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COMBINED PTERYGOID AND ZYGOMATIC IMPLANTS: ANALYSIS OF ANCHORAGE AND SINUS COMPLICATIONS

IMPLANTES PTERIGOIDEOS E ZIGOMÁTICOS COMBINADOS: ANÁLISE DE ANCORAGEM E COMPLICAÇÕES SINUSAIS

IMPLANTES COMBINADOS PTERIGOIDEOS Y CIGOMÁTICOS: ANÁLISIS DEL ANCLAJE Y COMPLICACIONES SINUSALES

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ABSTRACT

The rehabilitation of severely atrophic maxillae remains a relevant clinical challenge in implant dentistry, particularly when bone volume and density are insufficient for conventional implant placement. In this context, zygomatic and pterygoid implants have emerged as biomechanically stable alternatives capable of supporting immediate loading protocols and reducing the need for extensive bone grafting. This integrative review analyzed the scientific evidence published between 2015 and 2025 regarding the isolated or combined use of zygomatic and pterygoid implants in maxillary rehabilitation. A structured search was conducted in PubMed, SciELO, Scopus, and Web of Science using MeSH/DeCS controlled descriptors and Boolean operators. Twenty eligible studies were included after screening. The findings demonstrated high success rates (93–98%), strong primary stability, and clinical feasibility of immediate loading, particularly when both implant types were used synergistically. Reported sinus-related complications were low (3–6%) and predominantly resolved through conservative management. Methodological limitations were identified, including heterogeneity in study design, lack of standardization of clinical criteria, and short follow-up periods. Overall, the combined technique demonstrates high clinical predictability; however, further multicenter prospective trials and long-term investigations are required to establish standardized clinical protocols.

Keywords: Zygomatic Implants. Pterygoid Implants. Atrophic Maxilla. Oral Rehabilitation. Sinus Complications.

RESUMO

A reabilitação da maxila severamente atrófica permanece um desafio clínico relevante na implantodontia, especialmente em situações nas quais a densidade e o volume ósseo são insuficientes para a instalação de implantes convencionais. Nesse cenário, os implantes zigomáticos e pterigoideos surgem como alternativas biomecanicamente estáveis e com potencial de carga imediata, reduzindo a necessidade de enxertos ósseos extensos. Este estudo realizou uma revisão integrativa da literatura publicada entre 2015 e 2025, com o objetivo de reunir e analisar criticamente as evidências clínicas, biomecânicas e sinusais associadas ao uso isolado ou combinado desses implantes na reabilitação de maxilas atróficas. A busca foi realizada nas bases PubMed, SciELO, Scopus e Web of Science, por meio de descritores controlados MeSH/DeCS e operadores booleanos. Após triagem segundo critérios de elegibilidade, vinte estudos foram incluídos. As evidências demonstraram taxas de sucesso entre 93% e 98%, estabilidade primária elevada e viabilidade da carga imediata, especialmente quando as ancoragens zigomática e pterigoidea foram utilizadas em conjunto. As complicações sinusais apresentaram ocorrência baixa (3–6%) e, na maioria dos casos, resolução conservadora. Limitações metodológicas foram observadas, incluindo variabilidade nos desenhos dos estudos, ausência de padronização de critérios e seguimentos reduzidos. Conclui-se que a técnica apresenta elevada previsibilidade clínica, embora sejam necessários ensaios clínicos prospectivos e estudos multicêntricos para padronização definitiva de condutas.

Palavras-chave: Implantes Zigomáticos. Implantes Pterigoideos. Maxila Atrófica. Reabilitação Oral. Complicações Sinusais.

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RESUMEN
La rehabilitación de maxilares severamente atróficos sigue siendo un desafío clínico relevante en implantología dental, especialmente en situaciones donde la densidad y el volumen óseos son insuficientes para la colocación de implantes convencionales. En este escenario, los implantes cigomáticos y pterigoideos emergen como alternativas biomecánicamente estables con potencial de carga inmediata, reduciendo la necesidad de injertos óseos extensos. Este estudio realizó una revisión integrativa de la literatura publicada entre 2015 y 2025, con el objetivo de recopilar y analizar críticamente la evidencia clínica, biomecánica y sinusal asociada con el uso aislado o combinado de estos implantes en la rehabilitación de maxilares atróficos. La búsqueda se realizó en las bases de datos PubMed, SciELO, Scopus y Web of Science utilizando descriptores controlados MeSH/DeCS y operadores booleanos. Tras la selección según los criterios de elegibilidad, se incluyeron veinte estudios. La evidencia demostró tasas de éxito entre el 93% y el 98%, alta estabilidad primaria y viabilidad de carga inmediata, especialmente cuando se utilizaron anclajes cigomáticos y pterigoideos conjuntamente. Las complicaciones sinusales fueron poco frecuentes (3-6%) y, en la mayoría de los casos, se resolvieron de forma conservadora. Se observaron limitaciones metodológicas, como la variabilidad en los diseños de los estudios, la falta de estandarización de los criterios y los cortos periodos de seguimiento. Se concluye que la técnica presenta una alta predictibilidad clínica, aunque se necesitan ensayos clínicos prospectivos y estudios multicéntricos para la estandarización definitiva de los procedimientos.

Palabras clave: Implantes Cigomáticos. Implantes Pterigoideos. Maxilar Atrófico. Rehabilitación Oral. Complicaciones Sinusales.

1 INTRODUCTION

The rehabilitation of patients with severely atrophic maxilla represents one of the greatest challenges of contemporary implant dentistry. Posterior bone loss, often associated with maxillary sinus pneumatization and progressive resorption of the alveolar crest, limits the installation of conventional implants and compromises prosthetic stability. It is estimated that up to 60% of edentulous patients have some degree of significant maxillary resorption, which may exceed 80% of alveolar height in advanced cases (Balaji, 2017). Traditionally, treatment included autogenous bone grafts and maxillary sinus lifting, which are effective approaches, but associated with higher morbidity, high cost, and prolonged healing time.

In this scenario, zygomatic implants and, later, pterygoids emerged as less invasive and biomechanically favorable alternatives. Pterygoid implants, initially described by Tulasne (1992), are installed with bicortical anchorage in the pterygoid plate of the sphenoid, dispensing grafts and providing efficient posterior support. Recent studies demonstrate survival rates greater than 95%, primary stability, and low incidence of postoperative complications (Konstantinović et al., 2023; Mirdah, 2025).

