Original Research Paper

Volume - 15 | Issue - 10 | October - 2025 | PRINT ISSN No. 2249 - 555X | DOI : 10.36106/ijar

Dentistry

CONTEMPORARY PROSTHODONTIC APPROACHES FOR THE ATROPHIC MAXILLA: A NARRATIVE REVIEW

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ABSTRACT

Background: Rehabilitation of the severely atrophic maxilla presents significant challenges due to alveolar bone loss, sinus pneumatization, and reduced bone density, particularly in the posterior maxilla. Conventional implants often require bone grafting, sinus lifts, or distal cantilevers, increasing surgical complexity, cost, and risk of complications. **Objective:** This review evaluates the role of pterygoid implants as a graftless solution for posterior maxillary rehabilitation, emphasizing anatomical considerations, biomechanical principles, prosthodontic planning, and emerging digital and technological advances. **Methods:** Literature on pterygoid implant placement, survival rates, surgical protocols, prosthetic considerations, and technological innovations-including CBCT, guided surgery, AI-assisted planning, and robotic-assisted procedures-was reviewed. Emphasis was placed on studies reporting clinical outcomes, complication profiles, and biomechanical analyses. **Results:** Pterygoid implants anchor in the dense cortical bone of the pterygoid plate, pyramidal process, and maxillary tuberosity, achieving high primary stability and predictable osseointegration. Survival rates range from 91% to 95.5%, with low morbidity and reduced need for sinus augmentation. Oblique implant angulation necessitates careful occlusal planning, with mutually protected or group function occlusion mitigating non-axial loading. Digital workflows, advanced abutments, and implant designs further improve surgical precision, prosthetic outcomes, and allow immediate loading protocols.[93] Emerging technologies, including AI, robotic surgery, nanostructured implants, and bioprinted scaffolds, promise enhanced accuracy and accessibility. **Conclusion:** Pterygoid implants provide a minimally invasive, graftless option for full-arch rehabilitation of the atrophic maxilla, combining predictable biomechanical performance with improved patient outcomes. Integration of digital technologies and ongoing innovations may further optimize long-term success, making them a cornerstone in modern prosthodontics.

KEYWORDS : Pterygoid implants; Atrophic maxilla; Full-arch rehabilitation; CBCT; Graftless implant; Digital dentistry; Occlusion.

INTRODUCTION

Rehabilitation of the atrophic maxilla presents a considerable challenge due to ongoing alveolar bone loss, sinus pneumatization, and diminished bone density. These anatomical changes most significantly impact the posterior maxilla, resulting in limited vertical and horizontal bone volume available for implant placement. The pattern of bone resorption in this area tends to be both superior and medial, further complicating implant stabilization and prosthetic support.[1]

The maxillary tuberosity is primarily composed of Type III-IV trabecular bone, which provides limited primary implant stability. Additionally, maxillary atrophy is often linked to poor bone quality, classified as Type III or IV according to standard bone quality classifications, which adversely affects implant stability and long-term prognosis.[2] In contrast, the pterygoid plate consists of dense Type I cortical bone, offering a robust foundation for implant anchorage, while the zygomatic bone exhibits a combination of Type II-III bone, affording moderate to high implant stability.[3]

Pterygoid implants have emerged as an effective, minimally invasive solution for rehabilitating severely atrophic maxillae due to their biomechanical advantages. By anchoring into the dense cortical bone of the pterygoid plate, these implants achieve high primary stability, predictable osseointegration, and durable prosthetic outcomes. Compared to zygomatic and conventional implants, pterygoid implants have demonstrated lower morbidity, fewer complications, and avoid the need for bone grafting, making them a favorable technique for posterior maxillary rehabilitation.[4-6]

This review addresses the complexity of managing severe maxillary atrophy and the drawbacks associated with conventional removable prostheses, emphasizing the role of pterygoid implants as an alternative treatment. Anatomical considerations and biomechanical principles supporting graftless implant placement are explored, highlighting the advantages over traditional bone grafting techniques. Although zygomatic implants provide excellent stability through anchorage in the dense zygomatic bone and similarly obviate grafting, their surgical complexity is higher, with an increased risk of complications such as sinusitis, soft tissue recession, and potential injury to the infraorbital nerve.[7-8]

