated.

As stated, the following keywords were used for this review:

All four; all six; dental implant loading; dental implants; dental prosthesis; flapless implant surgery; full-arch implant prosthesis; immediate; immediate loading; implant-supported; edentulous/rehabilitation; jaw; edentulous/surgery; surgery; survival analysis; template-guided surgery; tilted implants; treatment outcome; decision making; edentulous maxilla; three-dimensional; virtual implant planning; accuracy of implant position; free hand implant surgery; static computer-assisted implant surgery; dimensional measurement accuracy; edentulous jaw; accuracy; parallelism; stereolithography. Computer-aided design; computer-aided manufacturing; computer-aided surgery; partially edentulous; patient-reported outcome measures: static computer-aided implant surgery (s-CAIS).

Therefore, advanced search strategies were established for articles related to the accuracy of digital prosthetically-derived surgical guides for dental implants in the PubMed database as follows:

("Dental Implants" [Mesh]) AND "Digital Technology" [Mesh];

((("Dental Implants" [Mesh]) AND "Digital Technology" [Mesh]) AND "Computer-Aided Design" [Mesh]) AND "Dental Prosthesis" [Mesh].

The literature was reviewed by applying the following inclusion and exclusion criteria:

Inclusion criteria:

1. Patients with dental implants placed using a prosthetic protocol.
2. In vivo studies.
3. Evidence published in the last 10 years (2013–2023).
4. The literature was written in English.
5. Studies with restrictive digital prosthetically-derived surgical guides for dental implants.
6. Partially or totally edentulous patients who required dental implants placed by means of a prosthetic protocol.
7. Randomized and nonrandomized trials to assess the beneficial effects of treatments and observational studies (including cohort and case control studies) for the assessment of harm.

Exclusion criteria:

1. Patients in need of guided bone regeneration or tissue regeneration.
2. Studies prior to 2013.
3. In vitro or sham treatment studies.
4. Patients with implants placed via the freehand technique.

In this systematic review, several stages were carried out under a pre-established protocol. Initially, two reviewers (MDV and MJT) applied eligibility criteria for the selection of studies to be included in the review. Both authors independently examined the records identified during the initial search using Mendeley software (version 1.19.8). Subsequently, a third person (CAC) examined and verified the decisions made by the two reviewers, maintaining a blinded approach to avoid bias. In this phase, title and abstract analyses were performed, classifying articles as "included", "excluded", or "uncertain". The full texts of records classified as "included" or "uncertain" were subjected to a more detailed eligibility assessment.

In situations where discrepancies arose in the selection of titles, abstracts, or full-text articles, the two principal investigators discussed the issue to reach a consensus. In cases of persistent disagreement, the opinion of the third reviewer (CAC) was solicited as an independent third point of view to make a final decision. Disagreements between individual judgments were resolved independently by a third reviewer (CAC), ensuring objectivity in the decision-making process. A Word spreadsheet (Microsoft, Redmond, Washington, USA) designated for this purpose was used to document and record all decisions. A retrospective analysis of the millimeter values representing implant position discrepancies was performed, and the results were compared with previously planned data. Two evaluators (MDV and MJT) were appointed to extract and verify the relevant data.

Thus, data extraction was performed independently, and subsequently, a third evaluator (CAC) performed a thorough verification of the extracted data.

To address possible missing data, a protocol was established that included contact with the study investigators. We sought to obtain incomplete information or additional details that might contribute to the integrity of the data collected.

The compilation and organization of the registry data were carried out using an Excel spreadsheet (Microsoft, Redmond, WA, USA), thus providing an efficient tool for the systematic management and analysis of the information collected in the study.

3. Results

Following the PRISMA protocol (Figure 2), the search strategy yielded a total of 24 results, discounting nine duplicates, resulting in 15 articles for preliminary review. After reviewing the titles, abstracts, and keywords, the researchers (MDV and MJT) included five results that met the search criteria and excluded 10 results. Among the data collected, one was considered uncertain and was evaluated by a third reviewer (CAC). After verification of the data extracted by the third reviewer (CAC), it was decided to exclude one article, resulting in four articles forming the basis of this review.

