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Major considerations and clinical outcomes of digital implant dentistry in guided bone regeneration: a systematic review

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Abstract

Introduction: It is estimated that up to 43% of osseointegrated implants require guided bone regeneration (GBR) as part of the patient's rehabilitation. Bone loss or insufficiency presents a major challenge for osseointegration. In this sense, the use of CAD-CAM systems (Computer-Aided Design/Computer-Aided Manufacturing) is highlighted in this process. **Objective:** It elucidated the current clinical considerations of the use of guided bone regeneration for dental implants through the use of CAD-CAM systems. **Methods:** The PRISMA Platform systematic review rules were followed. The search was carried out from November 2024 to January 2025 in the Scopus, PubMed, Science Direct, Scielo, and Google Scholar databases. 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:** 118 articles were found, 30 articles were evaluated in full and 12 were included and developed in the present systematic review study. Considering the Cochrane tool for risk of bias, the overall assessment resulted in 20 studies with a high risk of bias and 31 studies that did not meet GRADE and AMSTAR-2. Most studies did not show homogeneity in their results, with X^2=79.5%>50%. Guided bone regeneration is well documented and constitutes a predictable and successful approach to lateral and vertical bone augmentation of atrophic ridges. Thus, guided bone regeneration is considered one of the most commonly applied methods to reconstruct alveolar bone and to treat peri-implant bone deficiencies, as well as to replace lost bone and allow the implant to be fully integrated and maintained during functional loading. The use of digital tools for the automated fabrication of implant parts (CAD-CAM) is an optimizing reality in Dentistry. CAD-CAM enables high-quality, standardized, accurate, and detail-perfect prosthetic restorations. The use of metallic implants in the morse cone system in association with zirconia abutments guarantees a final product with mechanical resistance, biocompatibility, and aesthetics. Also, immunomodulatory guided bone regeneration membranes are developed mainly by improving macrophage recruitment and aggregation as well as regulating macrophage polarization.

Keywords: Bone regeneration. Guided bone regeneration. Implant dentistry. CAD-CAM.

Introduction

It is estimated that up to 43% of osseointegrated implants require guided bone regeneration (GBR) as part of patient rehabilitation. Bone loss or insufficiency represents a major challenge for osseointegration. To achieve a good long-term prognosis for osseointegrated implants, there must be a sufficient volume of bone at the implantation sites. Different strategies, such as bone grafting, alveolar distraction, and GBR techniques, have been applied to replace the lost bone and allow the implant to be fully integrated and maintained during functional loading. Guided bone regeneration is considered one of the most commonly applied methods to reconstruct alveolar bone and to treat peri-implant bone deficiencies [1,2].

In this context, GBR can be achieved when osteoprogenitor cells are left exclusively to repopulate the bone defect site, preventing the ingress of non-osteogenic tissues. Several reports have indicated that survival rates for implants placed in sites augmented by GBR are similar to those reported for implants placed in native sites. The membrane used for GBR is an essential component of the treatment [3-5].

In the setting of dental implant procedures, the intraoral scanner and a milling unit are used to manufacture a computer-aided design and a computer-aided surgical and radiographic guide [6]. In this sense, the use of CAD-CAM (Computer-Aided Design/ Computer-Aided Manufacturing) systems in the processes of prosthetics and dental implants stands out [7,8]. In this context, the CAD-CAM system was introduced in dentistry to promote the manufacture of prosthetics based on a state-of-the-art three-dimensional system [9].

Where the search for esthetic solutions has been increasingly challenging, given patient demand and the growing number of techniques and materials available for protective rehabilitation [10]. It is important to note that the resistance of the material is the primary factor in determining the indication of the technique, as well as the preservation of rehabilitation over time and the need for movements that lead to the possibility of performing rehabilitation of greater extensions [9,10]. In this sense, the CAD-CAM system performs an intraoral scanner, while the CAM is the milling machine [11-13].

Ceramic is the main alternative restorative material for dental structure due to its favorable properties [13,14]. In addition, a complete fixed dental prosthesis supported by a metal-acrylic resin implant is an important restorative option. However, maintenance and repair increase time, but CAD-CAM assistance can improve efficiency and reduce complications. Thus, CAD-CAM can manufacture a complete fixed dental prosthesis supported by a metal-acrylic resin implant that minimizes individual tooth fracture and facilitates efficient resurfacing of worn surfaces [15]. Thus, one of the main objectives of CAD-CAM is the simplification and optimization of the production of prosthetic structures with high quality and aesthetics [14-16].

