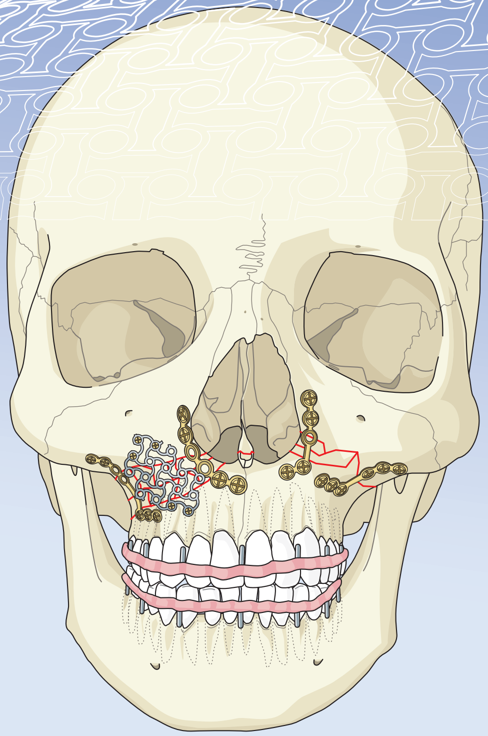
3 Midfacial fractures



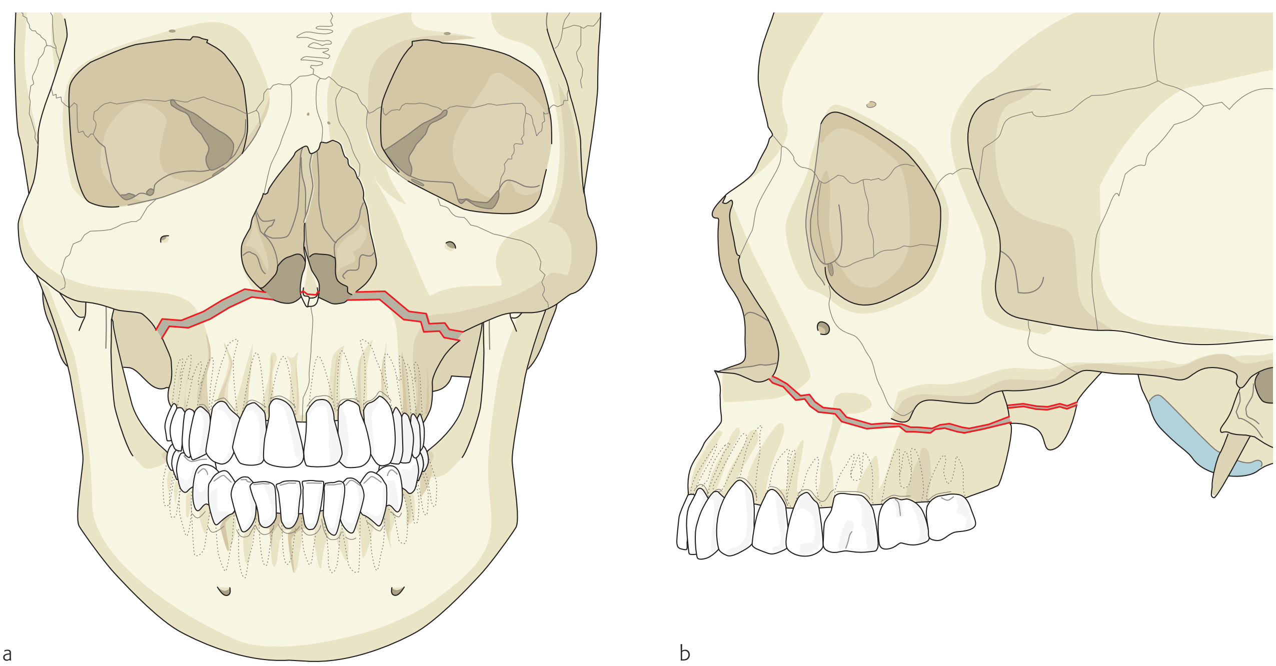
Author Ricardo Cienfuegos

3.1 Lower midface (Le Fort I and palatal fractures)

1 Definition

Le Fort I or Guérin fractures are central midface fractures, located transversally above the dental apices, disjoining the maxilla just above the alveolar process together with the hard palate and the pterygoid processes typically in a single block. The fracture runs horizontally, crossing through the base of the maxillary sinus and the lower border of the piriform aperture (**Fig 3.1-1a–b**).

Central midface fractures were classified in three types by René Le Fort in 1901, referring to low-energy impacts. Today, however, those classic patterns are seldom found, since many Le Fort fractures are caused by high-energy mechanisms, often with comminution and combinations of fracture type. Commonly, with high-energy injuries and oblique force vectors, the fracture is higher on one side than on the other.



a b

Fig 3.1-1a–b Le Fort I fracture, located transversally above the dental apices and disjoining the alveolar process, the hard palate, and the pterygoid processes.

Intrapalatal fractures are present in 8–15% of Le Fort fractures, or they may be part of more complex injuries. They usually follow a sagittal or parasagittal direction, splitting the maxilla longitudinally close to the midline (**Fig 3.1-2a–b**). They are associated with rotational instability of dentoalveolar segments.

Palatal fractures mostly exit anteriorly between the central incisors, or between the lateral incisor and the canine tooth. They may also surround the tuberosity of the maxilla, separating a dentoalveolar segment containing the molar teeth with superior, lateral, and posterior displacement.

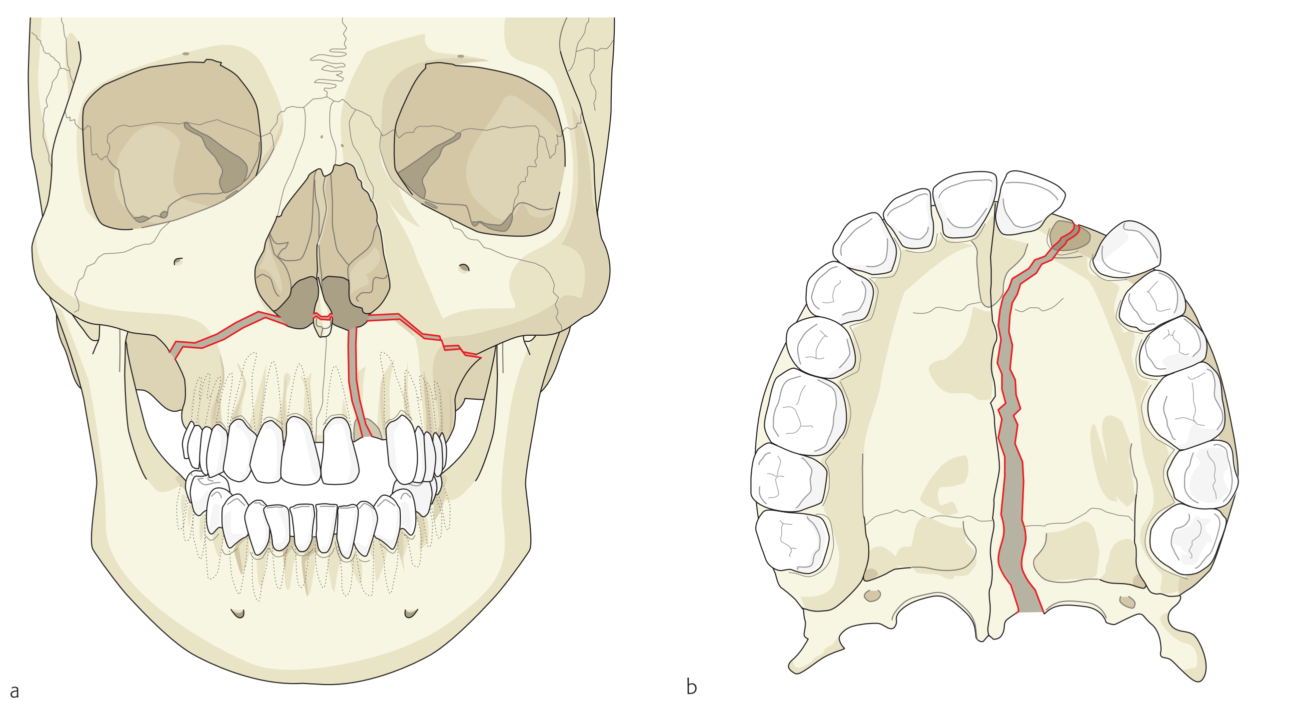


Fig 3.1-2a–b Le Fort I fracture combined with a sagittal palatal fracture. The maxilla is split longitudinally close to the midline.

2 Imaging

Diagnosis should initially be clinical, aided by imaging studies. Maxillary fractures are confirmed by axial, coronal, and sagittal CT scans. Plain x-rays are of minor value. CT scans provide detailed images of fracture patterns, degree of comminution, or bone loss (**Fig 3.1-3a–b**). 3-D reconstruction gives information on the degree of displacement of the midface in relation to the mandible and the orbits.

Special care should be taken when diagnosing fractures in edentulous patients, or in those wearing dentures. A complete superior denture may act as a splint, directing the fracture forces toward different areas in the midfacial skeleton.

If an adequate clinical and imaging diagnosis is not made, Le Fort I fractures with extension to the infraorbital rim may be incorrectly diagnosed as Le Fort II, especially on the basis of plain x-rays. Differential diagnosis depends on the presence or absence of fractures in the frontonasal region. Coexisting mandibular fractures, especially subcondylar fractures, should also be excluded.

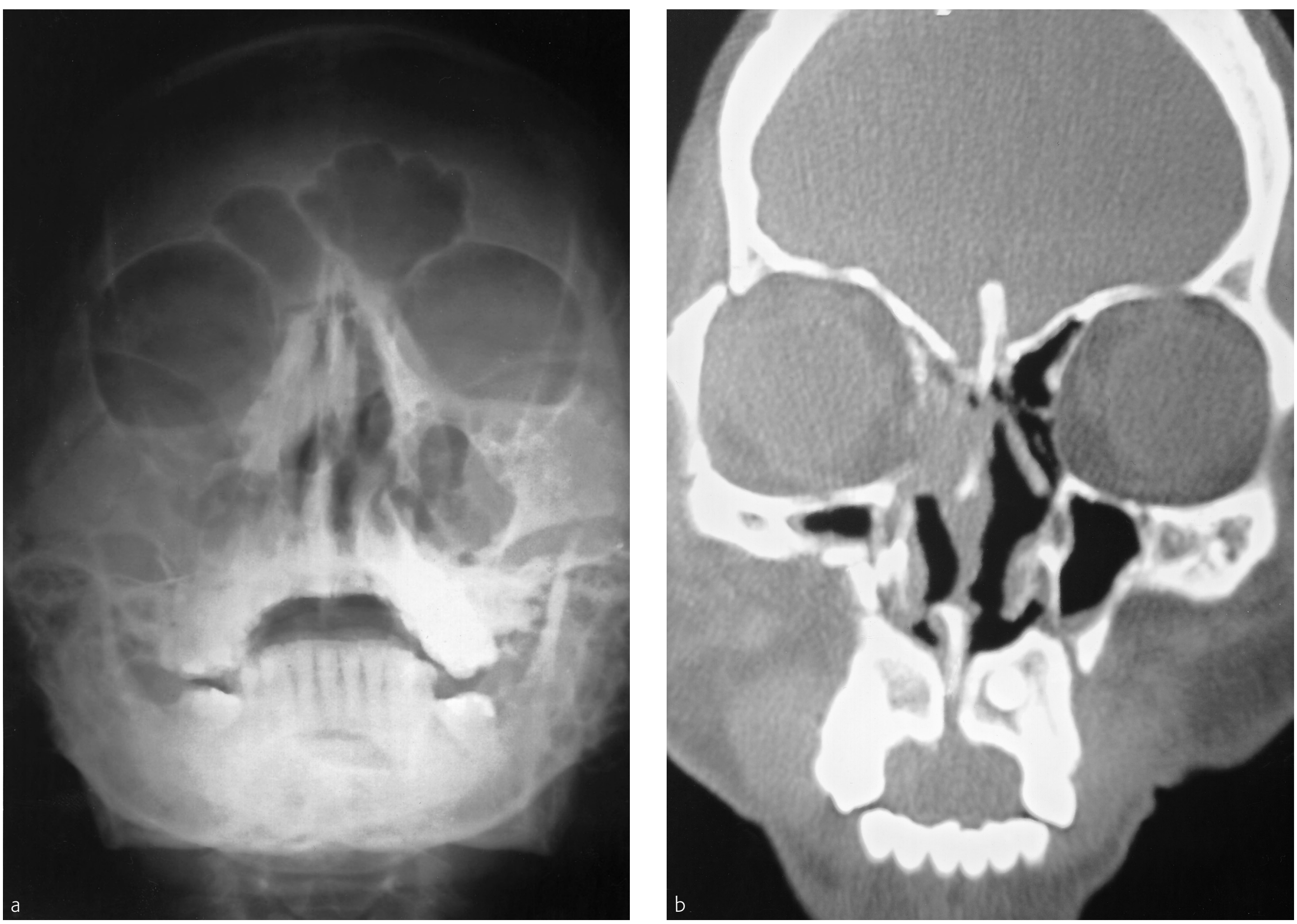


Fig 3.1-3a–b Preoperative evaluation
a X-ray (Waters' view) showing Le Fort I fracture.
b CT scan (coronal view) documenting a Le Fort I fracture in more detail.

3 Approaches

The standard approach to Le Fort I fractures is through a transoral vestibular incision. This approach is quick and simple, with few complications, and offers the additional benefit of leaving no visible scar. For irregular fracture types with higher fracture lines a facial degloving approach may also be appropriate.

The incision is typically in the mobile mucosa 5–10 mm above the attached gingiva around the maxillary arch, leaving a “flange” for easier suturing. A central intact bridge of mucosa may be preserved for alignment. An alternative is the crestal incision in edentulous patients. Before the incision it is advisable to infiltrate local anesthesia with diluted adrenaline, which reduces bleeding considerably (**Fig 3.1-4**). Rarely, fractures are intraorally or extraorally open and may be treated through the lacerations. Lacerations should never be extended in preference to transoral incisions.

A subperiosteal dissection makes it possible to identify the four anterior, surgically accessible, vertical buttresses of the midface. Avoid injury to the infraorbital nerve by first performing careful dissection medial and lateral to it, then approaching the nerve between the now completed dissection pathways. If segmental alveolar fractures are also present, special care should be taken to maintain blood supply to the injured segments.

Closure of the vestibular approach can be done with resorbable or nonresorbable sutures. Identify and reposition the alar base with a suture (**Fig 3.1-5a–b**) to avoid lateral position of the alae bases (the “alar-cinch technique”).

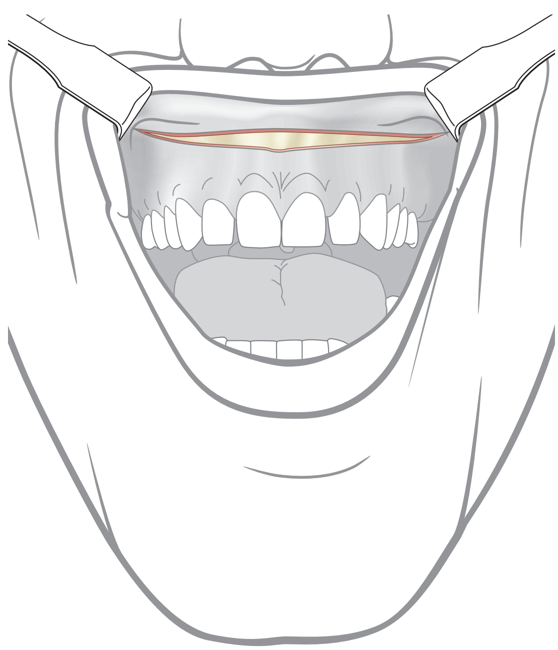


Fig 3.1-4 Upper vestibular incision for exposure of a Le Fort fracture. Incision is commonly longer and higher laterally.

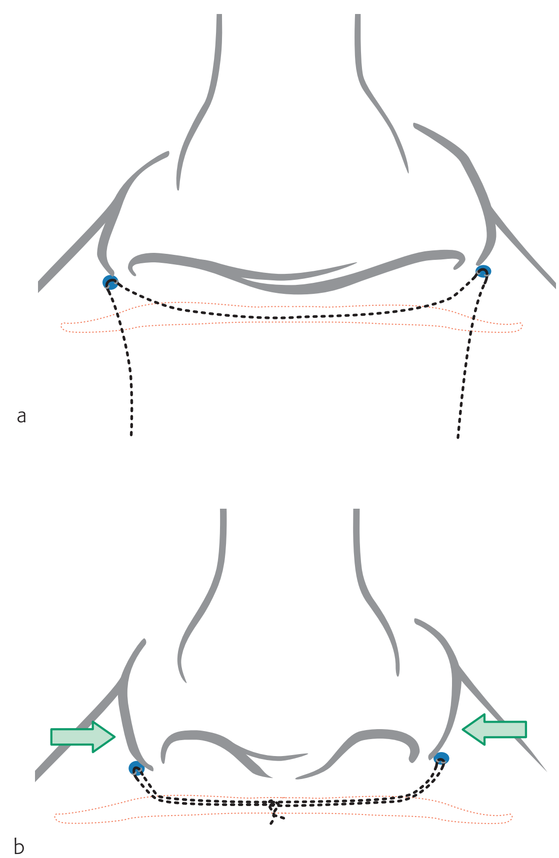


Fig 3.1-5a–b Alar-cinch technique.

4 Osteosynthesis techniques

The goal of treatment in Le Fort I fractures is correct repositioning of the fractured bones to restore their relation to the mandible, the cranial base, and the remaining midfacial structures. A successful maxillary reconstruction should involve recovering continuity, alveolar height, width and arch form of the maxilla, preserving the bone, and restoring the facial contour. Osteosynthesis with plates and screws offers the advantage of a precise reconstruction through 3-D stable fixation and improved chances of survival of bone grafts. Furthermore, the use of plates and screws for treating maxillary fractures has rendered postoperative mandibulomaxillary fixation (MMF) unnecessary, reducing costs of care and shortening recovery time.

Reduction must be performed before fixation, either with the help of reduction forceps such as Rowe's forceps, a stable wire loop placed through a drill hole near the thick bone of the anterior nasal spine, or simply by applying arch bars and repositioning the fractured elements through traction with elastics (**Fig 3.1-6**). Incomplete or greenstick fractures may require an osteotomy, if reduction is not otherwise possible. If treatment is delayed, osteotomies may be necessary. Impacted fractures may appear relatively stable and show minimal deformity. However, once disimpacted or reduced, they may be very unstable and require extensive osteosynthesis and bone grafting.

Before rigid internal fixation, dental occlusion should be reestablished and maintained through MMF. Inappropriate occlusion during surgery will lead to postoperative malocclusion, most commonly an anterior open bite. Unilateral fragmentation and loss of length may lead to a unilateral open bite. In edentulous patients and patients with a reduced dentition, in which an occlusal relation cannot be reestablished, the patient's denture or a Gunning splint may be used for correct repositioning of the lower maxilla.

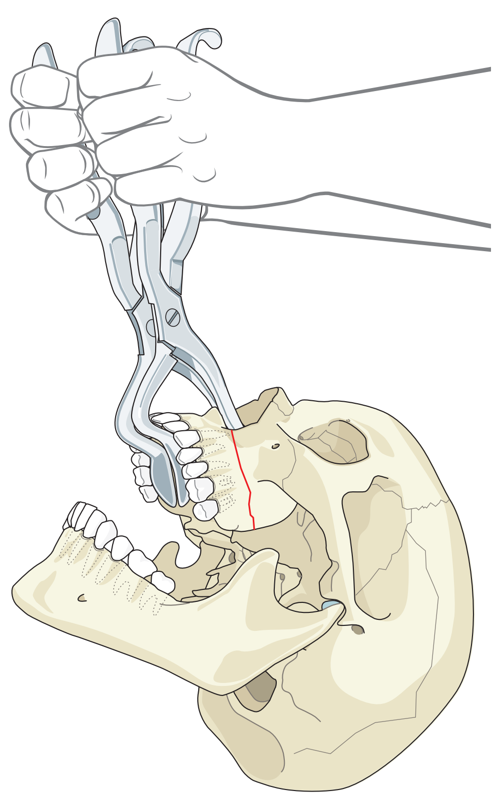


Fig 3.1-6 Repositioning of a Le Fort I fracture with the help of reduction forceps, shown here with Rowe's forceps.

In case of buttress fragmentation, undamaged buttresses should be used as a stable anatomical landmark for vertical height maintenance and fixation.

Internal fixation is achieved by applying miniplates 1.5 or 2.0, or corresponding plates from the Matrix Midface system, and screws to the medial and lateral (the paranasal and zygomaticomaxillary) buttresses. These buttresses have the highest bone density and thus provide adequate bone stock for stable screw anchorage. If the screws are anchored in low-density areas, there is a risk of screw loosening, plate fractures, and subsequent midface collapse.

Osteosynthesis is mostly performed with L- or Y-shaped plates, always placing two screws on either side of the fracture line to avoid rotational instability of the fracture segments (**Fig 3.1-7**). Plates should be carefully adapted to the bone surface in order to maintain the proper shape and dimensions of the maxilla, and to avoid forces such as traction on the underlying bone. Precise adaptation prevents secondary dislocation and avoids excess mechanical stress on the site of the screws, which may lead to microfractures in the bone. Particularly if the fracture lines are low, care should be taken to place the screws in the space between tooth roots.

Fixation of palatal fractures intends to restore the width and projection of the maxillary arch. Conventional fixation of palatal fractures involves the placement of long plates and screws anteriorly under the piriform aperture and the anterior nasal spine and submucosally in the palatal vault. The latter stabilizes posterior palatal width and prevents rotation

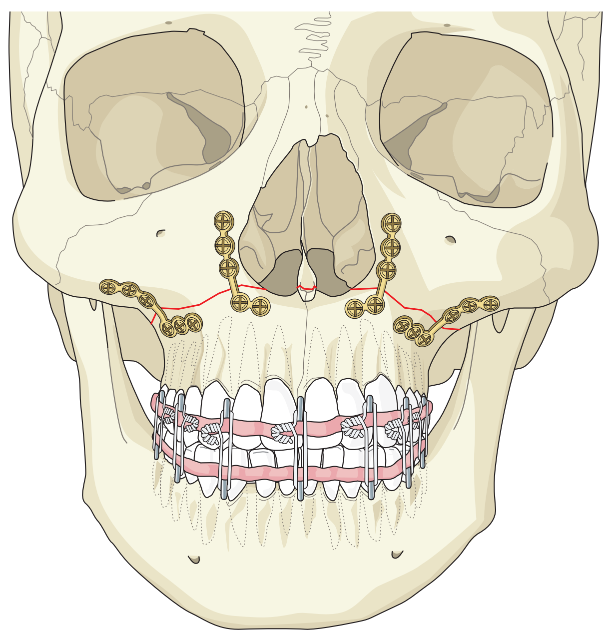
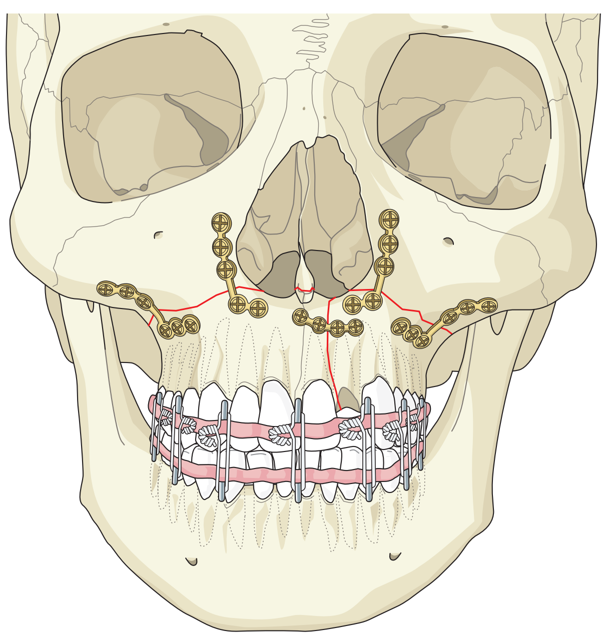
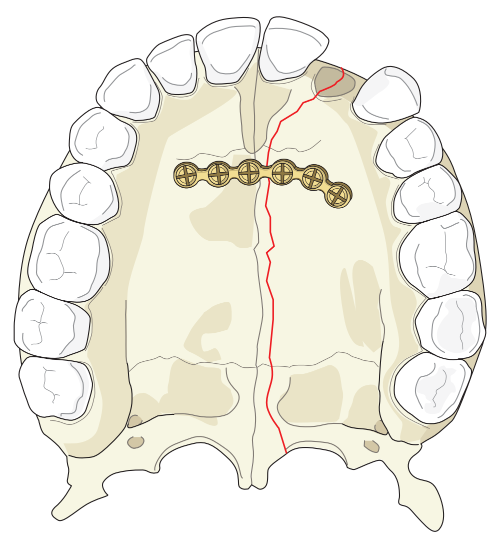


Fig 3.1-7 Stabilization with L-shaped miniplates (1.5 or 2.0). Fixation with at least two screws on either side of the fracture line in order to avoid rotational instability. MMF is maintained only during surgery.

of dentoalveolar segments. Placement of a plate across the posterior hard palate after reduction controls the posterior palatal width. This plate can be placed transmucosally if a locking miniplate is used to avoid compressing the mucosa. Additional fixation of the anterior and lateral buttresses is performed (**Fig 3.1-8a–b**).



a



b

Fig 3.1-8a–b

a Stabilization of Le Fort fracture as described in **Fig 3.1-7**. The additional sagittal fracture is stabilized subnasally with a miniplate 1.5 or 2.0.

b Fixation of the palatal fracture with a miniplate.

In the presence of comminution, longer plates should be used to bridge the fragmented zones with a minimum of two screws on either side of the comminuted zone. Bone fragments should be preserved and repositioned if possible. If the fragments are too small to be fixed with plates and screws, comminuted areas should be bone grafted (**Fig 3.1-9a–c**). The same applies for buttress defects. Bone grafts should be fixed with lag screws or separate plates and screws. Unstable "floating" bone grafts must be avoided. If plates are used to bridge bone defect zones without reconstruction of bony pillars, masticatory forces may lead to fatigue, rupture of the plates, and displacement.