Clinical success rates, complication profiles, and evolving digital workflows-including guided surgery and AI-assisted treatment planning-are also discussed.[9-10] Emerging trends in maxillary rehabilitation, such as robotic-assisted surgery and bioengineered bone substitutes, are considered to provide a comprehensive outlook on future advances in this field.[11]

Limitations Of Conventional Implant Placement In Severely Resorbed Maxilla

Successful traditional implant treatment relies on achieving primary stability, which depends on dense bone quality. However, the posterior maxilla presents unique anatomical challenges that significantly reduce the success rate of conventional implants. The bone quality in this zone is usually of poor density, classified as Type III or IV trabecular bone, resulting in weakened implant anchorage and increased failure risk.[12]

A key limiting factor is the pneumatization of the maxillary sinus. After tooth loss, the maxillary sinus often enlarges, a process called pneumatization, which reduces the vertical height of alveolar bone especially in premolar and molar areas. This diminishes the bone available for implants, making primary stability difficult to achieve and increasing risks such as sinus membrane perforation and implant displacement into the sinus. Generally, the residual bone height in affected areas may be less than 4 millimeters, often requiring additional surgical techniques like lateral sinus lifts or transcrestal augmentations.[13]

These procedures add complexity, prolong treatment time, increase cost, and pose greater morbidity risks. Despite grafting, complications such as membrane perforation, infection, graft resorption, and incomplete integration may still occur .[14] Furthermore, insufficient posterior bone support can necessitate cantilevered prosthetics, which escalate risks of mechanical complications including screw loosening and fractures. These significant anatomical and biomechanical challenges have encouraged the use of graftless solutions like pterygoid implants that anchor in the dense cortical bone of the pterygoid plate, bypassing the sinus and providing a more predictable and less invasive option for posterior maxillary rehabilitation[6-7,15]

Approaches To Prosthodontic Rehabilitation Of The Atrophic Maxilla

Rehabilitating the atrophic maxilla remains complex due to considerable bone resorption, maxillary sinus enlargement, and reduced bone quality. Effective prosthodontic planning must ensure functional stability, adequate prosthetic support, patient comfort, and long-term success. Various prosthetic options (fig.1) (TABLE.1)exist, spanning non-surgical and surgical modalities, some requiring bone grafting while others utilize graftless approaches. These treatment possibilities vary in surgical complexity, dependence on grafting, expected success rates, and treatment duration, with each approach tailored to the individual patient's anatomical and functional needs.[10-11]

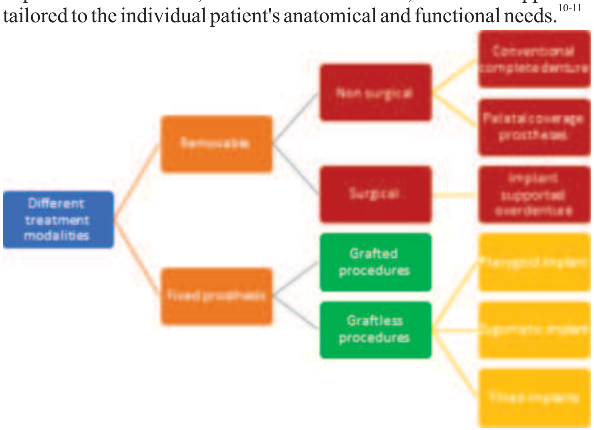


Figure 1: Overview of different treatment modalities for rehabilitating the atrophic maxilla.

Table 1: Comparative Analysis Of Treatment Approaches For Atrophic Maxilla Rehabilitation.

Treatment Modality	Surgical Complexity	Bone Grafting Required?	Success Rate	Treatment Duration
Conventional Dentures	None	No	Moderate	Immediate
Implant Overdentures	Moderate	No	High	3-6 Months
Pterygoid Implants	High	No	Very High	Immediate-3 Months
Zygomatic Implants	High	No	Very High	Immediate-3 Months
All-On-4/All-On-6	Moderate	No	High	Immediate
Bone Grafting + Implants	High	Yes	High	6-12 Months

Pterygoid implants offer a dependable and less invasive option for restoring the atrophic posterior maxilla without requiring bone grafts. Initially introduced in 1989, these implants are designed to anchor into the dense cortical bone of the pterygoid plate, the pyramidal process of the palatine bone, and the maxillary tuberosity.[16]

This anatomical approach provides stable support even in cases with severe maxillary bone loss.