Based on this entire scope, the present systematic review study elucidated the current clinical considerations of the use of guided bone regeneration for dental implants through the use of CAD-CAM systems.

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. Accessed on: 12/20/2024. The AMSTAR 2 (Assessing the methodological quality of systematic reviews) methodological quality standards were also followed. Available at: https://amstar.ca/. Accessed on: 12/20/2024.

Search Strategy and Search Sources

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 following descriptors were used in health sciences (DeCS/MeSH): "Bone regeneration. Guided bone regeneration. Implant dentistry. CAD-CAM), and the Boolean "and" was used between the MeSH terms and "or" between the historical findings.

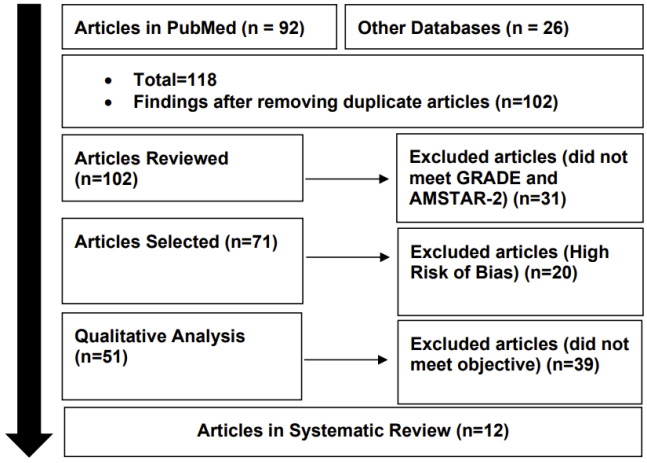
Study Quality and Risk of Bias

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-analyses 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 test (d).

Summary of Findings

A total of 118 articles were found and submitted to eligibility analysis, with 12 final studies selected to compose the results of this systematic review. The listed studies were of medium to high quality (Figure 1), considering the level of scientific evidence of studies such as meta-analysis, consensus, randomized clinical, prospective, and observational. Biases did not compromise the scientific basis of the studies. According to the GRADE instrument, most studies presented homogeneity in their results, with X^2=79.5%>50%. Considering the Cochrane tool for risk of bias, the overall assessment resulted in 20 studies with a high risk of bias and 31 studies that did not meet GRADE and AMSTAR-2.

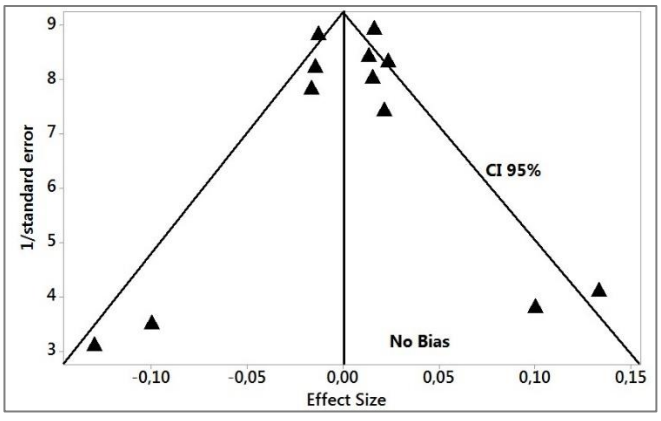
Figure 1. Flowchart showing the article selection process.



Source: Own Authorship.

Figure 2 presents the results of the risk of bias of the studies using the Funnel Plot, showing the calculation of the Effect Size (Magnitude of the difference) using Cohen's Test (d). Precision (sample size) was determined indirectly by the inverse of the standard error (1/Standard Error). This graph had a symmetrical behavior, not suggesting a significant risk of bias, both among studies with small sample sizes (lower precision) that are shown at the base of the graph and in studies with large sample sizes that are presented at the top.

Figure 2. The symmetrical funnel plot suggests no risk of bias among the studies with small sample sizes that are shown at the bottom of the graph. High confidence and high recommendation studies are shown above the graph (n=12 studies).



Source: Own Authorship.

