Secondary Reconstruction of the Zygomaticomaxillary Complex

Hessah M. Aman, DDS[1] Abdulrahman Alenezi, MB, Bch, BAO[2] Yadranko Ducic, MD, FRCS(C), FACS[3] Likith V. Reddy, DDS, MD, FACS[1]

[1] Department of Oral and Maxillofacial, College of Dentistry, Texas A&M Health Science Center, Dallas, Texas
[2] Department of Otolaryngology - Head and Neck Surgery, University of Manitoba, Manitoba, Canada
[3] Otolaryngology and Facial Plastic Surgery Associates, Fort Worth, Texas

Address for correspondence Likith V. Reddy, DDS, MD, FACS, Department of Oral and Maxillofacial Surgery, College of Dentistry, Texas A&M Health Science Center, 3302 Gaston Ave., Dallas, TX 75246 (e-mail: lreddy@tamu.edu).

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Abstract

Zygomaticomaxillary (ZMC) fractures are the second most common facial fractures after nasal bone fractures. The zygoma, with its location and multiple points of articulations, lends itself to both facial structure and esthetics. Secondary ZMC deformities are complications of inadequate primary correction, delayed repair, or lack of repair. Secondary revisions of ZMC aim to correct ZMC displacement and projection and to address orbital discrepancies. Extensive correction involving significant orbital and malar defects requires zygomatic repositioning osteotomies and would greatly benefit from the utilization of virtual surgical planning, intraoperative navigation, and imaging. Minor corrections in malar projection can be corrected by onlay grafting and soft tissue augmentation and resuspension. Isolated or minor orbital corrections can be managed by autogenous or alloplastic material to restore lost orbital volume and anatomy.

Keywords
- ► ZMC
- ► secondary reconstruction
- ► enophthalmos
- ► onlay graft
- ► surgical navigation

The zygoma is one of the most frequently injured facial bones due to its prominence and location. Ideal primary reconstruction is not always achieved, especially in the setting of post-traumatic injuries, and complications of secondary deformities pose significant challenges even to experienced surgeons.

The zygoma is the cornerstone of the midface. It is a thick quadrangular bone that forms two-thirds of the orbital floor and lateral wall. It provides the most anterolateral projection where it helps dissipates forces along the cranial base, augmenting the midface's strength and stability. The prominence of the zygoma relates to its five points of projection articulating with the frontal, sphenoid, temporal, and maxillary bones. Most fractures occur at or near these articulations.

A thorough history of the injury, physical examination, obtaining the pertinent imaging studies (i.e., computed tomography [CT] imaging) followed by a careful and organized evaluation of facial symmetry, bizygomatic width, orbital positions, and occlusion are crucial steps before treatment initiation.[1]

Principles of successful secondary reconstruction of the zygomaticomaxillary (ZMC) fractures hinge on the rebuilding of the midface height, width, and projection. Secondary deformities of the ZMC arise from delay in diagnosis, late corrections, or inadequate reduction of the zygoma. The majority of unfavorable outcomes relate to the zygomatic complex's improper three-dimensional orientation, which leads to failure to restore facial dimensions and contours. Poor cosmetic results and often enophthalmos are the most common complications. A displaced zygoma will result in facial widening and inadequate malar projection. Exophthalmos occurs when the zygoma is medially displaced, effectively reducing the orbital volume. In contrast, enophthalmos and ocular dystopia are manifestations of abnormal globe position due to increased orbital size and lateral canthus's malposition (►**Fig. 1**).

ZMC secondary correction shares the same principles of primary corrections of the zygomatic complex. There are two goals to the surgical treatment: (1) restoration of facial

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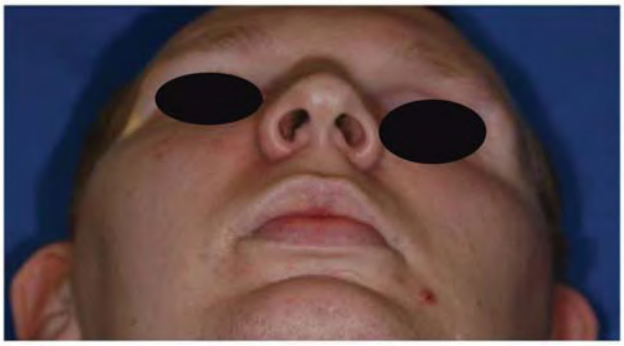