Zygomatic implants, in turn, allow installation in cases of severe anterior or total atrophy of the maxilla, anchoring themselves in the zygomatic bone. Systematic reviews report success rates between 95% and 97% and sinus complications ranging between 4% and 6%, mainly maxillary sinusitis, mucosal perforation, or peri-implant inflammation (Muñoz et al., 2021; Di Cosola et al., 2021).

Although both techniques present consistent results in isolation, recent research investigates the combined use of the two approaches, with the aim of optimizing the distribution of masticatory loads, increasing three-dimensional stability, and enabling immediate rehabilitation with fixed prostheses (Leoncavallo, 2023; Germana, 2023). Advanced biomechanical analyses, such as finite element modeling and extensometric testing, demonstrate lower stress concentration and better force dissipation when implants are used in an integrated manner (Bakay, 2025; Koga & Curi, 2025).

However, the literature still has relevant gaps, such as methodological heterogeneity, lack of standardization of clinical criteria, variation in surgical protocols, and scarcity of long-term clinical follow-ups. Sinus complications, although infrequent, constitute the main critical point of attention and require three-dimensional planning and in-depth anatomical knowledge (Lazarov, 2020; Aalam et al., 2023).

In view of these aspects, it is necessary to systematize the existing evidence to guide clinical decisions and support the standardization of protocols.

Thus, **the objective of this study was to perform an integrative review of the literature published between 2015 and 2025 on the combined use of pterygoid and zygomatic implants**, analyzing success rates, biomechanical stability, immediate loading, and associated sinus complications.

2 METHODOLOGY

The present study is characterized as an integrative review of the literature, conducted with the objective of gathering, analyzing and synthesizing recent scientific evidence on the combined use of pterygoid and zygomatic implants in the rehabilitation of severely atrophic maxillae. The choice of this type of review is based on the need to integrate findings from different methodological, clinical, and experimental designs, systematic reviews, and case reports, allowing for a broad, critical, and comparative understanding of the topic. The methodological process followed the steps proposed by Whittemore and Knafl (2005), as well as the recommendations of the Joanna Briggs Institute (JBI, 2020) applicable to this investigative format.

The guiding question was structured based on the adapted PICO model: *"What is the evidence published in the last ten years on biomechanical stability, success rate, and sinus complications related to the isolated or combined use of pterygoid and zygomatic implants in the rehabilitation of severely atrophic maxillae?"* From this question, the specific objectives of (1) identifying relevant publications in the area were established; (2) describe its methodological characteristics; (3) analyze clinical, biomechanical, and sinus results; and (4) integrate trends, gaps, and perspectives for future standardization.

The bibliographic search was carried out between December 1st and 15th, 2025 in the PubMed/MEDLINE, SciELO, Scopus, and Web of Science databases. Controlled descriptors of MeSH and DeCS vocabularies, associated with free terms and Boolean operators, were used. The combinations used included: *("zygomatic implants" OR "zygomatic implants") AND ("pterygoid implants" OR "pterygoid implants") AND ("anchorage" OR "stability" OR "sinus complications" OR "maxillary sinus")*. In addition, a complementary search was carried out using the *snowballing* technique, analyzing references from previously selected studies.

Studies published between 2015 and 2025, in English, Portuguese, or Spanish, that addressed zygomatic and/or pterygoid implants applied to the atrophic maxilla, with clinical

and biomechanical data, or reports of sinus complications, were included. Narrative reviews, studies not available in full text, duplicate publications, and articles not directly related to the topic were excluded.

The screening and selection of studies occurred in three stages: (1) reading of titles and abstracts; (2) complete reading of eligible texts; and (3) final inclusion according to the defined criteria. The Rayyan QCRI® software was used for organization and automatic removal of duplicates. Disagreements between reviewers were resolved by consensus.

Data extraction was performed using a structured spreadsheet in Microsoft Excel® 365, including author, year, country, type of study, methodological design, implant characteristics, surgical protocol, type of load, biomechanical results, success rates, and sinus complications. Data analysis was qualitative, categorized into three axes: (1) biomechanical stability and anchorage; (2) sinus complications; and (3) implant success and survival rates.

The methodological quality of the studies was assessed according to the type of design: for clinical studies, clarity of the inclusion criteria, follow-up time, and description of outcomes was observed; for experimental studies, the validity of the model, analytical methodology and reproducibility were considered; and for case reports, the descriptive completeness of the surgical and functional aspects. The synthesis of the results was presented in a narrative manner, without statistical meta-analysis, due to the heterogeneity of the included studies.

The limitation of this review is the restriction on the selected databases and the methodological variability among the included studies, which hindered quantitative comparative analyses. Even so, the rigor in the selection contributed to minimize bias and strengthen the consistency of the final synthesis.

3 RESULTS

After the stages of identification, screening, eligibility, and inclusion of the studies, **20 articles published between 2015 and 2025** were selected. The initial search retrieved **87 potentially relevant studies**, of which **24 were excluded due to duplication** and **43 were excluded after reading titles and abstracts** because they did not meet the previously established inclusion criteria. Thus, only studies with clinical and methodological relevance to the theme of atrophic maxillary rehabilitation using pterygoid and zygomatic implants were included in the final synthesis.

3.1 GENERAL CHARACTERIZATION OF THE INCLUDED STUDIES

The selected studies presented methodological diversity, contemplating different designs and approaches. Among the articles included, **9 were prospective clinical studies (45%), 5 retrospective (25%), 3 systematic reviews or meta-analyses (15%), 2 experimental biomechanical studies (10%)** and **1 case report (5%).** There was a predominance of publications from **Europe (55%),** followed by **Asia (30%)** and **the Americas (15%),** reflecting the growing global interest in the use of extra-alveolar implants in the last ten years.

In terms of outcomes, the studies showed **success rates ranging from 93% to 98%,** with emphasis on **immediate loading** protocols, which showed similar or superior performance to conventional protocols. The frequency of sinus complications reported was low (**3–6%)** and, when present, was mild and manageable without the need for implant removal or surgical reintervention.

In general, the descriptive analysis indicates a growing trend in the adoption of pterygoid and zygomatic implants as a predictable alternative to grafting procedures in severely resorbed maxillae.

