Journal of Chemical Health Risks
www.jchr.org
JCHR (2025) 15(5), 1420-1430 | ISSN:2251-6727

Zygomatic Implants: A Comprehensive Review of Indications, Techniques, and Clinical Outcomes

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(Received: 16 July 2025 Revised: 20 August 2025 Accepted: 20 September 2025)

KEYWORDS

Atrophic Maxilla, Bone Deficient maxillary arch, Pterygoid implants

Zygomatic implants

ABSTRACT:

Introduction:

Severe maxillary bone atrophy, congenital deformities, and maxillectomy defects present significant challenges for conventional dental implant placement due to insufficient bone volume and quality. Zygomatic implants (ZIs) offer a reliable alternative by anchoring in the dense zygomatic bone, providing stability and allowing for graft-free, immediate loading protocols.

Objective:

To provide a comprehensive overview of the indications, surgical techniques, biomechanical principles, complications, and outcomes of zygomatic implants in rehabilitating severely atrophic maxillae.

Methods:

A narrative review of current literature and clinical protocols was conducted, focusing on anatomical considerations, implant design, surgical techniques (Brånemark, ZAGA, Quad Zygoma, and Inverted Support Technique), prosthodontic planning, and biomechanical stability. The use of advanced imaging tools (CBCT, guided surgery) and treatment classifications (Bedrossian, ZAGA) were examined for treatment planning. Key clinical studies were reviewed to assess survival rates, complications, and functional outcomes.

Results:

Zygomatic implants demonstrated high survival rates ranging from 94.1% to 100% over 5 years. Immediate functional loading was feasible in most cases, providing prosthetic rehabilitation within 1–3 days. Complications such as sinusitis were reported in 5–6% of cases but were generally manageable. Biomechanical analyses showed that quad-cortical anchorage and cross-arch splinting significantly reduce stress concentration and implant displacement compared to bi-cortical stabilization. The Inverted Support Technique demonstrated high accuracy in implant placement and reduced surgical risks.

Conclusion:

Zygomatic implants represent an effective and predictable solution for the rehabilitation of severe maxillary atrophy where conventional implants are contraindicated. Their use reduces the need for bone grafting, minimizes treatment time, and achieves high stability and survival rates when proper surgical planning and prosthetic principles are followed. Despite potential complications, they remain a valuable tool in advanced maxillary reconstruction.

INTRODUCTION

The loss of teeth can significantly impact an individual's quality of life, affecting speech, Mastication, and aesthetics. Dental implants (also known as oral or endosseous implants) have been used to replace missing teeth for more than half a century[1].While conventional dental implants have revolutionized tooth replacement, they rely on anchorage within the jaw bone. However minimum amount bone width and height is an essential prerequisite for the successful placement of implants[2]. However, patients with severe maxillary bone atrophy face challenges in receiving traditional implants. Even more challenging are conditions such as cleft deformities, maxillary sinus aplasia, and maxillectomy defects which present a discontinuous maxilla and complex bony and soft tissue anatomy[3]. This is where zygomatic implants come into play. Zygomatic implants (ZI) have revolutionized the field of dental implantology, particularly for patients with severe maxillary bone loss where traditional implant procedures may not be feasible. These implants offer a solution by anchoring into the zygomatic bone. The zygomatic bone allows anchoring far from the occlusal level and presents regular and compact trabecular bone with 98% of bone density[4], providing stability and support for dental prostheses without the need for bone grafting procedures. The zygomatic bone, known for its density and strength, serves as a robust foundation for implant placement. This innovative approach was pioneered by Dr. Per-Ingvar Brånemark in the1980s, building upon his extensive research on osseointegration. Brånemark‟s work laid the foundation for modern dental implantology and paved the way for advancements such as zygomatic implants. One of the primary advantages of zygomatic implants is their ability to provide immediate load-bearing capacity, allowing for same-day delivery of fixed dental prostheses. Donor site morbidity is eliminated[5].This immediate function protocol has been shown to yield excellent clinical outcomes, as demonstrated in studies by Davó et al. (2017) and Maló et al. (2020). ZIs appear to show good survival rates in the short to medium term[6] .However, the success of zygomatic implant treatment relies heavily on proper patient selection, meticulous surgical technique, and comprehensive treatment planning. Advanced imaging modalities, such as cone beam computed tomography (CBCT), play a crucial role in preoperative assessment and surgical guidance. Based on 3D x-ray exploration, 2 several planning software options have been developed to facilitate zygomatic implant planning. Residual alveolar bone characteristics along with the curvature of the zygomatic bone are of utmost importance in decision making for defining the zygomatic implant critical zone and antrostomy zone[7].The main complication that seems to occur with ZIs is sinusitis, which can develop several years after their placement[8].