Fig. 1 Secondary deformity due to poor zygoma reduction (loss of projection and enophthalmos).

projection and facial symmetry and (2) restoration of orbital volume, globe position, and shape of the affected palpebral fissure. The golden window of correction is 4 months from the time of injury.[1]

Modalities for ZMC deformities' secondary corrections depend on the time of correction and the extent of deformities (►**Fig. 2**). Older defects will most likely require to be reosteotomized as well as bone grafting. More substantial revisions would sometimes require a combination of reosteotomy, repositioning, supplemental bone grafting, and high-density polyethylene/silicone malar implants. At the same time, minor defects can be managed with augmentation or reduction procedures, as well as attempts to camouflage the asymmetry with fat injections, and dermal fillers for soft tissue resuspension.

Zygoma Osteotomy

Secondary correction of the ZMC comes with its inherent challenges. Depending on the correction time, some or all landmarks and fresh fracture lines of the original anatomy can be lost to remodeling and scarring. The role of osteotomies is to recreate fracture lines. The extent of the said fracture, number of sutures interrupted, and loss of articulation directly affect the surgeon's ability to assess the zygoma's spatial orientation and location intraoperatively.

Different methods have been described to aid in ZMC intraoperative positioning. Traditionally and prior to the availability of newer technologies, surgeons often relied on temporarily fixing the zygoma into the new position and then assessing the reduction grossly on the table. Although the operating time might be reduced with this method, errors and chance of inadequate correction are more common.

However, direct examination of fracture reduction of the zygomatic sphenoid suture at the lateral orbital wall seems to be the most reliable assessment for adequate reduction. In most cases, reestablishing the normal anatomy and position of the ZMC also reestablishes the orbital floor continuity. The exception is with severe comminution along the orbital floor, as in high-velocity injuries, in which defects persist despite complete zygomatic reduction.

Surgical Planning and Guides

Innovations in surgical planning and intraoperative navigations and imaging have greatly improved the surgical outcome's predictability and success. CT imaging is an integral part of diagnosis and treatment planning. Utilizing initial CT imaging with CAD/CAM (computer-aided design/computer-aided manufacturing) technology allowed surgeons to recreate lost anatomy due to posttraumatic injury and remodeling in delayed healing. Virtual surgical planning uses CT imaging to produce a three-dimensional (3D) reconstructed mirror image of the unaffected side. Based on the data obtained, a surgical approach for osteotomies, final repositioning, and fixations are formulated.

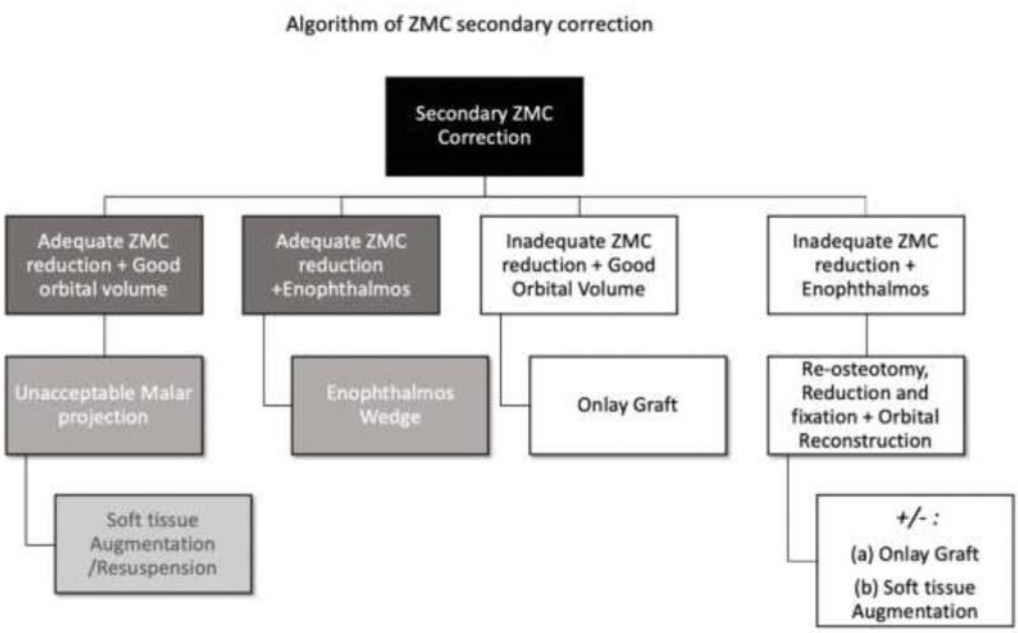

Fig. 2 Algorithm of ZMC secondary corrections. ZMC, zygomaticomaxillary.