3.2 SUMMARY OF FINDINGS

The comparative synthesis of the studies allowed the identification of the following patterns:

- Most authors reported **high clinical success rates (>93%)** for zygomatic and pterygoid implants and their combination.
- Immediate **loading protocols** were used in approximately **65% of the studies**, with favorable performance.
- Biomechanical modeling has shown that the **combined use of implants results in better distribution of masticatory stresses**, reducing micromovements and prosthetic overload.
- Sinus complications were **infrequent**, mild, and generally managed conservatively.

3.3 CLINICAL PERFORMANCE AND SUCCESS RATES

The clinical performance of the evaluated implants demonstrated **high predictability and functional stability**, with average success rates between **93% and 98%,** especially when associated with immediate loading protocols (Konstantinović et al., 2023; Germana,

2023; Leoncavallo, 2023). Pterygoid implants had **rates between 88.6% and 97.3%,** varying according to the follow-up time and anatomical conditions (Mirdah, 2025; Balaji, 2017). Zygomatic implants have shown similar results, with **success rates of over 95%,** reinforcing their effectiveness in extensive rehabilitation (Muñoz et al., 2021; Di Cosola et al., 2021).

Studies that evaluated combined use indicated **superior performance**, reduced need for bone grafts, and better prosthetic support, with rates above **96%** in follow-ups of up to 48 months (Leoncavallo, 2023; Germana, 2023).

3.4 BIOMECHANICAL STABILITY

The biomechanical results showed that clinical predictability is directly associated with the multicortical anchorage pattern when the two implants are used together (Bakay, 2025). Finite element models have shown **a significant reduction in stress concentration** when compared to the isolated use of implants (Koga & Curi, 2025). This evidence suggests that the combined system improves the dissipation of occlusal forces, reduces micromovements, and favors the viability of immediate loading.

3.5 SINUS COMPLICATIONS AND COMPLICATIONS

The complications reported were **infrequent and of low severity**, with a rate ranging from **3% to 6%,** with mild maxillary sinusitis being the most cited occurrence (Muñoz et al., 2021; Di Cosola et al., 2021). In a multicenter study, Lazarov (2020) reported **preservation of sinus integrity in 98% of cases**, even after long follow-up. No studies reported severe complications or irreversible failures related to the combined use of the implants, reinforcing a consistent safety profile.

4 DISCUSSION

4.1 GENERAL CLINICAL PERFORMANCE OF PTERYGOID AND ZYGOMATIC IMPLANTS

The scientific literature published in the last decade consistently demonstrates that both pterygoid and zygomatic implants have predictable clinical outcomes and high success rates in the rehabilitation of severely atrophic maxillae. These findings confirm the advancement of extra-alveolar anchorage techniques as viable alternatives to bone grafting procedures, traditionally used in cases of severe resorption. The survival rates reported in the studies ranged between 93% and 98%, with a low rate of complications, especially sinus,

whose prevalence remained between 3% and 6% (Muñoz et al., 2021; Konstantinović et al., 2023; Germana, 2023).

Pterygoid implants stand out for their bicortical anchorage at the pterygomaxillary junction, involving the pterygoid plate of the sphenoid, a region recognized for its high cortical bone density. This characteristic confers excellent primary stability, even in maxillae with type D3 or D4 bone, allowing the application of immediate loading protocols. Balaji (2017) reported 100% success in osseointegration of pterygoid implants installed without grafts, with immediate prosthetic rehabilitation and absence of sinus complications. Similarly, Konstantinović et al. (2023), in a prospective study with 48 patients and a 48-month follow-up, observed a survival rate of 97.3%, reinforcing the potential of pterygoid implantation as a safe and long-lasting alternative for posterior maxillary rehabilitation. The authors highlighted that bicortical anchorage, combined with insertion torque greater than 35 Ncm, is a determining factor for biomechanical predictability and treatment longevity (Balaji, 2017; Konstantinović et al., 2023).

Zygomatic implants, originally described by Brånemark, have similar clinical performance and have been consolidated as a therapeutic option in cases of severe bone resorption, especially in the anterior and lateral region of the maxilla. In a meta-analysis encompassing more than 1,200 implants, Muñoz et al. (2021) reported a mean success rate of 95.2%, with mild maxillary sinusitis being the most frequent complication, occurring in 4.7% of cases and usually controlled by conservative treatment. Corroborating these results, Di Cosola et al. (2021) observed clinical success of 96.4% in 78 patients rehabilitated with zygomatic implants, highlighting that greater sinus pneumatization was the main predisposing factor for mild local inflammation (Muñoz et al., 2021; Di Cosola et al., 2021). These findings reinforce the importance of three-dimensional planning with cone beam computed tomography (CBCT) and precise definition of the insertion trajectory to avoid excessive apical contact with the sinus mucosa.

On the other hand, studies such as that of Mirdah (2025) demonstrate that the success rate of pterygoid implants can be influenced by anatomical variables and bone density in the region of installation. In a sample of 60 patients, the overall success rate was 88.6%, with early failures associated with micromovements and difficulties in surgical access in the pterygomaxillary region (Mirdah, 2025). These data reinforce that, although the techniques present promising results, surgical experience and correct torque control during installation

are critical factors for maintaining primary stability and preventing initial failures (Konstantinović et al., 2023; Mirdah, 2025).

Overall, the reviewed studies demonstrate that both types of implant offer comparable clinical performance in terms of stability, success rate, and long-term functional maintenance. Pterygoid implants have better posterior stability and distal load distribution, while zygomatic implants provide efficient anterior and lateral anchorage, especially in cases of total maxillary atrophy. This technical complementarity explains the growing trend of association between the two approaches in hybrid protocols, which will be discussed below (Muñoz et al., 2021; Leoncavallo, 2023; Germana, 2023; Mirdah, 2025).

Despite the positive results, there are relevant methodological limitations to consider. Significant heterogeneity is observed in the study designs, sample sizes, follow-up periods, and success criteria used, which makes it difficult to perform more robust quantitative meta-analyses. In addition, part of the studies is retrospective, with the absence of control groups and variability in the prosthetic materials used (Balaji, 2017; Muñoz et al., 2021; Konstantinović et al., 2023; Di Cosola et al., 2021; Mirdah, 2025). Even so, the consistency of survival rates and the low incidence of complications point to the consolidation of techniques as predictable, safe, and long-lasting alternatives in the rehabilitation of atrophic maxillae (Muñoz et al., 2021; Germana, 2023; Leoncavallo, 2023).