Loose bone fragments are removed from the maxillary sinus, since they may act as sequestra. Loss of the anterior wall of the maxillary sinus may cause depression of overlying soft tissues, and later scar contractions may affect the infraorbital nerve. Larger anterior sinus wall defects should be treated with bone grafts or titanium meshes. Split calvarial bone grafts may be used for the maxillary sinus wall, as well as for reconstruction of the buttresses.

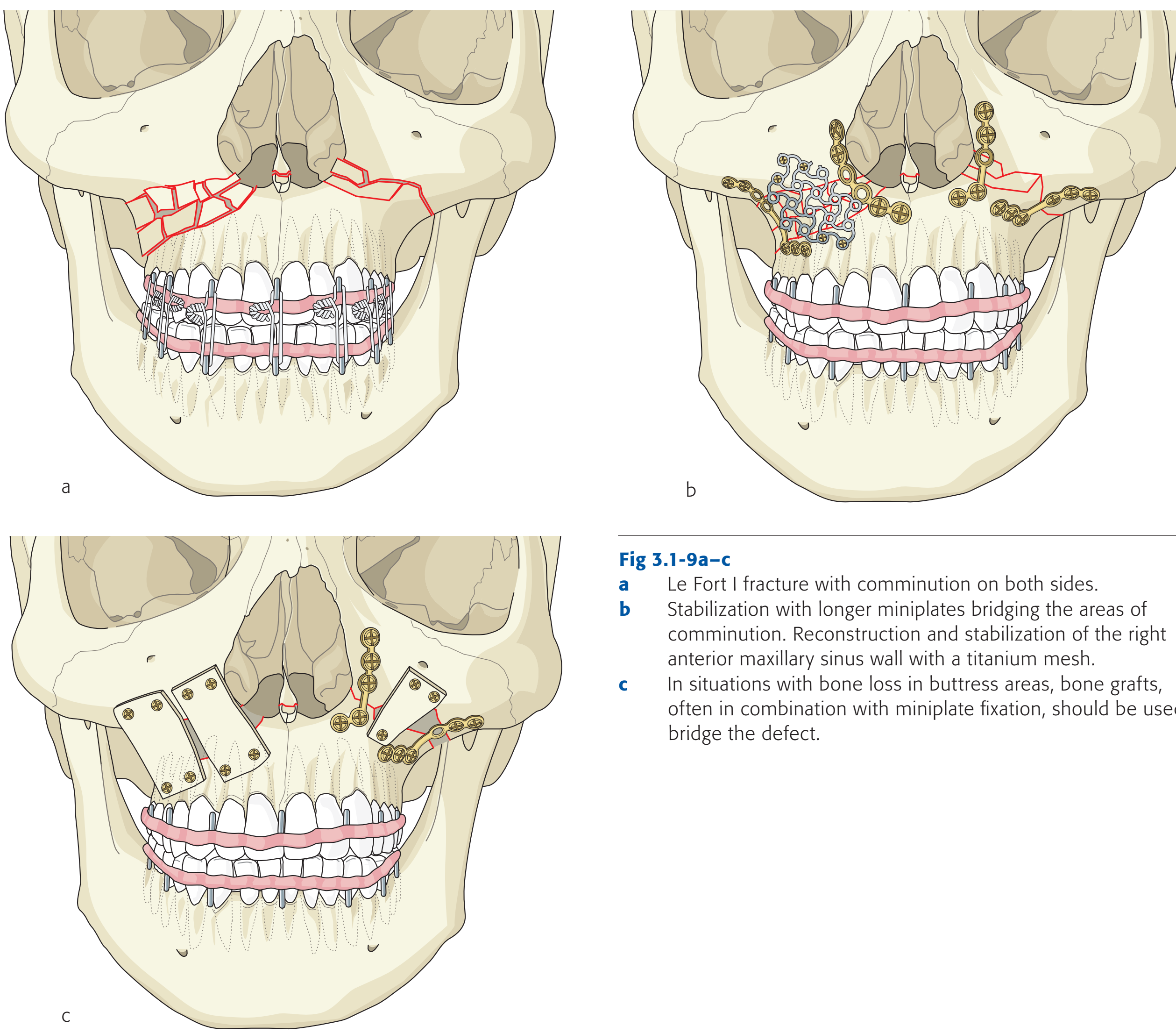


Fig 3.1-9a–c
a Le Fort I fracture with comminution on both sides.
b Stabilization with longer miniplates bridging the areas of comminution. Reconstruction and stabilization of the right anterior maxillary sinus wall with a titanium mesh.
c In situations with bone loss in buttress areas, bone grafts, often in combination with miniplate fixation, should be used to bridge the defect.

5 Airway management

Midfacial trauma may cause displacement of bony or cartilaginous structures, edema, and hematoma formation which may make nasal intubation more difficult. Orotracheal intubation sometimes interferes with establishing an adequate MMF, especially in patients with complete dentition. The surgeon must decide which technique of airway management is suitable for an individual patient.

At the end of surgery dislocated hard tissues which may compromise the airway, such as a luxated nasal septum or a dislocated medial wall of the maxillary sinuses, should be repositioned. If the fracture fixation has been done in nasal intubation, this may require a tube switch from nasal to oral intubation.

6 Perioperative and postoperative treatment

Dental and oral hygiene with tooth brush and mouth rinse must be encouraged. The fact that MMF is not used in the postoperative period makes oral hygiene easier and oral feeding possible; although a soft diet is recommended for 4 weeks.

Perioperative and postoperative antibiotics are indicated. Maxillary sinus drainage is supported by the use of nasal vasoconstrictors.

After repair of palatal fractures postoperative MMF for up to 3 weeks should sometimes be considered, especially in cases with comminuted fractures.

7 Complications and pitfalls

Fractures of the midface in general may be associated with severe, even life-threatening bleeding from the greater palatine arteries, internal maxillary arteries, or retromaxillary venous plexus. However, in isolated Le Fort I fractures this is rarely the case. If such bleeding occurs, anterior and posterior nasal packing and/or immediate reduction and internal fixation may be necessary as an emergency treatment.

Inadequate reduction of maxillary fractures may cause shortening of the midface, as well as an anterior open bite. Pseudoprognathism may also appear, as well as asymmetry between the maxillary and mandibular midline, malocclusion, and superior rotation of the nasal tip. If any of these findings are diagnosed postoperatively, the patient should be returned to surgery immediately for correction.

Infection is usually due to instability, mostly caused by loosening of one or more screws, or instability of a graft. The problem is solved by exchanging or removing the screw or graft, depending on whether the fracture has healed or not.

Inadequate or failed treatment of palatal fractures may lead to complications, such as increase in the transversal diameter of the maxilla, rotation of dentoalveolar segments, and fragment instability. Intraorally exposed osteosynthesis material should be eventually removed.

Authors Marcelo Figari, Thiam-Chye Lim

3.2 Upper midface (Le Fort II and III)

1 Anatomy and definition

The upper midface (Le Fort II and III) comprises the facial bones situated above the projection of the Le Fort level I fracture including the zygomas, the upper part of the maxilla with its frontal process, the bones that form the lateral, inferior, and medial orbital walls, and the nasal bones. It is located between the upper face (frontal and anterior temporal bones) above and the occlusal unit below; it includes the outer facial frame, the orbital, and nasoorbitoethmoidal (NOE) regions (**Fig 3.2-1**).

In 1901, René Le Fort described the facial fracture patterns observed in cadaver midfaces after blunt

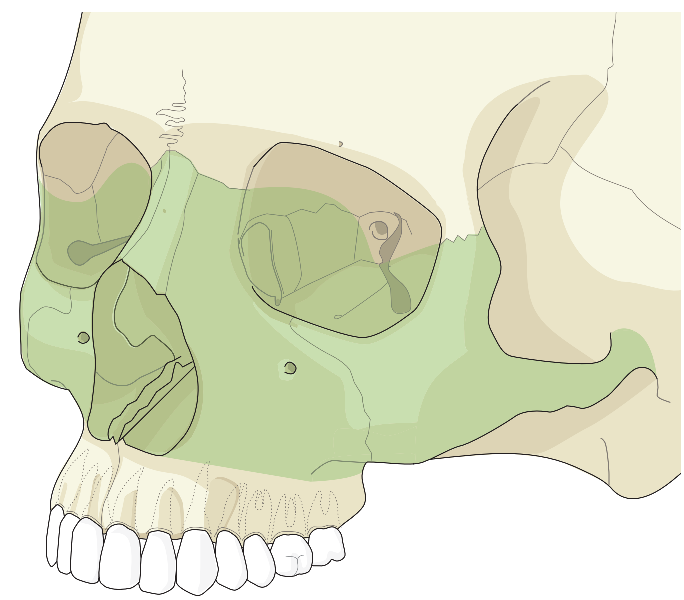


Fig 3.2-1 Upper midface, located between the occlusal unit and the frontal facial unit. It consists of the zygomas laterally, the NOE area centrally, and the internal portion of the orbits bilaterally.

impacts. Today, Le Fort II (**Fig 3.2-2a–b**) and III (**Fig 3.2-3a–b**) classic fracture patterns (pyramidal fracture and craniofacial disjunction, respectively) are rarely seen in pure form due to the increased amount of energy involved in trauma mechanisms. Most midfacial fractures today combine a variety of different midfacial fracture patterns and in addition are frequently associated with cranial vault, skull base, palatal, and mandibular fractures.

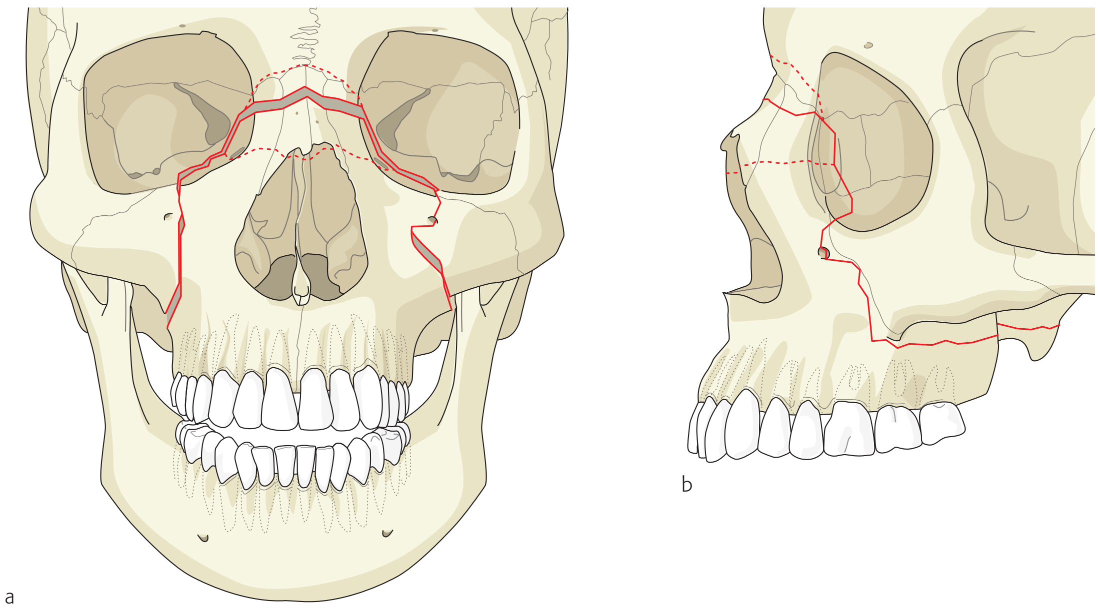


Fig 3.2-2a–b Le Fort II fracture shows dislocation and occlusal disturbance–high and low variations as it crosses the nasal bridge; high at the frontal bone, low variations just under the nasal bone.

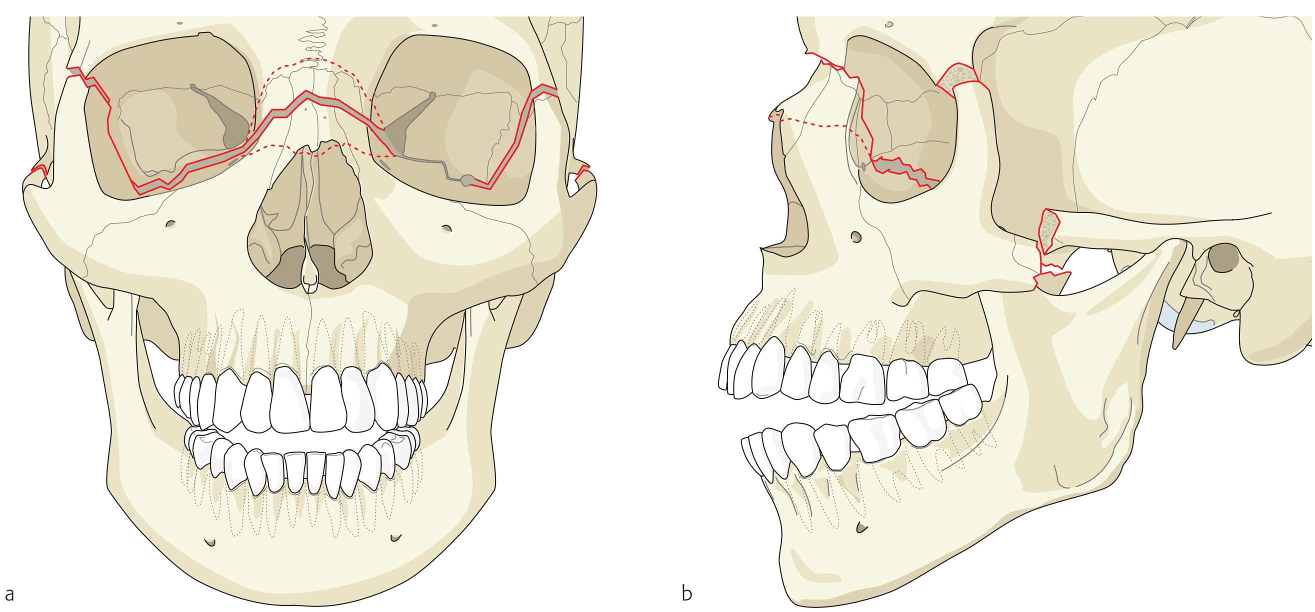


Fig 3.2-3a–b Le Fort III fracture shows typical dislocation and occlusal disturbance.

2 Diagnosis

Clinical evaluation provides some information in terms of occlusal disturbances, face shortening, nose flattening, or external facial frame dislocation, depending on the given fracture pattern. Nevertheless, soft-tissue swelling frequently masks underlying bone deformity.

Classic evaluation using plain facial x-rays is usually not helpful. Computed tomography (CT) with axial and coronal sections, bone and soft-tissue windows, and special (sagittal) reconstructions is the standard. These images provide clear understanding of fracture line location, bone displacement, and bone and soft-tissue relation. In recent years, volume CT scans have become more widely available in trauma centers and general hospitals. Besides the faster acquisition of data, enabling patients to have facial scans while other organ scans (spine, liver, spleen) are performed, the improved quality provides more accurate information of the comminution and displacement with less motion artifact than traditional CT scans. Additionally, 3-D reconstruction allows rapid orientation of the complex fracture pattern (**Fig 3.2-4a–d**).

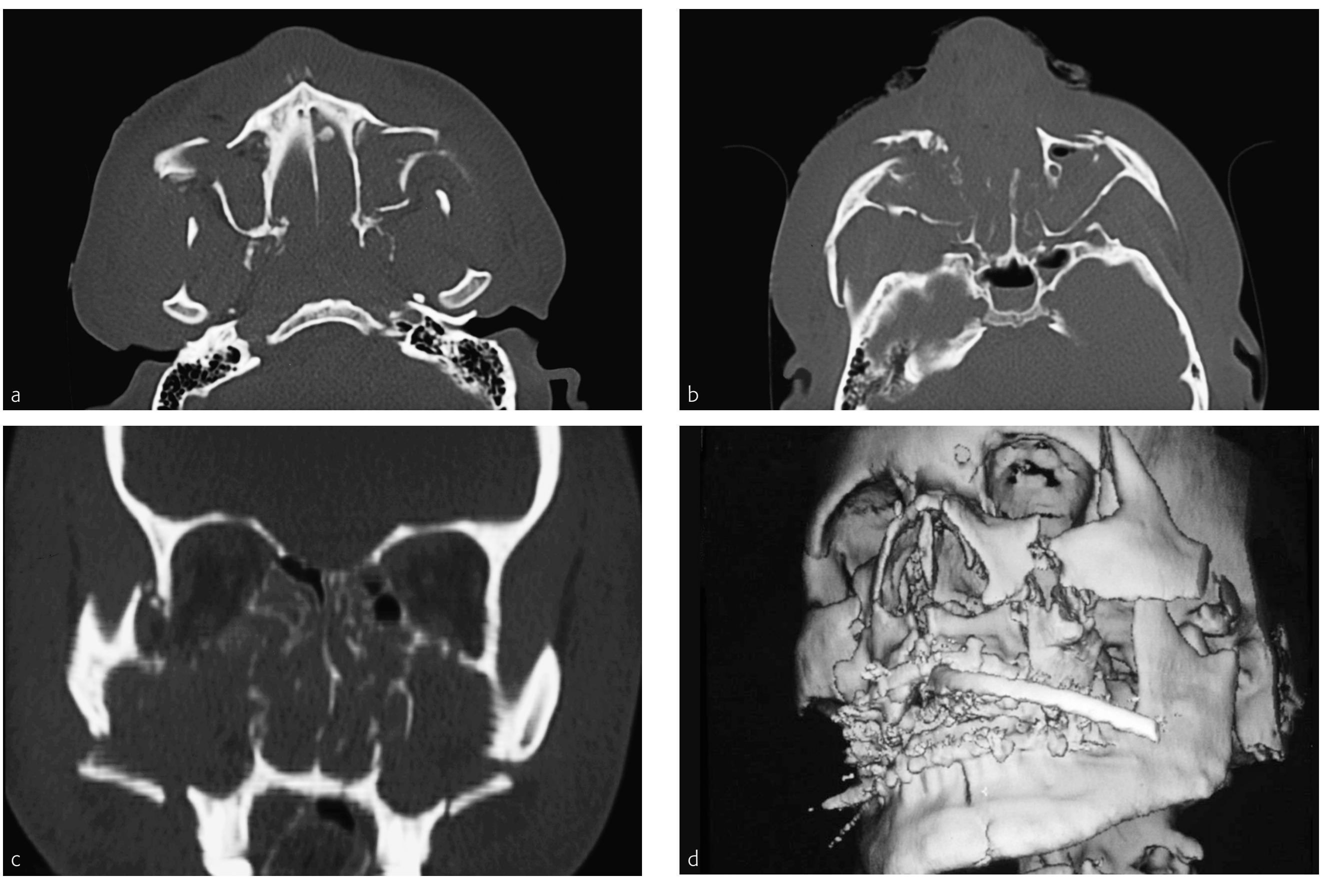


Fig 3.2-4a–d
a CT scan, axial view of a Le Fort II fracture, shows the fracture line through anterior and posterior maxillary sinus walls.
b CT scan, axial view of a Le Fort II fracture, shows the fracture line through both infraorbital rims and zygomatic arch on the right.
c CT scan, coronal view, shows the fracture at Le Fort III level on the right and Le Fort II level bilaterally.
d CT scan; 3-D reconstruction of a panfacial fracture.

3 Approaches

Le Fort II and III fractures require a wide surgical exposure for proper reduction and stabilization. The upper midface and the craniofacial junction may be exposed by coronal or transcutaneous incisions, and the combination of the two. The choice of approach depends on the fracture pattern, the amount of displacement, other accompanying fractures, and surgeon's preference. Today the coronal incision is the most important surgical approach, allowing exposure in the subperiosteal plane of the glabella, the supraorbital rims, both zygomatic arches, and the superior, medial, and lateral orbital walls. Routinely, the cutaneous incision is made from the helix root on one side to the vertex of the skull and then to the contralateral helical root. Depending on the need to completely expose the zygomatic arch or the temporomandibular joint capsule, further extension of the incision posteriorly or anteriorly to the tragus level may be necessary. Besides the classic linear incision, several modifications have been described, such as the sinusoidal or saw-tooth stealth incision, or the extension of the incision behind the pinna in the postauricular area instead of the preauricular region. In individuals with male-pattern baldness, the incision may be made further back over the vertex. These alternatives improve esthetical aspects, preserve hair vitality, and facilitate skin closure (**Fig 3.2-5a–e**).

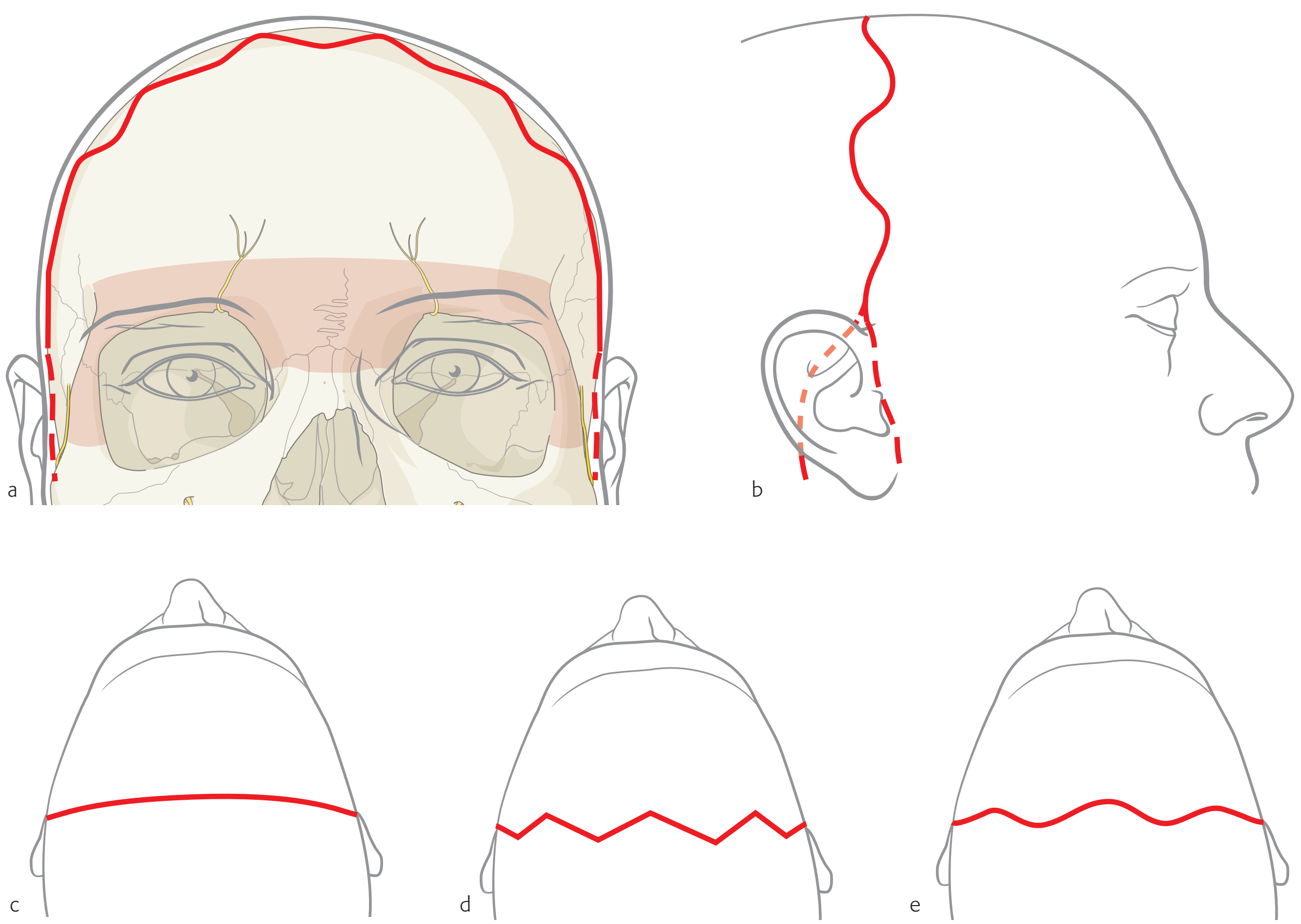


Fig 3.2-5a–e Incision lines for the coronal approach and the various modifications.

Care must be taken to preserve the frontal branch of the facial nerve by transection of the superficial layer of the deep temporal fascia about two finger widths above the zygomatic arch, thus protecting the nerve by dissecting only beneath the deep fascia. The surgical dissection and release of the supraorbital nerve is required for complete exposure of the orbital roof and medial and lateral orbital walls (**Fig 3.2-6**).

In some cases of craniofacial disjunction the zygomaticofrontal suture areas are exposed through the lateral portion of an upper blepharoplasty incision (**Fig 3.2-7a–b**), therefore avoiding a coronal incision. Nevertheless, this approach has the disadvantage of limited exposure, making a symmetrical control of reduction impossible, particularly in the zygomatic arch region. For the same reason, hemicoronal approaches should be avoided.

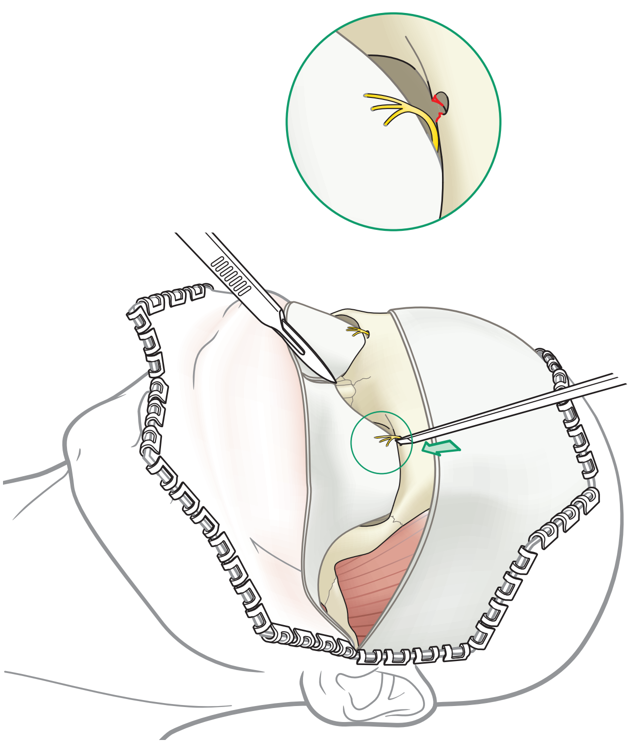


Fig 3.2-6 Surgical dissection and freeing of the supraorbital nerve for unhindered approach of the supraorbital rim and orbital roof. The nerves are freed from the foramina with small osteotomes. Additional periosteal incision in the nasal bridge area is helpful to improve access.