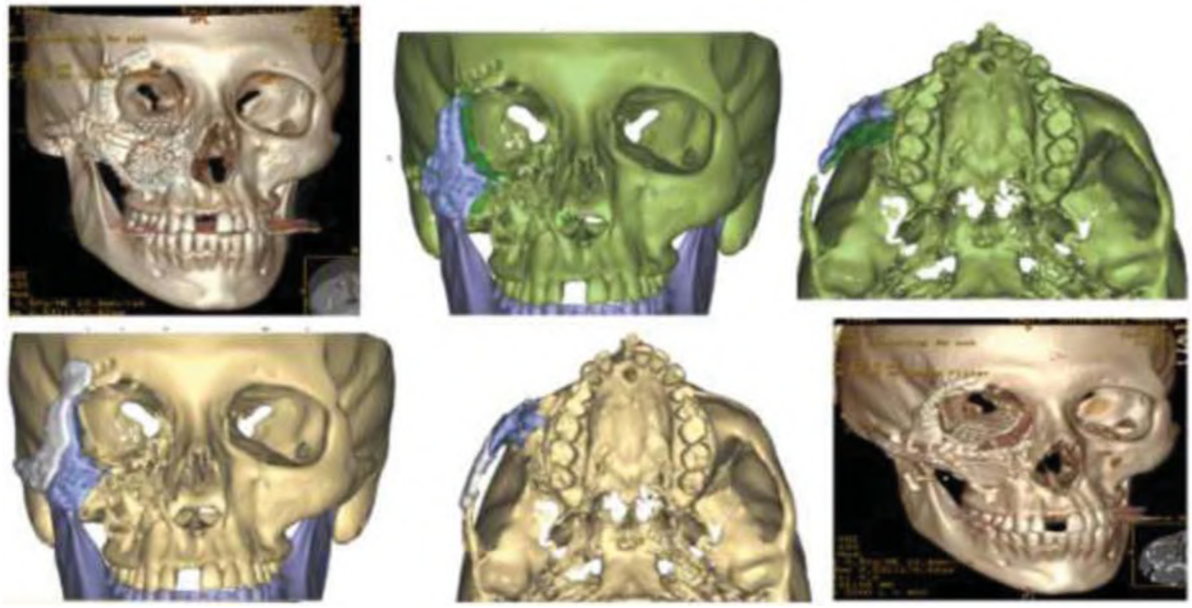

Fig. 3 Virtual surgical planning: demonstration of the proposed midface reposition (top middle and top right) and excision guide (lower left, middle left).

The customized cutting guides minimize errors in estimating the ideal locations to place osteotomies. At the same time, preplanned fixation guides and prebent plates provide the best fixation scheme. Virtual surgery planning and custom cutting guides and plates are quickly becoming the standard of care for facial reconstruction. Cutting guides provide the ideal cuts for proper reduction and fixation of a displaced ZMC, significantly reducing estimation errors to the table.

The use of intraoperative navigation has made strides in complex facial reconstruction. These systems open a prompt feedback window to the surgeon. A surgeon can quickly assess the restoration of the displaced segment orientation, volume, and reduction by comparing the healthy contralateral side with the affected side or using a mirror image of the unaffected side as a map to restore damaged areas (►**Fig. 3**).

Intraoperative Navigation and Imaging

Intraoperative monitoring technologies allows for a real-time comparison between the planned procedure and what is achieved on the table. Intraoperative navigation and imaging confirm the proper final positioning with reported precision of less than 2 mm.[2] It facilitates an unobstructed assessment of all articulation points, zygomatic arch contours, and orbital floor accurately. With C-arm or O-arm used in most institutions, intraoperative CT is becoming a standard of care. Although some believe that imaging adds time to the surgery, it provides invaluable information and, most importantly, reduces the potential of a second surgery for corrections. This is especially true as an accurate assessment of a repositioned zygoma or attempted orbital reconstruction is extremely difficult to achieve in the operating room due to the overlying soft tissue, onset of swelling, or tissue dissection (►**Fig. 4**).