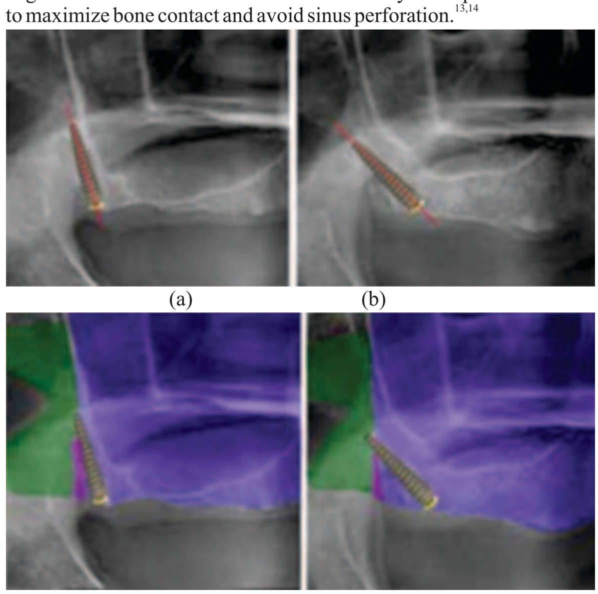
Key advantages of pterygoid implants include the avoidance of sinus augmentation surgeries, engagement with dense cortical bone for enhanced stability, capability for immediate or early loading, improved prosthetic support, and high success rates.[6-7,17]

However, their placement demands accurate planning and surgical skill due to the close proximity of critical structures such as the pterygoid venous plexus and maxillary artery.[18] The use of advanced imaging techniques, like cone-beam computed tomography (CBCT), combined with guided surgical methods, has significantly enhanced the predictability and outcomes of these implants.[9,10]

With improvements in implant design and surgical methodologies, pterygoid implants are increasingly favored for fixed prosthetic treatment in severely atrophic maxillae. Their clinical application, biomechanical advantages, and outcomes compared to other advanced techniques-including zygomatic implants, tilted implants, and the All-on-X concept-are topics of ongoing exploration.[4,5,19]

Anatomically, the pterygoid region, consisting of the maxillary tuberosity, the pyramidal process of the palatine bone, and the pterygoid process of the sphenoid bone, provides a robust bony foundation for implant support in the posterior maxilla(fig.2). The maxillary tuberosity, positioned posterior to the second molar, mainly contains low-density trabecular bone, limiting its ability to support implants long-term. When adequate in size, implants can be placed here successfully; otherwise, the implant trajectory is angled to engage the denser cortical bone in adjacent structures.[2,5,18]

The pyramidal process, a triangular extension between the maxilla and sphenoid bone, contains both cortical and cancellous bone and enhances implant stability when engaged during placement. Implant angulation in this area must consider maxillary sinus pneumatization to maximize bone contact and avoid sinus perforation.[13,14]



(a) (b) (c) (d)

Figure 2: Implant placement sites in the pterygoid region: (b) maxillary tuberosity, (c) pyramidal process of palatine bone, (d) pterygoid process of sphenoid bone.

The primary anchorage site is the pterygoid process of the sphenoid bone, known for its dense cortical bone that confers superior primary stability and resistance to functional load.[1-3] Securing implants here reduces micromotion and marginal bone loss, contributing to long-term success without the need for sinus lifts or grafting.[4]

Together, these anatomical features form a continuous, supportive bony column that improves load distribution and reduces the need for distal cantilevers in prostheses[5]. Preoperative CBCT imaging is essential for assessing individual bone anatomy, planning implant trajectory, and minimizing surgical risk. [6] This strategic placement bypasses the maxillary sinus and leverages dense cortical bone, providing a reliable solution for full-arch rehabilitation in atrophic maxillae[7]

Pterygoid implant placement is generally classified into two approaches depending on anatomical factors: high pterygoid and low pterygoid placement(fig.3).[8] High pterygoid implants take a more vertical path through the maxillary tuberosity to the pterygoid plate, suitable when bone volume is sufficient and sinus walls are positioned anteriorly. [9]The implant typically exits near the second or third molar, facilitating optimal load distribution[10]