INDICATIONS OF ZYGOMATIC IMPLANTS

The main indication for zygomatic implants is completely edentulous patients with severe maxillary atrophy. It provides maxillary support in patients who are completely edentulous with significant sinus pneumatization and severe posterior alveolar ridge resorption.

The zygomatic implants are combined with two to four anterior maxillary axial implants[10].

Contraindications

Acute sinus infection, maxillary or zygoma pathology and patients unable to undergo implant surgery because of underlying uncontrolled or malignant systemic disease.

Relative contraindications include chronic infectious sinusitis, the use of bisphosphonates and smoking more than 20 cigarettes a day. Any pathology of the maxillary sinus should preferably be treated before placement of the zygomatic implant[10].

Anatomical Considerations for ZI Placment

A thorough understanding of the zygomatic buttress (ZB) is essential when placing zygomatic implants (ZIs), particularly in terms of its bone volume, density, and architecture. The ZB generally features a trabecular bone structure that supports osseointegration, along with a thick cortical layer that provides excellent primary stability during implant placement.

Anatomically, the zygomaticofacial nerve exits through the zygomaticofacial foramen (ZFF) and supplies sensation to the cheek in the zygomatic area. For surgeons, identifying the location of the ZFF is crucial to avoid nerve injury during implant placement.

The central region of the ZB is typically considered the safest site for anchoring the zygomatic implant, as the ZFF is less commonly located in that area[17]. Additionally, both the lateral wall of the orbital cavity and the infraorbital rim are often suitable anchoring zones for ZIs, depending on the patient’s anatomy.

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JCHR (2025) 15(5), 1420-1430 | ISSN:2251-6727

Implant design for zygomatic implant

The original zygomatic implant is a self-tapping titanium implant with a machined surface and is available in various lengths from 30 to 52.5 mm. The apical part has a threaded design with diameter of 4 mm and the crestal part has a diameter of 4.5 mm. The implant head is angulated at 45° and consists of an inner thread for the connection of Bränemark system abutments. The commercially available zygomatic implants have a roughened oxidized surface[12].

The Atrophic Maxilla

Severely resorbed maxillae challenge conventional implant placement due to poor alignment with prostheses[26]. Advanced techniques like bone grafting, sinus lifts, alveolar distraction, and guided regeneration improve outcomes. While implant success in adequate bone ranges from 84–92%, maxillary bone loss is common and complicates placement due to sinus pneumatization, centripetal resorption, nasal anatomy, and poor bone quality[26].

Broadly, treatment options for implant-based rehabilitation in an atrophic maxilla fall into two categories:

Bone augmentation procedures to rebuild the lost bone.

Specialized implant designs adapted to compromised conditions.

A helpful tool for making treatment decisions in these cases is the Bedrossian classification, which is a radiographic system that evaluates the quantity and distribution of available bone. It considers the spatial relationship between the alveolar ridge, nasal floor, and maxillary sinuses.

Type I refers to cases where the premaxillary region (zone II) has at least 10 mm of vertical height and 5 mm of width. In such situations, 2 to 4 standard implants can be placed in the anterior region (zone I), either axially or tilted—depending on how close the anterior sinus wall is. Since the implants are placed in native bone, there's no need for grafting and minimal risk of complications like fenestrations or dehiscence. In the posterior regions, one zygomatic implant on each side is typically placed, with the implant head emerging around the first molar position. This approach ensures a good antero-posterior (A-P) spread and eliminates the need for a distal cantilever, thereby enhancing prosthetic support[27].

Type 2A features an atrophic premaxilla with ~10 mm bone height and 3–5 mm width, allowing placement of two narrow implants (e.g., nasal/vomer) with possible grafting due to thin bone[27]. Posteriorly, a single zygomatic implant is placed per side, emerging near the second premolar.
Type 2B involves severe resorption with inadequate bone height, width, and angulation for implants, even with grafting[27]. Bilateral double zygomatic implants ("quad zygomas") are used, with platforms in the anterior canine/lateral incisor and posterior second premolar regions. This supports a prosthesis ending near the first molar, limiting cantilever[27].

For these complex clinical situations, the ideal zygomatic implant system should help the surgeon achieve predictable and stable outcomes. It must provide both mechanical strength and biological compatibility, ensuring long-term success and functional prosthetic rehabilitation. To make the right choice, it's essential to understand the selection criteria—the key features a zygomatic implant system should have to best meet the clinical demands.