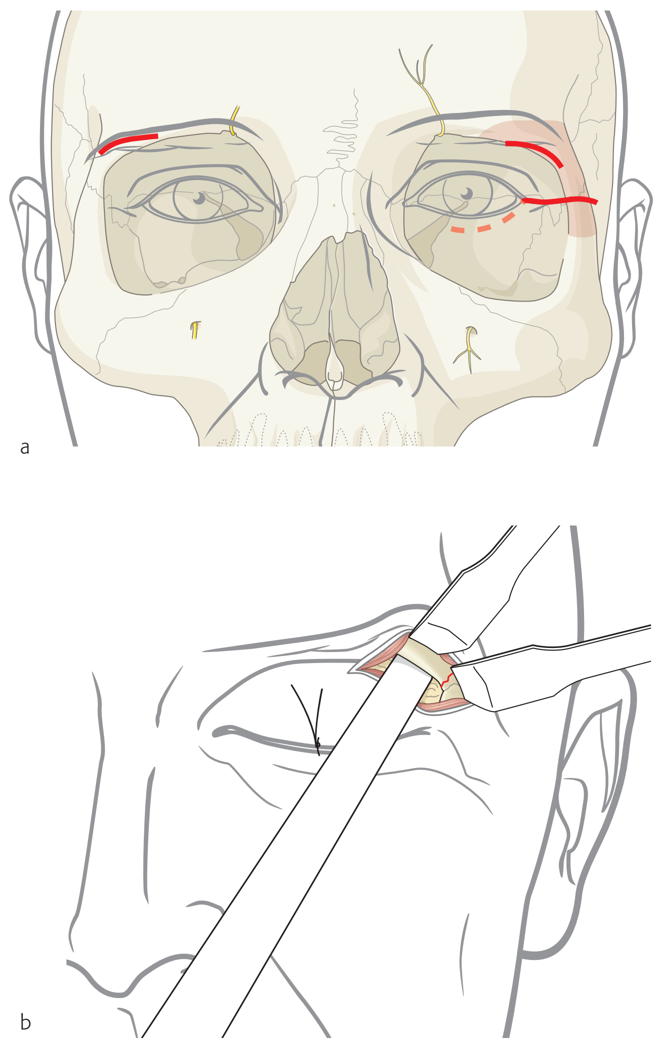


Fig 3.2-7a–b
- **a** Upper blepharoplasty and lateral eyebrow incisions, and transconjunctival incision with lateral canthotomy.
- **b** Exposure of the lateral orbital rim trough upper blepharoplasty incision.

Access to the orbital floor requires subciliary, midpalpebral, or transconjunctival approaches (**Fig 3.2-8a–d**). The decision is based on patient age, lid anatomy, orbicular muscle tone, and the presence of traumatic lacerations but mostly on the pattern and extent of the fracture. The older the patient and the more lax the eyelids, a lower placement of the cutaneous palpebral incision is recommended to avoid ectropion.

In case of Le Fort II fractures or combination with Le Fort I or palatal fractures, a transoral upper vestibular incision is necessary for reduction and stabilization of the nasomaxillary and zygomaticomaxillary buttresses.

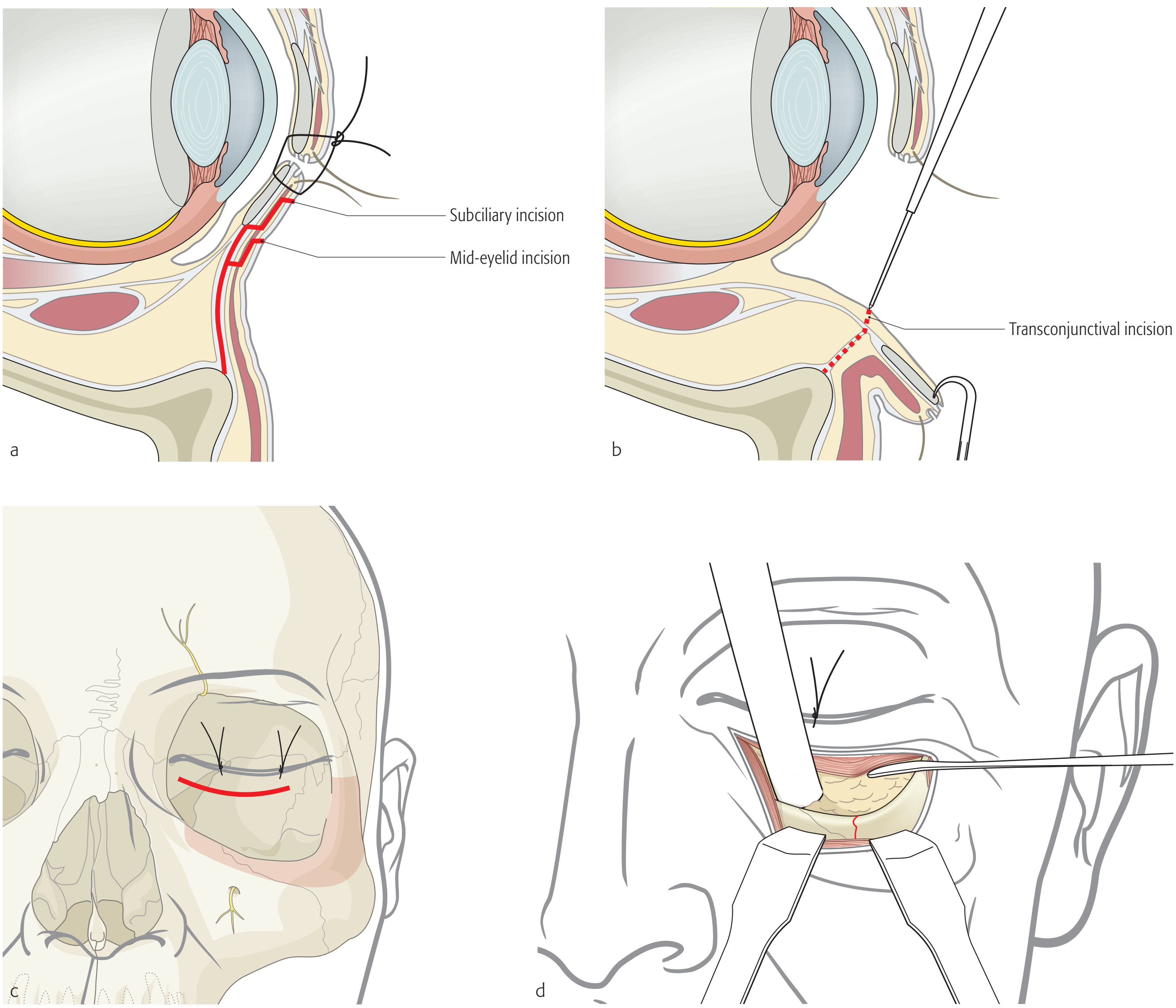


Fig 3.2-8a–d
a Subciliary and mid-eyelid incision (lateral view).
b Transconjunctival incision (lateral view).
c Mid-eyelid incision (frontal view).
d Exposure of the infraorbital rim through mid-eyelid incision.

4 Osteosynthesis technique

Once all fractures have been exposed, adequate reduction is critical before any osteosynthesis is performed. Heavily impacted or partially fractured midfacial trauma frequently necessitates osteotomies or, less preferably, the use of reduction clamps to reposition the fragments.

Although restoration of pretrauma occlusion by means of arch bars, screws, or wire dental ligatures is mandatory, it is insufficient to reestablish facial contour, especially in the upper midface. In the past, it was stressed that reestablishing occlusion was the initial and most important step of facial reconstruction. The combination of mandibulomaxillary fixation (MMF), wire osteosynthesis, and craniofacial suspensions frequently led to midfacial bone-segment telescoping and did not reliably stabilize fragments in a three-dimensionally accurate position, causing long-term facial deformation, despite the occlusion being correct. Today, open reduction and internal fixation using plates and screws is the most reliable way to achieve and preserve proper and stable three-dimensional bone-segment alignment. In some cases, such as severely comminuted fractures, temporary wire ligatures may help achieve preliminary bone approximation before definitive osteosynthesis with plates and screws is performed.

Adequate selection of osteosynthesis material depends on several factors. A variety of implants should be available at all times for the surgical team. The surgeon must know and select the most suitable plate and screw combinations for each location. The reconstruction of nasomaxillary and zygomaticomaxillary pillars at the Le Fort I level and the zygomatic arches allows for the use of miniplates of the 2.0, 1.5, or Matrix Midface systems, thus taking advantage of their rigidity in a region where the soft tissues are thick enough to provide sufficient coverage and to avoid postoperative palpability. The periorbital regions, such as the frontozygomatic suture and infraorbital rim, and other smooth facial areas with thin soft-tissue coverage such as the glabella, are better fixed with miniplates 1.5, 1.3, or corresponding Matrix Midface plates. Small fragments and bone in nonloaded areas, such as the frontal sinus walls, may be stabilized with microplates 1.0, 1.3, or corresponding Matrix plates. In other words, loaded areas are fixed with stronger plates and nonloaded areas with weaker plates. The quality and quantity of the overlying soft tissues as well as plate thickness have to be considered to avoid palpability and, sometimes, visibility of plates.

The sequencing of osteosynthesis in Le Fort II and III fractures depends on associated facial injuries, the degree of displacement, and the surgeon. Comminuted areas providing insufficient stable bone for adequate screw fixation may need to be bridged with longer plates, and defect areas may need to be bone grafted.

In an isolated pyramidal Le Fort II fracture, the contour of the upper facial unit and the zygoma area provides excellent reference for proper reduction. In addition, MMF avoids postoperative malocclusion. After satisfactory reduction, the frontomaxillary area and infraorbital rims are fixed with miniplates 1.3, and the strong zygomaticoalveolar crest is typically fixed with L-shaped miniplates 1.5 or 2.0 or corresponding implants from the Matrix Midface system (**Fig 3.2-9**).

Le Fort III fractures, in the rare case of isolated craniofacial disjunction or in association with additional NOE patterns, first require the reconstruction of the outer facial frame (**Fig 3.2-10**). Today it is generally accepted, as originally described by Gruss et al, that precise reduction of the zygoma and zygomatic arches and subsequent stable fixation with fixation in the root of the zygomatic arch and in the frontozygomatic suture represent a crucial step in reestablishing facial dimension in this type of facial injuries. The best place

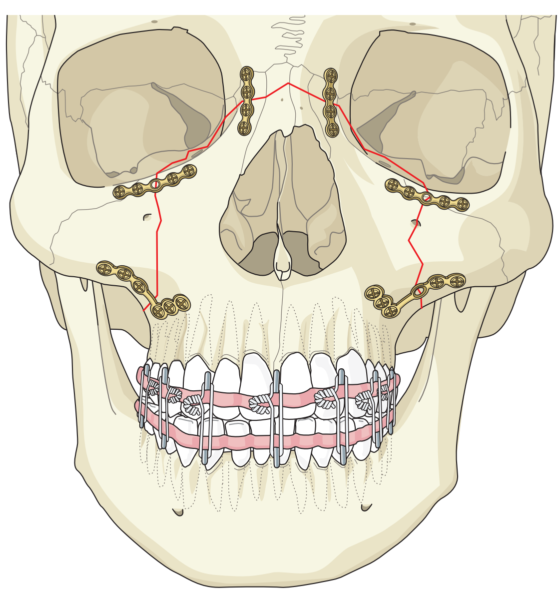


Fig 3.2-9 Le Fort II fracture miniplate osteosynthesis. The infraorbital and NOE area are stabilized with miniplates 1.3. Zygomaticomaxillary buttresses are stabilized with miniplates 2.0. MMF is maintained during surgery only.

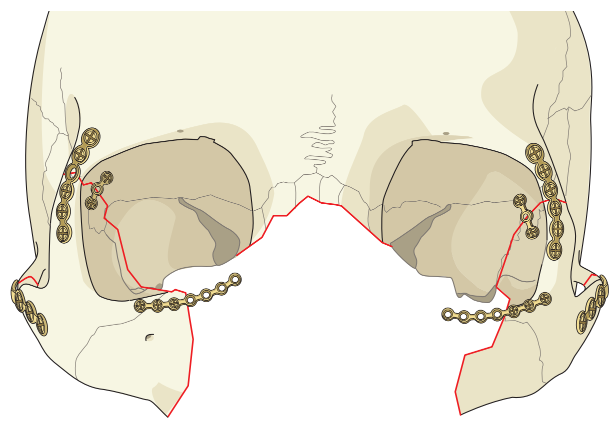


Fig 3.2-10 Reconstruction and fixation of outer facial frame as the first step during repair of a Le Fort III fracture.

to control the position of the zygoma is the junction between the greater wing of the sphenoid and the zygoma in the lateral orbital wall. Multiple point position control is preferred. After reconstruction of the so-called outer facial frame the remaining surgical treatment will depend on the existence of associated NOE, Le Fort II, or Le Fort I fracture lines (**Figs 3.2-11a–b**, **3.2-12**).

Approximately 10% of Le Fort fractures are not accompanied by maxillary mobility due to incomplete fractures. The only physical finding may be a subtle malocclusion. This is frequently not detected in polytrauma patients with oral intubation. Early detection and timely treatment of these fractures depends on the clinical experience of the attending craniomaxillofacial surgeon. The possibility of such a fracture is suggested by the presence of bilateral maxillary sinus fluid levels.

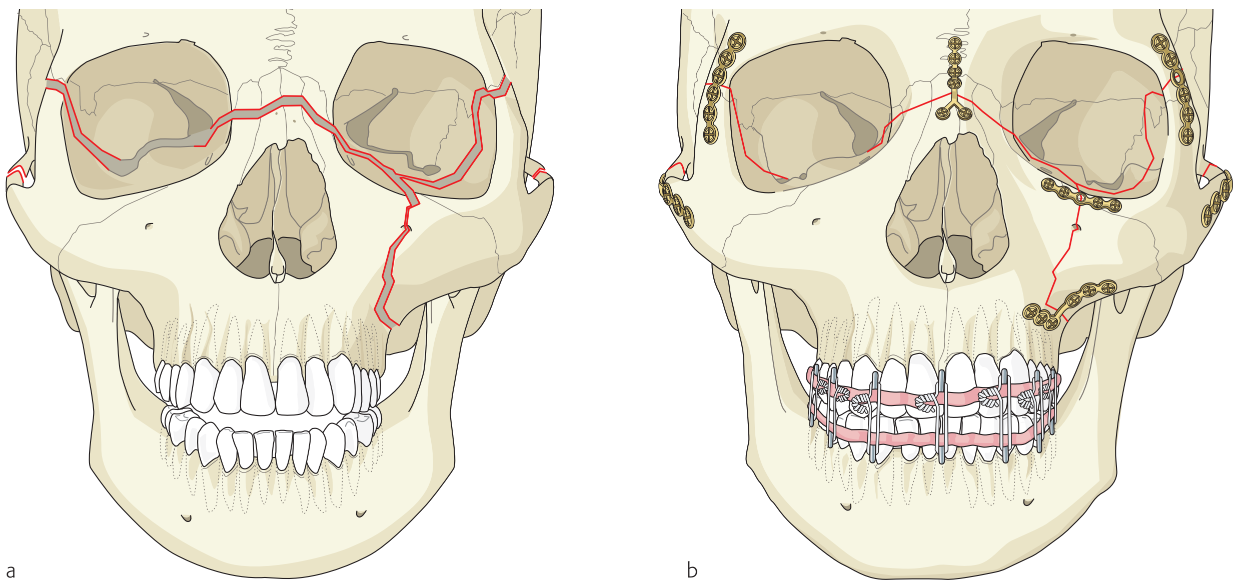


Fig 3.2-11a–b
a Le Fort III fracture in combination with zygomatico-orbital fracture on the left and typical occlusal disturbance.
b Fixation of Le Fort III and zygomatico-orbital fracture with miniplates 2.0 and 1.3. The patient is in MMF during surgery only.

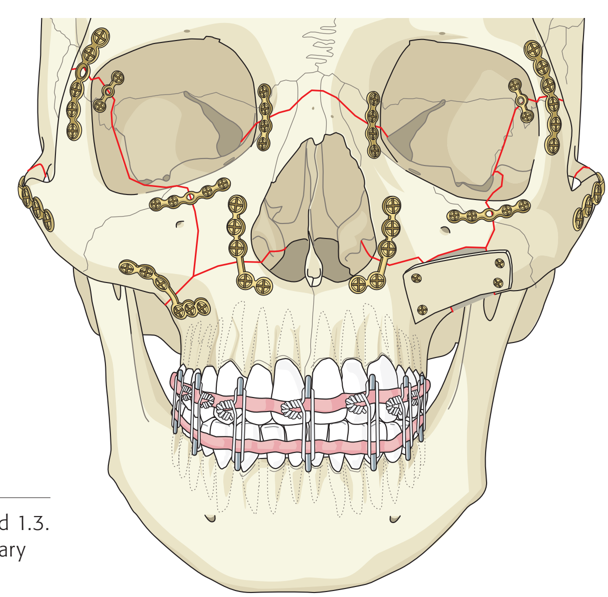


Fig 3.2-12 Fixation of Le Fort I, II, and III fractures with miniplates 2.0 and 1.3. On the left, a bone graft is covering a bony defect at the zygomaticomaxillary buttress area. MMF during surgery only.

5 Airway management

During the early postinjury period, Le Fort fractures may produce various degrees of airway compromise which are rarely critical. Nasopharyngeal bleeding may obstruct the nasal airway while the posteroinferiorly displaced hard palate and swollen soft palate/uvula may cause oropharyngeal obstruction. However, these are infrequent reasons for urgent intubation, routinely managed through careful clearing of oral secretions, and if necessary by the placement of an oropharyngeal cannula. On initial assessment the emergency room physician must be aware of potential cranial base involvement when introducing a nasogastric tube. For the same reason, orotracheal intubation is preferred for airway control. 75% of patients, who sustained a severe facial trauma and require airway control, are best managed through orotracheal intubation. Only a minority of these patients (< 12%) will need a surgical tracheotomy.

With respect to intraoperative airway control, the selected method must not interfere with the application of MMF. This is necessary to reproduce the preinjury occlusal status. Nasotracheal intubation is common, and in cases of skull-base injuries performed with the help of an endoscope. Oral intubation is feasible, passing the spiraled tube behind the last teeth or through an edentulous area.

Submental intubation, a method described by Hernandez Altemir in 1986, has progressively gained acceptance over the last decade. It is essentially an oral intubation where the tube is afterward passed through the submental area, internal to the mandibular arch and anterior to the facial artery and lingual nerve. The procedure must be converted again to an oral or nasal intubation after surgery. It has few complications and provides excellent access to the nasal and oral cavities during surgery.

Finally, transcutaneous or endoscopically assisted tracheostomy can be preformed if none of the above-mentioned procedures are feasible.

At the end of the surgical procedure the nasal cavity must be inspected, and septal luxations as well as loose bony fragments must be treated (chapter 3.1 Lower midface: Le Fort I and palatal fractures).

6 Perioperative and postoperative treatment

Preoperative and postoperative ophthalmologic consultation is important. A number of midfacial trauma cases will have associated ocular impairment related to the trauma mechanism, either direct injury to the globe and adnexae, or indirect functional disability related to orbital wall compromise or muscular entrapment. These examinations are not only important for medico-legal reasons but the preoperative examination may also modify the timing of the surgery.

Patients with fractures of the upper midface should be treated surgically under antimicrobial prophylaxis with broad-spectrum antibiotics. As a guideline, antibiotic administration can be stopped immediately after surgery or after a number of postoperative doses, depending on the hospital protocol. Drains are rarely used after Le Fort fracture therapy.

Postoperative MMF is considered individually. It is recommended that patients stay on a soft diet for approximately 4 weeks. In comminuted and panfacial fractures, a brief period of MMF may be indicated.

7 Complications and pitfalls

Postoperative complications are generally related to inadequate surgical planning and/or therapy. Inadequate surgical access and poor reduction of the fracture may lead to misalignment of the fragments. In patients with associated palatal fractures, special emphasis must be given to establishing and controlling palatal width. Incomplete assessment or incorrectly treated orbital wall or NOE fractures may be associated with postoperative enophthalmos or telecanthus, respectively.

Inaccurate repositioning of the outer facial frame is the main cause of undesired changes in facial proportions, typically presenting increased facial width and orbital dystopia. Furthermore, insufficient midface disimpaction may result in a lack of anteroposterior facial projection.

Postoperative plate palpation is sometimes caused by inadequate implant selection for the location, or thin soft-tissue cover. Sensory disturbances during extreme temperature exposure may require implant removal.

Author Carl-Peter Cornelius

3.3 Zygomaticomaxillary complex (ZMC) fractures, zygomatic arch fractures

1 Anatomy and definition

The zygoma or cheek bone is the most prominent element in the upper lateral midface, connecting to the adjacent craniofacial skeleton with five articulations (**Fig 3.3-1**). In an upward, downward, medial, backward, and dorsomedial direction, these are the following:

- Frontal process
- Maxillary margin building the zygomaticomaxillary buttress
- Infraorbital margin going into the infraorbital rim
- Temporal process conveying into the zygomatic arch, three quarters of which belong to the temporal bone
- Lateral orbital process (orbital surface or facies orbitalis) or zygomaticosphenoid flange constituting the anterior part of the lateral wall of the internal orbit

The zygomatic bone is solid, acts as a vertical and horizontal buttress, and does not relate directly to the maxillary antrum. Only the anterolateral 40% of the orbital floor (inferior orbital process) consists of the zygoma, while the medial 60% is formed by the maxilla.

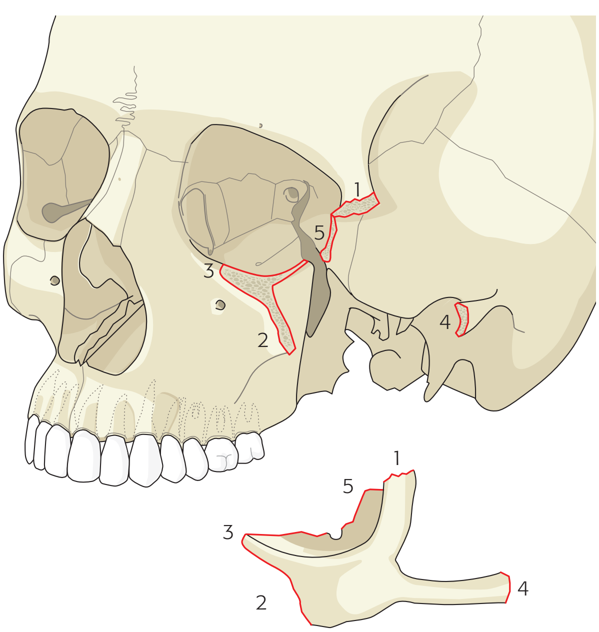


Fig 3.3.-1 Zygomatic bone separated from the craniofacial skeleton. Five articulations are identified:
1 Frontal process
2 Zygomaticomaxillary buttress
3 Infraorbital rim
4 Zygomatic arch
5 Lateral orbital wall

Since fractures involving the zygoma are not usually confined to its strict anatomical boundaries but most often extend into adjacent maxillary or orbital structures (antrum, orbital walls including the infraorbital canal, rim, and orbital floor, respectively) it is appropriate terminology to refer to them as zygomaticomaxillary complex (ZMC) or orbito-zygomaticomaxillary fractures. Fractures of the zygomatic arch are often associated with ZMC fractures, but also occur as an isolated fracture (**Fig 3.3-2a–b**).

Prior to imaging, the diagnosis of a ZMC fracture is clinically confirmed by the presence of characteristic acute sequelae and signs of potential long-term consequences (**Table 3.3-1)**. Depending on the type and extent of the zygomatic injury (degree and vector of displacement, involvement of the globe and orbit, comminution, etc) clinical signs and symptoms will vary.

Skeletal deformities	Ocular/ophthalmic symptoms	Sensory impairment	Oral symptoms	Nasal symptoms
• Asymmetry of the midface • Depression/flattening of the malar prominence • Flattening, hollowing (bony indentation) or broadening over the zygomatic arch • Palpable step offs or gap deformities of orbital margins (infraorbital/lateral)	• Periorbital edema or hematoma ("monocle hematoma") • Pseudoptosis • Increased scleral show • Downward slant of palpebral fissure or horizontal lid axis respectively • Malposition of the lateral canthus • Vertical shortening of the lower eyelid (ectropion) • Subconjunctival ecchymosis (temporal/medial) • Chemosis • Pupillary or globe level disparity (hypoglobus) • Proptosis bulbi • Enophthalmos (outward displacement of zygoma) • Exophthalmos (inward displacement of zygoma) • Subcutaneous periorbital air emphysema (skin crepitation) • Pneumoexophthalmos • Diplopia (neurogenic ocular motility disorder – III, IV, VI; enophthalmos; entrapment, revealed by forced duction test) • Amaurosis • Superior orbital fissure syndrome	Sensory deficit (hypoesthesia, anesthesia) in the distribution of the following nerves: • Infraorbital nerve: - lower eyelid - upper lip - ala and lateral sidewall of the nose • Zygomatiofacial nerve: - malar eminence - cheek • Zygomaticotemporal nerve: - lower lateral orbital rim - anterior temporal/lateral/frontal region	• Ecchymosis of the gingivobuccal maxillary sulcus • Subjective occlusal disorder due to altered sensation of the maxillary premolars/molars and gingiva, no objective malocclusion • Palpable contour disturbance of zygomaticomaxillary buttress • Restriction of mandibular opening (trismus) or closing–blockage of temporal muscle or coronoid process either by impacted zygomatic arch or retrodisplaced zygoma	• Ipsilateral epistaxis • Ipsilateral hematosinus

Table 3.3-1 Possible clinical signs and symptoms accompanying ZMC fractures.