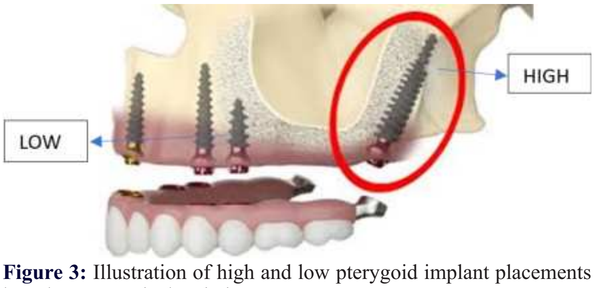


Figure 3: Illustration of high and low pterygoid implant placements based on anatomical variations.

Low pterygoid implants follow a steeper, more posterior path, traversing the maxillary tuberosity, pyramidal process, and anchoring deeply in the pterygoid plate[11] This is recommended when sinus pneumatization reduces tuberosity bone height. The implant platform emerges around the third molar or slightly mesial, and requires careful angulation to avoid anatomical complications.[12]

Both techniques aim to maximize cortical bone engagement while avoiding sinus perforation, with CBCT imaging vital for surgical planning[13]. Implants are placed typically at angles between 45° and 70°, passing through the anatomical landmarks to ensure cortical stability.[14]

Bone quality in the pterygoid region surpasses that of the posterior maxilla, where the tuberosity offers weaker trabecular bone, but the pterygoid plate consists of dense cortical bone, ensuring greater primary stability, better load distribution, and minimal marginal bone loss. This accounts for reported long-term survival rates exceeding 94% for pterygoid implants, even in severely resorbed maxillae.[16]

Given the region's proximity to critical structures such as the pterygoid venous plexus, maxillary artery, and greater palatine nerve and vessels, thorough preoperative imaging and surgical precision are required to minimize risks such as hemorrhage, nerve injury, and soft tissue trauma. Use of CBCT, guided surgery techniques, and careful soft tissue handling help mitigate these complications[18]

Overall, evidence supports pterygoid implants as a reliable and minimally invasive treatment option that leverages the dense cortical bone of the pterygoid region to achieve stable implant anchorage and predictable prosthetic outcomes in patients with severe maxillary atrophy.[19]

Indications And Contraindications For Pterygoid Implants

Table 2: Indications And Contraindications For The Use Of Pterygoid Implants.

Indications	Contraindications
Severe posterior maxillary atrophy – Inadequate vertical and horizontal bone preventing standard implant placement.[1]	Uncontrolled systemic diseases – Conditions like uncontrolled diabetes, osteoporosis, or immunosuppression affecting healing.[1]
Pneumatized maxillary sinus – Extensive sinus pneumatization reducing bone availability, eliminating the need for sinus lifts.[4]	Severe hemorrhagic disorders – Risk of excessive bleeding due to proximity to the pterygoid venous plexus and maxillary artery.[2]
Edentulous maxilla rehabilitation – Provides stable posterior support for full-arch prostheses in multiple missing teeth cases.[3]	Severe parafunctional habits – Bruxism or clenching increasing implant stress and prosthetic complications.[7]
Failed sinus grafting procedures – Alternative for patients with unsuccessful sinus augmentation.[7]	Poor oral hygiene and non-compliance – Increases risk of peri-implantitis and implant failure.[3]
Patients seeking immediate or early loading – High primary stability in cortical bone allows for immediate prosthetic loading.[2]	Unfavorable anatomical variations – Excessively thin or irregular pterygoid plates compromising implant anchorage.[5]

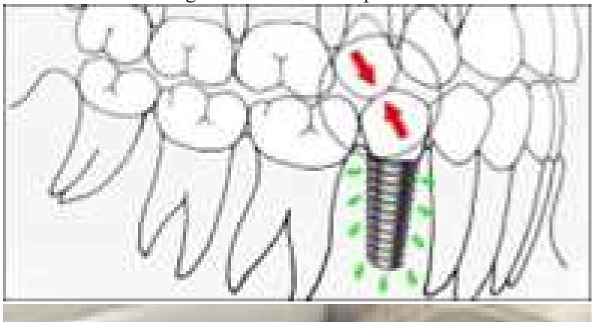
Successful prosthetic rehabilitation using pterygoid implants relies on several key factors including appropriate occlusal loading, careful loading protocols, precise prosthetic design, and accurate impression techniques.[20] Unlike conventional maxillary implants, pterygoid implants are placed at an oblique angle which requires detailed biomechanical planning to ensure long-term stability and functional success.[21]