The results analyzed reinforce that the clinical success of pterygoid and zygomatic implants depends on a combination of technical and anatomical factors, including local bone density, surgeon experience, insertion torque, and adequate three-dimensional planning. The integration of these elements ensures stable anchorage, reduces the risk of micro-movements, and favors immediate loading, providing functional and aesthetic rehabilitation in the short term (Balaji, 2017; Konstantinović et al., 2023; Germana, 2023; Leoncavallo, 2023). Thus, the findings of this review support the growing adoption of these techniques in modern clinical practice, consolidating their role as effective and high-performance biomechanical protocols in contemporary implant dentistry (Muñoz et al., 2021; Leoncavallo, 2023; Germana, 2023).

4.2 COMBINED USE OF TECHNIQUES: ADVANTAGES AND LIMITATIONS

The combined use of pterygoid and zygomatic implants has been consolidated in the recent literature as a predictable and biomechanically efficient approach for the rehabilitation of severely atrophic maxillae. This hybrid strategy integrates the structural advantages of both

types of implants, allowing anchorage in regions of high bone density, the zygomatic bone and the pterygoid plaque of the sphenoid, and eliminating the need for bulky bone grafts, traditionally associated with greater morbidity and prolonged surgical time. As a result, the combined technique has been recognized as one of the most innovative and advanced alternatives in contemporary implant dentistry, especially in cases of extreme bone resorption in which conventional implants are not feasible (Leoncavallo, 2023; Germana, 2023; Aalam et al., 2023).

Clinical evidence published in the last decade reinforces the predictability and safety of this association. Leoncavallo (2023) demonstrated that the simultaneous use of pterygoid and zygomatic implants provides a more balanced and stable prosthetic base, distributing masticatory forces between four cortical, two zygomatic, and two pterygoid pillars. This structural arch configuration creates a three-dimensional anchorage capable of reducing stress on the alveolar crest and increasing the rigidity of the prosthetic assembly, which favors immediate loading and the functional longevity of rehabilitations (Leoncavallo, 2023). Similarly, Germana (2023) followed 25 patients with severely atrophic maxillae treated with the combined protocol and observed a success rate of 96.8% after 24 months, with no record of relevant sinus complications, emphasizing the functional and aesthetic gain associated with the immediate installation of fixed prostheses (Germana, 2023).

In addition to the clinical benefits, the association between pterygoid and zygomatic implants offers relevant biomechanical advantages. While zygomatic implants ensure anterior and lateral anchorage in high-density cortical bone, pterygoids provide posterior bicortical support, establishing a three-dimensional balance that improves the dissipation of vertical and oblique masticatory forces. This structural synergy reduces micromovements, increases primary stability, and distributes stresses on the maxillary arch more evenly, especially in maxillae with type D3 or D4 bone. In a retrospective study with 60 patients, Mirdah (2025) compared the performance of isolated pterygoid implants and combined protocols, observing an increase in the success rate from 88.6% to 95.4% when both techniques were applied together (Mirdah, 2025). According to the author, the integration of the two types of implant allows a more balanced dissipation of occlusal stresses and reduces the risk of early failure, reinforcing the biomechanical predictability of the hybrid protocol.

Another benefit widely reported in the literature is the significant reduction in treatment time and postoperative morbidity. The absence of the need for autogenous or allogeneic grafts reduces the invasiveness of the procedure, the number of surgeries, and the total

rehabilitation time. Leoncavallo (2023) and Germana (2023) highlighted that the combined protocol reduces surgical time by up to 40%, improves postoperative comfort, and favors early functional recovery. In addition, the better distribution of masticatory stresses on the prosthesis reduces the need for extensive cantilevers, minimizing the risk of occlusal overload and prosthetic fractures, which are determining factors for the longevity of fixed rehabilitation (Leoncavallo, 2023; Germana, 2023).

However, despite the favorable results, the combined technique requires anatomical mastery, surgical experience, and detailed three-dimensional planning. Access to the pterygomaxillary region and the correct orientation of zygomatic implants require the use of digital technologies, such as cone beam computed tomography (CBCT), 3D planning software, and personalized surgical guides. Mirdah (2025) reported that early failures occurred in cases with extremely low bone density and absence of a surgical guide, while Aalam et al. (2023) demonstrated that three-dimensional digital navigation substantially reduces the risk of perforation of the sinus mucosa and improves the angulation control of implants (Mirdah, 2025; Aalam et al., 2023). Such evidence reinforces that the predictability of the technique depends directly on the application of digital tools and technical rigor during surgical planning and execution.

The literature also points out that the learning curve associated with the combined technique is a determining factor for clinical results. The simultaneous installation of zygomatic and pterygoid implants requires advanced training in maxillary anatomy, mastery of lateral and oblique approaches, and consolidated experience in access surgeries to the zygomatic-pterygomaxillary complex. Leoncavallo (2023) and Germana (2023) emphasize that the best outcomes are obtained in specialized centers, with adequate infrastructure and a multidisciplinary team composed of implantologists, radiologists, and biomedical engineers (Leoncavallo, 2023; Germana, 2023). Thus, although the hybrid protocol is safe and effective, it should not be considered a routine technique, but a highly complex approach, indicated for cases of severe bone resorption and performed under strict technical and technological control.

In general, the convergent literature of the last ten years confirms that the combined use of pterygoid and zygomatic implants represents a modern, functional and predictable solution for the rehabilitation of severely atrophic maxillae. This association provides superior three-dimensional stability, reduces the need for bone grafts, optimizes treatment time, and improves the distribution of masticatory forces on the prosthesis (Leoncavallo, 2023;

Germana, 2023; Aalam et al., 2023). However, the success of the technique depends on interrelated factors, such as the surgeon's degree of experience, the patient's bone quality, the use of digital planning, and the adoption of individualized loading and rehabilitation protocols (Mirdah, 2025; Leoncavallo, 2023). Thus, the choice for this approach must be carefully based on clinical, anatomical, and technical criteria, ensuring biomechanical predictability, functional longevity, and biological safety of the treatment (Leoncavallo, 2023; Germana, 2023; Aalam et al., 2023).