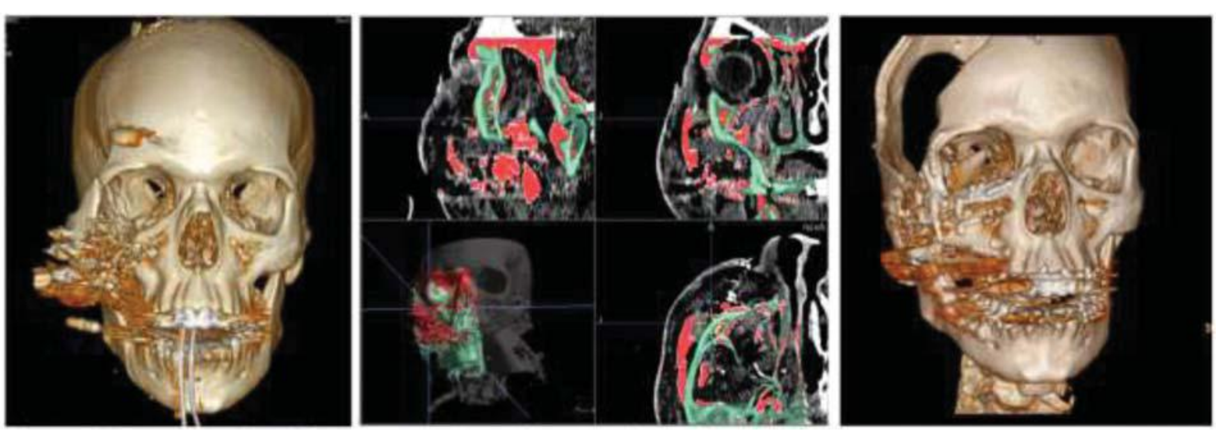

Fig. 4 Zygoma and orbit reconstruction with mirroring and navigation.

Malar Augmentation

Minor secondary deformities from zygoma malposition can be managed by onlay grafting and recontouring. Grafting material used must be biocompatible, dimensionally stable, and amendable to skeletal fixation. Onlay site and extent of augmentation should be established preoperatively. Depending solely on the intraoperative judgment is not recommended as overlying soft tissue distorts due to surgical access, edema, and the presence of endotracheal tube. Also, overcorrection and stabilization to maintain the desired contours of bony onlay graft are essential given the fact that the graft will most likely have some resorption over time.[1] Onlay grafts include autogenous grafts (calvarial, rib, and iliac crest), alloplastic implants, or more recently customized polyetheretherketone (PEEK) implants.

Patient-specific implants have gained popularity now more than ever. Those are implants that are created with a specific prescription to fit a patient's defect specifically. A preoperative CT provides data to be shared with the implant manufacturer.

Custom 3D-printed PEEK implants have gained popularity in craniofacial reconstruction due to their well-documented favorable qualities. Recent studies have shown that PEEK implants demonstrated higher clinical efficacy compared with precontoured plates in orbital volume and shape reconstruction.[3] PEEK is a semicrystalline and thermoplastic material. Its modulus of elasticity closely resembles that of cortical bone. It is biocompatible, stiff, lightweight, fatigue, and chemical-resistant. It is degradation proof with sterilization. PEEK implants are easy to contour intraoperatively with high-speed burrs and are amendable to fixation with conventional plates/screws. It is also a nonmagnetic material eliminating artifacts in CT/MRI (magnetic resonance imaging) images, which facilitate postoperative monitoring.[4]

Orbital Involvement

Injuries to the orbital skeleton commonly complicate injuries to the midface. The literature cites a range of 2.7 to 90.6% of concurrent ophthalmic injuries.[5] While evaluating an orbital fracture, a surgeon must investigate the fracture mechanism, fracture pattern (lateral wall/floor versus blow out), any associated periorbital deformity, and the presence of orbital dystopia, diplopia, and vision loss.[6] The orbit's open face is truncated in a manner that the lateral wall is behind the axis of the globe and the medial wall is in the front of it. The anteroposterior position of the eye following trauma is dependent on the integrity of the orbital cavity and volumetric changes posterior to the globe meridian.[6]

Enophthalmos can be a cause of secondary correction or a result of the secondary correction. The zygomatic repositioning may increase orbital volume, creating a larger orbit and subsequently leading to enophthalmos.

In general, patients experiencing persistent enophthalmos after ZMC fractures correction would benefit from reosteotomy of the zygoma with complete reduction of the displaced bone, rigid fixation in the new position, and intraorbital volume replacement by orbital implants (grafting, floor plating).