Occlusal loadingplays a critical role in implant longevity, bone preservation, and prosthetic outcomes[22](fig.3,4).Given that pterygoid implants achieve anchorage in the posterior maxilla, prosthetic designs must balance occlusal forces to avoid overloading the implants, prevent prosthetic fractures, and reduce the risk associated with cantilever extensions.[23]

Understanding the effects of axial and non-axial loading is important. Axial loading occurs when occlusal forces are directed along the implant's long axis, promoting even distribution of stress on the surrounding bone.[24] This loading minimizes micromotion, reduces marginal bone loss, and enhances the integration of the implant with bone, ultimately increasing implant durability.[25] Proper axial loading also decreases incidences of mechanical complications such as screw loosening and framework breakage. [26]However, achieving purely axial loading in pterygoid implants is challenging due to their angled placement, necessitating meticulous implant positioning and occlusal adjustments to optimize force transmission and minimize excessive strain on the bone-implant interface.[27]

Non-axial loading happens when forces apply at an angle to the implant axis, often seen in prostheses with cantilever designs or improperly adjusted occlusion.[29]Such off-axis loading generates uneven stress concentrations which can lead to increased micromotion, bone resorption, and prosthetic complications.[30] In pterygoid implants, some degree of non-axial loading is typical because of their anatomical angulation required to bypass the maxillary sinus while engaging dense cortical bone. Excessive non-axial stress, however, may compromise implant stability and increase failure risk[31]

To enhance the success of pterygoid implants, prosthetic occlusion should be strategically designed to maximize axial force application and minimize non-axial stresses.[32] This can be achieved through specific occlusal schemes such as mutually protected occlusion or group function. [33]Furthermore, utilizing digital treatment planning and guided implant placement greatly aids in achieving optimal implant angulation and prosthetic fit, thus improving long-term prosthetic outcomes and reducing biomechanical complications.[34]



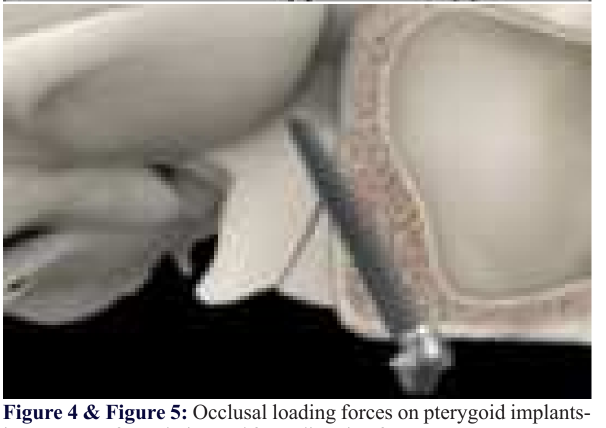


Figure 4 & Figure 5: Occlusal loading forces on pterygoid implants- importance of angulation and force direction for success.

Pterygoid implants require specialized abutments designed to optimize prosthetic alignment and ensure functional stability(fig.6).[35] Because of their angulated placement, multi-unit abutments are commonly employed to correct the emergence profile of the prosthesis and to facilitate proper distribution of occlusal loads. [36] These abutments come in various angulations such as straight, 17 degrees, and 30 degrees, along with different collar heights to accommodate variations in soft tissue thickness around the implant site.[37] To ensure an optimal fit and adequate soft tissue management, try-in abutments are used during the prosthetic phase to measure soft tissue thickness before final abutment selection.[38] For immediate loading protocols, titanium temporary abutments can be utilized for provisional restorations, while multi-unit cover copings are typically used when a delayed loading approach is intended. [39] This careful selection and use of abutments are critical to achieving a well-aligned prosthesis that promotes long-term implant success and patient comfort.[40]