4.3 BIOMECHANICAL ASPECTS OF COMBINED ANCHORAGE

Understanding the biomechanical aspects involved in the combined use of pterygoid and zygomatic implants is essential to justify the high rates of clinical success reported in the literature. The severely atrophic maxilla poses a significant biomechanical challenge due to loss of bone volume, reduced cortical thickness, and the predominance of low-density cancellous bone (types D3 and D4). Under these conditions, the installation of conventional implants has important limitations in terms of primary stability and resistance to functional loading (Bakay, 2025; Koga & Curi, 2025). The combination of pterygoid and zygomatic anchorages, on the other hand, provides a three-dimensional support system that redistributes masticatory forces, reduces concentrated tensions, and improves the overall mechanical behavior of the prosthetic assembly (Bakay, 2025; Koga & Curi, 2025).

Pterygoid implants, anchored in the pterygomaxillary region, formed by the union of the pyramidal process of the palatine and the pterygoid plate of the sphenoid, offer bicortical fixation in a high-density bone, which guarantees primary stability even in cases of severe atrophy. This posterior anchorage functions as a biomechanical buttress that supports vertical loads and prevents distal displacement of masticatory forces. Zygomatic implants, fixed to the malar bone, provide anchorage in a thick and highly resistant cortical region, responsible for supporting oblique and lateral forces. When combined, these two structures form an arched anchoring system, similar to an architectural bridge, capable of balancing the force vectors and increasing the structural stiffness of the rehabilitation (Bakay, 2025; Koga & Curi, 2025).

In a three-dimensional finite element analysis study, Bakay (2025) evaluated the mechanical behavior of different implant configurations in atrophic maxillae and observed that the association of zygomatic and pterygoid implants reduces the concentration of stresses in the alveolar crest by up to 25% when compared to the use of conventional implants (Bakay,

2025). The author demonstrated that zygomatic implants efficiently absorb oblique loads, while pterygoids dissipate posterior vertical forces, creating a dynamic balance that minimizes the risk of bone overload. Koga and Curi (2025), using photoelastic analysis and extensometry, corroborated these findings, showing that the bicortical anchorage of pterygoid implants promotes uniform distribution of stresses and reduces the concentration of forces in the cervical region of the implant, favoring osseointegration and long-term stability (Koga & Curi, 2025).

These biomechanical observations are in agreement with the clinical results reported by Germana (2023) and Leoncavallo (2023), who found excellent occlusal adaptation and low incidence of prosthetic fractures in patients treated with the combined protocol. The arrangement of the four cortical pillars, two zygomatic and two pterygoids, confers three-dimensional rigidity and reduces rotational torque on the prosthetic arch, which increases the durability of the structures and minimizes deleterious micromovements during chewing (Germana, 2023; Leoncavallo, 2023). According to these authors, the hybrid anchorage system works similarly to a compression arch, in which the lateral and vertical forces are balanced by the geometry and density of the bone support points.

Another important aspect identified in biomechanical studies concerns the influence of the angulation and length of the implants on the distribution of stresses. Bakay (2025) highlighted that insertion angles between 30° and 45° for zygomatic implants and 40° to 55° for pterygoids provide better load dispersion and lower concentration of apical stresses. The use of long implants, crossing multiple corticals, increases the bone contact area and confers greater resistance to displacement under repetitive masticatory loads (Bakay, 2025). These geometric parameters, combined with the use of digital planning software and personalized surgical guides, are decisive for the biomechanical success of the combined protocol (Bakay, 2025; Koga & Curi, 2025).

From a functional point of view, the association of the two anchorages also positively influences the dynamic behavior of the prosthesis under immediate load. Computational modeling studies demonstrate that, in situations of asymmetric mastication, the hybrid set has lower prosthetic deflection and greater stability in the occlusal plane compared to conventional implants. This three-dimensional stability reduces the shear forces at the bone-implant interface and improves the distribution of compressive stresses, favoring the maintenance of osseointegration and the longevity of the treatment (Bakay, 2025; Koga & Curi, 2025; Leoncavallo, 2023). Leoncavallo (2023) observed that patients treated with the

hybrid protocol had less marginal bone loss after 24 months of follow-up, a fact attributed to the efficiency in dissipating masticatory forces and the absence of localized overloads (Leoncavallo, 2023).

In addition to the structural aspects, the biomechanics of the combined system must also be analyzed from the perspective of the adaptive bone response. The mechanical stimulation provided by the balanced distribution of forces favors physiological bone remodeling, according to the principles of mechanotransduction. In other words, the controlled mechanical stimulus acts as a protective factor against bone resorption, especially in areas of higher cortical density, such as the zygomatic bone and the pterygoid plaque. This functional bone adaptation is essential for the maintenance of long-term stability and reinforces the biomechanical relevance of the combination between both anchorages (Bakay, 2025; Koga & Curi, 2025).

In summary, the biomechanical findings gathered in this review demonstrate that the combination of pterygoid and zygomatic implants results in a stable, resistant, and functional three-dimensional anchorage system. This integration between anterior and posterior supports allows better dissipation of masticatory forces, reduces micromovements, preserves the bone-implant interface, and increases the longevity of the prosthetic assembly (Germana, 2023; Leoncavallo, 2023; Bakay, 2025; Koga & Curi, 2025). Such evidence explains the high clinical success rates (95–98%) observed in the analyzed studies and justifies the growing adoption of the combined protocol as one of the most biomechanically advanced and predictable solutions for the rehabilitation of severely atrophic maxillae (Muñoz et al., 2021; Leoncavallo, 2023; Germana, 2023).

4.4 SINUS COMPLICATIONS AND ANATOMICAL CONSIDERATIONS

Sinus complications are one of the main clinical concerns associated with the use of zygomatic implants and, to a lesser extent, pterygoid implants, due to the close anatomical relationship of these anchorages with the maxillary sinus. Although success rates are high, with implant survival rates between 93% and 98%, the risk of inflammatory sinus changes, such as chronic sinusitis or local congestion, remains a relevant clinical variable, especially in cases of severe sinus pneumatization or inadequate surgical planning (Muñoz et al., 2021; Di Cosola et al., 2021).

In general, studies indicate that the incidence of sinus complications associated with zygomatic implants varies between 3% and 6%, with mild and self-limited maxillary sinusitis

being the most frequent occurrence. In a meta-analysis covering more than 1,200 zygomatic implants, Muñoz et al. (2021) reported a mean complication rate of 4.7%, emphasizing that most cases were transient, resolved with antibiotic therapy and sinus irrigation. According to the authors, the most common cause of these complications is excessive apical contact of the implant with the sinus mucosa, which can trigger chronic irritation and impairment of the sinus' natural drainage (Muñoz et al., 2021).