A detailed functional and structural ophthalmic examination is of priority during initial clinical assessment, listed in **Table 3.3-2**.

Functional examination	Structural examination
Visual field loss	Corneal abrasion
Anisocoria or mydriasis	Hyphema
Amaurosis	Iridodialysis
Diplopia	Lens subluxation or dislocation
	Vitreous hemorrhage
	Retinal detachment
	Globe rupture

Table 3.3-2 Functional and structural opthalmic examination for ZMC fractures.

2 Imaging

Among imaging modalities, high-resolution CT scans in axial, coronal, and sagittal reconstructions provide complete radiological visualization of the fracture sections with bone and soft-tissue windows:

- Comprehensive and precise information on the number, localization, and extent of fracture lines
- Displacement, angulation, and rotation of the individual fragments, and the condition of soft tissues within the orbital cavity (eg, retrobulbar hematoma)
- Integrity of its osseous orbital walls and any adjacent fractures

Systematic analysis of CT sections of the face in axial planes starts at the maxillary alveolar process and extends cephalad until the anterior cranial fossa is passed. Conventional plain x-rays in combination with a detailed clinical examination are an option if CT scans are not available; however, only limited radiological information is provided.

The axial sections (**Figs 3.3-2a**, **3.3-3a–b**, **3.3-4a–b**) have to be checked successively for discontinuities, defect size, and malposition:

- Zygomaticomaxillary buttress, anterior and posterior antral walls, pterygomaxillary fissure, retromaxillary space
- Temporal root of the zygomatic arch, articular tubercle, course of zygomatic arch
- Infraorbital canal, infraorbital rim, inferior orbital fissure
- Postequatorial convexity at the transitional zone between orbital floor and medial wall (“posteromedial bulge”)
- Outer orbital frame: frontal process and lateral orbital flange of zygoma, and junction with the greater sphenoid wing

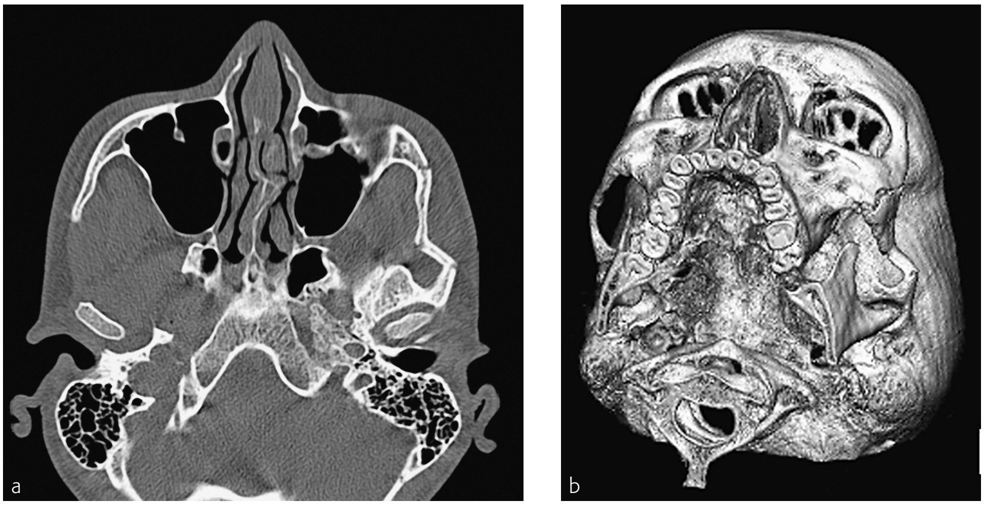


Fig 3.3-2a–b CT scans of isolated zygomatic arch fracture. The apex of the V-shaped fracture is indented toward the coronoid mandibular process.

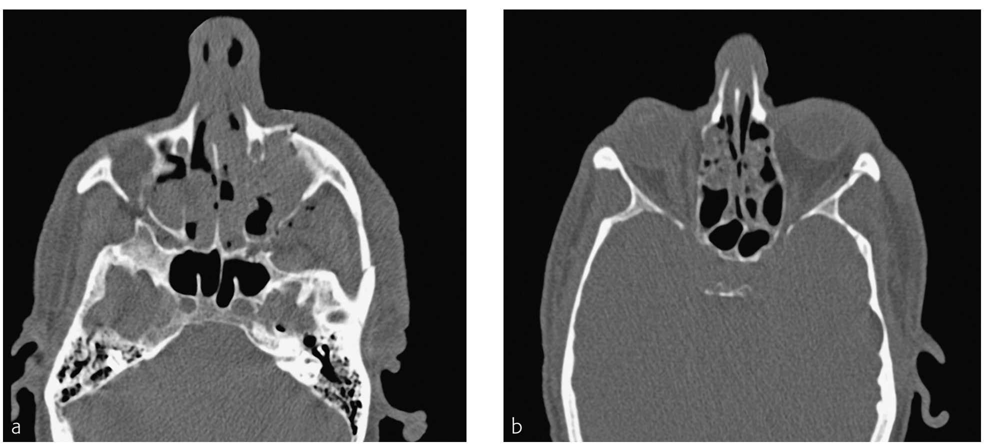


Fig 3.3-3a–b CT scans of low-energy ZMC fracture.

- **a** Axial scan through maxilla: undisplaced zygomatic arch–small antral impaction of the zygomaticomaxillary buttress.
- **b** Axial scan through orbit: undisplaced zygomaticosphenoid suture.

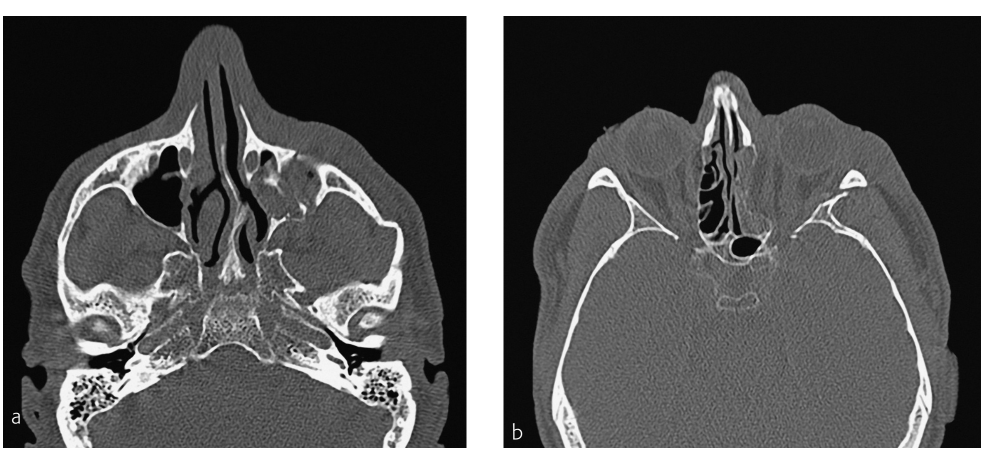


Fig 3.3-4a–b CT scans of mid-energy ZMC fracture.

- **a** Axial scan through the maxilla: lateral displacement of the triple fractured zygomatic arch, comminution of the zygomaticomaxillary buttress.
- **b** Axial scan at midglobe level: dorsolateral displacement of the lateral orbital rim, outward bending of greater wing of sphenoid, medial wall blow-out fracture with tissue herniation into the ethmoid sinus.

Evaluation in the perpendicular coronal plane sections will begin with anterior slices at the level of the nasal skeleton and pass posteriorly to the level of the mastoid and temporal bone. In the coronal sections (**Figs 3.3-5a–b**, **3.3-6a–b**) it is essential to check systematically for anatomical irregularities:

- Circumference of the zygomaticomaxillary buttress, lower antral walls
- Infraorbital rim, cross-sections of zygoma body and arch
- Inferior orbital fissure, infraorbital canal, lateral orbital wall
- Orbital floor (teardrop herniation), medial orbital wall, posteromedial bulge
- Posterior recess of maxillary antrum (sinus roof), infraorbital groove, transformation of orbital cross-section from rhomboid into a triangle shape indicating entrance to the orbital apex

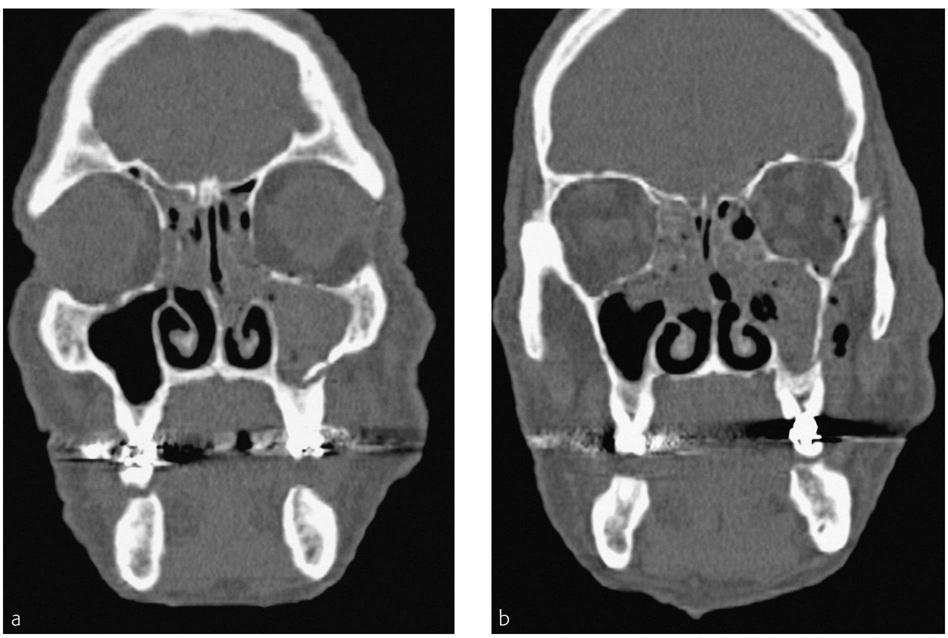


Fig 3.3-5a–b Low-energy ZMC fracture.

a Coronal scan at the level of anterior orbit: rotation of the ZMC into the maxillary sinus, zygomaticomaxillary buttress disrupted, linear fracture of orbital floor, hemorrhage of left maxillary sinus and ethmoid.

b Coronal scan posterior to the globe: medial impaction of the lateral antral wall.

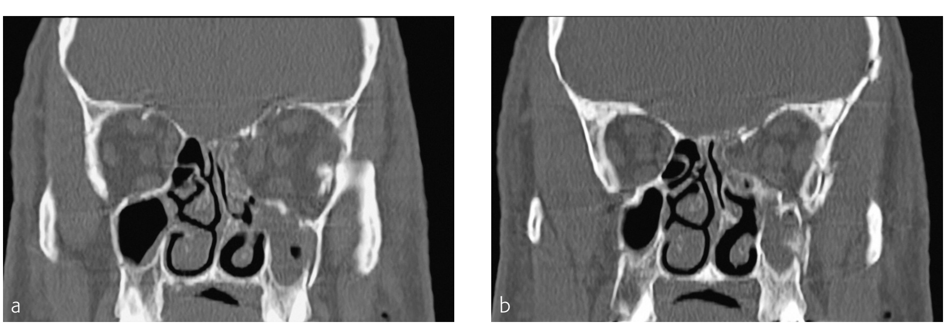


Fig 3.3-6a–b High-energy ZMC fracture.

a Coronal scan at midorbit level: dorsolateral dislocation of the zygoma, comminution of orbital floor, defect in lamina papyracea, medial orbital roof fracture.

b Coronal scan at the rear end of inferior orbital fissure confirming the 4-wall orbital fracture: depression of posterior third of orbital floor, fragmentation of lateral antral wall, fragmentation of lamina papyracea extending into orbital roof, loss of posterior medial "bulge" of the orbit, fragmentation of the zygomatic process of the frontal bone, and disruption of the lateral orbit.

Additional reformatted sagittal views can depict the presence of stable bony ledges on the sides of defects in the posteromedial orbit and help determine the required extent of surgical exploration of the orbit (periorbital dissection) and the selection of adequate material for reconstruction.

3-D reformatted views assist in spatial visualization of the fracture pattern and displacement, but provide little additional diagnostic value over 2-D scans. Valuable information on soft tissues or orbital walls is not obtained in 3-D reformatted images, and therefore cannot replace 2-D multiplanar CT scans. Based on the imaging features, the severity of fractures of the ZMC can be clearly delineated to ascertain indication and invasiveness of surgery, particularly the necessity for concomitant reconstruction of the internal orbit.

Several classification systems of lateral midface fractures were proposed in the past, mostly using plain film x-rays in different projections with the intention of identifying cases for closed reduction and predicting postoperative stability or the risk of secondary dislocation.

Currently, three basic fracture categories are differentiated according to treatment relevance based on CT findings.

These categories are characteristic for low-, medium-, and high-energy trauma mechanisms and range from nondisplaced or minimally displaced en bloc fractures (**Figs 3.3-3a**, **3.3-5a**) at the lower end, over displaced fractures with or without fragmentation at the infraorbital rim and the zygomaticomaxillary buttress, to extreme variants with massive displacement, comminution of the zygomatic body and arch (**Figs 3.3-4a–b**, **3.3-6a–b**), as well as fragmentation at or beyond the articulations. Such extended fractures require more invasive treatment with craniofacial techniques of wide exposure, primary bone repair, and multiple reduction and fixation points. Isolated fractures of the zygomatic arch frequently display three fracture lines, creating two fragments. These may be medially displaced in a V-shaped fashion (**Fig 3.3-2a–b**). In response to the vector of the traumatic impact M- or W-shape displacement occurs with multiple fragmentation.

In complex fracture patterns and following difficult surgical procedures, postoperative imaging is best done with CT scans, which provide an accurate assessment of the reassembly of fragments, an estimate of the precision of fracture reduction, and the position of bone grafts or radiopaque alloplasts for defect repair inside the orbit and for volume restoration. Plain x-rays in two plains are seldom helpful and are not suited for precise quality control.

Malposition and malalignments require revisional surgery in a separate operative session. Intraoperative navigation, cone beam CT, or CT scanning allows immediate assessment and facilitates immediate correction within the same intervention.

3 Approaches

A stepladder concept for ZMC and isolated arch fracture repair encompasses a variety of surgical routes from limited exposure to extended access according to the degree of fracture severity. The ZMC can be exposed through anterior and posterior approaches.

Anterior

- Inferior maxillary approach
  - Upper gingivobuccal sulcus incision (**Fig 3.3-7**)
- Inferior orbital approaches
  - Transconjunctival exposure (pre- and postseptal) (**Fig 3.2-8b**, page 198)
  - Transconjunctival incision combined with lateral split canthus ("swinging lower eyelid") (**Fig 3.2-7a**, page 197)
  - Medial transconjunctival / transcaruncular (semilunar fold) exposure
  - Transcutaneous lower eyelid incisions
  - Subciliary/extended subciliary incision (**Fig 3.2-8a**, page 198)
  - Midtarsal or mid lower eyelid incision (**Fig 3.2-8c**, page 198)
  - Infraorbital rim or lower eyelid incision
- Superolateral approaches
  - Supraorbital lateral eyebrow incision
  - Upper blepharoplasty-type incision (**Fig 3.2-7a–b**, page 197)
  - Transconjunctival combined with complete lateral incision
  - Canthotomy/cantholysis ("swinging upper eyelid")
  - Lateral transconjunctival retrocanthal incision

Posterior

- Superioposterior approach
  - Coronal incision (**Fig 3.2-5a–e**, page 196)
- Lateroposterior approach
  - Preauricular (pretragal or transtragal)/ temporal = hemicoronal

The location and displacement of the fracture sites define the type and number of approaches needed to adequately treat a given ZMC fracture. The osteosynthesis concept is also of influence. Noncomminuted medially displaced ZMC fractures are typically approached anteriorly, aiming at a 1- to 3-point fixation concept, depending on the degree of displacement and the involvement of the zygomaticofrontal suture, whereas comminuted laterally displaced fractures often require extended craniofacial approaches. The indication for surgical orbital floor exploration and treatment is based on preoperative CT imaging. Severe sensory disturbances of the infraorbital nerve may be an indication for a nerve release and neurolysis. Simple one-piece fractures of the zygoma and isolated V-shaped zygomatic arch fractures are often stable after closed reduction and do not require internal fixation.

The zygomatic arch can be visualized and repaired under endoscopic visualization. Through a maxillary antrostomy window, the orbital floor is also accessible for transantral control and reconstruction under endoscopic assistance.

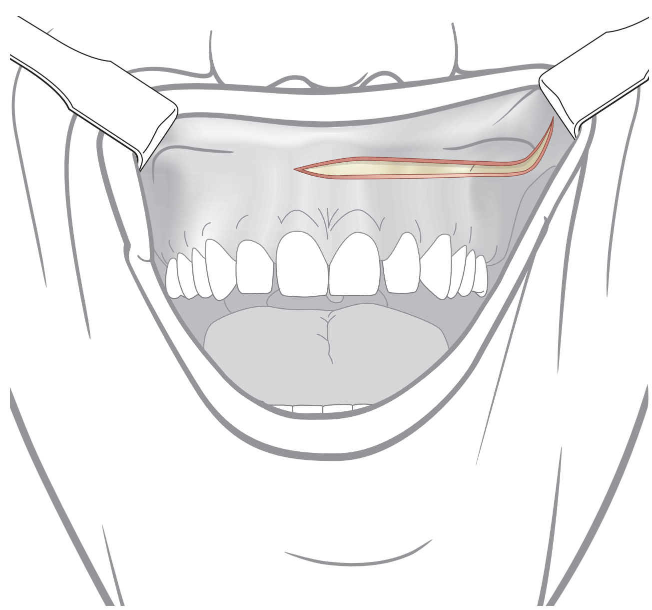


Fig 3.3-7 Upper gingivobuccal sulcus incision in a hockeystick shape to expose the anterior antral wall up to the infraorbital rim.

4 Osteosynthesis techniques

An optimal fracture repair of the ZMC will proceed in the order of precise skeletal reduction, subsequent internal fixation with plates and screws, and, if necessary, contour and volume restoration of the internal orbit.

Facial dimensions must be reestablished in transverse width, sagittal projection, and vertical height by relocating the zygoma into its original position. The length of the zygomatic arch is a key parameter for determining the sagittal projection of the zygoma. Outward or inward bowing of the arch will shorten the arch length resulting in retrodisplacement of the zygoma, whereas unbending, flattening, or elongation of the arch will cause advancement and increased projection (**Fig 3.3-8a–b**).

A rotational motion of the zygoma about a vertical hinge axis and transverse shifting ensue simultaneously. Outward rotation and lateralization create a diastasis along the zygomaticosphenoid suture line and increase facial width and orbital volume. The typical impaction dorsomedially of the zygoma into the maxillary antrum produces a step-off dislocation of the anterior lateral orbit.

The severity of the injury increases with the amount and direction of displacement and the location and number of zygomatic articulation sites that are comminuted. The solid zygomaticofrontal process almost always separates along the suture line, but the zygomaticomaxillary buttress, the infraorbital rim, and the zygomatic arch are commonly comminuted in medium- and high-energy trauma. Comminution of the infraorbital rim often extends far medially into the ascending process of the maxilla. The sphenozygomatic suture line is important because it provides an excellent anatomical reference to the skull base in the reassembly of zygomatic fractures with multifragmented articulations.

Incomplete, nondisplaced, or minimally displaced fractures usually do not justify any surgical treatment.

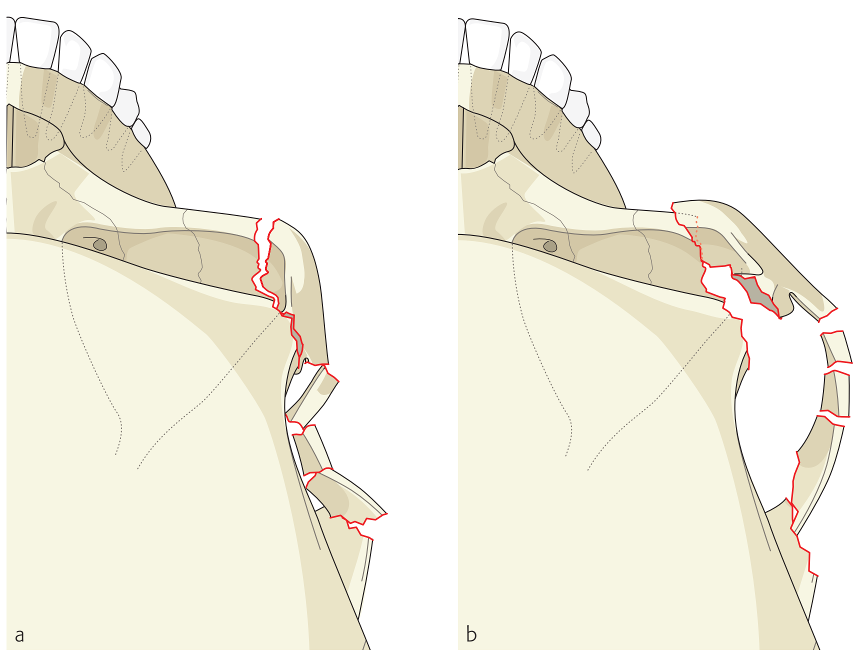


Fig 3.3-8a–b
a Inward bending due to multifragmentary fracture of zygomatic arch with medial displacement.
b Outward bending due to multifragmentary fracture of zygomatic arch with lateral displacement.

4.1 Reduction

Very simple one-piece fractures not requiring orbital floor repair have predictable postreduction stability and can frequently be managed by transcutaneous reduction only.

A direct percutaneous elevation of the depressed zygoma and/or the zygomatic arch can be accomplished using the Strohmeyer hook (**Fig 3.3-9a**). The J-curved bone hook is inserted through a short incision posterior to the zygomaticomaxillary buttress and rotated medially and upward to engage behind the temporal surface of the zygoma or the inner aspect of the arch fragments. Care is taken not to enter the inferior orbital fissure. Anterior and lateral traction under palpation and external inspection brings the bone back into its proper position often accompanied by an audible crepitation sound.

Alternate reduction procedures use small transoral (buccal sulcus) or external incisions (temporal) for the passage of elevators underneath the zygomatic body or zygomatic arch.

Carrol-Girard or Byrd bone screws with a T-bar handle (**Fig 3.3-9b**) are typically inserted percutaneously or transorally or by using extended transeyelid approaches during open reduction to manipulate the disrupted zygoma in a joystick fashion.

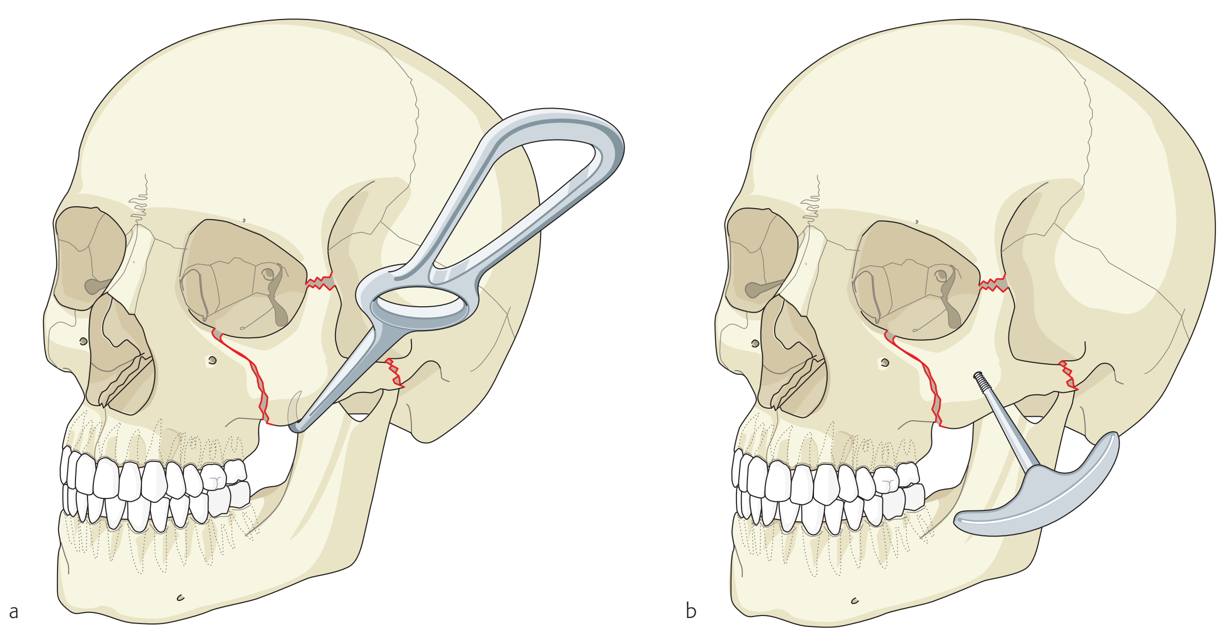


Fig 3.3-9a–b Instrumentation and reduction techniques for ZMC fractures:
a Strohmeyer bone hook for percutaneous elevation.
b Carrol-Girard bone screw inserted into the zygomatic body.

In an individualized stepladder concept, zygomatic fractures of moderate severity are managed by 1-point up to 5-point visualization for reduction control and fixation (**Table 3.3-3**). The stepladder sequence begins at the zygomaticomaxillary buttress site for the following arguments.

A wide transoral degloving approach allows exposure up to the anterior aspect of the infraorbital rim without external scarring. Transoral reduction and position control of the ZMC is achievable. It is a first-rate fixation site because of the solid bone at the buttress area. Additional osteoplastic fenestration in the canine fossa allows transantral reposition of the tuber region or endoscopic control and endoscopically assisted repair of the orbital floor.