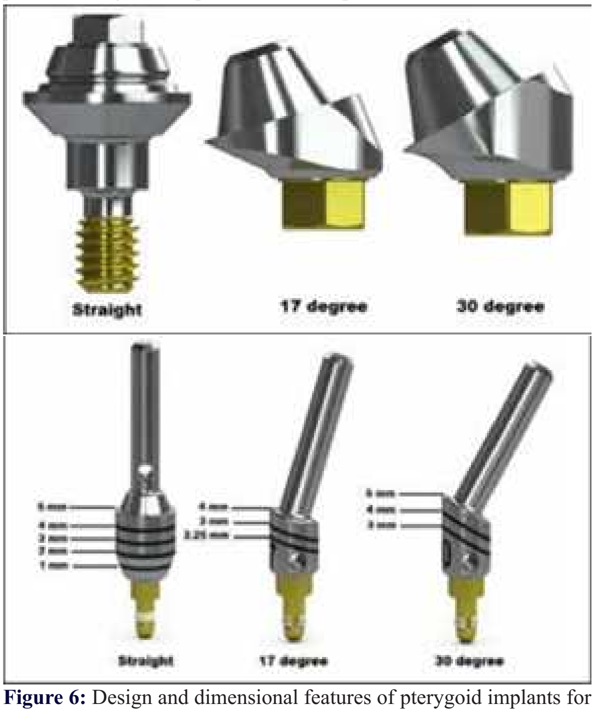


Figure 6: Design and dimensional features of pterygoid implants for posterior maxillary rehabilitation.

Pterygoid implants vary in length and diameter to suit anatomical constraints of the posterior maxilla. The most commonly used pterygoid implants range from 15 mm to 20 mm in length, which allows for adequate bicortical engagement with the pterygoid plate.[41] For example, the PTG implant typically has a diameter of 4.2 mm with a reduced apical diameter of 2.2 mm, designed specifically for precise placement in the narrow and complex pterygoid region. Its dual-tapered body design and aggressive buttress thread profile provide enhanced primary stability, which is essential given the angled placement of these implants.[42]

Several manufacturers produce implants tailored for pterygoid placement. BioHorizons offers the PTG implant designed for use either within the pterygoid region or mesial to the maxillary sinus, which helps avoid sinus augmentation procedures. [43] Other well-known companies like Nobel Biocare and Straumann provide longer implants adaptable for the pterygoid implant technique, offering varied thread designs and surface treatments that promote better osseointegration and long-term stability.[44]

Design considerations of pterygoid implants focus on geometry to optimize biomechanical performance in the complex posterior maxillary anatomy.[45] Their length allows bypassing the pneumatized maxillary sinus and engaging the dense cortical bone of the pterygoid plate[46]. A tapered shape facilitates insertion into narrow spaces and helps minimize undue stress on surrounding bone[47] The apical portion is often narrower to allow deeper cortical engagement without risking damage to nearby vital structures such as the maxillary artery or pterygoid venous plexus.[48] Thread profiles tend to be aggressive and buttress in design, aiding primary stability especially during immediate loading phases. Some implant designs incorporate dual-thread zones-coarser threads apically to aid cutting and finer threads coronally for soft tissue adaptation[49].

The combination of implant length, diameter, thread geometry, and surface technology has greatly improved the success of pterygoid implants, making them a reliable option for fixed full-arch rehabilitation in severely atrophic maxillae.[50] Careful selection of abutments with appropriate angulation further enhances prosthetic alignment and load distribution.[51]

From a prosthodontic perspective, occlusal design plays a crucial role in managing biomechanical forces on pterygoid implants. Mutually protected occlusion is often preferred because it allows anterior teeth to guide excursive movements, thereby reducing non-axial loading on posterior implants.[52] This approach reduces risks such as screw loosening, prosthetic fractures, and marginal bone loss.[53] Alternatively, group function occlusion may be indicated when enhanced lateral stability is required, such as in patients with parafunctional habits or compromised anterior guidance. [54] In this scheme, posterior teeth share lateral loads, distributing forces more evenly across implants.[55]

Clinical evaluations show that both occlusal schemes can be effective if combined with proper implant positioning and prosthetic design. 56The choice between these schemes should consider individual patient factors including neuromuscular control, arch form, and implant support.57 The use of digital occlusal analysis tools helps in verifying and calibrating occlusal contacts to optimize force distribution.