Major Results

In sites with insufficient bone, guided bone regeneration (GBR) is performed before or in conjunction with implant placement to achieve a three-dimensional implant position driven by the prosthesis. To date, GBR is well documented and constitutes a predictable and successful approach for lateral and vertical bone augmentation of atrophic ridges. Evidence suggests that the use of barrier membranes maintains the main biological principles of GBR. Since the material used to construct barrier membranes ultimately dictates their characteristics and their ability to maintain the biological principles of GBR, various materials have been used over time [17]. In this sense, the implantation of GBR membranes triggers an immune response, which can lead to inflammation and failure of bone augmentation. Macrophages play crucial roles in immune responses and participate in the entire process of bone injury repair. The significant diversity and high plasticity of macrophages complicate the understanding of the immunomodulatory mechanisms underlying GBR. Macrophages can promote osteogenesis or fibrous tissue formation in bone defects and fibrous degradation or encapsulation of membranes. Furthermore, GBR membranes can influence macrophage recruitment and polarization. Therefore, immunomodulatory GBR membranes are mainly developed by improving macrophage recruitment and aggregation, as well as regulating macrophage polarization [18].

In this context, CAD-CAM has advanced the dental restoration process to include implant-supported crowns. Thus, a study compared the fracture resistance after mechanical loading and thermocycling of various combinations of screw-retained and cemented ceramic materials and polymethyl methacrylate using the TiBase abutment compared with implantretained crowns. Screw-retained implant restorations demonstrated higher fracture loads than their cemented counterparts. Lithium disilicate hybrid implant-supported abutment/crown restoration using the TiBase abutment may be an ideal clinical choice due to its simplicity [19–23].

A study described a technique to fabricate a custom anatomic healing abutment for delayed-loading implants using CAD-CAM from a polymethylmethacrylate (PMMA) blank. The dimensions of the custom healing abutment are measured from a conventional dental radiograph and diagnostic models. The healing abutment is used in the second surgical phase to guide soft tissue healing [24].

In addition, the CAD-CAM technique is particularly beneficial for a long scanning period and large edentulous spaces with multiple scan bodies, and a verification device can be used to confirm the accuracy of a definitive implant impression [25]. Another study presented eight patients who underwent three-dimensional fibular flap reconstruction with iliac crest graft and dental implants using virtual CAD/CAM planning. The increase in the vertical crest and horizontal dimensions of the fibula, the peri-implant bone resorption of the iliac crest graft, the implant

success rate, and the functional and esthetic results were evaluated. The vertical reconstruction ranged from 13.4 mm to 10.1 mm, with a mean of 12.22 mm. A total of 38 implants were placed in the new mandible, with a mean of 4.75 ± 0.4 implants per patient and an osseointegration success rate of 94.7%. All patients were rehabilitated with fixed implant-supported prostheses with good esthetic and functional results [26].

A retrospective study of 25 patients analyzed the differences in terms of mechanical and biological complications in multi-unit zirconia fixed dental prostheses (FPDs) on posterior implants produced through a digital workflow. The occlusal and interproximal corrections were not clinically significant. In the study sample, the survival rate and success rate of FPDs after 3 years were 100% and 96%, respectively. Monolithic zirconia FPDs and partial veneer FPDs had a 100% survival rate, presenting an interesting alternative to metal-ceramic restorations. Partial veneer FPDs had a higher technical complication rate than monolithic FPDs but without statistical significance [27].

A review article analyzed that bioactive high-performance polymers (BioHPP) and CAD/CAM computer-aided composite resin materials are a relatively new class of dental biomaterials. To avoid many disadvantages of metals and their alloys in dental practice, such as inappropriate color, high density, thermal conductivity, and possible allergic reactions, polymer-based materials (BioHPP) and CAD/CAM composite resins are being developed. They are biocompatible, lightweight, strong, durable, and have high flexural and compressive strength. However, most of their characteristics have been demonstrated through laboratory tests, while clinical studies are relatively scarce [28].

Conclusion

It was concluded that guided bone regeneration is well documented and constitutes a predictable and successful approach for lateral and vertical bone augmentation of atrophic ridges. Thus, guided bone regeneration is considered one of the most commonly applied methods to reconstruct alveolar bone and to treat peri-implant bone deficiencies, as well as to replace lost bone and allow the implant to be fully integrated and maintained during functional loading. The use of digital tools for automated manufacturing of implant parts (CAD-CAM) is an optimizing reality in Dentistry. CAD-CAM allows high-quality, standardized, precise, and detailed prosthetic restorations. The use of metal implants in the Morse taper system associated with zirconia abutments ensures a final product with mechanical resistance, biocompatibility, and aesthetics. In addition, immunomodulation-guided bone regeneration membranes are developed mainly to improve macrophage recruitment and aggregation, as well as to regulate macrophage polarization.

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Conflict of Interest

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Similarity Check

It was applied by Ithenticate@.

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It was performed.

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