No further surgical steps (and external incisions) subsequent to this open 1-point approach are required if the zygomaticofrontal suture is undisplaced, or if palpation reveals a stable reposition of the zygoma and if the postreduction status of the lateral and medial orbital walls is unimpaired. However, with the exception of linear fractures and minimal presurgical involvement (or postreduction transantral endoscopic control, intraoperative cone beam CT, or CT control) confirmation of the integrity of the internal orbit remains questionable.

The common need for an orbital exploration, especially in fractures with more displacement, is the rationale for choosing the infraorbital rim as the second exposure and reduction site. Together with the horizontal and vertical reorientation of the zygoma along the infraorbital rim, the periorbital dissection into the orbital cavity offers visualization of the zygomaticosphenoid junction at the lateral wall.

The zygomaticosphenoid suture line, ie, the junction between the lateral orbital process and the greater wing of the sphenoid, is ranked as a reliable positioning guide in the reduction of isolated fractures of the ZMC or in the rebuilding of the outer facial frame in major midface or panfacial trauma. Even if the zygomaticomaxillary buttress and the infraorbital rim are highly fragmented, comminuted, or present with bony defects, it is still possible to reduce the zygoma exactly by gap and pivot control at the zygomaticosphenoid junction.

Access from inside the orbit to the zygomaticosphenoid junction as the third reduction point in the graduated realignment of the zygoma is greatly facilitated by an appropriate single lower eyelid incision or an additional upper blepharoplasty approach. The extended subciliary approach or the swinging lower eyelid option with complete cantholysis gives a full view over the caudolateral surface of the orbital cavity and makes additional exposure of the zygomaticofrontal suture line unnecessary. The zygomaticofrontal suture is the fourth reduction point. In concert with control of points 1 to 3 (particularly 3) it enhances the precise readjustment of the zygoma in the overall reduction process. The zygomaticofrontal suture line is unreliable for 1-point reduction because its short course in one plane does not exclude unnoticeable rotation, mainly around the transverse and sagittal axis.

Assessing accuracy of reduction in descending order	Stability of fixation
1. Zygomaticosphenoid suture	1. Zygomaticomaxillary buttress
2. Zygomatic arch	2. Zygomaticofrontal suture line
3. Zygomaticomaxillary buttress	3. Zygomaticosphenoid suture
4. Infraorbital rim	4. Zygomatic arch
5. Zygomaticofrontal suture line	5. Infraorbital rim

Table 3.3-3 Zygomatic articulation points in descending order and stability of fixation in descending order.

The classic tripod concept for the treatment of malar fractures breaks down the zygoma into a simple 3-limb structure consisting of the frontal process, the infraobital rim, and the zygomaticomaxillary buttress. These articulations are handled via open reduction accompanied by a closed arch reduction with an accuracy left somewhat at random. The tripod concept works in most moderate trauma cases, but obviously meets its limits if there is comminution at the medial and lower limb ends. In these more severe fractures the tripod concept may lead to malalignment and malrotation, since it omits multipoint reduction in a tetrapod or pentapod fashion under visualization of the zygomaticosphenoid junction or exposure of the zygomatic arch.

In fact, more serious high-energy fracture variants and their rare extremes require aggressive treatment by way of a coronal flap approach for reduction and stabilization right from the beginning of the procedure.

The following criteria mandate extended exposure (anterior and posterior approaches) and multipoint realignment supported by the zygomatic arch:

- Multifragmentation of the arch with lateral displacement of the middle section
- Fracture of the temporal arch root and glenoid fossa with tendency to shear and telescope posteriorly
- Fragmentation of the zygomatic body
- Fragmentation of the lateral orbital margin and orbital process with need for fixation
- Fractures through the upper base of the zygomatic process of the frontal bone
- Extensive fractures of the medial orbital wall or associated nasoorbitoethmoidal (NOE) fractures
- Skull-base fractures involving the orbital apex, the greater wing of the sphenoid, and its transition into the middle cranial fossa

The reassembly of the seriously injured, multifragmented ZMC starts with an initial arbitrary reduction of the zygoma and the simultaneous reversal of the laterally displaced arch to its former position and length by finger pressure. After this approximation, a provisional link at the zygomaticofrontal suture with a loose temporary wire fixation holds the major fragments in place. The interfragmentary positioning wire limits the degree of freedom eliminating translational movements but allowing for some rotation of the fragments. With transverse or diagonal fragmentation of the zygomatic body in particular, the lateral orbital wall is realigned at the zygomaticosphenoid junction from inside the orbit as the next step. This provides a basis for the realignment of the zygoma under guidance of the zygomatic arch. With a one-piece zygoma body fragment it is beneficial to refine the initial bone approximation reviewing the zygomaticosphenoid suture line and the zygomatic arch configuration and visualizing both alternately.

Fragmentation of the zygomaticosphenoid junction is not uncommon but usually easy to overcome. The separated and encroached rectangular bone pieces along the suture line can be conveniently reintegrated into the reestablished straight plane course of the lateral orbit. Severe displacement of the greater sphenoid wing and loss of this rather constant reference to the skull base is exceedingly rare. In that instance, restoration of the posterior lateral orbit and apex is performed via a temporal/infratemporal fossa approach.

With the most serious injury types including craniofacial structures, no single predetermined sequence for reduction and repair can be mandated. The loss of all points for reduction due to comminution or defects will necessitate free positioning and reshaping of the zygomatic bone remnants.

4.2 Stabilization

The zygoma as a subunit of the midfacial buttress system is subject to dynamic forces during mastication and contraction of the facial muscles. Biomechanical data detailing the intricate real-life conditions are not available. In a rudimentary model, stress distribution varies in loading cycles of downward tension and upward compression produced by masseter and temporal muscle action and the transfer of occlusal bite forces at alternating sites along the dental arch.

Plate and screw fixation must resist these muscle vector forces and stabilize the ZMC against translational movements and rotation. For optimal support and long-term bone healing the plates and screws must be congruent with pretraumatic anatomical load paths that match with the major buttresses. A number of issues has to be considered for selection of the appropriate hardware.

At the zygomaticomaxillary buttress the use of stronger miniplates 1.5, 2.0, or corresponding plates from the Matrix Midface system is necessary regardless of the overall fracture constellation.

Comminution and missing bone at any one of the remaining zygomatic articulations may turn a load-sharing into a load-bearing situation requiring larger plates for adequate interfragmentary support. Weakness and mobility due to comminution at one articulation site can be compensated by stronger or longer plates at that or other locations.

An otherwise intact midfacial skeleton contributes to the stability of ZMC fractures through a rigid fixation point at the zygomaticomaxillary buttress. It allows the application of miniplates 1.3, 1.5, or corresponding Matrix Midface plates at the zygomaticofrontal suture. In coexisting midface fractures, however, a stronger fixation at the frontal process is required.

The thinness of soft tissues above the zygomaticofrontal process and the infraorbital rim can present a relative contraindication for large profile plates. The infraorbital rim, for instance, in view of its delicate cross-section and horizontal orientation, does not add much to the total stability, so a low-profile plate 1.3 or similar Matrix Midface plate will suffice for realignment.

In theory, 28 combinations of a 1-point up to a 5-point plating pattern exist. The essence of any mechanically efficient stabilization pattern is to build up 3-D stability through a framework of self-retaining articulations (buttressing) and/or osteosyntheses. Note that the stability of fixation differs at the points of articulation due to bone properties and spatial orientation.

In practice, a few schemes using plate combinations from the whole assortment will cover standard fracture situations. In the clinical setting, stabilization of the reduced ZMC with titanium plates is obtained in incremental steps. No fixation is added if the position of the zygoma is stable after the initial reduction maneuver.

A 1-point fixation with an L-, T-, or Y-shaped miniplate 1.5, 2.0, or corresponding Matrix Midface plates at the zygomaticomaxillary buttress provides sufficient stability in less severe injuries (**Fig 3.3-10**). The same is true for a 1-point fixation at the zygomaticofrontal suture with the use of the above-mentioned plates, although this site alone is associated with the drawbacks of an external incision, potential palpability, and lack of confirmation of reduction of the remainder of the zygoma (**Fig 3.3-11**).

After each fixation step, stability is rechecked by rocking the zygoma moderately. For more stability, a 2-point fixation may be accomplished using miniplates 1.5, 2.0, or corresponding Matrix plates placed at the zygomaticomaxillary buttress combined with plating of the infraorbital rim (especially if exploration of the orbital floor is indicated) or the zygomaticofrontal suture (**Figs 3.3-12**, **3.3-13**).

A 3-point fixation at the zygomaticomaxillary buttress, the zygomaticofrontal suture, and the infraorbital rim has been classically advised to deal with comminution zones at the lower vertical and the inner horizontal buttress in the medium injury category (**Fig 3.3-14**).

While this 3-point fixation pattern can still be achieved with anterior approaches, every 3-point plate osteosynthesis in other locations will demand an additional posterior approach, commonly a coronal flap.

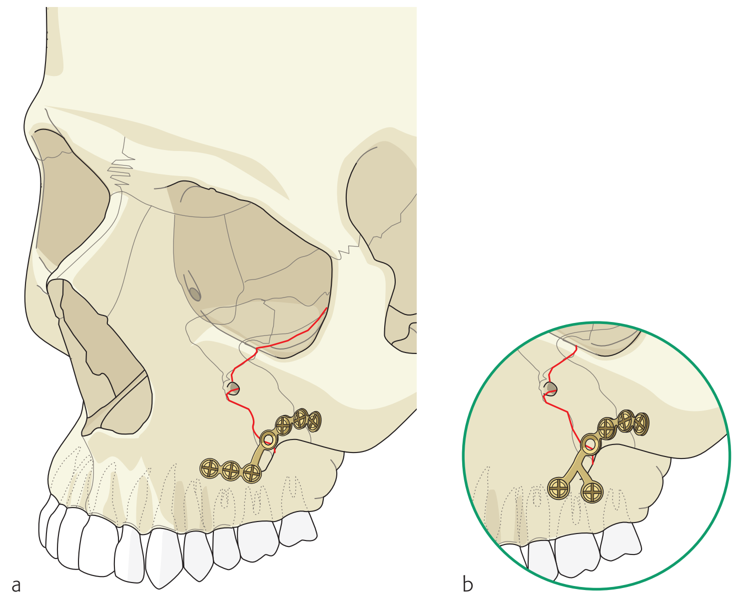


Fig 3.3-10 1-point fixation using an inverted L-plate at the zygomaticomaxillary buttress. The inset shows a Y-plate as an alternative.

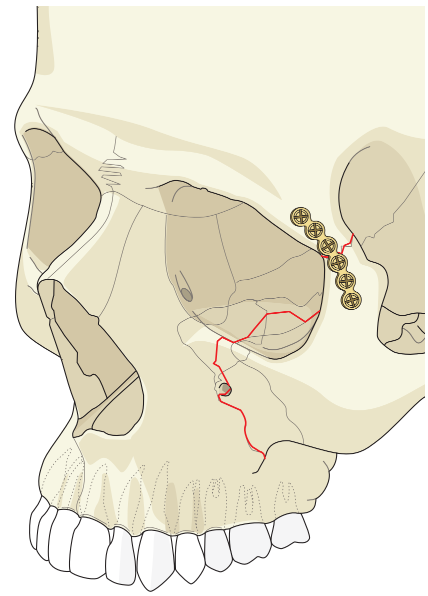


Fig 3.3-11 1-point fixation using an adaptation plate 2.0 at the zygomaticofrontal suture.

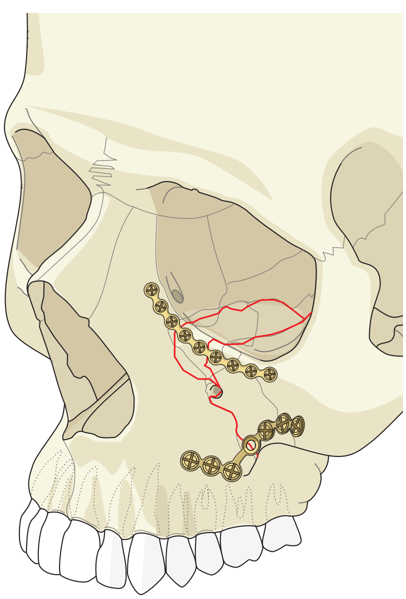


Fig 3.3-12 2-point fixation using an L-plate at the zygomaticomaxillary buttress and a nonstabilizing, curved orbital plate 1.0 for realignment of the comminuted infraorbital rim.

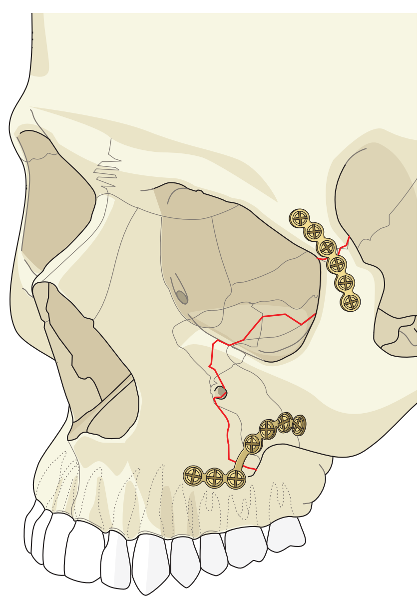


Fig 3.3-13 2-point fixation for increased stabilization using an L-plate 2.0 at the zygomaticomaxillary buttress (Y- or T-plates are also possible) and an adaptation plate 2.0 at the zygomaticofrontal suture.

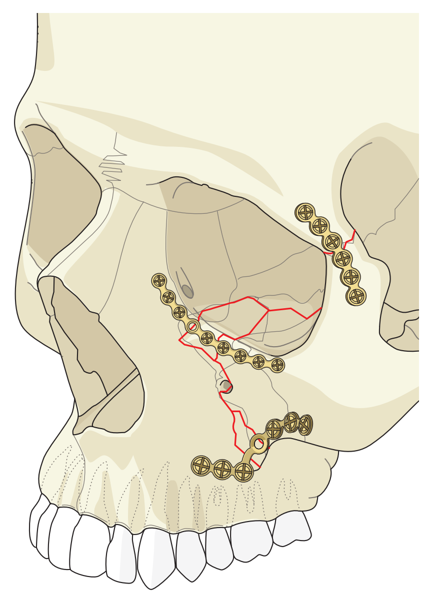


Fig 3.3-14 3-point miniplate fixation: Comminution at the zygomaticomaxillary buttress and the infraorbital rim demands miniplate application at the three anterior fracture sites. Option for use of miniplates 1.3, 1.5, 2.0, or corresponding Matrix Midface plates.

Severely dislocated, comminuted, and defect ZMC fractures typically require wider exposure, mostly by a combination of anterior and posterior approaches, for adequate reduction and fixation. This can be a 4-point or a 5-point fixation (**Figs 3.3-15a–e**, **3.3-16a–c**). Plating the lateral orbital wall after elevation of the temporal muscle is reserved for those extreme injuries that displace the adjacent skull base (rarely indicated).

The typical V-shaped isolated zygomatic arch fracture can be reduced and does not require any fixation. In contrast, isolated zygomatic arch fractures may be multifragmented, grossly displaced, and free floating, resulting from the downward pull of the masseter muscle. In such rare instances instability exists and predetermines open reduction via an extended preauricular incision or a coronal or hemi-coronal approach.

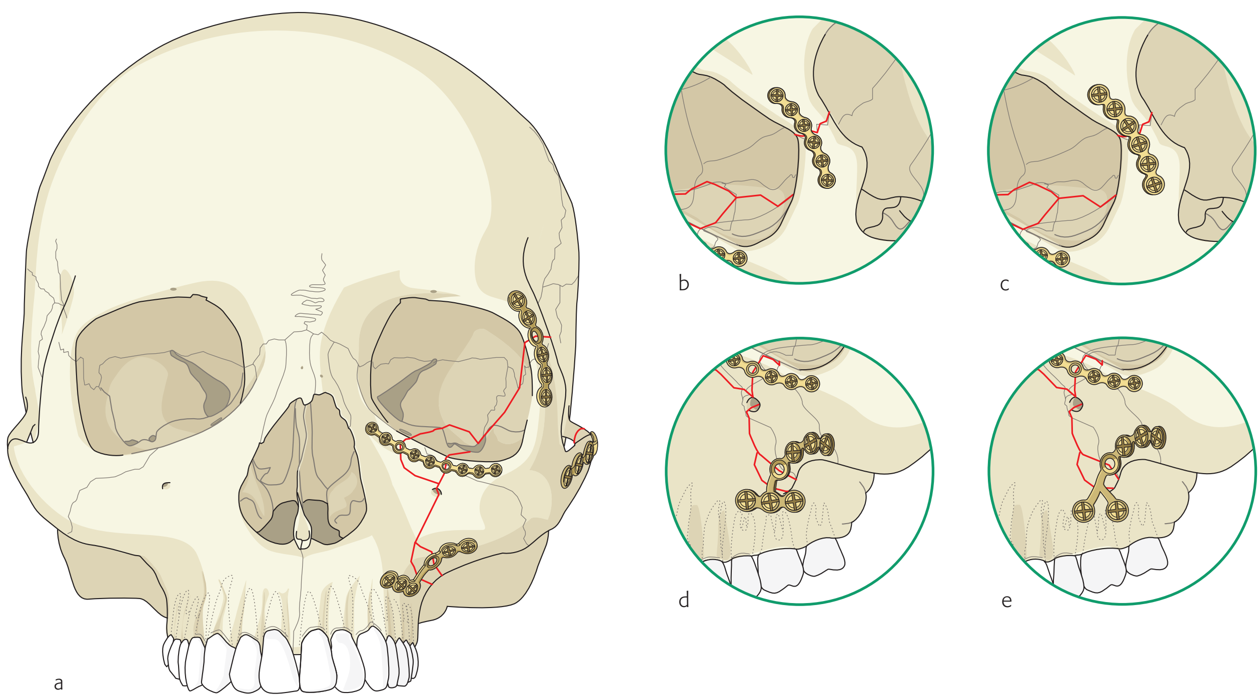


Fig 3.3-15a–e 4-point fixation pattern: comminution of the zygomaticomaxillary buttress, the zygomatic arch, and the infraorbital rim.

a Miniplates 1.3–2.0 may be applied.
b Adaptation plate 1.3.
c Adaptation plate 2.0.
d T-plate 2.0.
e Y-plate 2.0.

The craniofacial locking plates 2.0 and similar Matrix Midface plates offer the advantages of larger plate profiles and enhanced security against secondary displacement, since tightening the screws will not pull the fragments onto the plate surface causing torsion. The locking plates can be applied at the zygomaticomaxillary buttress, the zygomatic arch, and in thick-skinned individuals at the zygomaticofrontal process.

The size and the biomechanical properties of bioresorbable plates and screws have raised questions about their routine use in ZMC fractures. In selected cases (low- to medium-energy category) these plates may be indicated and are best applied in a 2-point or 3-point pattern. Bioresorbable plates can also be used in a hybrid fashion together with titanium miniplates.

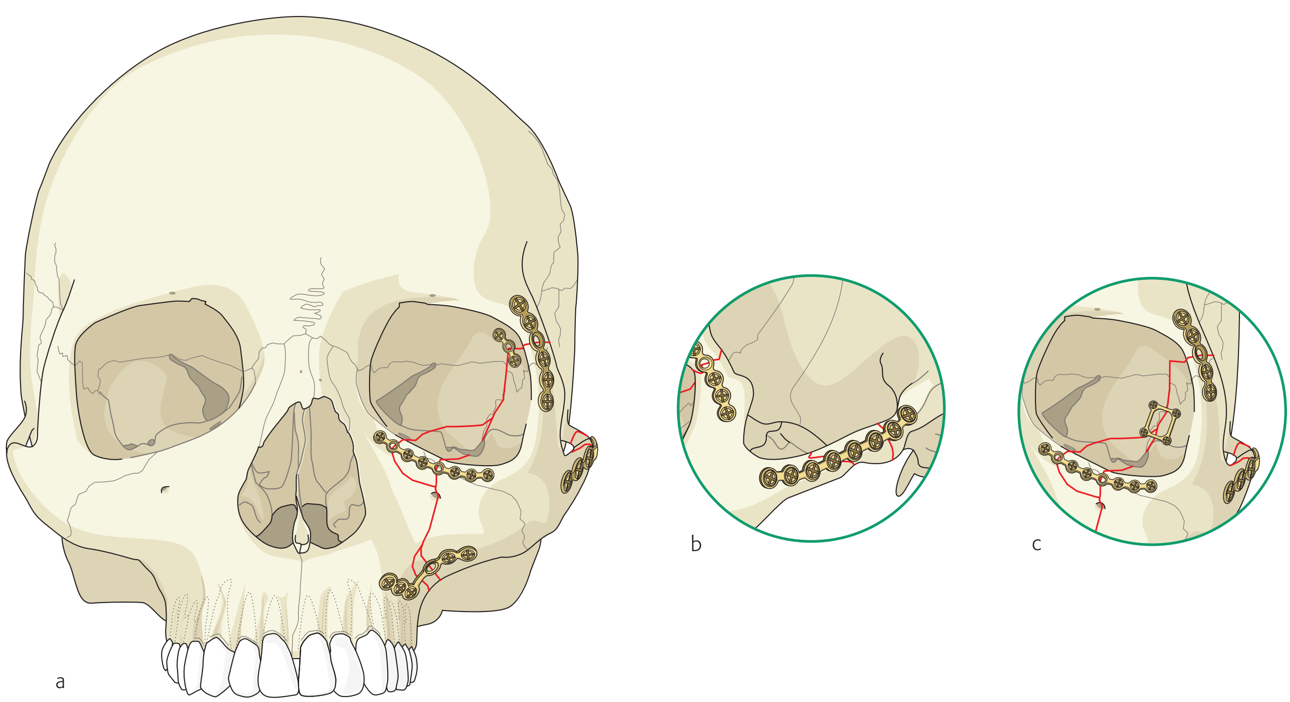


Fig 3.3-16a–c 5-point fixation using all accessible articulation sites of the ZMC. The insets show different types of miniplates.

5 Treatment of the internal orbit

The lateral orbital wall will usually be restored together with the realignment and fixation of the zygomatic part of the external orbital rim. Defects of the lateral wall, if present, are uniplanar and simple to bone graft or to cover with titanium meshes. Defects and fragment dislocations within the internal orbit are commonly treated after the external orbital frame and the facial buttresses have been reestablished. For details of repair and volumetric restoration of orbital wall defects refer to chapter 3.4 Orbital fractures.

6 Perioperative and postoperative treatment

A complete ophthalmologic examination is necessary prior to any surgery to determine the structural and functional status of the globe itself and the orbital contents.

Acute or gradually occurring blindness is of major concern before or after the repair of ZMC fractures and orbital surgery. Since any intervention must be immediate, eye examination and monitoring of the visual function at short intervals is the standard of care. Any dressings on the eye are an obstacle to regular observation and should be minimized. Only transparent eye ointments, lubricants, or eye drops should be instilled before, during, and after surgery in order not to interfere with visional testing.

Nose blowing is not allowed pre- and postoperatively in order to prevent orbital and subcutaneous emphysema which predisposes to infection. Perioperative antibiotic cover with single-dose intravenous administration immediately before surgical intervention, or repeated doses in long surgical interventions, is routinely used. Serious injuries and polytrauma may require different regimens. The risk of infection may increase with a history or signs of chronic sinusitis. Short-term use of nasal decongestants and mucolytic agents may be indicated in such cases to help resolve antral hematomas and nasal congestion.

High-dose preoperative and intraoperative steroids reduce tissue swelling and periorbital edema. Postoperative ice packs contribute to the resolution of chemosis and diminish the intensity of pain. For the same reason regional nerve blocks with long-acting local anesthetics may be performed at the end of surgery. Regular pain medication is administered over several days to provide sufficient analgesia.

The risk of a dehiscence along the upper buccal sulcus incision is minimized with a soft diet. Chlorhexidine mouth rinses and a good oral hygiene keep the incision line clean.

Following the reduction of an isolated zygomatic arch fracture, protection (taping or splints) may be used to prevent recurrent displacement.

7 Complications and pitfalls

The acute and late sequelae of ZMC fractures may persist as a result of no intervention or inadequacy of treatment. Errors in the management of ZMC fractures relate to poor imaging techniques, underestimation of fracture severity, and the effects of localized comminution, inappropriate exposure for multipoint reduction, malreduction of bone, inadequate or loose fixation, fixation without proper reduction, instability, persistence of orbital volume changes, and failure of the resuspension of soft tissues. A thorough understanding, a systematic approach, and precise reduction and fixation help prevent unwanted sequelae and surgical complications after treatment. Critical issues are impairment or loss of vision, neurogenic ocular motility disturbances, and neurosensory deficits of involved maxillary trigeminal branches. All of the above symptoms may be encountered posttrauma or postsurgery. Suitable investigative and precautionary measures as part of a coordinated interdisciplinary strategy of treatment are mandatory, in particular to deal with potential optic nerve lesions and their disastrous consequences (details in chapter 3.4 Orbital fractures).

Author Carl-Peter Cornelius

Author Christoph Kunz

3.4 Orbital fractures

1 Definition

Fractures involving the orbit are observed frequently. In more than 40% of all facial fractures, parts of the orbital rim and/or the internal orbit are injured showing various fracture patterns. Commonly, multiple portions of the orbit are involved. Zygomaticomaxillary complex, nasoorbitoethmoidal (NOE) injuries and combinations thereof reveal fractures of the orbital rim and (several) internal orbital walls ranging from simple to complex comminuted fractures, the latter being responsible for most unfavorable results. In simple fracture patterns, such as the common single-wall "blow-out" fracture, only one portion of the internal orbit is involved. However, even these should not be underestimated, as the orbit is a complex 3-D structure which needs precise repair after traumatic derangement.

2 Anatomy

The shape of the bony orbit is similar to a pyramid, quadrilateral at its base, the orbital rim, and triangular at its apex. The configuration changes by the transition of the posterior part of the orbital floor into the medial wall. This area, the posteromedial wall, is of major impact for orbital reconstruction and is therefore known as the "key area." The posteromedial wall together with the posterolateral wall support the globe and are responsible for its anterior projection. Being a very thin bony structure, it is often damaged in orbital fractures and its rigid reconstruction may be required for complex internal orbital fracture treatment.