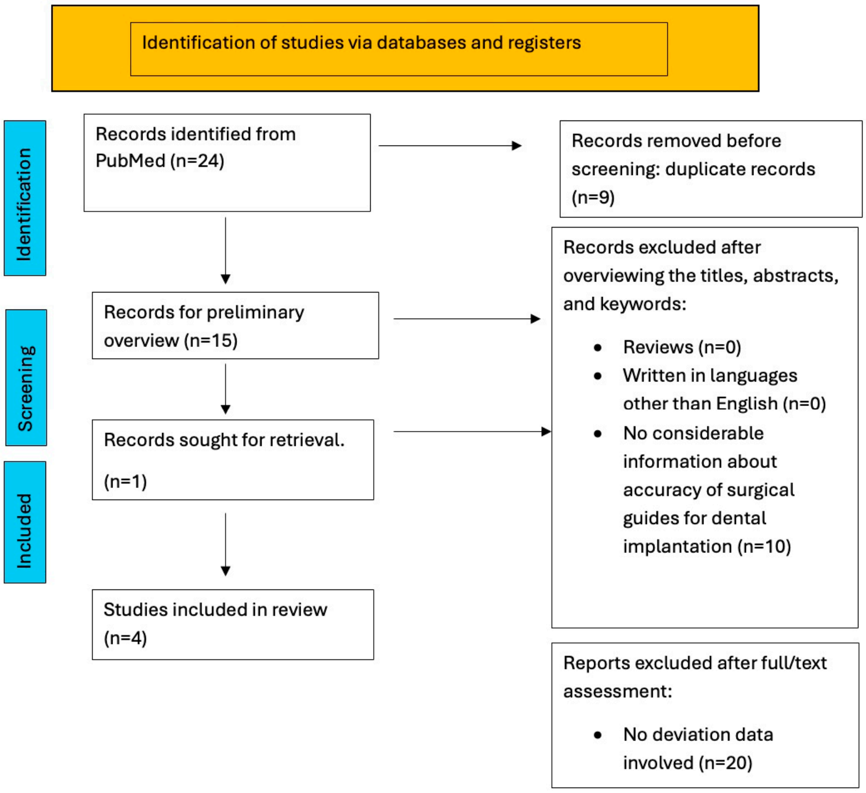

Figure 2. Search flowchart according to PRISMA guidelines (n = number of records).

Among the 24 articles, only four had available deviation data and met all the inclusion requirements. The remaining articles (20 articles) were excluded because they were literature reviews, videos, or included information about robotic surgery. The four articles that were included in this review were in vivo studies, all of which were clinical investigations (Table 1). Among the four clinical investigations, two were clinical reports, one was a clinical trial, and one was a prospective clinical study.

Table 1. Classification of clinical research.

Type of Clinical Research	Number
Clinical report	2
Clinical trial	1
Prospective clinical study	1

A descriptive summary of the four included articles is presented in this review with the deviation data (Table 2). The included deviation data were global/horizontal coronal deviation (mm), global/horizontal apical deviation (mm), angular deviation (°), and vertical deviation (mm) in the form of the mean ± SD and/or median (min, max). The information presented and discussed in the remainder of the review is based on the corresponding information. The comparison criteria (type of implant surgical guide, number of patients, number of implants, implant site, type of support, method of manufacturing the digital prosthetically-derived surgical guide, and number of fixation screws) and accuracy-related deviation data are also summarized in a table (Table 3).

Table 2. Descriptive analysis of the articles included after this review.

Ref. No.	Author (Year)	Research Type	Full- or Half-Guided	No. of Patients	No. of Implants	Implant Site	Supported Type	Fabrication	No. of Fixation Screws
1	Ngamprasertkit C, Aunmeungthong W, Khongkhunthian P. (2022) [13]	Clinical trial	Comparison of full with free hand	15	15	Anterior tooth or premolar	Tooth-supported	3D printed.	-
2	Barros, V. et al. (2015) [14]	Clinical trial	Full	1	1	22	Bilateral tooth-supported	3D printed.	2
3	Cristache, C. (2021) [15]	Clinical trial	Full	24	56	25 in the maxilla, 31 in the mandible	Bilateral Tooth-supported	3D printed.	-
4	Mario Beretta, Pier Paolo Poli Carlo Maiorana (2014) [16]	Prospective clinical study	Full	2	14	Maxilla and mandible (Edentulous)	Mucosoportada.	3D printed.	3

Table 3. Table of data extracted (mean ± SD, median (min., max.)).