These findings were corroborated by Di Cosola et al. (2021), who, when evaluating 78 patients rehabilitated with zygomatic implants, observed that individuals with greater sinus pneumatization were predisposed to postoperative discomfort and mild inflammation, especially in the first weeks after surgery. The study demonstrated that the risk of inflammation increases when the apical tip of the implant exceeds the limit of the Schneider mucosa, reinforcing the importance of well-planned trajectories that touch, but do not penetrate, the sinus cavity (Di Cosola et al., 2021).

On the other hand, Lazarov (2020), in a prospective study that evaluated 131 maxillary sinuses rehabilitated with zygomatic implants and Strategic® pterygoids, observed preserved sinus integrity in 98% of cases, with no occurrence of clinically significant sinusitis, even after long periods of follow-up. These results indicate that, when correctly planned and executed, extra-alveolar anchorage techniques have a low risk of sinus complications and excellent anatomical integration (Lazarov, 2020).

From an anatomical point of view, the maxillary sinus presents great individual variability in terms of its extension, volume, and relationship with the alveolar ridge, which directly influences the ideal path of the implants. In maxillae with severe pneumatization, the distance between the rim and the sinus floor can be reduced to a few millimeters, increasing the risk of mucosal perforation. In these cases, the use of cone beam computed tomography (CBCT) and three-dimensional planning software is indispensable for accurate mapping of the sinus cavity and adjacent structures, as emphasized by Aalam et al. (2023). These authors highlight that the use of personalized surgical guides and digital navigation significantly reduces the risk of mucosal perforation and improves the predictability of the implants' angle and insertion depth (Aalam et al., 2023).

Pterygoid implants, on the other hand, are rarely associated with sinus complications, since their surgical path occurs posterior to the maxillary sinus, towards the pterygoid plate of the sphenoid. However, technical failures, trajectory deviations, or excessively inclined insertions can cause unwanted contact with the sinus floor or pterygopalatine fossa,

generating discomfort and localized inflammation. Mirdah (2025) reported that such complications are more frequent in cases operated without surgical guidance and in patients with extremely low bone density, where three-dimensional orientation is difficult (Mirdah, 2025).

Recent literature indicates that the introduction of digital resources, such as assisted navigation and prototyped surgical guides, contributes decisively to the prevention of these complications. In addition to improving positioning accuracy, these methods allow for the prior identification of critical anatomical variations, such as the maxillary sinus ostium and the path of the superior posterior alveolar artery, minimizing the risk of intraoperative perforation or bleeding (Leoncavallo, 2023; Germana, 2023; Aalam et al., 2023).

From a clinical point of view, the most common manifestations of sinus complications include facial pain or pressure, nasal obstruction, purulent discharge and, rarely, oroantral fistula formation. Most of these cases are managed conservatively, with antibiotic therapy and local irrigation, and the need for surgical intervention, such as functional endoscopic antrostomy, is quite rare (Muñoz et al., 2021; Di Cosola et al., 2021). Di Cosola et al. (2021) highlight that persistent inflammation is strongly associated with planning failures, poor apical orientation, and deficiencies in sinus drainage, and not with the presence of the implant itself.

Proper patient selection is another critical factor in preventing sinus complications. Individuals with a history of chronic sinusitis, uncontrolled allergic rhinitis, nasal polyposis, or heavy smoking should be carefully evaluated before indicating zygomatic or pterygoid implants. In such situations, the interdisciplinary involvement of otolaryngologists and radiologists is essential for diagnosis and planning of a safe and predictable treatment (Lazarov, 2020; Aalam et al., 2023).

In summary, the contemporary literature demonstrates that sinus complications associated with the installation of zygomatic and pterygoid implants are rare events, usually mild and controllable. The correct anatomical understanding of the sinus cavity, the use of computed tomography, the use of personalized surgical guides, and the application of digital planning protocols are fundamental strategies to reduce the incidence of these complications (Muñoz et al., 2V021; Di Cosola et al., 2021; Lazarov, 2020; Aalam et al., 2023). Thus, pterygoid and zygomatic techniques, when properly performed, have high biological safety, preservation of sinus mucosal integrity, and consistent clinical predictability in the long term (Muñoz et al., 2021; Germana, 2023; Leoncavallo, 2023).

4.5 CRITICAL INTEGRATION OF LITERATURE FINDINGS AND GAPS

The critical analysis of studies published between 2015 and 2025 reveals a significant evolution in the understanding and clinical applicability of pterygoid and zygomatic implants, both in their isolated uses and in combined protocols. The body of evidence gathered in this integrative review demonstrates a remarkable consistency in clinical and biomechanical results, which reinforces the predictability and safety of these techniques for the rehabilitation of severely atrophic maxillae (Balaji, 2017; Muñoz et al., 2021; Konstantinović et al., 2023; Germana, 2023). However, despite this positive convergence, important methodological and scientific gaps still persist that limit the standardization of clinical protocols and the universal extrapolation of results.

The most relevant clinical studies, such as those by Balaji (2017), Konstantinović et al. (2023), Muñoz et al. (2021) and Germana (2023), have demonstrated high success rates, ranging from 93% to 98%, with a low incidence of sinus complications, generally less than 6%. These findings support the biological safety and predictability of pterygoid and zygomatic implants, alone or in combination, especially when applied to carefully selected patients and under preoperative digital planning (Muñoz et al., 2021; Konstantinović et al., 2023; Germana, 2023). However, it is important to highlight that the success and failure criteria vary significantly between studies, which makes it difficult to directly compare data and formulate robust meta-analyses with high statistical power. This lack of methodological uniformity is one of the main limitations of the current literature (Balaji, 2017; Muñoz et al., 2021; Di Cosola et al., 2021; Mirdah, 2025).

Another critical point identified in this review refers to the heterogeneity of the experimental designs. Most of the publications are retrospective, with small samples and a follow-up time of less than five years. Although these studies offer valuable information, they do not have the same methodological rigor as randomized controlled trials, which are still scarce in the field. Konstantinović et al. (2023) and Mirdah (2025), for example, presented promising results, but based on small samples and specific clinical contexts, which limits the generalization of findings (Konstantinović et al., 2023; Mirdah, 2025). The scarcity of long-term, multicenter prospective studies represents a significant scientific gap and a challenge to consolidating high-level evidence.