Zygomatic Implant Dimensions and Design

Zygomatic implants are significantly longer than conventional implants, typically ranging from 30 mm to 62.5 mm in length. Most commonly, lengths between 30 mm and 52.5 mm are used[28]. The implant emergence can vary depending on the surgical technique and patient anatomy—it may exit through the palatal side or along the resorbed alveolar ridge[29].

To ensure optimal bone engagement and avoid vital structures, the apex of the implant is usually positioned infero-anterior to the 90° orbital rim, maximizing contact with dense cortical bone while keeping a safe distance from the orbital cavity[30]. The apical region often has aggressive threads, which enhance primary stability and enable immediate loading.

Cervical Design Types

Zygomatic implants come in different cervical configurations, adapted for specific anatomical situations:

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- Model I: Threaded and surface-treated at both the apex and cervical region—best used when there is sufficient alveolar bone for engagement.
- Model II: Surface-treated only at the apex—designed for extra-sinus placement in cases of severe maxillary atrophy.
- Model III: Fully threaded throughout the implant length. Some systems now offer unthreaded or smooth cervical zones (e.g., Neodent, Straumann) to promote soft tissue compatibility, or even threadless cervical designs (e.g., Nobel Biocare).

Implant Thickness and Fracture Risk

The diameter of zygomatic implants varies depending on the manufacturer. While implant fractures are rare, they can occur due to factors such as:

- Lack of splinting between implants,
- Excessive cantilevers in prosthetic design,
- Insufficient cervical bone support.

Surface Treatment and Bone Compatibility

Because the zygomatic bone is highly cortical and dense—especially due to masseter muscle insertion—it responds well to implants with surface-treated finishes, enhancing osseointegration[30].Surface coatings like hydroxyapatite, sandblasting/acid-etching, and antibiotic layers enhance osseointegration, reduce healing time, and improve implant stability, especially in compromised bone conditions. These coatings are critical for long-term success and improved prosthesis retention[60,61].

Insertion Torque and Handling

Zygomatic implants usually require high insertion torque. However, excessive torque can damage the implant or its components. For example, Titaniumfix recommends a maximum torque of 45 Ncm. It's also advised not to force the abutment assembler if resistance is felt during placement.

Prosthetic Components and Angulation

The implant head design varies:

- Angled heads (45° or 55°) are commonly used to align with the prosthetic path.
- Straight heads (0°) offer more flexibility in prosthetic planning and often eliminate the need for additional assemblers.

Mini-abutments with 17° or 30° angulation are used to correct access and emergence profiles. Straight abutments are typically avoided, as they may not suit the anatomical angulation.

Though palatal screw access is common in zygomatic implants, most patients tolerate it well.

A point to note: Titaniumfix systems offer limited abutment heights (usually 2–3 mm) and use side-inserted screws, which could become exposed if soft tissue dehiscence occurs[30].

Biomechanical Principles of Zygomatic Implants

Original Surgical Protocol

The Brånemark technique (OST)[52] involves drilling through the maxillary alveolus and sinus floor to reach the zygomatic bone. This achieves quad-cortical anchorage—two cortical contacts in the maxilla and two in the zygoma—providing strong initial stability and effective stress distribution[23].

Common Surgical Errors

Osteotomies initiated too far anteriorly or palatally, particularly by less experienced clinicians, may result in palatal implant emergence. This misplacement can compromise both function and prosthesis design.

Maxillary Sinus Health

Branemark's 2004[53] findings demonstrated that placing implants within the sinus did not induce infection or inflammation. The Schneiderian membrane often adapted by either partially or completely covering the implant, with no adverse effects noted.

Extra-Sinus Technique

Malo's 2008[54] adaptation utilized the natural curvature of the lateral sinus wall to place the implant outside the sinus cavity. While this simplifies surgery, it removes maxillary cortical support, relying entirely on the zygoma for anchorage—potentially reducing biomechanical effectiveness.

Stress Concentration and Implant Length

Studies consistently show that stress accumulates around the implant platform and adjacent 3–5 mm, regardless of the implant's overall length. This has been confirmed by multiple authors including Iplikcioglu, Akça, and Nishihara[55,56].

Fixation Types: Quad vs. Bi-Cortical

- Quad-cortical stabilization (QCS) engages both the maxilla and zygoma, offering greater mechanical stability.
- Bi-cortical stabilization (BCS) depends solely on the zygomatic apex for support, resulting in elevated stress levels.