Ref. No.	Author (Year)	Global Coronal Deviation (mm)	Horizontal Coronal Deviation (mm)	Global Apical Deviation (mm)	Horizontal Apical Deviation (mm)	Angular Deviation (°)	Vertical Deviation (mm)
1	Ngamprasertkit C, Aunmeungthong W, Khongkhunthian P. (2022) [13]	0.48 ± 0.22 (min. 0.20–max. 0.87)	0.39 ± 0.26 (min. max. 0.08–0.87)	0.71 ± 0.31 (min. 0.18–max. 1.34)	0.64 ± 0.37 (min. 0.03–max. 1.33)	2.03° ± 1.00 (min. 0.88–max. 4.03)	0.19 ± 0.14 (min. 0.01–max. 0.51)
2	Barros, V. et al. (2015) [14]	/	/	/	/	/	/
3	Cristache, C. (2021) [15]	0.44 mm	/	1.03 mm	/	2.12°	0.45 mm
4	Mario Beretta, Pier Paolo Poli Carlo Maiorana (2014) [16]	0.56 mm	/	0.64 mm	/	2.42°	/

As presented in Table 2, the measures of deviation are based on the comparison criteria. Tooth-supported guides, specifically bilateral guides, are the most commonly applied in studies conducted in the last 10 years; of the four selected articles, three involved tooth-supported guides, and only one involved mucosa-supported guides.

Only two of the four articles included the use of fixation pins for digital prosthetically-derived surgical guides; one study used two pins, while the other used three pins. Of the four articles, three indicated that the guides were manufactured with 3D printing, and one study did not specify the information on the type of manufacturing. The review was carried out to maintain impartiality by avoiding bias, using the tools described for the selection of each of the articles.

4. Discussion

This systematic review presented several results that, for a better understanding, can be divided according to the different factors analyzed: type of digital prosthetically-derived surgical guides for dental implants, type of support of the surgical guide, method for the elaboration of surgical guides, and number of fixation screws. Each of them will be described below.

Type of digital prosthetically-derived surgical guide.

The prosthetically guided implant protocol is the process of virtual planning of a dental implant using 3D planning software. This flow requires a wax-up file of the tooth or teeth to be replaced, in conjunction with a CBCT, considering the esthetic, functional, and anatomical criteria of the prosthesis to achieve a correct 3D position of the implant. To answer the question of whether the type of surgical guide used might influence the accuracy of planning and placement of prosthetically guided implants, the types of surgical guides described in the literature were analyzed. The types of implant guides were classified according to the level of guidance (partial or total) and the ability to allow intraoperative changes (static or dynamic). Although the literature has shown that fully guided static surgery provides a more accurate position, a synthesis of the published evidence is necessary to verify whether there is greater efficacy in implant treatment [17,18]. Digital prosthetically-derived surgical guides for dental implants can be applied using three protocols during surgery: in the fully guided or restrictive surgical protocol, the guide is used from the first drilling in the bone to the final implant placement [19]. In the partially guided surgical protocol, the digital prosthetically-derived surgical guides are used only to form the bone socket for the implant and are then removed for the placement of the implant. Finally, surgical guidance is used only in the first pilot drilling of the osteotomy. As shown in Table 2, this systematic review focused on fully guided surgical protocols because their accuracy is significantly greater, and they have demonstrated superiority over other protocols [20,21]. According to the articles reviewed, the transfer of the planned position of the implant with respect to its clinical environment is more accurate when using a static-guided technique, in which a fully guided workflow is performed. The deviation values in each study performed were minimal, not exceeding 1.03 mm of overall apical deviation. However, it can be suggested that a safety zone of at least 1.5 mm should be established in digital planning.