In addition, there is great variation among the load protocols adopted. While some authors, such as Leoncavallo (2023) and Germana (2023), opted for immediate loading protocols with screw-retained fixed prostheses, others preferred late or progressive loading

approaches, which directly influences the reported success and stability rates (Leoncavallo, 2023; Germana, 2023). The differences also extend to the type of prosthetic rehabilitation used, from metal bars to cast titanium structures and CAD/CAM prostheses, which interferes with the distribution of forces and, consequently, the biomechanical and clinical results. This diversity of operational variables reinforces the need for standardization of clinical, prosthetic, and radiographic criteria in future studies (Muñoz et al., 2021; Leoncavallo, 2023; Germana, 2023).

Regarding the biomechanical analysis, the works of Bakay (2025) and Koga and Curi (2025) provided important experimental evidence on the structural efficiency of the combination of pterygoid and zygomatic implants. These authors demonstrated, through computer simulations and extensometric analyses, that the association of the two anchorages reduces the concentration of stresses in the alveolar crest and increases the stiffness of the prosthetic assembly (Bakay, 2025; Koga & Curi, 2025). However, most of the available evidence still comes from theoretical models and in vitro experiments, lacking clinical validation under real physiological conditions. Thus, longitudinal clinical studies with standardized radiographic evaluation are needed to confirm biomechanical behavior and peri-implant bone stability over time (Bakay, 2025; Koga & Curi, 2025; Germana, 2023).

Another limitation identified refers to the lack of uniformity in the characterization of sinus complications and the scarcity of data on the influence of individual anatomical variations. While Lazarov (2020) reported total preservation of sinus integrity in 98% of cases, Di Cosola et al. (2021) observed a higher incidence of mild inflammation in patients with highly pneumatized sinuses, suggesting that sinus volume and morphology exert a significant influence on the risk of complications (Lazarov, 2020; Di Cosola et al., 2021). This divergence highlights the need for studies that incorporate three-dimensional anatomical variables, such as sinus volume, mucosal thickness, and floor angulation, in predictive models of surgical risk.

From a functional point of view, the literature is still limited regarding the evaluation of the quality of life and psychosocial impact of patients rehabilitated with pterygoid and zygomatic implants. Although several studies have proven the biomechanical and aesthetic efficacy of the combined protocol, few have evaluated subjective parameters, such as chewing comfort, phonetics, and aesthetic satisfaction (Germana, 2023; Leoncavallo, 2023). Multidimensional investigations, including validated questionnaires and functional

performance measures, are key to providing a broader understanding of clinical outcomes from the patient's perspective.

Another aspect that has been little explored is peri-implant bone remodeling and its correlation with insertion torque and immediate loading. The absence of longitudinal histological and radiographic studies makes it difficult to understand the biological mechanisms of bone adaptation, especially in long implants subjected to complex forces. The use of cone-beam computed tomography (CBCT) with serial follow-up could better elucidate the behavior of the bone-implant interface and the evolution of bone density under functional loading, contributing to the formulation of more accurate and safer clinical protocols (Aalam et al., 2023; Bakay, 2025; Koga & Curi, 2025).

Finally, there is a lack of multicenter and comparative studies between populations with different anatomical patterns, bone densities and demographic characteristics. Most of the studies identified in this review were conducted in European and Asian reference centers, with restricted samples and specific methodologies, which limits the global extrapolation of the results (Muñoz et al., 2021; Lazarov, 2020; Konstantinović et al., 2023). Multicenter, controlled, randomized clinical trials, with a follow-up of more than ten years, are essential for the consolidation of the combined protocol as the gold standard in the rehabilitation of severely atrophic maxillae.

In summary, although the scientific literature of the last decade presents consistent evidence on the efficacy and safety of pterygoid and zygomatic implants, alone or in combination, there are still methodological gaps that prevent the consolidation of a universal clinical consensus. The main limitations include the heterogeneity of the designs, the lack of standardization of success criteria, the scarcity of long-term studies, and the lack of data on bone remodeling and patients' quality of life (Balaji, 2017; Muñoz et al., 2021; Lazarov, 2020; Di Cosola et al., 2021; Konstantinović et al., 2023; Germana, 2023; Mirdah, 2025). Scientific advancement in this field will depend on randomized clinical trials, in vivo biomechanical analyses, and multidisciplinary investigations that integrate anatomical, functional, and technological aspects, in order to establish standardized, safe, and highly predictable clinical protocols (Bakay, 2025; Koga & Curi, 2025; Leoncavallo, 2023; Aalam et al., 2023).

4.6 CLINICAL IMPLICATIONS AND FUTURE PROSPECTS

The integrated analysis of the reviewed studies shows that the combined use of pterygoid and zygomatic implants represents one of the most advanced, predictable and

functionally efficient strategies of modern implantology for the rehabilitation of severely atrophic maxillae. This hybrid technique is consolidated as a safe and high-performance alternative, eliminating the need for bulky bone grafts and allowing immediate rehabilitation in patients with extreme bone resorption (Muñoz et al., 2021; Leoncavallo, 2023; Germana, 2023). The set of clinical and biomechanical evidence points to a paradigmatic change in the approach to maxillary atrophies, with direct implications in clinical practice, professional training and technological development of contemporary implant dentistry.

From a clinical point of view, the main contribution of the combined technique is the possibility of performing immediate rehabilitation, even in fully resorbed maxillas, reducing the total treatment time and the number of surgeries. Studies such as those by Leoncavallo (2023) and Germana (2023) have shown that the simultaneous use of pterygoid and zygomatic implants eliminates the need for autogenous and allogeneic grafts, significantly reducing surgical morbidity and providing better comfort and postoperative recovery (Leoncavallo, 2023; Germana, 2023). These results are consistent with those reported by Muñoz et al. (2021) and Di Cosola et al. (2021), who observed low rates of sinus complications and a high clinical success rate, consolidating the protocol as a predictable option for cases of severe atrophy (Muñoz et al., 2021; Di Cosola et al., 2021).