Access to the orbit's lateral wall is gained through coronal or hemicoronal accesses. Access to the orbital floor is mainly through a transconjunctival or lower eyelid incision.

Enophthalmos

Several etiologies have been investigated to explain the development of enophthalmos following ZMC fractures, such as increase in bony orbital volume, soft tissue contracture, orbital fat atrophy, and musculature contracture. All have been described and investigated; however, the increases in size and shape of the posterior orbit segment from conical/pyramidal to round behind the axis of the globe remain the most well studied and understood reasons.[7]

In ZMC fractures, the zygoma usually is displaced laterally and inferiorly secondarily to masseteric pull, thus increasing the intraorbital space. As a result, the volume ratio of soft tissue and bony orbit behind the globe's axis is lowered. The combination of natural posterior-inferior vector of orbital floor concavity, gravity, and extraocular muscles pull that originates from the orbit's apex, all position the globe in a retruded position once that ratio balance is violated. Studies have provided a wide range of 0.4 to 1 mm in enophthalmos for every 1 cm^3 increase in bony orbital volume.[8] Enophthalmos often develops due to an inadequate reduction of the ZMC fracture primarily. Persistent diplopia is the most debilitating functional complication.

After zygomatic reduction, both globes are compared for any discrepancies of anteroposterior projection and vertical position. If enophthalmos persists, it is mostly due to inadequate mobilization and reduction of ZMC fracture. The surgeon must consider inadequate repositioning of the zygoma first before deciding to add intraorbital volume to compensate.[6]

Enophthalmos wedge is a porous polyethylene implant. The implant is inserted in a subperiosteal plane posteroinferior to the globe to recreate posterior orbit anatomy and resuspend orbital soft tissue. Detailed planning and preoperative and intraoperative imaging are necessary (►**Fig. 5**).

Diplopia

Diplopia can be either monocular or binocular; a distinguishing diagnosis is made by covering one eye. Monocular diplopia occurs due to lens disturbances or displacement along the visual axis and persists once one eye is closed. Binocular diplopia resolves after occlusion of one eye. It occurs secondarily to trauma due to edema/hematoma, muscle entrapment/paresis, nerve damage, herniation of orbital content, or displacement of the globe suspensory ligaments. A displaced globe in an expanded bony orbit is unable to functionally compensate for the anteroposterior or vertical discrepancies of the globe position, leading to double vision perception.

Orbital Reconstruction

Secondary enophthalmos from ZMC fractures require orbital implants to recreate the posterior orbit's internal anatomy and replace lost volume. The superior and lateral bony orbit is accessed through a coronal or hemicoronal incisions, whereas the orbital floor is accessed with transconjunctival

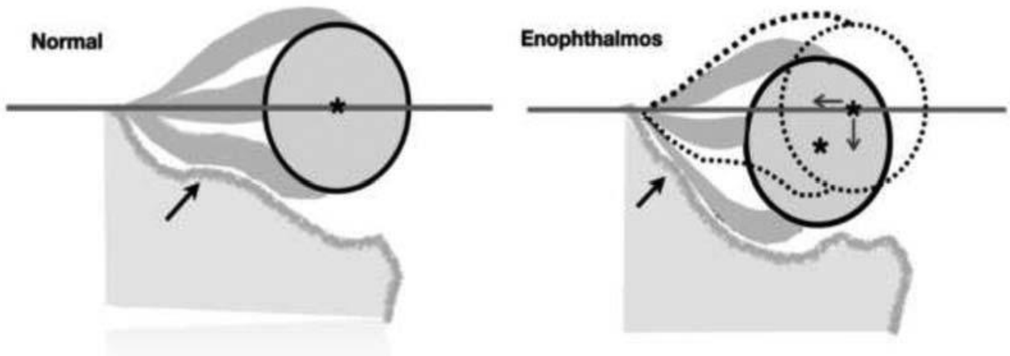

Fig. 5 Posttraumatic alteration of the posterior orbital floor and the corresponding change in the globe position.

or lower eyelid incisions. Multiple options for implant material are available. Although there is no unanimous opinion favoring one option over the other, in theory, such an implant is readily available, resorbable, biocompatible, easy to contour, and easy to use, and has the strength to support the orbital contents.[9]

Calvarial bone has been a popular choice for autogenous bone grafts in orbital reconstruction. It is readily available with inherent contours, does not require a separate incision to harvest, and is resistant to resorption. In contrast, other autogenous bone grafts have shown variable and unpredictable resorption patterns.[10] There are two forms of autogenous bone grafts, namely the cortical and the cancellous grafts. Cancellous grafts are revascularized faster than cortical bone, however, with less strength and usually require additional support. This is especially true when reconstruction is required for significant defects, in which minimal support exists for the graft at the site.[11] In terms of obtaining the grafts, they are obtained from several primary donor sites that include the mandible, iliac crest, calvarium, and the anterior wall of the maxillary sinus.[12] The main advantage of its use was that it was readily available, biocompatible, and incorporated in new bone growth. However, the use of autogenous grafts has declined on account of donor site morbidity.