Type of support of the digital prosthetically-derived surgical guides for dental implants

According to this review, the type of support influences the accuracy of digital prosthetically-derived surgical guides. Depending on the type of support, the guides can be bone-supported, mucosa-supported, or tooth-supported. Theoretically, anatomical differences in the teeth, bone, and mucosa can lead to differences in the accuracy of the guides. Bilateral tooth-supported surgical guides provide better retention and stability, as they are anchored in hard tissue and, therefore, offer greater accuracy. Bilateral guides are indicated for patients whose teeth are mesial and distal to the edentulous area. On the other hand, unilateral tooth-supported guides are indicated for patients with distal extension edentulism because they provide efficient retention. Bone-supported guides are placed over the exposed alveolar ridge by means of a full-thickness mucoperiosteal flap operation and secured with fixation screws. The positioning of this type of support is affected by the surgical incision and elevation of the surrounding tissue, so the accuracy is relatively low. Mucosal-supported guides are indicated for totally edentulous patients or patients with very few residual teeth. These guides are stabilized by means of fixation screws [22,23]. It has been emphasized that implant placement using a guide will depend on the feasibility of prosthetic rehabilitation, bone availability, and the condition of the surrounding target tissues. However, the characteristics of the implants and their compatibility with the guided procedure also influence the predictability of prosthetic rehabilitation for implants placed using a guide [24].

When evaluating the accuracy of implant placement, the various types of support for the different types of guides in different clinical situations should be observed. As shown in Table 2, most of the studies were performed with tooth-supported guides because, according to the literature, these guides are the most accurate during surgery for implant placement. In a study by Bover et al. in 2018, it was also demonstrated that guides supported by teeth were more accurate than those supported on bone and mucosa [25]. Most of the studies chosen demonstrate that there is less angular deviation with tooth-supported guides. The highest degree of angular deviation (2.42°) (Table 3) occurred in one case involving mucosa-supported guidewires.

Method for the elaboration of digital prosthetically-derived surgical guides for dental implants.

Undoubtedly, several factors influence the accuracy of digital prosthetically-derived surgical guides for implant placement. One of these factors is the manufacturing technique. Digital prosthetically-derived surgical guides for implants can be manufactured in two ways: additive (3D printing) or subtractive (milling or grinding). The additive technique is based on a union of sequential printed layers, while subtractive production is based on a polymeric structure produced by a milling machine [26,27]. The technology behind the development of digital prosthetically-derived surgical guides is still being studied to determine which is the best option for successful results in terms of the least discrepancy between planning and placement of the implant. Deformation of the guides has been observed more in printed guides than in milled guides because the latter are manufactured from machined blocks whose structure is not altered dimensionally. However, studies such as those of Mukai et al. concluded, based on the results of an in vitro study, that there were no differences in the overlap of printed and milled guides [28]. A study by Henprasert et al. also indicated that there were no significant differences in terms of the type of guide fabrication since 3D-printed guides have the same degree of accuracy as milled guides. This study highlights the advantages of printed guides: easier fabrication, less material waste, reduced laboratory time, and increased cost-effectiveness [29]. According to a study by Herschdorfer et al., printing technology, whether it was stereolithography (SLA), polyjet, or multijet technology, had no significant effect on the accuracy of the guide. As shown in Table 2, all publications included in this review used 3D manufacturing from 2014 to 2022. It is currently the most commonly chosen manufacturing method by professionals, taking into account the disadvantages of milled guides, such as the high cost of materials and equipment and the difficulty in producing highly complex models [30,31]. In addition, the four articles included in this review described fully constrained guides using 3D printing, where their high accuracy can be related to this type of manufacturing. Currently, postproduction processes on printed guides have substantially improved due to the use of specific, automatic, and integrated machines for washing, drying, and polymerization of the material.

Number of fixation screws.

