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Zygomatic Implants in Modern Implant Dentistry: A Comprehensive Review

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ABSTRACT

Zygomatic implants have emerged as a predictable graftless solution for the rehabilitation of patients with severe maxillary atrophy, extensive bone loss, and failed conventional implant therapy. By anchoring in the zygomatic bone, they reduce the need for complex bone grafting and facilitate immediate loading in selected cases. Recent advances in implant design, digital planning, guided surgery, and prosthetic rehabilitation have significantly improved treatment outcomes. This review highlights the evolution, indications, implant design, surgical techniques, digital workflow, clinical outcomes, complications, and recent innovations in zygomatic implantology. Current evidence supports zygomatic implants as a reliable and effective treatment option with high long-term survival rates for the rehabilitation of the severely resorbed maxilla.

Keywords: Zygomatic implants; Implant rehabilitation; Digital dentistry

INTRODUCTION

The rehabilitation of patients with severe maxillary bone resorption remains one of the greatest challenges in implant dentistry.[1] Progressive alveolar bone loss following tooth extraction, periodontal disease, trauma, congenital deformities, maxillary sinus pneumatization, and tumor resection often results in inadequate bone volume for the placement of conventional dental implants. Traditionally, these patients required extensive reconstructive procedures, including autogenous bone grafts, sinus floor augmentation, Le Fort I osteotomy with interpositional grafts, or distraction osteogenesis. Although these procedures can provide satisfactory outcomes, they are associated with increased surgical morbidity, prolonged treatment duration, donor-site complications, additional costs, and variable graft resorption.[2,3]

The concept of zygomatic implants was introduced by Professor Per-Ingvar Brånemark in the late 1980s as an innovative alternative for rehabilitating patients with severely atrophic maxillae. Unlike conventional implants, zygomatic implants are considerably longer (typically 30–55 mm) and obtain primary stability by anchoring within the dense cortical bone of the zygomatic body rather than relying solely on the deficient alveolar ridge. This unique anchorage enables clinicians to provide fixed implant-supported prostheses even in cases where conventional implant placement is impossible without extensive bone augmentation.

Initially developed for patients undergoing maxillectomy following head and neck cancer surgery, the indications for zygomatic implants have expanded considerably. They are now widely used in the management of severe maxillary atrophy, failed implant rehabilitation, congenital craniofacial defects, trauma-related maxillary defects, and complex revision cases. Their ability to avoid bone grafting, reduce overall treatment time, and facilitate immediate loading has made them an increasingly popular treatment option.

Recent advances in digital dentistry have transformed zygomatic implant therapy. Cone-beam computed tomography (CBCT), virtual surgical planning, computer-guided implant placement, dynamic navigation systems, intraoral scanning, CAD/CAM prosthetics, and artificial intelligence-assisted planning have significantly improved surgical precision and prosthetic outcomes while reducing complications. Furthermore, modifications in surgical techniques—including intrasinus, extrasinus, sinus slot, and zygoma anatomy-guided approaches (ZAGA)—allow clinicians to tailor implant placement according to individual patient anatomy, improving soft tissue health and prosthetic emergence profiles.[4-6]

The purpose of this review is to comprehensively summarize the current evidence regarding zygomatic implants, including their historical evolution, anatomical considerations, indications, surgical techniques, digital workflow, prosthetic rehabilitation, clinical outcomes, complications, and future developments.

Indications for Zygomatic Implants: Zygomatic implants are indicated for patients with severe maxillary bone deficiency in whom conventional implant placement is not possible without extensive bone augmentation. They provide a graftless alternative for rehabilitating the severely atrophic maxilla by utilizing the dense zygomatic bone for primary stability. Common indications include severe edentulous maxillary atrophy (Cawood and Howell Class V or VI), failed implant or bone graft procedures, maxillary defects following tumor resection or trauma, congenital craniofacial anomalies such as cleft palate, and extensive posterior maxillary bone loss with sinus pneumatization. They are also suitable for patients who are medically unfit for bone grafting or prefer shorter treatment times. When combined with conventional anterior implants, zygomatic implants provide stable support for full-arch fixed prostheses and facilitate immediate loading in appropriately selected case.[4,7]

Implant Design: Zygomatic implants differ considerably from conventional dental implants because they are specifically designed to traverse the maxillary sinus and engage the dense zygomatic bone. Their unique geometry enables secure anchorage even in the absence of adequate alveolar bone.

Modern zygomatic implants are manufactured from commercially pure titanium or titanium alloy and are available in lengths ranging from approximately 30 to 60 mm, depending on patient anatomy. The apical threaded portion, typically around 4.0 mm in diameter, is designed to achieve firm fixation within the zygomatic bone, whereas the coronal portion is slightly wider (approximately 4.5–5.0 mm) to enhance stability at the crestal level.