Overall, the clinical outcomes of pterygoid implants demonstrate high success rates, attributable to their engagement with dense cortical bone and good primary stability which minimizes marginal bone loss.[58] These factors contribute to predictable, long-term function and patient satisfaction in the rehabilitation of atrophic maxillae.[59]

Success Rates Across Studies

Study	No. of Patients	Follow-Up Period	Survival Rate (%)
Bidra et al. (2011)	1053	1–10 years	91.0%
Candel et al. (2012)	676	5–15 years	90.7%
Araujo et al. (2020)	634	6–10 years	94.8%
Peña-Cardelles et al. (2023)	911	6 years	95.5%
Rodríguez et al. (2012)	454	1–5 years	97.1%
Curi et al. (2015)	60	Up to 3 years	94.16%
Bidra et al. (2022)	911	6 years	95.5%

Comparison with Other Treatment Modalities

Pterygoid implants offer several advantages over conventional and alternative implant techniques, including zygomatic implants, All-on-4/All-on-6, and sinus augmentation with conventional implant.

1. Comparative Survival Rates

Treatment Modality	Survival Rate (%)	Follow-Up Duration	Complications
Pterygoid Implants	**91-95.5%**	6-10 years	Low risk of peri-implantitis, high biomechanical stability.
Zygomatic Implants	**96-98%**	5-15 years	Higher risk of **sinusitis, soft tissue recession, and prosthetic fractures**.
All-on-4/All-on-6	**88-94%**	5-10 years	Increased risk of **anterior-posterior stress and prosthetic failure** in atrophic cases.
Sinus Augmentation + Conventional Implants	**85-92%**	6-12 years	**High failure rate in severe atrophy** and **increased surgical morbidity**.

2. Advantages of Pterygoid Implants Over Other Modalities

Advantage	Pterygoid Implants	Zygomatic Implants	Sinus Lift + Conventional Implants
Avoids Grafting?	√Yes	√Yes	×No (Requires sinus lift or bone augmentation)

Primary Stability	√High (Dense cortical bone engagement)	√High (Anchored in zygoma)	×Moderate (Trabecular bone-dependent)
Surgical Complexity	√Moderate (Advanced but predictable)	×High (Extensive dissection, sinus risk)	×High (Graft resorption, long healing times)
Risk of Complications	√Low	×Moderate to High (Sinus complications, prosthetic misalignment)	×High (Graft failure, prolonged treatment duration)

For patients with severe maxillary atrophy, pterygoid implants are often the preferred choice due to their balance of predictability, minimal surgical morbidity, and high success rates.

Research in the field of pterygoid implantology is advancing rapidly, focusing on improving implant integration, surgical accuracy, and expanding treatment options for patients with significant maxillary bone loss. One focus area is the development of advanced implant surface modifications, such as nano-textured surfaces, bioactive coatings like calcium phosphate, and titanium-zirconium alloys, all of which enhance bone integration, reduce healing times, and improve the success of immediate loading protocols.[60-62]

Artificial intelligence and machine learning are also being integrated into treatment planning, with AI tools analyzing cone-beam computed tomography (CBCT) scans to determine optimal implant angulations and predict outcomes based on individual patient anatomy.[63-64]This technology can help clinicians tailor treatment plans and better predict implant success.

Robotic-assisted surgery is an emerging technology designed to increase precision during implant placement by stabilizing drills and ensuring accurate angulation, thereby minimizing human error and reducing the risk of damaging critical anatomical structures65. Additionally, finite element analysis (FEA) is used to model biomechanical forces on implants, enabling improvements in implant geometry and design that reduce bone stress and enhance durability[66].

Further innovations include bioengineered bone graft substitutes and customized 3D-printed scaffolds infused with growth factors to stimulate bone regeneration in severe atrophic conditions[67] Digital dentistry advancements, such as intraoral scanners, dynamic navigation systems, and CAD/CAM technologies, are streamlining surgical workflows, allowing for real-time adjustments and greater prosthetic accuracy[68-69]

Looking forward, promising developments incorporate nanotechnology, bioprinting, and smart implant systems equipped with sensors to monitor healing, load distribution, and tissue health in real time.[70-72] These smart implants could enable early detection of complications and support proactive clinical interventions.