In addition to the clinical benefits, the combined protocol has relevant economic and logistical advantages. By dispensing with bone grafts and prolonged hospitalization, the technique reduces operating costs and the patient's time away from their daily activities. This therapeutic simplification expands the accessibility of treatment, especially for elderly patients or those with systemic conditions that contraindicate multiple reconstructive interventions. Germana (2023) highlighted that the average reduction of 40% in surgical time and early functional return are among the main clinical differentials of this approach, directly reflecting on patient satisfaction and quality of life after rehabilitation (Germana, 2023).

In the technological field, the advancement of digital tools has played an essential role in the consolidation of this technique. The use of cone-beam computed tomography (CBCT), 3D planning software, and guided surgery has proven to be indispensable to ensure precision in the angulation and positioning of implants, minimizing anatomical risks and increasing the predictability of results. Aalam et al. (2023) demonstrated that three-dimensional digital navigation substantially reduces the risk of sinus perforation and improves control of the depth and direction of insertion of zygomatic implants, which results in a lower incidence of complications and greater prosthetic stability (Aalam et al., 2023). At the same time, the

integration of additive manufacturing technologies, such as 3D printing of customized guides and anatomical prototypes, has allowed for more detailed and individualized preoperative planning, favoring more accurate surgical and prosthetic results (Leoncavallo, 2023; Germana, 2023).

From a biomechanical point of view, the studies by Bakay (2025) and Koga and Curi (2025) reinforce that the hybrid protocol offers superior structural advantages, promoting better distribution of masticatory stresses and greater three-dimensional rigidity of the prosthetic assembly. This characteristic is decisive for the feasibility of immediate loading, as it reduces micromovements at the bone-implant interface and contributes to the longevity of the treatment. The combination of zygomatic and pterygoid anchorages creates a biomechanical arch support system, which behaves similarly to a stabilizing architectural structure, dissipating vertical and oblique forces in a balanced manner (Bakay, 2025; Koga & Curi, 2025; Leoncavallo, 2023; Germana, 2023). This principle explains, in part, the high success rates reported in multicenter clinical trials and the low rates of structural and prosthetic complications observed over time (Leoncavallo, 2023; Germana, 2023).

However, despite the positive results, the combined technique requires a high degree of specialization and surgical experience. The learning curve is long and requires in-depth knowledge of craniofacial anatomy, mastery of lateral and oblique maxillary approaches, and familiarity with digital planning technologies. Leoncavallo (2023) and Mirdah (2025) highlighted that the success of the protocol is directly related to the surgeon's experience and execution in specialized centers with a multidisciplinary team (Leoncavallo, 2023; Mirdah, 2025). In this sense, the technique should not be seen as a routine procedure, but as an advanced solution intended for cases of extreme anatomical complexity, performed under controlled conditions and rigorous digital planning (Aalam et al., 2023; Germana, 2023).

In the context of professional training, the findings of this review reinforce the need for specific and continuous training of implantologists. The mastery of guided surgery, three-dimensional tomographic reading, and the integration between surgery and prosthesis is essential to ensure predictability and safety. Thus, the dissemination of the combined protocol should be accompanied by advanced training programs and the incorporation of digital simulations and anatomical models in a teaching environment, allowing the reduction of technical errors and the improvement of evidence-based clinical practice (Leoncavallo, 2023; Germana, 2023; Aalam et al., 2023).

Future perspectives point to an even greater integration between digital technology, biomechanics and artificial intelligence applied to surgical planning. The use of intraoral scanning systems, torque sensors, and failure prediction software will allow, in the coming years, the creation of customized installation protocols, based on the individual anatomical and densitometric mapping of each patient. This evolution tends to make the pterygoid-zygomatic protocol fully digitized, reducing variability between operators and increasing the standardization of clinical outcomes (Bakay, 2025; Koga & Curi, 2025; Aalam et al., 2023). In addition, the incorporation of machine learning algorithms in preoperative analysis may assist in the automated identification of safe trajectories and risk prediction for sinus or biomechanical complications, consolidating a new paradigm of intelligent guided surgery (Aalam et al., 2023; Leoncavallo, 2023).

On the other hand, the definitive consolidation of this technique as a reference standard in maxillary rehabilitation depends on the strengthening of the scientific base. There is still a lack of randomized clinical trials, multicenter studies, and longitudinal follow-ups longer than ten years that evaluate the durability of combined implants and bone remodeling over time (Muñoz et al., 2021; Lazarov, 2020; Konstantinović et al., 2023; Mirdah, 2025). Future investigations should seek to integrate clinical, radiographic, and functional parameters, in addition to including subjective outcomes related to patient satisfaction and quality of life, in order to provide a holistic view of the effectiveness and impact of the technique on clinical practice (Germana, 2023; Leoncavallo, 2023; Aalam et al., 2023).

In summary, the clinical implications and future perspectives of the combined use of pterygoid and zygomatic implants point to a mature, safe technique in constant technological improvement. The integration between advanced biomechanics, digital planning and professional training represents the way to consolidate this protocol as a definitive solution for complex rehabilitations of the atrophic maxilla. With the expansion of digital implant dentistry and the advancement of scientific evidence, it is plausible to predict that this approach will become, in the next decade, the new standard of excellence for oral rehabilitation in patients with severe maxillary bone deficiency (Muñoz et al., 2021; Leoncavallo, 2023; Germana, 2023; Bakay, 2025; Koga & Curi, 2025; Aalam et al., 2023).

5 CONCLUSION

The findings of this integrative review indicate that pterygoid and zygomatic implants, used alone or in combination, have predictable clinical performance, high success rates (93–

98%), and low complication rates, especially sinus complications. The association of the two anchorages demonstrated relevant biomechanical advantages, including greater three-dimensional stability, better distribution of masticatory loads, and feasibility of immediate loading even in severely atrophic maxillae, reducing the need for extensive bone grafts.

Despite the favorable results, the consistency of the available evidence is limited by the methodological heterogeneity of the included studies, the predominance of retrospective analyses, and the short clinical follow-up time. Thus, although the combined pterygoid-zygomatic protocol proves to be a promising and functionally efficient alternative, its application should be directed to carefully selected patients, conducted by experienced surgeons, and supported by advanced digital planning.

It is recommended that future research include prospective, multicenter clinical trials with a follow-up of more than ten years, as well as assessments of quality of life and functional outcomes, in order to strengthen the body of evidence and allow for greater clinical standardization. Consolidating these elements will be essential to definitively establish this approach as a reference in the management of the severely atrophic maxilla.

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