Unlike conventional implants, zygomatic implants possess a 45° angulated prosthetic platform, facilitating proper prosthetic emergence despite their oblique trajectory through the maxilla. Contemporary implant systems incorporate moderately rough or oxidized surfaces produced through sandblasting, acid etching, or anodization to enhance osseointegration and long-term stability.

Recent design innovations include platform-switching concepts, improved thread geometry, tapered apical configurations, and soft tissue-friendly collar designs that reduce bacterial accumulation and improve peri-implant tissue health. Several manufacturers also provide customized abutments and digital prosthetic components compatible with CAD/CAM workflows.[7]

The Zygomatic Bone as an Anchorage Site: The zygomatic bone serves as the principal anchorage site for zygomatic implants because of its dense cortical architecture and favorable anatomical characteristics. Anatomically, the zygoma resembles a pyramidal structure that provides excellent bone quality and sufficient volume for achieving primary implant stability.

Histological studies have demonstrated that the zygomatic bone consists predominantly of dense cortical bone with well-organized trabecular architecture and bone density approaching 98%, making it one of the strongest bones of the craniofacial skeleton. This exceptional density contributes to excellent primary stability, which is essential for immediate loading protocols and long-term implant success.

The zygomatic bone has long been utilized in maxillofacial surgery as a stable anchorage site for fixation of facial fractures using miniplates and screws. It is also widely employed in orthodontics as a source of skeletal anchorage using temporary anchorage devices (TADs) and miniplates to facilitate complex tooth movements. In maxillofacial prosthetic rehabilitation, extraoral implants placed in the zygoma provide retention for orbital, nasal, and auricular prostheses following ablative surgery.

Following maxillectomy, zygomatic implants may be combined with conventional anterior implants to support fixed or removable implant-supported prostheses, restoring mastication, speech, facial aesthetics, and patient confidence. Cadaveric and radiographic studies have shown that the average thickness and dimensions of the zygomatic body provide adequate bone volume for secure implant anchorage while maintaining a safe distance from adjacent anatomical structures.

The success of zygomatic implants relies on careful preoperative evaluation using cone-beam computed tomography (CBCT), which allows accurate assessment of zygomatic bone volume, sinus anatomy, implant trajectory, and the relationship to critical structures such as the orbit and infraorbital nerve. With modern digital planning and navigation systems, clinicians can maximize the advantages of the zygomatic bone while minimizing surgical complications, making it one of the most reliable anchorage sites in contemporary implant dentistry.[8,9]

Patient Selection, Pretreatment Assessment, and Digital Treatment Planning: Successful zygomatic implant rehabilitation depends on careful patient selection, thorough pretreatment assessment, and meticulous digital planning. Ideal candidates include patients with severe maxillary atrophy, failed implant or bone graft procedures, maxillary defects due to trauma or tumor resection, and those requiring graftless full-arch rehabilitation with immediate loading. Contraindications include active sinus disease, uncontrolled systemic conditions, poor oral hygiene, heavy smoking, severe bruxism, inadequate zygomatic bone, and patients unable to maintain long-term follow-up.

Pretreatment evaluation involves comprehensive clinical and radiographic assessment. Clinical examination should assess residual ridge anatomy, occlusion, soft tissue condition, restorative space, and oral hygiene. Cone-beam computed tomography (CBCT) is the imaging modality of choice for evaluating residual bone volume, zygomatic bone anatomy, maxillary sinus condition, implant trajectory, and proximity to vital structures. Digital planning using CBCT, intraoral scanning, and virtual implant planning software enables prosthetically driven implant positioning, improves surgical accuracy, and minimizes complications, making it an essential component of modern zygomatic implant therapy.[10,11]

Digital Treatment Planning: Digital technology has revolutionized zygomatic implant therapy by improving surgical precision, reducing complications, and enhancing prosthetic outcomes. Modern digital workflows integrate diagnostic imaging, virtual planning, guided surgery, and CAD/CAM prosthetic fabrication into a comprehensive treatment protocol.

The digital workflow generally includes:

Intraoral or laboratory scanning to obtain digital dental models.

CBCT acquisition for three-dimensional evaluation of the maxilla and zygomatic bone.

Image fusion by superimposing CBCT data with intraoral scans.

Virtual implant positioning using specialized planning software.

Prosthetically driven implant planning based on the desired final restoration.

Fabrication of patient-specific surgical guides through 3D printing or milling.

Computer-guided or dynamic navigation-assisted implant placement.

CAD/CAM fabrication of provisional and definitive implant-supported prostheses.

Dynamic navigation systems provide real-time tracking of surgical drills, allowing greater flexibility than static guides while improving implant accuracy. Robotic-assisted implant placement and augmented reality navigation are emerging technologies that may further enhance surgical precision in the future.