Finite Element Analysis (FEA) Findings
Kato et al[57]used FEA models to compare cross-arch splinted (BBQ) and non-splinted (BBB) zygomatic implants. Results showed:

- QCS implants had minimal vertical displacement (11 µm),
- BCS implants had much higher displacement (300 µm), underscoring the importance of maxillary support.

Load Response Under Functional Forces
When subjected to 100 N vertical and 50 N horizontal forces:

- Splinted QCS implants experienced low apical stress (~40 MPa),
- Splinted BCS implants showed much higher stress (~857 MPa),
- Non-splinted BCS implants faced extreme stress levels (~1954 MPa), compared to just 58 MPa in non-splinted QCS implants.

Stress Transfer to Bone Structures

- QCS implants distribute forces efficiently, minimizing stress on the zygoma.
- BCS implants concentrate load on the zygomatic cortex and trabecular bone, increasing the risk of mechanical overload or fatigue.

Clinical Guidelines
Whenever possible (ZAGA types 0–3), surgeons should preserve and engage maxillary crestal bone to aid in stabilization. Although some post-placement bone resorption may occur, there is no conclusive evidence of total loss, and intentional bone removal is discouraged.

Treatment Planning: Radiographic Tools

- 2D Bedrossian Zone System divides the maxilla into:
  - Zone 1: Premaxilla
  - Zone 2: Premolar area
  - Zone 3: Molar area Zygomatic implants are indicated if bone is deficient in Zones 2 or 3.
- 3D ZAGA Classification evaluates lateral sinus wall concavity and palatal resorption. Approximately 93.8% of cases (ZAGA 0–3) permit platform anchorage. ZAGA 4 cases, however, often lack sufficient bone for this[23].

Prosthetic Implications
In patients with palatal resorption, implants may emerge more palatally—not due to incorrect angulation, but due to anatomical bone drift. The prosthetic design must accommodate this change to avoid complications.

Bone Quality and Load Handling

- Kato (2005)[57] observed variable trabecular density in the zygoma.
- Ujigawa (2007)[59] highlighted the zygomatic arch's role in bearing occlusal loads.
- Freedman (2013)[58] confirmed that removing crestal bone support significantly increases platform stress under functional loads.

Cross-Arch Splinting: A Key Principle
Linking zygomatic and anterior axial implants via cross-arch splinting reduces platform stress and ensures more even load distribution. Studies by Ujigawa and Bedrossian–Brunski (2023) emphasized that non-splinted zygomatic implants are biomechanically unfavorable and should be avoided.

Evolution of Zygomatic Implant Techniques[51]

1. Original Brånemark Technique (1980s)[51]
   - Used a palatal entry with implants routed through the sinus and anchored in the zygoma, typically in a two-stage surgical process.

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JCHR (2025) 15(5), 1420-1430 | ISSN:2251-6727

- While effective, the palatal emergence led to bulky prostheses and made hygiene difficult.

2. Sinus Slot Technique (Stella & Warner, 2000; Peñarrocha et al.)[31]
    - Introduced a slot window in the zygomatic buttress for better visualization.
    - Improved implant angulation and reduced palatal emergence but didn't eliminate oral-antral communication risks.
3. Exteriorized Approach (Miglioranza et al., Aparicio, 2006)[34]
    - Avoided entry into the sinus altogether by placing the implant outside it.
    - Enhanced prosthetic alignment and minimized sinus complications, though there's a risk of soft tissue recession.
4. ZAGA (Zygomatic Anatomy-Guided Approach, Aparicio, 2011–2012)[21]
    - Emphasized a patient-specific approach based on individual sinus wall anatomy.
    - Introduced ZAGA classification (0–4) and tailored implant trajectories (ZAGA Round & Flat).
    - Minimally invasive, with optimal prosthetic outcomes and reduced sinus trauma.
5. Quad Zygoma Technique[11]
    - Used in cases of extreme maxillary atrophy (anterior and posterior).
    - Places two zygomatic implants per side for full-arch support and immediate loading.
    - Requires careful spacing in the zygoma to prevent fractures[11].
6. Computer-Assisted Surgery (CAS)[24]
    - Incorporates CBCT imaging and real-time navigation for accurate implant positioning.
    - Enhances precision and reduces risks near critical structures but comes with high cost and technical demands[24].