From a functional point of view, it is helpful to divide the bony orbit into three sections (**Fig 3.4-1**). The anterior section is a thick bony structure, the orbital rim. The middle section consists of four subunits: orbital floor, medial orbital wall, lateral orbital wall, and orbital roof. The bone of this section is thin with the exception of the lateral wall and often primarily affected by fractures before the orbital frame breaks. The bone in the posterior section is thick protecting cranial nerves which enter the orbit in the apex. It contains the optic foramen and the inferior and superior orbital fissures.

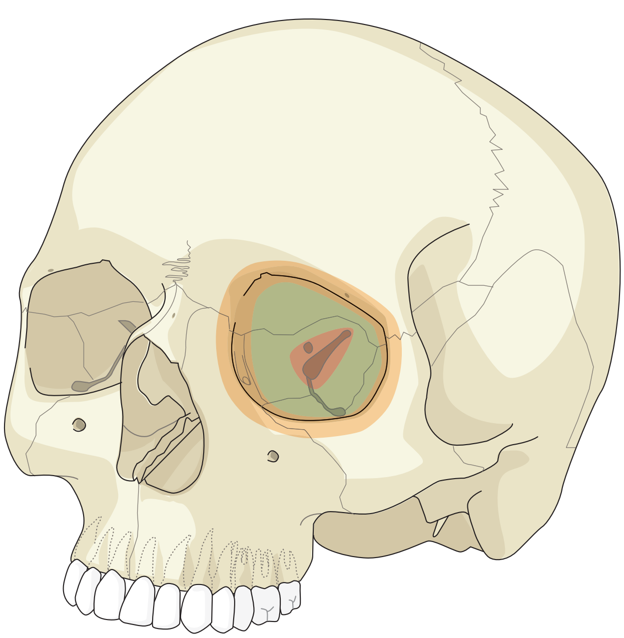


Fig 3.4-1 The three sections of the orbit:
- Anterior orbital section: thick bony structure forming the orbital rim
- Middle orbital section: including orbital floor, medial orbital wall, lateral orbital wall, orbital roof, and inferior orbital fissure
- Posterior orbital section: thick bone protecting the cranial nerves which enter through the apex region, containing the optic foramen, and the inferior and superior orbital fissures

2.1 Anterior orbital section

The orbital rim itself is subdivided into three segments: the NOE (medial), the zygomatic (lateral and inferior), and the supraorbital (superior) segment. The NOE segment, ie, the lower two-thirds of the medial orbital rim, is characterized by the attachment of the medial canthal ligament and the medial insertion of Lockwood's ligament, a part of the inferior support sling of the globe. It blends to the inferior orbital rim, formed by the zygomatic bone, which extends as the lateral orbital rim to the frontozygomatic suture. The lateral canthal complex inserts onto the orbital surface of the zygomatic bone. It consists of the anterior (superficial) and posterior (deep) limbs of the lateral canthal ligament, the latter attaching to Whitnall's tubercle located 3–4 mm posterior to the lateral rim, 8–10 mm below the frontozygomatic suture. The lateral portion of Lockwood's ligament and the levator aponeurosis is also attached here. The supraorbital segment includes the frontal bone laterally and lateral aspects of the frontal sinus medially, and extends from the frontomaxillary to the frontozygomatical suture. The orbital rim is perforated by the supraorbital foramen (or notch), the zygomaticofacial foramen at the lateral aspect of the malar eminence, and the infraorbital foramen. The latter is often involved in fractures which may result in symptoms of anesthesia or hypesthesia of the infraorbital nerve.

Surgical impact: The thick bone of the rim allows stable fixation of the orbital frame as a basis for internal orbital reconstruction. Reattachment of the canthal ligaments to the orbital rim must be performed to reestablish bone–soft-tissue relations after detachment. Adequate decompression of the infraorbital nerve should be insured after each reduction.

2.2 Middle orbital section

The middle orbital section has four thin bony walls: the lateral wall, roof, medial wall, and floor. The lateral orbital wall consists of the greater wing of the sphenoid and the orbital process of the zygoma. Anteriorly, the small zygomatico-orbital artery perforates the bone. Because of its firm structure, higher energy is necessary for it to fracture compared with the other orbital walls. However, the thickness of the bone allows stable fixation of plates, and alignment of the entire lateral wall is of major impact for correct orbital volume restoration. The inferior orbital fissure separates the lateral orbital wall from the floor. It communicates with the retromaxillary space and is crossed by several smaller arteries and nerves. Posteriorly, the maxillary portion of the trigeminal nerve, the infraorbital artery, and the zygomaticofacial nerve pass through. Fractures of the orbital floor with extension to the posterior third of the orbit and displacement of the posterior wall of the maxillary sinus may result in critical enlargement of the inferior orbital fissure. Repair of these fractures should provide complete obliteration of the fissure to prevent enophthalmos.

Surgical impact: As the lateral wall usually is not comminuted, it is a reliable starting point for orbital dissection. Alignment and rigid fixation of the lateral wall may be a key step in restoration of orbital volume in complex orbital fractures.

Dissection of the inferior orbital fissure requires meticulous hemostasis for assessment of a possible enlargement of the inferior orbital fissure. It should be performed in case of a posteriorly extended floor fracture to expose the complete fracture pattern.

The orbital roof separates the orbit from the anterior cranial fossa as a thin, curved structure. In a sagittal plane from anterior to posterior the roof first inclines upward just behind the supraorbital rim. The midportion extends posteriorly followed by a final inclination inferiorly to the apex region.

The medial orbital wall is a paper-thin delicate structure formed by the orbital plate of the ethmoid bone, reinforced by the septae of the ethmoid sinuses. Looking at the orbit from anteriorly, the wall is directly in line with the optic foramen. The two ethmoid arteries perforate the bone at the same vertical level as the optic nerve enters into the orbit. Thus, they allow reliable orientation with regard to the optic canal. The foramina can be used as a landmark, being located about 25 mm and 35 mm posterior to the anterior lacrimal crest. The optic nerve lies 5–8 mm posteriorly to the posterior ethmoid artery (40–45 mm from the anterior lacrimal crest).

Surgical impact: Dissection of the medial wall must be delicate with regard to the thin bony plate and possible natural bony gaps. The anterior ethmoid artery usually requires transsection for adequate exposure of extended medial wall fractures, whereas the posterior ethmoid artery should be preserved as a sentinel. The posterior medial wall and its transition into the posterior orbital floor is one of the most critical components of orbital reconstruction and therefore called the key area. The restoration of injuries with an intact key area is much less difficult than the repair of fractures involving this area. Thus, it is recommended to restore the key area by means of rigid fixation as a first step.

The orbital floor is often involved in orbital wall injuries. It separates the orbit from the maxillary sinus and contains the infraorbital nerve, which lies in a canal or in a groove in the middle orbit. Lateral to the nerve, the floor is more resistant to fractures. Therefore, floor fractures tend to extend to the inferior medial wall. Anteriorly (in a sagittal plane) the floor follows a concave curve behind the rim, inclines upward behind the globe and also upward towards the medial wall (key area), forming a postbulbar constriction. For correct projection of the globe this retroocular bulge has to be restored (**Fig 3.4-2a–c**).

2.3 Posterior orbital section

The posterior third contains the apex of the orbital pyramid, where the cranial nerves III, IV, V, and VI enter the orbit from the middle cranial fossa through the superior orbital fissure, and the optic nerve through the optic canal. The superior orbital fissure is formed by the greater and lesser wings of the sphenoid bone. The bone of this section is thicker and rarely involved in fractures, thus protecting the delicate structures contained in the fissure.

The inferior orbital fissure originates in the posterior orbit, separating the lateral wall from the floor in the middle section of the orbit.

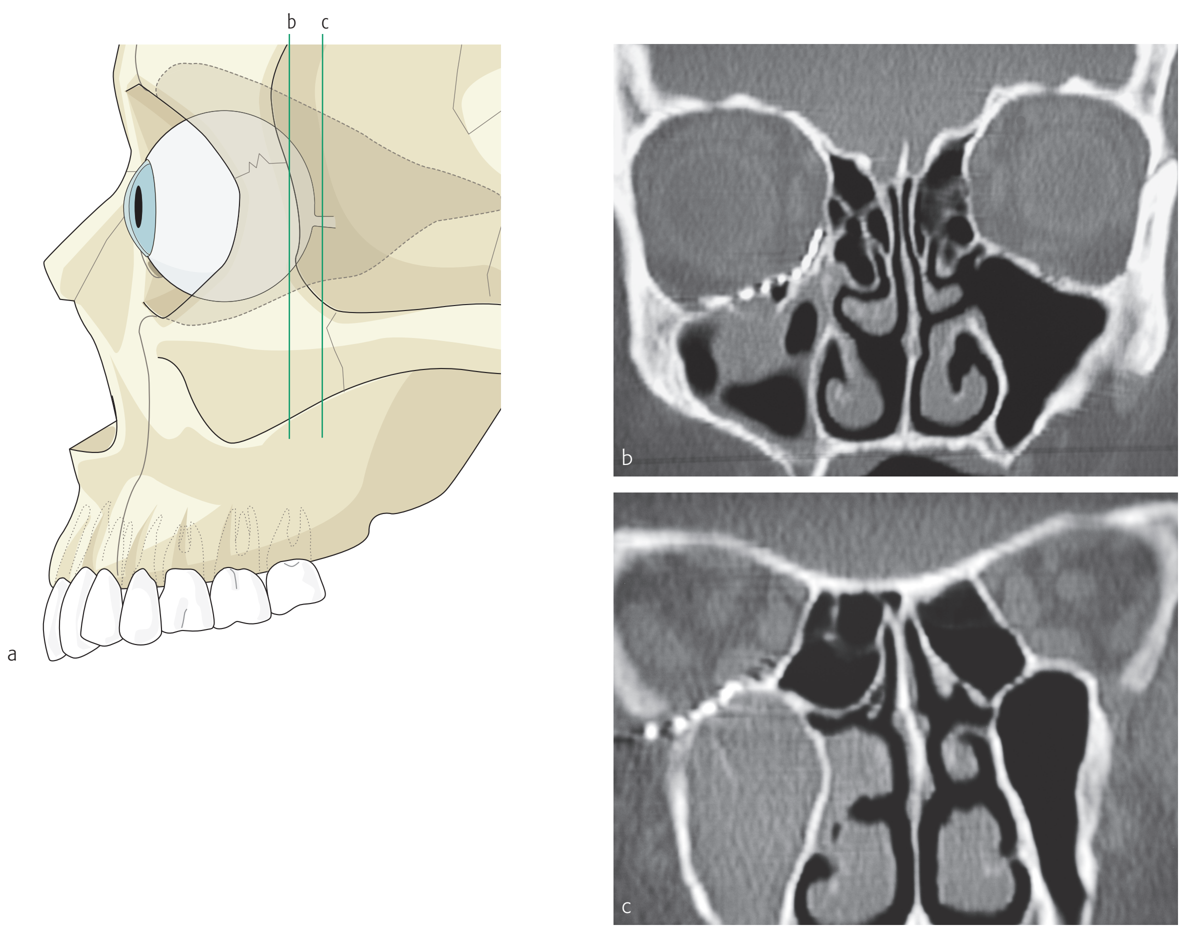


Fig 3.4-2a–c

a Lateral view of the orbit showing concavity of the orbital floor behind the rim and more posteriorly the convexity right behind the globe. The vertical lines b and c mark the CT cuts as shown in 3.4-2b and c.

b Reconstruction of orbital floor and lower third of medial orbital wall; relatively straight curved line.

c Retrobulbar area reconstruction of floor and medial orbital wall with typical convexity.

3 Diagnosis

3.1 Clinical assessment

The diagnosis of orbital fractures requires clinical and radiological examination. As orbital fractures often present a rather uniform clinical appearance, radiological assessment is of major impact for precise diagnosis. However, clinical examination may provide important hints about the severity of the trauma and indications for further diagnostic procedures and treatment. Fractures of the bony orbit are frequently associated with trauma to adjacent structures. Thus, clinical examination has to identify simultaneous injuries of the globe and adnexae. Every patient with an orbital fracture should have a preoperative ophthalmologic assessment to prevent visual impairment or additional trauma to the globe by means of reconstruction of the bony orbit. Rupture of the globe and intraocular hemorrhage or posttraumatic glaucoma may be reasons for visual impairment with a need for immediate ophthalmologic intervention. An ophthalmologic assessment should include eye inspection, visual acuity in the cooperative patient, pupillary function testing, ie, testing of relative or incomplete afferent pupillary defect RAPD (also adequate for the unconscious patient), as well as an assessment of eye motility (double vision testing).

Compression of the structures traversing the superior orbital fissure by fracture of the greater sphenoid wing or hematoma in the posterior orbit may result in the superior orbital fissure syndrome. Dysfunction of the cranial nerves III, IV, V1, and VI with internal ophthalmoplegia, ptosis of the upper eyelid, sensory disturbance (V1), and retrobulbar pain may indicate compression of the orbital apex. In case of additional involvement of the optic nerve, the orbital apex syndrome is apparent. Other frequently associated injuries in orbital trauma are fractures of the frontal sinus or the skull base, which are often difficult to assess by clinical examination alone.

3.2 Imaging

Plain x-rays may be adequate for fracture diagnosis of the outer orbital frame and in some instances for fracture assessment of the inner orbital frame. However, fractures of the orbital walls usually cannot be detected directly. Adequate projections for the diagnosis of orbital wall fractures are the Waters' view or the submental vertex view.

The most precise information about orbital fractures is provided by computed tomography (CT) in several planes (coronal and axial, hard- and soft-tissue windows, and perhaps sagittal images) and should be a routine part of orbital trauma diagnosis. CT allows precise assessment of the extent of fractures of the bony orbit and adjacent structures. For an accurate diagnosis bone windows as well as soft-tissue windows should be assessed, the latter being helpful in detection of retrobulbar hematoma, adhesions between the musculoseptal apparatus and the bony orbital walls, or optic nerve sheath edema and muscle incarceration or injury.

A systematic approach enhances interpretation of the fracture pattern. Fractures of the orbital frame are assessed with regard to the degree of fragmentation and displacement.

Besides diagnosis of orbital wall defects, CT scans allow assessment of important features of orbital fracture patterns. A widened inferior orbital fissure, a possible reason for enlargement of the orbital volume, can be detected in the coronal plane. Axial scans allow the assessment of the posterior orbital cone with regard to the presence or absence of a bony shelf, providing support to bone grafts or orbital plates. If this posterior ledge is lacking, rigid reconstruction is highly recommended.

However, under certain circumstances, evaluation of CT scans may be misleading and may result in underestimation of the fracture pattern. Linear fractures creating orbital wall instability and enlargement are sometimes difficult to detect and the size of orbital wall defects is difficult to assess correctly. Defects are often larger than they actually appear on CT scans.

Certain symptoms demand immediate CT examination, such as visual impairment, retrobulbar pain, severe exophthalmos, or obvious displacement of the globe and severe disturbances of the motility of the globe.

Magnetic resonance imaging (MRI) is no alternative to CT examination; the assessment of the thin bony structures and the orbital walls is insufficient. However, there are advantages in the diagnosis of adhesions and in herniation of orbital soft tissues or optic nerve injury. Additional information may be gained by oculodynamic MRI examination, a technique which is currently being evaluated.

4 Treatment

4.1 Indications

Treatment of orbital fractures is planned according to the severity of the fracture. Note that possible secondary problems, such as enophthalmos and diplopia, often develop as a late functional impairment due to scar formation or asymmetric shrinkage of the intraorbital tissues, are difficult to correct, and often result in an insufficient final appearance.

Displacement of the orbital rim, fractures involving several orbital walls or including the posterior orbital floor and medial wall (key area) are indications for a surgical treatment. Vertical globe dystopia and/or enophthalmos immediately after trauma may be signs of a distinct enlargement of the bony orbit. Injuries revealing severe restriction of eye motility (confirmed by forced duction testing) indicate herniation of orbital soft tissues with the need for release.

Especially in cases of direct entrapment of muscles immediate surgery has to be performed to minimize damage to the traumatized soft tissues. Herniation itself requires less acute exploration.

4.2 Exposure

Extent and type of exposure depend on the fracture pattern of the orbital frame, the orbital walls, and the patterns of associated midfacial fractures. Basically, exposure should provide a view of the complete extent of the injury. Simple fracture patterns (including nonfragmented lateral midface fractures) and single orbital wall defects are usually treated by local incisions. The lower and lateral aspects of the orbit can be adequately exposed by mid-eyelid, subciliary, or transconjunctival approaches, which can include a lateral canthotomy, detaching the lateral canthal ligament (**Fig 3.4-3**). The transcannular approach offers additional access to the medial wall. However, isolated displacement or defects of the posterior orbital floor and medial wall (key area) must not be underestimated. They can be indications for a wider exposure via combined local and coronal approaches, the latter exposing the entire upper midface skeleton including the zygomatic arches, crucial for correct facial projection, and providing 3-D assessment of the medial and lateral orbital wall as well as the roof including the deep (posterior) third of the orbital cone (**Fig 3.4-4**). In addition, the access to the posterior cone can be enhanced by supraorbital marginotomies providing an excellent visualization of the ethmoid arteries, which are landmark structures for dissection. Complex fracture patterns requiring wide exposure are:

- Complex orbitozygomaticomaxillary fractures
- NOE fractures
- Combined lateral and central midface fractures
- Large defects in the posterior third of the orbit

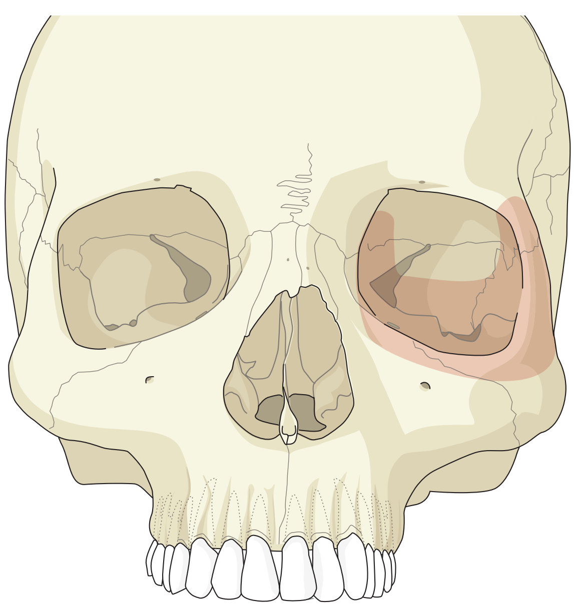


Fig 3.4-3 Area of possible orbital exposure (pink) through local incisions.

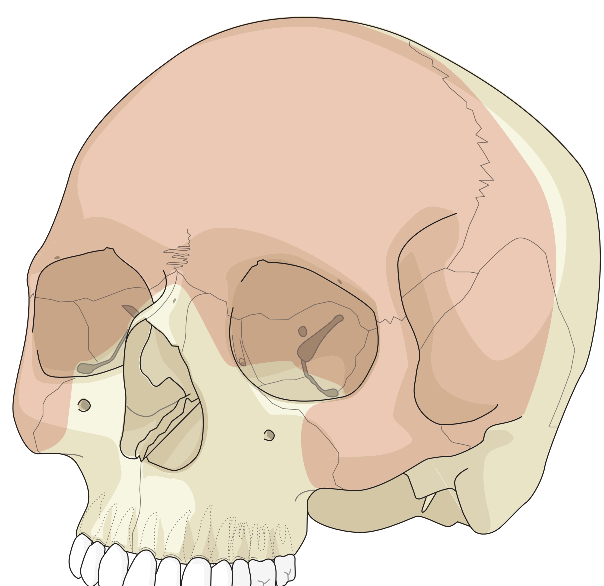


Fig 3.4-4 Area of possible exposure (pink) through coronal approach.

In case of orbital wall defects, it is of utmost importance to expose intact bony ledges on all sides of the defect during dissection and to identify widening of the inferior orbital fissure. Performed before and after dissection, the forced duction test provides assessment of the mobility of the muscular ligament system which may be influenced by edema or impingement of the musculofibrous system. It is important to repeat the duction testing after reduction and reconstruction of the orbit to recognize impingement of the musculofibrous ligament system (MFLS) by implants and prevent secondary herniation and motility disorders of the adnexae of the eye.

4.3 Materials for reconstruction

Isolated internal orbital defects can be reconstructed using either bone grafts or alloplastic implants, such as titanium mesh and orbital plates, porous polyethylene implants, bioactive glass or resorbable materials, and others. Due to the complex 3-D orbital shape, autogenous bone grafts are often difficult to contour. In complex orbital fractures with large wall defects the need for a rigid, but highly malleable implant is obvious. In these fractures prefabricated orbital plates or titanium mesh plates are considered the gold standard today. There is no evidence of a higher short-term infection rate using alloplastic implants compared with autogenous tissues. It is important to cut alloplastic materials to the minimum required size, to meticulously contour internal orbital plates and titanium meshes, and to trim anchoring tabs and edges to prevent malposition and interference with the adjacent intraorbital soft tissues.

To prevent displacement of a bone graft or alloplastic implant, they should be anchored to the orbital rim or the lateral orbital wall which provides bone stock adequate for screw fixation. For bone grafts the “cantilever” technique is useful (**Fig 3.4-5a–d**); if alloplastic materials are used direct fixation with screws or sutures is possible.

For complex wall defects, insertion and rigid fixation of orbital floor or wall plates provide the support for additional grafts or sheets to cover remaining defects (**Fig 3.4-6a–b**).

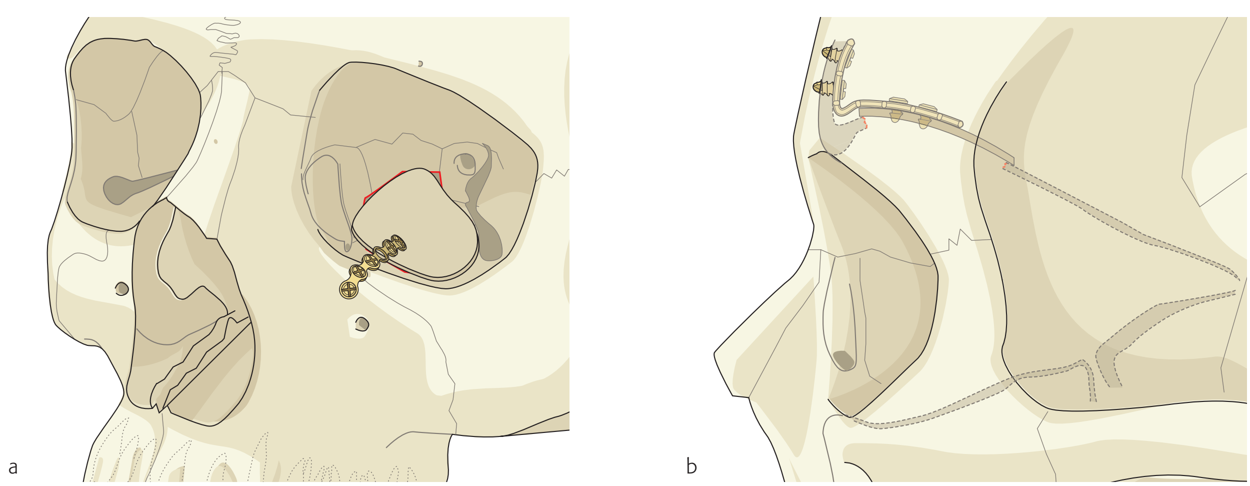


Fig 3.4-5a–d
a Fixation of bone graft for orbital floor reconstruction with cantilever technique.
b Orbital roof reconstruction with intracranial plating for bone graft fixation.

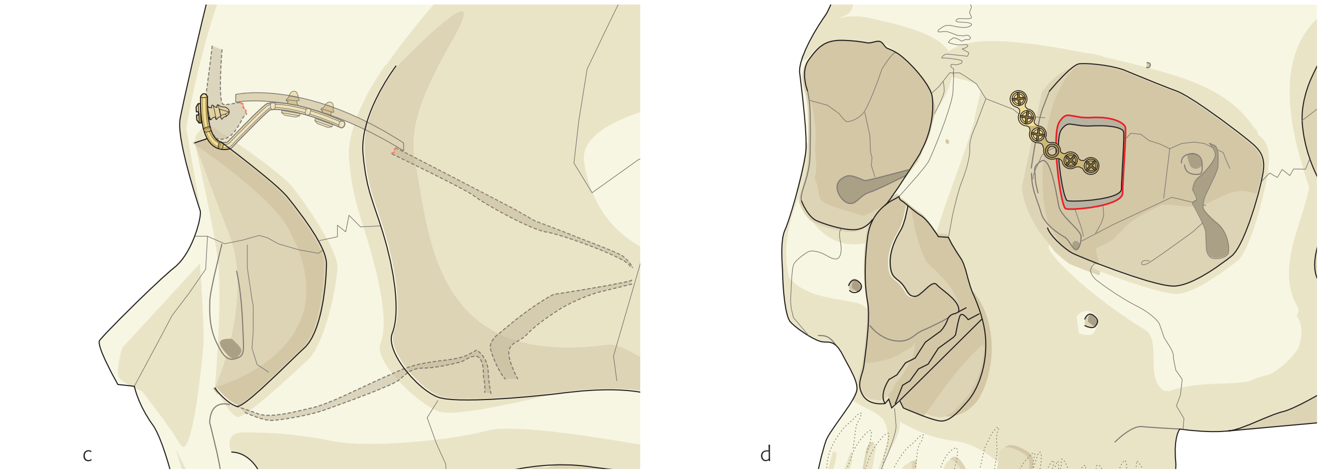


Fig 3.4-5a–d (cont)
c Orbital roof reconstruction with extracranial plating for bone graft fixation.
d Reconstruction of medial orbital wall (ethmoid defects) with a bone graft stabilized with cantilever technique.