Artificial intelligence (AI) is also increasingly being incorporated into implant planning software. AI algorithms can assist in anatomical landmark identification, segmentation of CBCT images, automated implant positioning, risk assessment, and prediction of treatment outcomes, thereby improving efficiency and reducing operator-dependent variability.[12-14]

Advantages of Digital Planning

Improved surgical accuracy and safety.

Better visualization of critical anatomical structures.

Prosthetically driven implant placement.

Reduced risk of sinus and orbital complications.

Shorter surgical time.

Improved prosthetic fit and long-term clinical outcomes.

Surgical Procedure: Zygomatic implant surgery is a technically demanding procedure that differs significantly from conventional implant placement because the implant traverses the maxillary sinus or its lateral wall to engage the body of the zygomatic bone. Successful treatment depends on detailed anatomical assessment, prosthetically driven planning, and precise surgical execution. Advances in digital technology have substantially improved the safety and predictability of this procedure by enabling three-dimensional planning, guided implant placement, and dynamic navigation.

The surgery may be performed under local anesthesia with conscious sedation or under general anesthesia, depending on the complexity of the case, the number of implants planned, patient anxiety, and associated reconstructive procedures. Strict aseptic protocols are mandatory throughout the procedure to minimize postoperative infection.

Following administration of anesthesia, a crestal incision with bilateral posterior releasing incisions is made to expose the maxillary alveolar ridge, lateral wall of the maxilla, zygomatic buttress, and anterior aspect of the zygomatic bone. Careful reflection of the full-thickness mucoperiosteal flap provides adequate surgical access while preserving soft tissue integrity for tension-free closure.

The implant trajectory is established based on the patient's individual anatomy. Contemporary treatment philosophies such as the Zygoma Anatomy-Guided Approach (ZAGA) recommend customizing the implant path according to the morphology of the maxillary wall and zygomatic buttress rather than following a single standardized route. Depending on anatomical conditions, implants may be placed using intrasinus, extrasinus, or extramaxillary approaches, each offering specific prosthetic and biological advantages.

Sequential osteotomy preparation is carried out using specially designed long drills under continuous sterile saline irrigation to prevent thermal injury. Osteotomy preparation proceeds from the residual alveolar crest toward the zygomatic body while maintaining the predetermined angulation. In many centers, computer-generated surgical guides or dynamic navigation systems are employed to enhance drilling accuracy and reduce the risk of damage to adjacent anatomical structures such as the orbit, infraorbital nerve, and maxillary sinus.

Implant length is selected according to the planned trajectory and zygomatic bone dimensions, typically ranging from 30 to 60 mm. High primary stability is achieved by engaging the dense cortical bone of the zygoma, frequently exceeding insertion torque values required for immediate loading. Depending on the treatment protocol, conventional implants may simultaneously be placed in the anterior maxilla to support a cross-arch prosthesis.

After implant insertion, multi-unit abutments are connected to correct implant angulation and establish an appropriate prosthetic platform. Flap closure is performed with interrupted or mattress sutures to obtain tension-free primary wound healing. Most contemporary protocols advocate immediate or early loading with a screw-retained provisional prosthesis when adequate implant stability is achieved, allowing rapid restoration of esthetics, speech, and masticatory function.

Recent technological developments—including robotic-assisted implant placement, augmented reality visualization, artificial intelligence-assisted planning, and patient-specific 3D-printed surgical guides—are further improving surgical precision and reducing operator-dependent variability. Nevertheless, successful outcomes continue to rely on comprehensive case selection, meticulous surgical technique, and careful postoperative monitoring.[15,16]

Prosthetic Rehabilitation: Prosthetic rehabilitation represents the final and most critical stage of zygomatic implant therapy, as long-term treatment success depends not only on implant survival but also on functional efficiency, esthetic integration, phonetics, oral hygiene maintenance, and patient satisfaction. Because zygomatic implants usually emerge more palatally than conventional implants, prosthetic planning must be performed before surgery to ensure an optimal restorative outcome.

Following successful osseointegration—or immediately after surgery in immediate loading protocols—prosthetic impressions are obtained using conventional open-tray techniques or digital intraoral scanning. Digital workflows incorporating CAD/CAM technology have significantly improved the precision of prosthesis fabrication while reducing laboratory errors and treatment time.

Definitive restorations are generally fabricated as screw-retained full-arch prostheses because they facilitate retrievability, maintenance, and management of biological or mechanical complications. Depending on patient requirements, prostheses may consist of titanium-acrylic hybrid restorations, monolithic zirconia, zirconia layered with ceramic, or titanium frameworks veneered with composite resin. Material selection should consider occlusal forces, esthetic demands, opposing dentition, and long-term maintenance requirements.