<u>Complications of Zygomatic Implants and Their Management</u>

<u>Immediate (Surgical) Complications</u>

1. Orbital Floor Involvement
    - Caused by misaligned drilling too close to the orbit ("yellow line").
    - Preventive Measures: Preoperative CBCT and real-time guidance help avoid this[35].
2. Injury to Infraorbital Nerve (V2)
    - Results from aggressive retraction.
    - Minimized by gentle dissection and maintaining safe distance (6–10 mm from infraorbital rim)[35].
3. Subperiosteal Infection
    - Can occur if drill debris is not cleared.
    - Managed with proper irrigation and prophylactic antibiotics[36].
4. Periorbital Hematoma & Nosebleeds
    - Often due to trauma to surrounding vessels.
    - Managed with ice packs and hemostatic agents, and by avoiding over-dissection near key arteries[32].

<u>Delayed (Late) Complications</u>

1. Vestibular Dehiscence
    - Seen in extrasinus approaches where unsupported threads face soft-tissue pull.
    - Best avoided by following the traditional Brånemark technique and

educating patients (especially in ZAGA 4)[38,39].

2. Implant Failure
    - Often occurs during the osseointegration period (first 6 months).
    - Replacement is possible, typically with a different trajectory[40,41].
3. Fractured Implants
    - Linked to inadequate cross-arch splinting and excessive lateral forces.
    - Avoided by rigid splinting and minimizing cantilevers[43].
4. Sinus Complications
    - Most patients show benign mucosal thickening; symptomatic sinusitis is uncommon.
    - Treated with decongestants, humidification, and antibiotics when necessary[44].

Zygomatic Implant Survival & Prognostic Indicators

- Success Rates: 94.1–100% over 5 years[45].
- Key Predictors:
    - Bone quality—D3 bone poses more stress than D2[45].
    - Cross-arch splinting—minimizes mechanical failure[43].
    - Soft-tissue management—keratinized tissue is essential for long-term health[25].

Inverted Support Technique: A Modern Approach to Guided Zygomatic Implant Placement[24]

1. Digital Planning and Guide Design

- Imaging: High-res CT (<0.4 mm) with radiopaque stents.
- Software Integration: CBCT and intraoral scans merged using TRUMATCH CMF (Materialise).
- Implant Simulation: 3D virtual planning enables collaborative adjustments to length, angle, and position.
- Guide Features: Titanium guides with irrigation ports and screw fixation slots.

2. Surgical Protocol

- Incision: Mid-crestal with minimal vertical extensions.
- Guide Placement: Fixed securely on the maxilla or zygoma.
- Osteotomy: Grooves formed using diamond burs, preserving the Schneiderian membrane[24].
- Implant Insertion: High primary stability (≥40 Ncm) achieved in most cases.
- Indexing: Glide checks confirm prosthetic angulation.

3. Accuracy and Outcome

- Deviation Metrics: Comparison of planned vs actual placement using Geomagic software.
- Measured Parameters: Apex/platform deviation and angular discrepancy.
- Subgroup Analysis: Assessed by implant region (anterior/posterior, right/left).

4. Safety and Loading

- Complication Tracking: Avoids orbital intrusion, fracture, or implant failure.
- Loading: Immediate functional loading within 1–3 days in most cases.

Prosthodontic & Biomechanical Insights

Prosthetic Planning[24]

- Diagnostic Stents: Aid in preoperative orientation.
- Provisional Restorations: Allow for occlusal and esthetic testing.
- Final Prosthesis:
    - Cross-arch splinted framework minimizes stress.

- CAD/CAM technology ensures fit and long-term performance[24].

Biomechanical Stability

- Minimum Implants: 2 zygomatic + 2–4 anterior axial implants.
- Force Management: Reduced cantilever and balanced occlusion principles (per Beyron's guidelines)[24].

Conclusion

Zygomatic implants are a reliable solution for patients with severe maxillary bone loss where conventional implants are not feasible. Anchored in the dense zygomatic bone, they are especially useful in cases of failed implants, unsuccessful grafts, trauma, or tumor resection. Anatomically, the zygoma remains largely unaffected by jaw atrophy, retaining sufficient bone density and volume for implant placement.

Key benefits include:

1. Minimal grafting need, utilizing existing bone;
2. Reduced treatment time, often with single-stage placement;
3. Enhanced stability due to longer implant length.

Used alongside standard implants, zygomatic implants show high survival rates (96–100%). Although complications like sinusitis (5–6%) can occur, they are generally manageable with antibiotics. Overall, the potential for immediate loading and graft-free protocols makes zygomatic implants a valuable option in maxillary rehabilitation

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