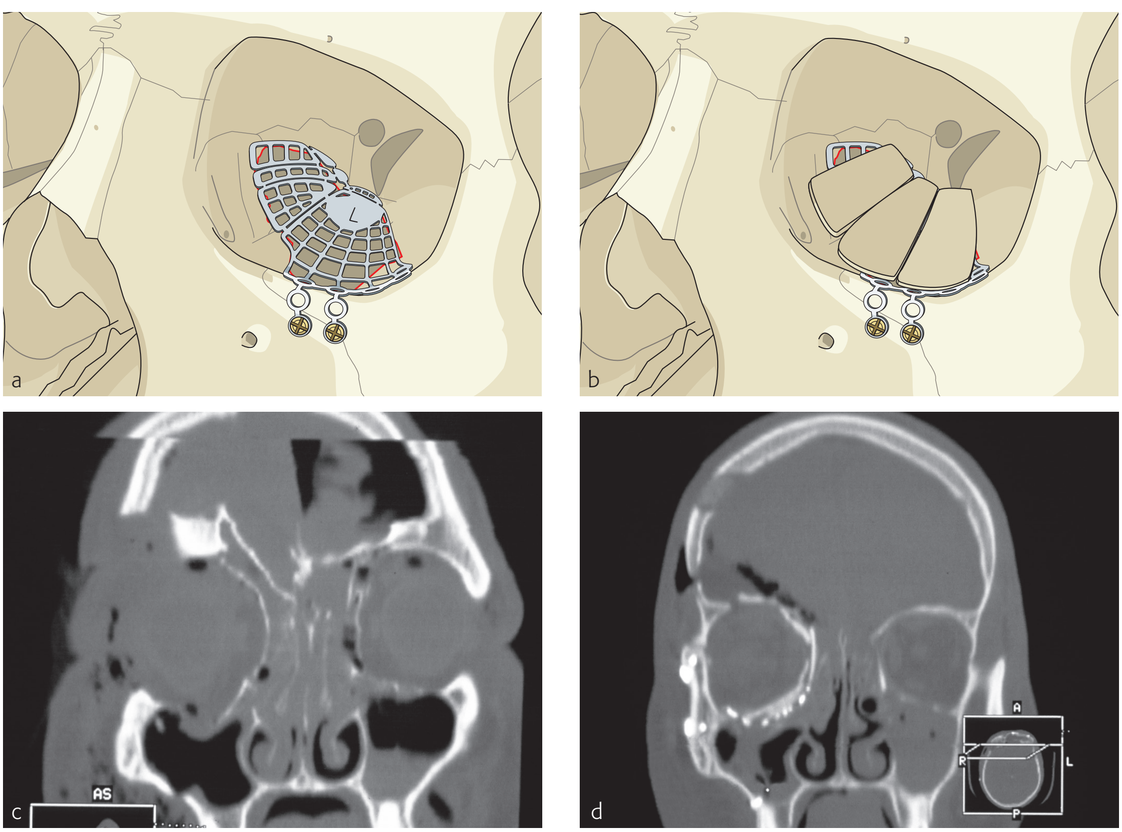


Fig 3.4-6a–d
a Extensive defect of orbital floor and medial wall reconstructed with an orbital floor plate.
b Reconstruction of same defect with orbital floor plate and bone grafts.
c Extensive defect of the orbital roof, middle orbital wall and orbital floor on the right side.
d Reconstruction of right and left orbits. Right orbit reconstruction with a combination of orbital floor plate and bone grafts.

4.4 Principles of orbital fracture repair

Trauma to the bony orbit may occur as isolated internal orbital fractures or injuries, simultaneously involving the internal orbital walls and the orbital frame. With higher energy impact during trauma, increased severity fracture patterns are observed. Defects involving two or more orbital walls extending to the posterior third of the orbital pyramid indicate high-energy impact.

As a principle, anatomical reassembly of the orbital frame should precede orbital wall reconstruction because reduction of associated orbital frame fractures will alter the size of orbital defects. Among the defect fractures of the orbital walls simple fracture patterns have to be distinguished from complex orbital wall defects, as inadequate treatment in the latter often results in severe functional and esthetic problems.

In simple (one wall) defects of less than 2 cm in diameter located in the anterior and middle third of the orbital floor, commonly referred to as blow-out fractures, exposure is achieved by eyelid local incisions such as the mid-eyelid, subciliary, or transconjunctival approach (**Fig 3.2-8**, page 198). After identification of the stable bony ledges around the defect, herniated soft tissues are retrieved atraumatically and the defect is bridged with bone grafts or alloplastic materials. If the graft overlaps the defect 3–4 mm, fixation is not usually necessary.

Defects extending to the posterior section of the orbit and/or involving more than one orbital wall significantly add to the complexity of the injury.

These defects usually cannot be assessed by one single approach and fat protrusion after periorbital laceration impairs visibility. The posterior bony ledge may be difficult to identify and may be insufficient for adequate graft support. Moreover, a widening of the inferior orbital fissure is easily missed and results in a critical enlargement of orbital volume. To find the posterior ledge (which is often covered by prolapsed fat), it is recommended to place a freer elevator against the posterior wall of the antrum and move it superiorly. The ledge will be felt as a distinct shelf which the elevator encounters under the fat. The fat may then be gently lifted from the ledge, remembering that the inferior rectus muscle is just within the most inferior fat. In secondary or late reconstruction cases, it is prudent to do an osteotomy at a nonfractured area and extend the exposure to the area of entrapment. The contents can then be “teased” from their adherence to mucosa with minimal injury.

For adequate treatment of complex intraorbital fractures complete exposure of all defect cases is crucial, and in most cases a combination of a lower eyelid incision and a coronal approach is required. Dissection is started at an uninjured part of the internal orbit and visibility enhanced by temporary insertion of a flexible sheet, such as a polydioxan sheet (PDS) 0.25 mm, preventing protrusion of orbital fat. Additional orbital rim marginotomies (osteotomies in nonfractured rim bone) may be useful to improve access to the posterior orbital walls. Fractures where the posteromedial orbital wall is left intact are less difficult with regard to reconstruction. Therefore, in complex orbital defect repair, reconstruction of this key area should be the first step. As this area, when fractured, offers little or no support for grafts, rigid reconstruction using cantilevered bone grafts or titanium preformed orbital plates is performed providing a stable shelf for further grafting (**Fig 3.4-6a–d**). Small residual defects are covered with either thin bone grafts or thin alloplastic sheets. Anatomical positioning of the walls frequently results in slight overcorrection of about 2–3 mm in the anteroposterior dimension, as the globe tends to sink back postoperatively due to resolution of intraorbital edema, bone graft resorption, and possible fat atrophy or scarring. The vertical dimension, however, remains nearly unchanged and should not be overcorrected.

Before soft-tissue suspension and wound closure is accomplished, a final forced duction test is performed to ensure free motility of the eye and MFLS.

Soft-tissue resuspension after extended exposure of complex orbital fractures minimizes eyelid and cheek ptosis and is crucial for achieving the best possible cosmetic result. Due to the extent of subperiosteal undermining, the anterior and lateral cheek is resuspended at the infraorbital rim and at the temporal fascia. After detachment of the lateral canthal ligament, transosseous reinsertion in a slightly overcorrected position is important to avoid asymmetry. After coronal flap exposure additional reattachment of the upper eyebrow at the supraorbital rim is recommended. This is accomplished by closing the incision in the periosteum over the frontal process of the zygoma.

4.5 Superior orbital rim and roof fractures

Isolated orbital roof fractures, more frequently seen in children, are uncommon in adult patients and in most cases result from simultaneous injuries of the supraorbital rim with involvement of the frontal sinus. As the orbital roof is a part of the anterior skull base, interdisciplinary treatment is required. Exploration of the complete fracture may in some cases require removal of the supraorbital rim and the segments of the frontal bone. The segments should be marked in sequence in order to simplify the reassembling. Additional intracranial neurosurgical exposure by frontal craniotomy may be recommended for an optimal assessment of the complete fracture pattern and for treatment of additional dural injury at the skull base. As the frontal bone commonly consists of external and internal tables, harvesting of the internal table provides an ideal source for bone grafts for frontal bone reconstruction or orbital wall repair.

After dural repair and reconstruction of the frontal bar, the orbital roof has to be aligned anatomically to achieve a proper globe position. The graft should not be placed within the orbit in order to prevent reduction of the orbital volume. Rigid fixation either by intracranial or extracranial fixation (**Fig 3.4-5a–d**) is important, the latter offering an easier approach in case of postoperative removal. As an alternative for large orbital roof and combined wall defects, anatomical reconstruction using a titanium mesh plate fixed at the orbital rim can be recommended (**Fig 3.4-7**). Additional layering of bone grafts at the skull base provides bony repair of the skull-base floor, of the frontal sinuses, and supraorbital ethmoid areas. Following orbital roof reconstruction and management of the frontal sinus, realignment and fixation of the frontal bone segments is performed, beginning with the frontal bar (supraorbital rim segments).

Fig 3.4-7 Reconstruction of extensive roof and medial orbital wall defects with titanium mesh plates.

5 Perioperative and postoperative treatment

Orbital surgery should not be performed without preoperative visual assessment with the goal to detect conditions where immediate treatment by the ophthalmologist is required and reconstructive surgery should be postponed. Moreover, as orbital surgery may affect visual acuity and result in motility disorders, reliable preoperative documentation is important for medical record reasons. Preoperative, intraoperative, and postoperative administration of steroids to prevent severe intraorbital edema is considered, especially when extensive surgery is planned. To protect the cornea from iatrogenic damage it is recommended to close the eyelids with a 6-0 intermarginal suture or insertion of a protective eye shield. This is particularly important when a coronal flap interferes with a direct evaluation of the periorbital region. As it is the most sensitive evaluation of optic nerve dysfunction, pupillary reaction to light is checked regularly. Pupillary dilatation may occur during deep orbital reconstruction, and is not related to visual loss, but to pressure on the ciliary ganglion. A final check by the surgeon either before leaving the operating theatre or postoperatively in the recovery room should be performed in every case. During orbital dissection and reconstruction, close communication with the anesthesiologist is helpful to minimize dangerous bradycardia by vagal stimulation.

Postoperatively, close follow-up of visual acuity and pupillary functions during the first 24 hours is advisable, as delayed development of increased intraconal pressure or loss of visual acuity can occur. Regular monitoring should be continued for several days. Close continuous ophthalmologic assessment should also be provided for the unconscious patient, although monitoring is more challenging.

For documentation of double vision, long-term follow-up by Hess screen evaluation and evaluation of the binocular field of vision are the most efficient methods. As swelling and intraorbital edema resolve over time, Hertel exophthalmometry may document enophthalmos.

Early evaluation of postoperative CT scans allows precise confirmation of proper graft position and therefore restoration of orbital volume. Alternatively, the scan may indicate a need for corrective surgery in case of malaligned grafts or malreduction of the orbital walls.

6 Complications and pitfalls

Besides local hematoma and infection, specific problems related to the orbit may occur as early postoperative complications. Severe retrobulbar hematoma is characterized by intraorbital pain, exophthalmos, visual impairment and/or diplopia, often combined with mydriasis. These symptoms indicate the need for immediate CT examination and immediate orbital decompression. A lateral canthotomy and release of lid sutures may be performed at the bedside before the CT is performed. Visual impairment may also result from malpositioned bone grafts or orbital plates, detectable by CT evaluation. Immediate surgical intervention is indicated.

Postoperative ocular motility disorders due to edema causing diplopia frequently occur and disappear after resolution of swelling. More frequent, however, is muscle damage due to dissection. This is minimized by exceedingly careful dissection. However, as the reason for restricted mobility of the eyeball may also result from malaligned bone fragments, bone grafts, or intraorbital plates, diplopia not resolving or improving within 3–4 days requires CT evaluation.

Late complications include deformities caused by malpositioning of the orbital frame and inadequate reconstruction of the orbital volume. Enophthalmos is the most common postoperative deformity following orbital reconstruction. Mild enophthalmos of less than 3 mm (the difference between the unaffected eye measured by Hertel exophthalmometry) is hardly noticed by the patient and usually needs no correction if functional sequelae are absent. Severe enophthalmos (more than 3 mm difference between the unaffected eye measured by Hertel exophthalmometry) is esthetically disturbing and may be correlated with functional problems as it is usually related to untreated volume defects in the posterior orbit. The muscle may be prolapsed, resulting in an altered muscle pathway and diplopia. Other reasons for facial deformities may be telecanthus by malreduction of the inner orbital frame, and/or inadequate reattachment of the medial canthal ligament, malpositioning of the zygoma, or malposition of the lateral canthus.

Among functional problems, visual impairment and diplopia are the most severe sequelae after blindness which follows orbital surgery. Early diagnosis is crucial for the best outcome. While the prognosis for improvement of visual loss on admission is poor, early optic nerve decompression for relief of nerve compression and retrobulbar hematoma or removal of malpositioned intraorbital grafts may be successful.

Significant diplopia may be based on motility disorders (neurogenic or mechanical), incongruent visual axes by malposition of one or both eyeballs, or fusion problems. When mechanical reasons such as residual herniation, entrapment of orbital soft tissues, or impinging graft material have been excluded or treated, further management is symptomatic as spontaneous improvement of edema and neurogenic disorders can be expected over 6–12 months. Usually, extraocular muscle surgery is postponed for 10–12 months.

Frontal nerve palsy after coronal incision can be avoided by dissecting beneath the deep temporal fascia when approaching the zygomatic arch. The frontal branch runs with the superficial temporal fat pad. The deep fascia is located underneath the nerve. Cranial nerve dysfunction (superior orbital fissure syndrome or optic nerve injury) may occur after compression of the superior orbital fissure or optic canal during trauma or deep orbital dissection. Clinical symptoms are upper lid ptosis, internal ophthalmoplegia (III, IV, and VI), disturbance of V1 sensation, or visual loss.

Frequent complications related to approaches are lid shortening, scleral show, or permanent ectropion more common after high (subciliary) eyelid incisions. Unfavorable scars may result from incisions at any location, but are most frequent after lateral eyebrow incisions, lower orbital rim, and medial nasal transcutaneous incisions.

Visible and palpable plates may be observed in the region of the lateral and inferior orbital rim where the skin is thin. If possible, plates placed anterior to the lacrimal crest or the medial nose and orbital frame should be avoided.

Fractures of the NOE region may result in epiphora due to lacrimal duct obstruction. Initially this may be observed, but chronic dacryocystitis may follow. If this is persistent secondary dacryocystorhinostomy is recommended.

Pitfalls

Severe orbital fracture repair is a challenging and difficult procedure with potential for severe iatrogenic complications. Underestimation of the fracture pattern (due to insufficient diagnosis) may result in inadequate exposure and fracture treatment and will lead to unfavorable results. Thus, meticulous diagnosis including proper CT evaluation is crucial for treatment planning. The indication for a wide exposure including a coronal incision and possibly additional access osteotomies should be fully evaluated. The assessment of CT scans should detect linear fractures causing dents and gaps or widening of the inferior orbital fissure, both resulting in enlargement of the orbital volume. Orbital floor defects are often combined with a displaced medial wall but may be underdiagnosed as isolated floor fractures. Therefore, exposure of the entire fracture pattern has to be the first step with no graft or plate inserted until evaluation has been used as a determinant of treatment.

As a rule, correct 3-D reconstruction of the orbital frame should precede internal orbital wall repair. Errors made during reduction of the frame are transmitted to the internal orbit. The shearing of the root of the zygomatic arch is one reason for abnormal facial dimensions and is often underestimated. If this problem is not adequately addressed, a lateral midfacial malposition will result, creating volume expansion in the lateral orbital wall. Therefore, the lateral orbital wall, where the alignment of the zygomatic body and the greater sphenoid wing can be assessed, is a landmark for reduction of lateral orbital fractures and should be routinely exposed to prevent errors in positioning. The inferior orbital rim is often fragmented and cannot serve as a reliable landmark due to its small cross-section. Generally, the inferior orbital rim is straight and not curved inferiorly.

Bridging large orbital wall defects with unstable "too flexible" sheets is a common error and results in orbital enlargement. Large defects need rigid fixation of the walls and usually cannot be grafted with one single graft. Identification of the position of posterior bony ledge is of utmost importance and no graft should be inserted unless posterior support is provided. If the posterior ledge cannot be identified, rigid fixation of a properly angulated graft is mandatory.

If the graft is laid over the edges of the defect, care has to be taken to prevent penetration into the soft tissues. It is therefore recommended to assure that the transition of the graft to the defect is smooth (with or without rigid fixation), in order to provide a smooth surface over the circumference of the defect.

Author Oleh Antonyshyn

3.5 Nasoorbitoethmoidal (NOE) fractures

1 Anatomy, definition, and classification

The nasoorbitoethmoidal (NOE) complex is a distinct anatomical region in the central upper midface defined by the interorbital space. It is circumscribed by the anterior cranial fossa superiorly and the medial orbital walls laterally. NOE fractures therefore potentially involve the cranial, orbital, and nasal cavities, as well as the lacrimal pathways.

The interorbital space is supported anteriorly by structural buttresses consisting of the frontal processes of the maxilla, nasal processes of the frontal bone, and the paired nasal bones (**Fig 3.5-1**). The roof of the NOE complex is made up of the floor of the anterior cranial fossa. Specifically, this consists of the fovea ethmoidalis, strengthened in the midline by the cribriform plate. These bones are thin and closely associated with the olfactory nerves and dura.

Within the interorbital space (**Fig 3.5-2**) lie the paired upper nasal fossae separated by the septum and the perpendicular plate of the ethmoid in the midline. The intervals between the nasal fossae and the medial orbital walls are occupied by the ethmoid labyrinths.

The medial walls of the orbit are composed of the lacrimal bone anteriorly and the lamina papyracea of the ethmoid bone posteriorly. These extremely thin and fragile bones form the lateral boundaries of the NOE complex. The lacrimal drainage system is intimately related to the bone in this area.

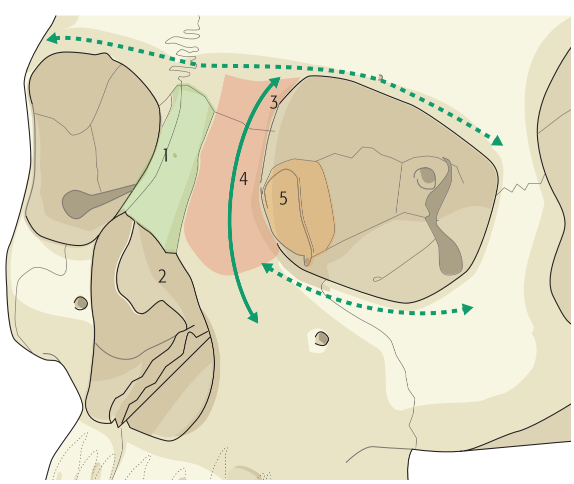


Fig 3.5-1 NOE region:
1 Nasal bones
2 Septum
3 Frontal bone
4 Nasal process of maxilla
5 Lamina papyracea (orbital plate of ethmoid bone)
Green dotted lines: supraorbital and infraorbital transverse buttresses

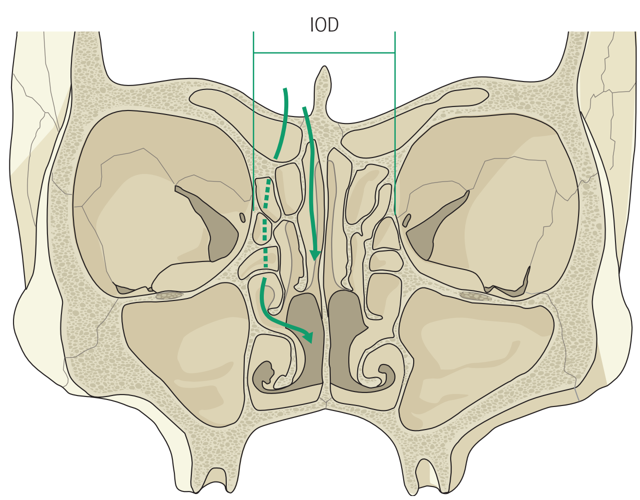


Fig 3.5-2 Coronal section (interorbital space).
Interorbital distance (IOD). Green arrows indicate potential sites of cerebrospinal fluid (CSF) leaks.

The medial canthal tendon anchors the tarsal plate and the orbicularis oculi musculature to the medial wall of the orbit. At its point of insertion, the tendon splits into anterior, posterior, and superior limbs, attaching to anterior and posterior lacrimal crests. Morphologically, the medial canthal tendon maintains the configuration of the palpebral fissure and the intercanthal distance.

In formulating a treatment plan, the surgeon must be able to recognize the pattern of NOE injury, the status of the medial canthal tendon and central bone fragment, and the degree of disruption or loss of stability in the NOE complex. Markowitz et al first described and classified NOE fractures according to the involvement of the so-called central fragment, defined as the fragment of bone on which the medial canthal tendon inserts. Three fracture patterns are recognized: Type I, single segment central fragment (**Fig 3.5-3a**). Type II, comminuted central segment with fractures remaining external to the medial canthal insertion, but with the medial canthal ligament attached to a fragment large enough to be stabilized with a plate (**Fig 3.5-3b**). Type III, comminuted central fragment with fractures extending into the bone which bears the canthal insertion. In this case the canthal ligament is either attached to a bone fragment too small for plate fixation, or totally detached (**Fig 3.5-3c**).

Classification of the fracture pattern with respect to the central bone segment is clinically useful in that it provides guidelines for graded exposure and fixation appropriate to the degree of injury.

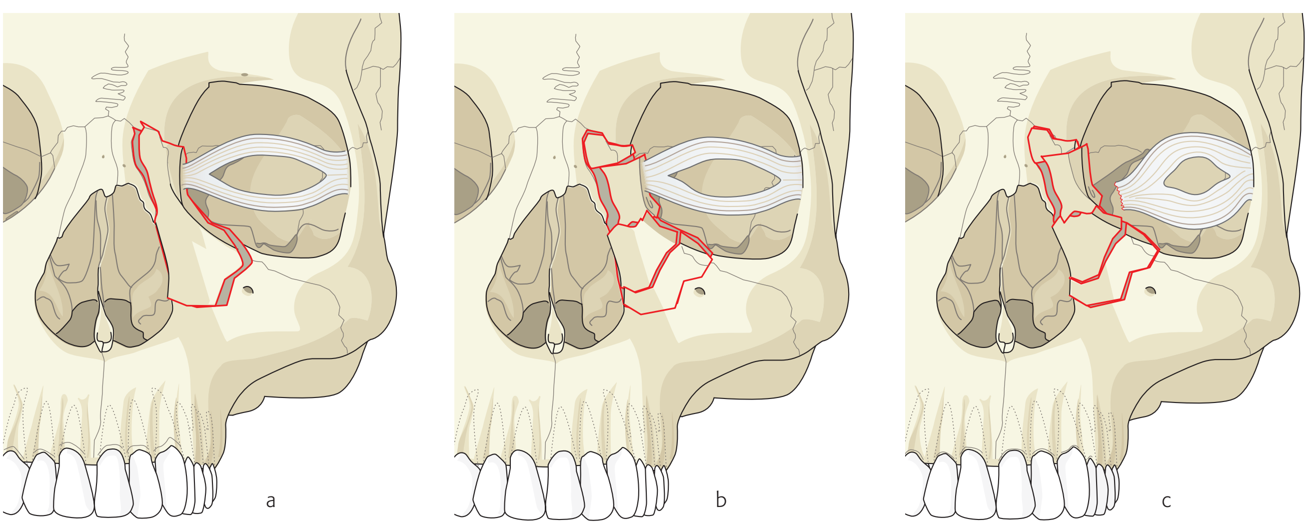


Fig 3.5-3a–c Three fracture patterns are recognized:
a Type I: Single central fragment bearing the canthal ligament.
b Type II: Comminuted central segment with medial canthal ligament still attached to a bone fragment.
c Type III: Comminuted central segment with totally detached medial canthal ligament.

2 Imaging

Optimal visualization of the NOE region is provided by coronal CT images (**Fig 3.5-4**). Coronal images clearly demonstrate fractures through the anterior cranial base, medial orbital rim and medial orbital walls. Coronal images are particularly useful in comparative analysis of orbital dimensions.

Unfortunately, coronal images can be difficult to obtain in a patient with potential cervical spine or head injury. With most acute trauma patients, image data is acquired using high-resolution axial CT scans which are subsequently reformatted into coronal images.

3-D images can also be constructed from standard volume CT scans (**Fig 3.5-5**). These images are particularly useful to demonstrate the orientation and displacement of the central fracture fragment and to plan how to approach the NOE injury.

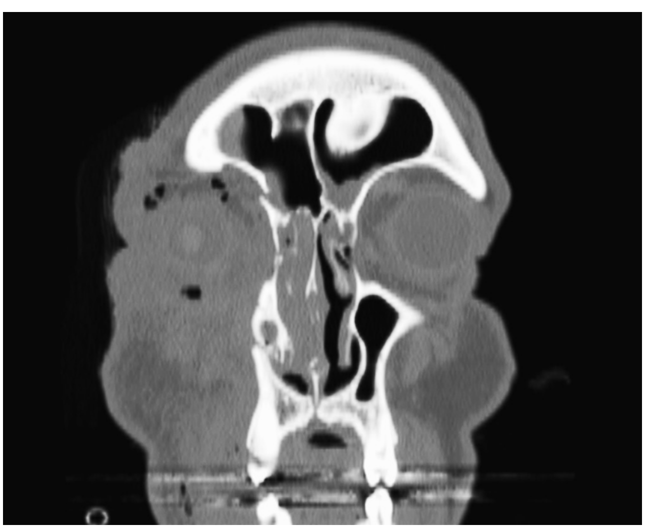


Fig 3.5-4 Coronal CT scan showing fractures through the anterior cranial base. Comparative analysis of medial orbital rims and walls is particularly useful in understanding orbital dimensions.