The prosthetic design should provide passive fit, favorable occlusal load distribution, adequate lip support, and sufficient clearance beneath the prosthesis to permit effective oral hygiene. Cross-arch splinting of zygomatic and conventional implants distributes functional stresses more evenly across the prosthetic framework while minimizing cantilever forces. Occlusal schemes are carefully adjusted to reduce excessive lateral loading and protect both implants and prosthetic components.

Patients treated with immediate loading protocols usually receive a screw-retained provisional prosthesis within 24–72 hours after surgery. This provisional restoration restores mastication, speech, facial appearance, and psychological well-being while allowing soft tissue maturation before fabrication of the definitive prosthesis.[17-20]

Recent Advances in Zygomatic Implantology: Over the past decade, zygomatic implant therapy has undergone remarkable advancements driven by innovations in digital dentistry, biomaterials, surgical navigation, and prosthetic rehabilitation. These developments have enhanced surgical precision, reduced complications, improved patient comfort, and expanded the indications for zygomatic implants in the management of complex maxillary defects.

Digital Treatment Planning and Virtual Surgery: Three-dimensional planning using cone-beam computed tomography (CBCT) combined with intraoral scanning has revolutionized preoperative assessment. Virtual implant planning software enables prosthetically driven implant positioning by accurately evaluating the residual maxillary bone, zygomatic anatomy, maxillary sinus, and adjacent vital structures. This digital workflow facilitates precise implant angulation, optimal prosthetic emergence, and predictable treatment outcomes while minimizing surgical risks.[21]

Static Guided Surgery: Computer-aided design and computer-aided manufacturing (CAD/CAM) technology has enabled the fabrication of patient-specific surgical guides. Static surgical guides assist clinicians in reproducing the preplanned implant trajectory with greater accuracy, particularly in anatomically challenging cases. Guided surgery reduces operative time, improves implant positioning, and decreases the likelihood of injury to the orbit, infraorbital nerve, and maxillary sinus.[22]

Dynamic Navigation Systems: Dynamic computer-assisted navigation provides real-time tracking of surgical drills during implant placement. Unlike static guides, navigation systems allow intraoperative modifications according to clinical findings while continuously displaying drill position relative to the patient's anatomy. Several studies have demonstrated improved angular accuracy, reduced deviation at implant entry and apex, and enhanced surgical confidence with navigation-assisted zygomatic implant placement.[23]

Zygoma Anatomy-Guided Approach (ZAGA): The introduction of the Zygoma Anatomy-Guided Approach represents one of the most significant conceptual advances in zygomatic implant surgery. Rather than using a standardized implant pathway, ZAGA individualizes implant placement according to each patient's maxillary wall morphology and zygomatic anatomy. This patient-specific approach reduces sinus complications, improves soft tissue health, enhances prosthetic emergence profiles, and provides superior long-term functional outcomes.[24]

Improved Implant Surface Technology: Modern zygomatic implants incorporate moderately rough, sandblasted, acid-etched, or anodized titanium surfaces that enhance osseointegration by promoting faster bone formation and stronger bone-implant contact. Optimized thread geometry and tapered implant designs further improve primary stability while reducing insertion trauma.[25]

CAD/CAM Prosthetic Rehabilitation: Digital prosthodontics has significantly improved the precision and efficiency of zygomatic implant rehabilitation. Intraoral scanners, digital impressions, CAD/CAM frameworks, and monolithic zirconia prostheses provide excellent passive fit, improved esthetics, reduced laboratory errors, and simplified maintenance. Customized multi-unit abutments further optimize prosthetic alignment despite the angulated trajectory of zygomatic implants.[26]

Robotic and Augmented Reality-Assisted Surgery: Robotic-assisted implant placement and augmented reality (AR) navigation represent the next generation of implant surgery. These technologies provide enhanced visualization, precise instrument guidance, and improved hand–eye coordination, potentially reducing operator-dependent variability. Although currently limited to specialized centers, these innovations are expected to become increasingly integrated into routine clinical practice.[27]

Future Perspectives: Future developments in zygomatic implantology are likely to focus on fully digital workflows, AI-assisted diagnosis, robotic navigation, smart implant surfaces with antimicrobial coatings, bioactive surface modifications, patient-specific implant designs, and regenerative approaches that combine tissue engineering with implant rehabilitation. These innovations are expected to further improve treatment predictability, reduce complications, and enhance long-term clinical outcomes.

CONCLUSION

Zygomatic implants have become a predictable and effective treatment option for the rehabilitation of patients with severe maxillary atrophy and complex maxillary defects. Their ability to provide stable anchorage without extensive bone grafting reduces treatment time, surgical morbidity, and overall cost while enabling immediate loading in selected cases. Advances in digital planning, guided surgery, implant design, and prosthetic rehabilitation have further improved clinical outcomes and long-term success.

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