Overall, these technological and scientific advancements aim to make pterygoid implant placement more accessible, reliable, and efficient, broadening the scope of treatment for patients requiring full-arch rehabilitation due to severe maxillary atrophy.

Pterygoid implants present a reliable, graftless solution for rehabilitating atrophic maxillae, offering high primary stability with long-term success rates between 91% and 95.5%[73]. Their design enables them to engage dense cortical bone, reducing the need for sinus augmentation, decreasing treatment time, and optimizing load distribution, which minimizes prosthetic complications. Clinical outcomes consistently demonstrate high patient satisfaction, with improvements in function, aesthetics, and speech.[74] The integration of digital workflows, guided surgery, and CAD/CAM technologies has further enhanced surgical precision, reduced intraoperative risks, and improved prosthetic outcomes[75] Immediate loading protocols are increasingly feasible due to these advancements, although surgical expertise and thorough preoperative planning with CBCT remain crucial to ensure optimal results and avoid complications. Future advances such as AI-driven planning, robot-assisted surgery, and nanostructured implants promise to further elevate the field. Developments in 3D bioprinting and prosthetic manufacturing may broaden treatment options and make full-arch rehabilitation more widely accessible and effective. Considering the demand for predictable, minimally invasive therapies, pterygoid implants will continue to be a cornerstone of modern prosthodontics, balancing functional success with surgical feasibility and patient-centered care

DISCUSSION

Pterygoid implants have emerged as a reliable solution for rehabilitating the atrophic posterior maxilla, offering high primary stability and avoiding the need for sinus augmentation procedures.[76] Their design engages dense cortical bone, facilitating immediate loading protocols and reducing treatment time.[77] Clinical studies report survival rates exceeding 90%, with some reaching up to 98.3%.[78]

Advancements in digital technologies, such as cone-beam computed tomography (CBCT) and robotic-assisted surgery, have enhanced the precision of pterygoid implant placement.[79] These innovations improve surgical outcomes by providing real-time imaging and minimizing human error.[80]

Occlusal design plays a pivotal role in the long-term success of pterygoid implants.[81] Mutually protected occlusion is often preferred to minimize non-axial loading, reducing risks of screw loosening and marginal bone loss.[82] Alternatively, group function occlusion may be indicated in patients with parafunctional habits, distributing lateral forces more evenly across implants.[3]

The integration of artificial intelligence (AI) and machine learning into treatment planning is revolutionizing implant dentistry.[84] AI tools analyze CBCT scans to determine optimal implant angulations and predict outcomes based on individual patient anatomy, facilitating tailored treatment plans and better predicting implant success.[85]

Future developments in nanotechnology, bioprinting, and smart implant systems equipped with sensors to monitor healing and load distribution are poised to further enhance the field of pterygoid implantology, making treatments more accessible and efficient.[86]

CONCLUSION

pterygoid implants represent a highly effective and reliable solution for rehabilitating the severely atrophic posterior maxilla without the need for extensive bone grafting or sinus augmentation. By engaging dense cortical bone in the pterygoid region, these implants provide excellent primary stability, optimized load distribution, and high long-term success rates ranging between 91% and 95.5%. Advanced implant designs, tailored abutments, and precise prosthetic considerations further enhance their clinical performance and patient comfort.

Recent technological advancements, including digital workflows, guided surgery, and improved implant surface modifications, have increased the predictability and efficiency of pterygoid implant placement, enabling immediate or early loading protocols in many cases. Emerging innovations such as artificial intelligence in treatment planning, robotic-assisted surgery, nanostructured implant surfaces, and bioengineered materials are poised to revolutionize maxillary rehabilitation by improving precision, reducing complications, and expanding treatment accessibility.

Clinical evidence underscores the high patient satisfaction associated with pterygoid implants, noting improvements in function, speech, and esthetics following rehabilitation. While surgical expertise and thorough preoperative imaging with CBCT remain crucial to minimizing risks and complications, the consistent success documented across numerous studies validates pterygoid implants as a cornerstone in modern prosthodontics. As the demand for minimally invasive yet predictable full-arch rehabilitations increases, pterygoid implants stand out as an innovative and practical choice that balances surgical feasibility with durable functional and esthetic outcomes.

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