Numerous alloplastic materials have been described and studied for orbital floor reconstruction. Most of the alloplastic materials described in the literature allow the added benefit of sparing donor-site morbidity and shorter operative time. Alloplastic grafts are two major groups, porous or nonporous. Titanium mesh is the most popular nonporous alloplastic material used for facial fractures. It is malleable, biocompatible, and visible on radiographic imaging. Most manufacturing companies provide precontoured, anatomical plates. It also allows the coverage of a larger area of disruption, can be used alone or in conjunction with bone grafts, and has a low infection rate.[13] Its disadvantages include difficulty in insertion due to sharp edges interferences and difficulty in removal due to fibrovascular ingrowth.[12]

Medpor (porous polyethylene) is a porous alloplastic material that has been commonly used with excellent clinical results. In a study published by Romano, the Medpor implant was used in a series of 140 patients who sustained facial trauma. These injuries included those of zygomatic complex fractures, delayed fracture repair, Le fort injuries, and delayed onlay augmentation. Results were very satisfactory, with only one reported implant infection with no cases of migration or exposure.[14]

The main advantage of Medpor is that it is available in various thickness sheets. It is malleable yet sturdy and allows fibrous growth. The documented cases of Medpor implant infections are low, and as a growing trend in practice, most surgeons soak the implant in antibiotic solution before insertion.

A hybrid material of titanium-embedded porous polyethylene provides the workability, strength, and radiopacity of the titanium and the potential of fibrous ingrowth of Medpor. Fixation is easy, with one screw in most cases. Complications are rare, mostly as vertical overcorrection because of the thickness of the implant have been reported.[12]

Although the type of material of the orbital implant has been a subject of debate between surgeons, the implant's precise placement is the primary subject. Before implant placement over the orbital floor, the surgeon must expose the fracture's full extent and directly visualize the posterior shelf stop. The orbital floor slopes superiorly toward the apex of the orbit; this would place the posterior shelf superior to the orbital rim. Maintaining this spatial concept prevents the placement of the implant in the maxillary sinus (►**Fig. 6**).

Orbital Implant Fixation and Wound Closure

As with all technique-sensitive procedures, the surgeon's experience and skills are major outcome determinants. With orbital implants fixations and wound closure, the debate centers around whether to fixate the implant or not and if the closure of periosteum/conjunctiva is necessary or not.

The fact remains that a wide range of options, approaches, and techniques are adopted. In regard to implant fixation, the importance of placing and resting the implant on the sound bone is agreed upon. In orbital floor fractures, as an example, the posterior ledge or the vertical part of the palatine bone is a favorable location for resting the implant. The question then remains if the implant requires placement of screws in the infraorbital rim or not. This is usually dependent on the clinical scenario, the degree, and complexity of the fracture, and the surgeon's clinical experience.

There is no consensus on whether the periosteum should be closed or left open in terms of wound closure.

Fig. 6 Correction of zygoma projection and severe enophthalmos with cranial bone.

Theoretically, closing the periosteum provides an added stabilization for the repaired fracture site. One of the noted complications is the development of entropion. Depending on the surgeon and skills in achieving meticulous closure, the odds of developing entropion, as the conjunctiva is inadvertently sutured to the periosteum, is quite low. However, it is a known drawback and potential complication in the transconjunctival approach that one must be aware of during the management of orbital trauma.

Conclusion

In secondary deformities of the ZMC, proper early diagnosis and appropriate primary correction are critical; however, they are not always feasible or attainable. With extensive secondary ZMC deformities, reosteotomy and repositioning of the displaced ZMC would provide optimal results. When the deformity is complicated with orbital involvement, such reduction and orbital reconstruction are often corrective. If the involved ZMC deemed to have adequate reduction but lacks projection, an onlay graft can restore the lost facial balance.

Conflict of Interest
None declared.

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