The digital prosthetically-derived surgical guides must transport the planned implant position to the correct clinical location for successful treatment [32]. The number of fixation screws in surgical guides is another factor that may influence the discrepancy in the results obtained for the placed implants. Pessoa et al. conducted a study of the impact of the placement of fixation pins in digital prosthetically-derived surgical guides, analyzing the possible discrepancies between the planned design and the clinical position of the placed implant. They established that the discrepancy was statistically significant for apical and vertical deviation. Guide fixation is recommended for bilateral posterior edentulous spaces. The accuracy of implant placement is improved when the template is fixed with screws, for example, in cases of fully edentulous patients [33,34].

Only two of the four publications included in this review mentioned the number of fixation pins used in digital prosthetically-derived surgical guides, which were used with dental support in one patient and mucosa support in another patient. According to the articles reviewed, the number of impression pins will depend on the type of support, either tooth-supported or mucosa-supported. It is recommended to use at least two fixation pins in tooth-supported cases and at least three in mucosa-supported cases.

In the articles reviewed, there was evidence of greater deviation at the apical level compared to the coronal and vertical deviation of the implants placed. On the other hand, the vertical deviation is the deviation that presented the least variation between the planned and obtained locations. Table 3 shows six parameters that show the deviation between the planned and achieved results. Based on the data available for each article, the global coronal deviation ranged from 0.44 mm to 0.56 mm; the global apical deviation ranged from 0.64 mm to 1.03 mm; the angular deviation ranged from 2.03° to 2.42°; and the vertical deviation ranged from 0.19 mm to 0.45 mm. It is important to note that some authors did not provide data for all deviation measurements. The values varied among the different studies, underscoring the need for further research with quantitative data.

Among the limitations of this review, more databases were not included due to the accessibility of the researchers, nor were articles in other languages and gray literature used. In vivo studies that can compare virtual planning with the final position of dental implants are recommended to obtain more reliable results that solidly support the frequent use of prosthetically guided implants.

It is important to emphasize the role of study designs with control groups. It would be very important in future research to include a control group in the same study with respect to the technique of implant placement, using drill guides, restrictive guides, and freehand implant placement surgery. In two of the articles selected in this systematic review, the results are analyzed based on the presence of a different control group in each study. The first article, by Ngamprasertkit, compares implant placement using restrictive guidance with a control group performing freehand placement. The results indicate a reduction in discrepancy in all measurements. In Cristache's article, partially digital and fully digital workflows are investigated, showing that procedures with a fully digital protocol, which includes intraoral scanning instead of analog post-impression scanning, have a lower discrepancy between planning and final implant placement.

Four articles were finally included after an exhaustive search with inclusion and exclusion criteria. The limited number of articles selected supports the fact that there is scarce scientific literature and evidence on the subject of this systematic review. In addition, the position of the implant and the type of edentulism (total or partial) are not supported by sufficient evidence in the selected articles to draw quantitative conclusions regarding the discrepancy values.

Within the limitations of this review, the authors have considered that several results are duplicated in other databases that have already been indexed in the record of what has been reviewed. The heterogeneity of the methodology of the studies should be taken into account, so the bias analysis was fundamental. As of the writing and completion of this article, there may be other articles in this time window that may not have been considered.

5. Conclusions

After this systematic review, the following conclusions were obtained:

- A surgical guide that comes from a planning with a primary wax-up of the prosthesis leads to the placement of a dental implant that can be functionally and esthetically rehabilitated.
- The final position of the implant would be more precise when using a static-guided technique.
- Bilateral digital prosthetically-derived surgical guides for dental implants supported by teeth provide better retention and stability since they are anchored in hard tissue and, therefore, offer greater accuracy.

- There were no significant differences regarding the type of manufacturing of the guides. 3D-printed materials may involve lower costs and be more accessible to clinicians.
- The number of fixation pins will depend on the type of support. It is recommended to use a minimum of two fixation pins in tooth-supported cases and a minimum of three in mucosa-supported cases.
- Greater deviation was evident at the apical level than at the coronal and vertical levels deviation of the implants placed. On the other hand, the vertical deviation presented the least variation between the planned location and the one finally obtained.
- Homogeneous and randomized clinical studies on this subject are needed to quantitatively and qualitatively support the final position of the implants after they have been digitally planned and originated from the reverse design of the prosthesis.

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