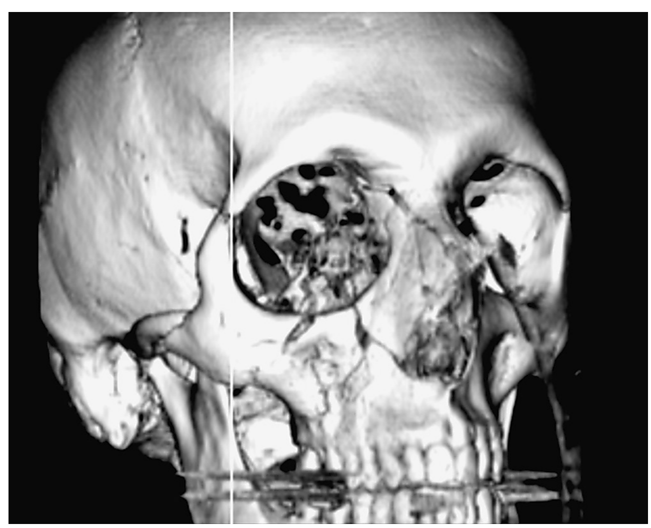


Fig 3.5-5 3-D reconstruction showing the displacement of the central fracture fragment.

3 Approaches

Reconstruction of the fractured NOE complex begins with an adequate exposure. Local lacerations generally do not suffice. Although they can provide useful adjunctive visualization of immediately underlying fractures, formal craniofacial approaches are favored in accessing the NOE complex.

The coronal flap provides access to the superior aspect of the NOE complex, the entire upper and lateral craniofacial skeleton, and the roof, lateral, and medial walls of the orbital cavity. Significant fracture segments are dissected subperiosteally. The margins of the central fragment in particular, and the anterior and posterior lacrimal crests are specifically identified. The insertion of the medial canthal tendon into the central fragment is preserved. The central fragment is then dislocated anteriorly and laterally to facilitate direct access to the medial orbit.

Access to the inferior aspect of the NOE complex is obtained through lower eyelid incisions. Periosteum is widely elevated to expose the inferior orbital rims, inferomedial aspect of the orbital cavity, and anterior surface of the maxilla. When fracture lines extend into the lower midface, further access is provided by a transoral upper buccal sulcus approach.

Isolated NOE fractures in which the nasofrontal junction is undisplaced or minimally disrupted (type I injuries) can be accessed through limited local incisions. Generally, combined upper eyelid (blepharoplasty) and lower eyelid incisions, or alternatively a retrocaruncular transconjunctival incision, are employed for this purpose. It is extremely important, however, to be aware of the limitations of these local incisions in providing adequate visualization when the nasofrontal junction is disrupted.

4 Osteosynthesis techniques

Once sufficient exposure of the craniofacial skeleton is obtained, displaced fracture segments are anatomically reduced. This is accomplished most effectively if a strategy for fracture reduction is consistently followed in all cases.

4.1 Reduction sequence

The craniofrontal and zygomaticomaxillary regions have a higher impact tolerance than the NOE region, and tend to fracture into larger segments. Accurate 3-D reconstruction of the upper (craniofrontal) and outer zygomaticomaxillary facial skeletal frame is technically simpler and anatomically more reliable, and is therefore always completed first. There is, of course, no single acceptable method. The arguments for doing the NOE segment first are also valid (see chapter 5 Panfacial fractures). The presence of stable and reliable skeletal references peripherally is very helpful in restoring an anatomically accurate NOE complex.

Within the NOE complex itself, reconstruction proceeds from the deepest and most inaccessible areas toward the surface. In the presence of lacerations, fractured nasal bones and nasomaxillary segments are displaced laterally to allow unrestricted access to the medial orbits. Following completion of medial wall reconstruction, the central segments are reduced and rigidly fixed. The nasal bones and restoration of dorsal nasal projection are addressed last.

4.2 Rigid skeletal fixation

Rigid skeletal fixation of NOE fractures requires specific identification and control of regional functional forces. In the upper NOE region, the functional forces acting on fracture segments are those exerted by the orbicularis oculi muscle through the medial canthal tendon, and the forces generated by overlying soft tissue, particularly during the phase of postinjury edema and subsequent soft-tissue contracture. Titanium miniplates 1.3 or corresponding Matrix Midface plates are therefore generally sufficient. Lower NOE fractures, ie, fractures of the medial buttresses of the maxilla, must resist transmitted forces of mastication and, therefore, larger plate systems (1.5, 2.0, or corresponding Matrix Midface plates) are most commonly used for this purpose.

4.3 Primary bone grafting

Primary bone grafting in the acute management of NOE fractures is indicated in comminuted unstable NOE injuries when actual loss of bone or the degree of bony comminution preclude a stable 3-D reconstruction. Under these circumstances, bone grafts obliterate defects and restore bony continuity, thereby increasing stability of the reconstruction. Primary bone grafts are employed for three specific purposes in NOE reconstruction:

- Restoration of bony continuity along the nasomaxillary buttresses or orbital rims. The bone graft is carved meticulously and precisely to fit into the skeletal defect as an inlay graft. Any contour irregularity will be clearly visible externally and must be avoided. The inlay graft is fixed using miniplates. The use of bone grafts under these circumstances ensures normal external contour, maintains stability at the fracture site, and potentially speeds consolidation.
- Reconstruction of the medial orbital wall to prevent orbital soft-tissue prolapse and to provide a skeletal base for medial canthal tendon attachment. Bone grafts are shaped to the appropriate size for the medial orbital wall and are rigidly fixed in place by miniplates both at the superior and at the inferior orbital rims. Calipers measure the distance between the two medial orbital walls to ensure that the interorbital distance does not exceed 25 mm.
- Reestablishment of dorsal nasal projection in central maxillary fractures which destroy the perpendicular plate of the ethmoid, the septum, and the nasomaxillary buttresses. This is an absolute indication for primary dorsal nasal bone grafting. Split skull bone graft is best employed for this purpose. The bone is fixed as a cantilever graft.

5 Management of the central segment

The specific approach to rigid fixation of NOE fractures is based on the pattern of NOE injury. Type I fractures are most effectively treated by anatomical reduction and rigid fixation of the central segment (**Fig 3.5-6**). Three plates are generally required at the frontomaxillary, zygomaticomaxillary, and medial maxillary buttress fracture lines, respectively. When there is virtually no disruption of one of these fracture sites, fixation at two sites may be sufficient. The type I fracture is frequently "greensticked" superiorly and can be managed without fixation superiorly.

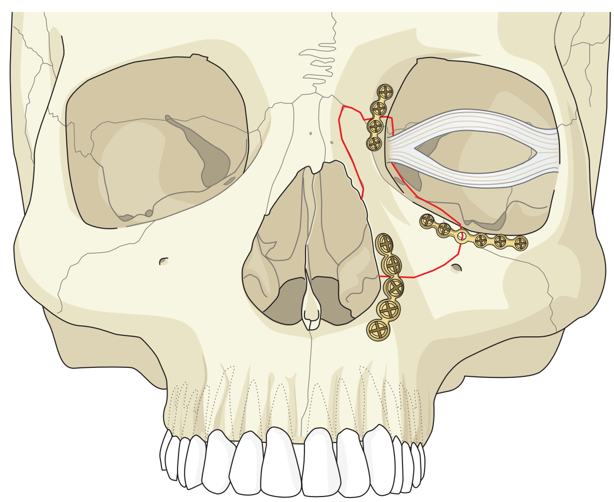


Fig 3.5-6 Fracture fixation of a type I fracture with three miniplates (1.3, 1.5, or corresponding Matrix Midface plates).

Type II injuries are comminuted NOE fractures which circumscribe and spare a central canthal tendon-bearing bone segment. Such injuries are more difficult to treat due to the number of comminuted segments, the small size of these segments, and the inherent instability of the medial canthal tendon-bearing bone. Reconstruction requires sequential reduction of each bone segment to restore the nasomaxillary buttresses bilaterally, and, frequently, supplemental inlay bone grafts where skeletal gaps exist (**Fig 3.5-7a**). Miniplates are used to span defects in the nasomaxillary buttress. The critical part of the procedure is to ensure anatomical 3-D placement of the central canthal ligament-bearing bone segment. The tendency to outward rotation or displacement of the central segment often requires placement of supplementary transnasal canthopexy wires posterior to the medial canthal tendon insertion (**Fig 3.5-7b**). At all times the insertion of the medial canthal tendon is preserved and no attempt is made to dissect it.

Type III injuries are comminuted NOE fractures which transect or avulse the medial canthal tendon. As such, there is no sizeable bone fragment to use in reconstruction. Under these circumstances, a formal medial canthoplasty must be performed (**Fig 3.5-8**). Fracture reduction is performed by sequential alignment of comminuted segments as described above. However, a formal transnasal medial canthopexy is absolutely necessary. Frequently such injuries are associated with marked comminution of the medial orbital walls and rims, and bone graft reconstruction of the medial orbits is required to provide an adequate skeletal fixation point for medial canthal tendon insertion.

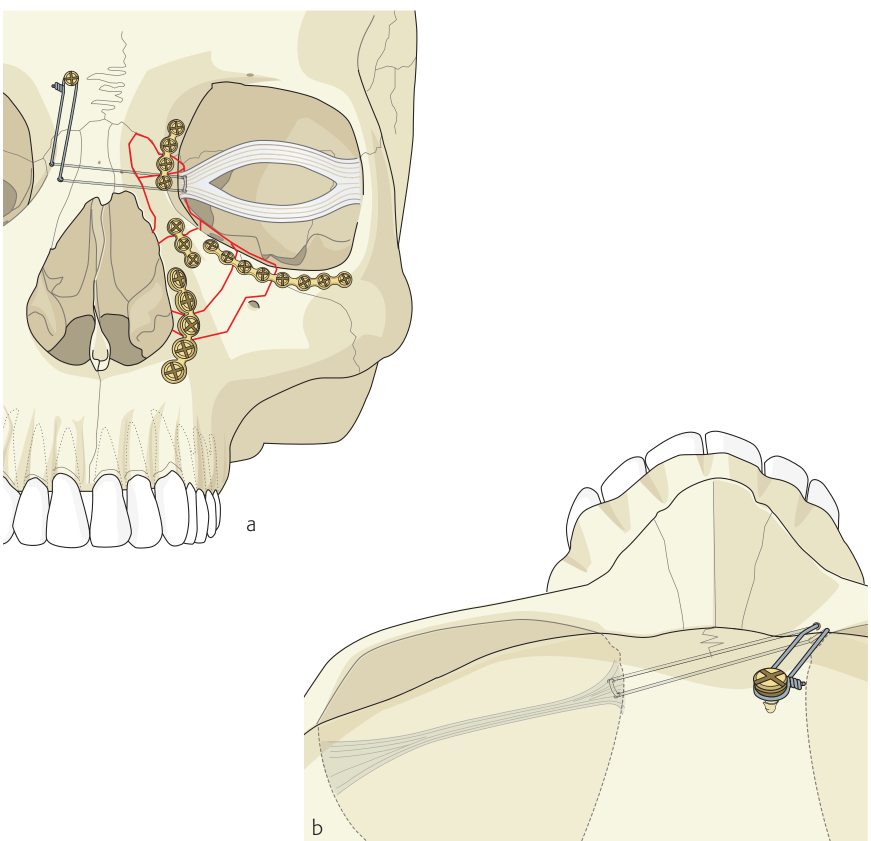


Fig 3.5-7a–b Reconstruction of a type II fracture. Plate fixation as in type I fracture.
a Special attention must be given to the correct anatomical 3-D placement of the bone segment to which the medial canthal ligament is attached.
b Placement of a transnasal canthopexy wire avoids outward rotation or displacement of the bone fragment to which the medial canthal ligament is attached. The insertion point of the transnasal canthopexy wire must be posterior and superior to the lacrimal fossa.

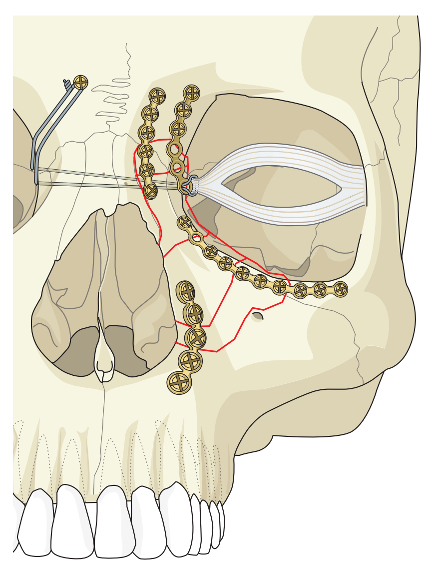
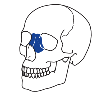


Fig 3.5-8 Fracture reduction in type III injuries is performed by sequential alignment of comminuted segments as described in **Fig 3.5-7a**. A formal transnasal medial canthopexy is absolutely necessary.



6 Medial canthoplasty

Restoration of the premorbid medial canthal position is the single most important step in restoring preinjury NOE and orbital surface morphology. In types I and II injuries, anatomical reduction of the tendon-bearing fracture segment generally ensures adequate placement of the medial canthus. However, in type III injuries and in total avulsions or lacerations of the medial canthal tendon, specific restoration of the medial canthal bony insertion is indicated.

The reconstructed medial orbital walls will provide the skeletal base for tendon reinsertion. Medial wall bone graft must be perfectly stable so that there is no tendency for lateral displacement, and the distance between the medial walls must not exceed 25 mm.

Once an adequate skeletal foundation is provided, the 3-D location of the medial canthal tendon insertion is precisely identified. Ideally, the tendon is inserted at the superior aspect of the posterior lacrimal crest. This ensures appropriate depth and vertical placement of the medial canthus. However, in grossly comminuted fractures when all adjacent anatomical landmarks are destroyed, placement is chosen arbitrarily at a point 5 mm posterior to the medial orbital rim, midway between the orbital roof and floor, just superior to the upper edge of the lacrimal fossa.

Various techniques for canthal tendon fixation have been published. Classically, a 3.0 stainless steel wire, used to secure the medial canthal tendon insertion, is passed transnasally through a drill hole in the medial orbital wall or bone graft to the contralateral medial orbit. The wire is secured distally over bone or bone graft in the contralateral orbit, or over a central screw in the glabella (**Figs 3.5-7a–b**, **3.5-8**). The transnasal wiring techniques offer the advantage of providing additional stability to the fractured medial orbital wall or medial wall bone graft by providing a posterior point of fixation. However, disadvantages include the need for dissection in the contralateral orbit and the mechanical disadvantage associated with a substantial length of wire. The wire can stretch, potentially leading to medial canthal drift.

An alternative means of medial canthoplasty uses a bone-anchoring device (**Fig 3.5-9a–b**) to allow ipsilateral fixation of the medial canthal tendon to the medial orbital wall. These ipsilateral techniques isolate the dissection and fixation to the affected side only, and are therefore particularly effective in cases of unilateral medial canthal dystopia. Use of this technique is restricted to those cases where the medial orbital wall is intact or previously reconstructed with a perfectly stable bone graft.

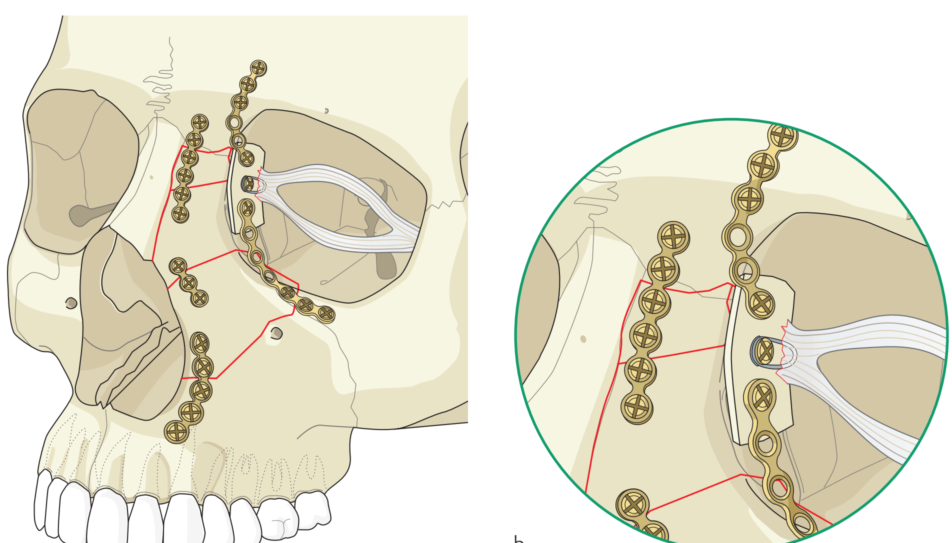


Fig 3.5-9a–b A bone-anchoring device allows ipsilateral fixation of the medial canthal tendon to the medial orbital wall. Use of this technique is restricted to those cases where the medial orbital wall is intact or reconstructed with a perfectly stable bone graft.

7 Nasal reconstruction

The degree of nasal disruption dictates the requirements for optimal restoration and maintenance of nasal projection. This is determined clinically by the resistance of the nasal dorsum to direct digital pressure, ie, the Brown-Gruss vault compression test (**Fig 3.5-10**), and radiologically by the degree of comminution of the nasal bones and septum.

7.1 Nasal bone fixation

Open reduction and fixation of the fractured nasal bones can effectively restore dorsal nasal projection provided two conditions are met. First, the nasal fracture segments must be of an adequate size to permit mini- or microplate fixation. Second, the residual structural integrity in the septum and upper lateral cartilages must be sufficient to support the middle third of the nose.

The proximal nasal bones are reduced and fixed to the glabella with an H- or T-shaped miniplate, taking care to restore the nasofrontal angle (**Fig 3.5-11**). Fractures of the septum are then repaired. The entire reconstructed osseocartilaginous framework is further stabilized by suspending the septal cartilage and/or upper lateral cartilages with suture fixation to drill holes in the distal margin of the fixed nasal bones.

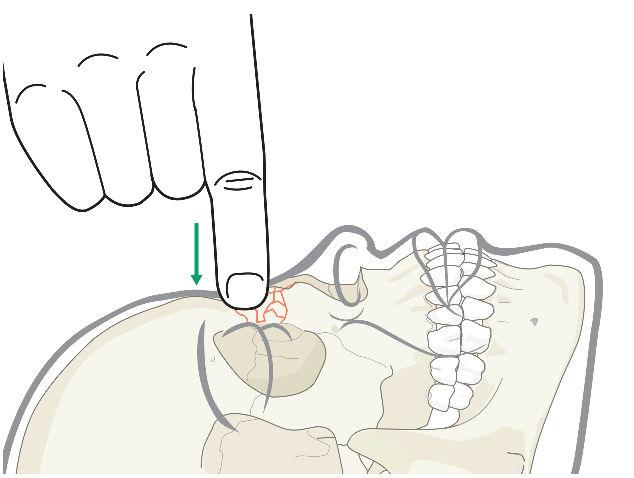


Fig 3.5-10 A positive Brown-Gruss vault compression test suggests that a cantilever primary bone graft will be required.

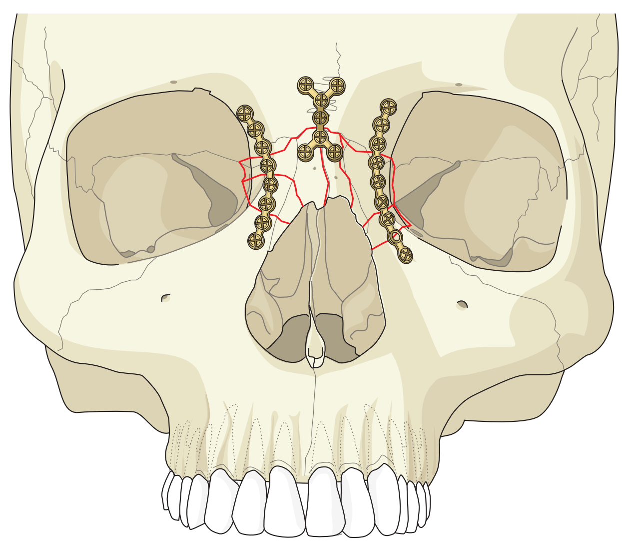


Fig 3.5-11 The proximal nasal bones are reduced and fixed to the glabella with an X-shaped miniplate, taking care to restore the nasofrontal angle.

7.2 Nasal cantilever bone graft

Telescoping collapse of the nasal dorsum with direct digital pressure indicates complete loss of support and the need for cantilever bone graft reconstruction (**Fig 3.5-12a–b**). A split skull bone graft is best used for this purpose. The bone is fixed as a cantilever graft. Particular attention must be paid to the following details:

- The bone graft must be of adequate length to support the nasal dorsum.
- If nasal tip support is adequate, the bone graft extends only as far as the alar domes. If, however, nasal tip support is inadequate, the graft must span the distance from the root to the tip of the nose.
- Stabilization must be adequate and is achieved by a single miniplate from the glabella to the dorsal nasal graft.
- Finally, it is imperative that the nasofrontal angle be maintained and not obliterated by the bone graft.

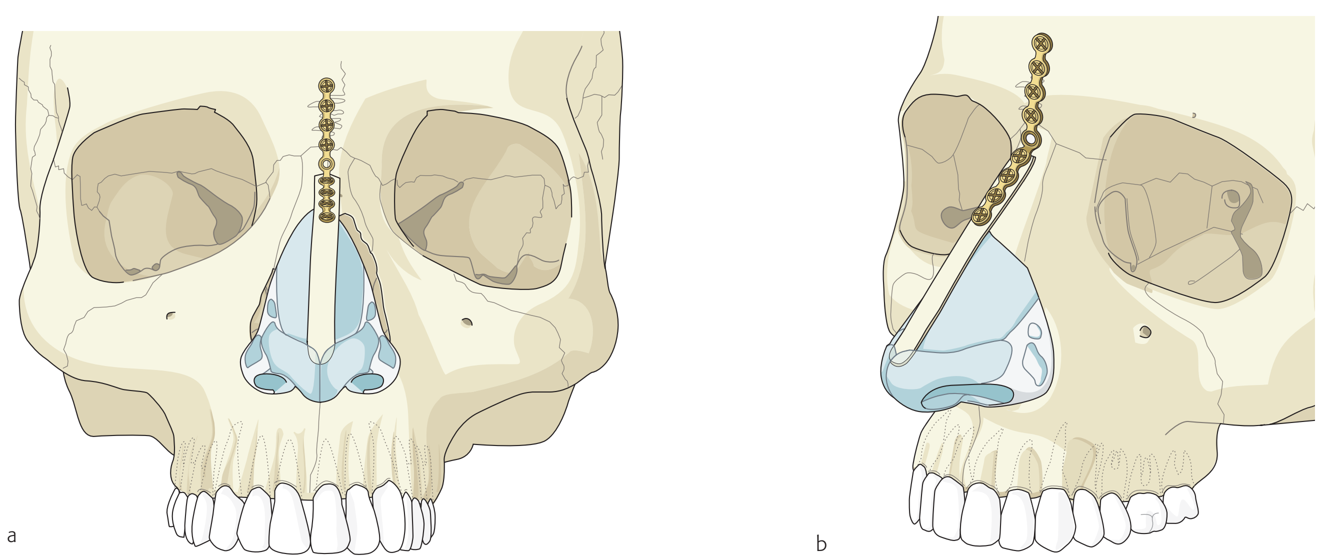


Fig 3.5-12a–b Split skull bone fixed as a cantilever graft to reconstruct the nasal dorsum. Fixation with a single plate from the glabella to the dorsal nasal graft.

8 NOE fracture-related problems

Control of soft-tissue redraping is the single most problematic issue in NOE fracture reconstruction. When widely undermined, tissues must be redraped and the ridges and depressions comprising the surface contours of the NOE region are easily obscured. Postoperative edema and formation of subperiosteal seroma or hematoma result in a permanent thickening of the soft tissue, loss of definition in the nasofrontal angle and nasoorbital valley, and development of epicanthal fullness.

The redraping of soft tissues can be controlled by surgically ensuring direct and accurate apposition of soft tissues to bone in key areas. This is done most effectively by using external bolsters which are adapted to the surface of the lateral nose (**Fig 3.5-13**). Metal splints padded with foam or felt are secured by transnasal wires to compress the soft tissues. These bolsters adapt the soft tissues only, and play no role in fracture stabilization.

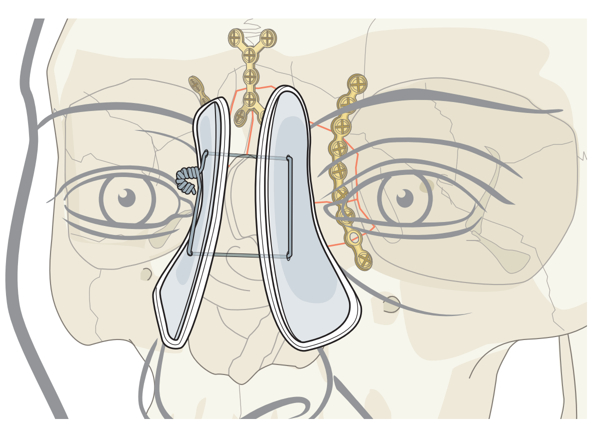


Fig 3.5-13 Metal or lead splints padded with foam, used as external bolsters contoured to the nasal surface for the adaptation of the soft tissues of the nose. Application of these should be done with great caution to avoid skin necrosis.

9 Lacrimal duct injuries

During NOE fracture repair, the nasolacrimal sac should be identified but not probed or intubated unless obviously lacerated. The upper lacrimal pathway is protected by the medial canthal ligament. Obstruction usually occurs in the bony nasolacrimal canal, and can arise as a consequence of bone displacement, impingement, or swelling and duct stenosis.

Postoperative epiphora is generally due to eyelid malposition or edema, and will resolve spontaneously in more than 80% of patients. Formal assessment with probing and dacryocystography is undertaken only in those patients with persistent epiphora more than 2 months following primary fracture repair. When dacryocystorhinostomy is necessary, it should be performed at least 3 months after the primary repair.

10 Frontal sinus injuries

The floor of the frontal sinus and nasofrontal duct are generally involved in NOE fractures. Despite this, specific frontal sinus repair is not undertaken in the absence of anterior or posterior wall fractures. Under those circumstances when a concomitant fracture of the anterior or posterior wall of the frontal sinus exists, formal repair of the anterior and sometimes the posterior wall, obliteration, and/or exclusion from the nasal cavity are performed.

11 Skull-base injuries

The anterior cranial fossa defines the superior boundary of the interorbital space. NOE fractures therefore frequently extend superiorly to involve the skull base. Specific clinical and radiological assessment of the forehead and cranial base is required in all patients with NOE fractures to rule out associated cerebral spinal fluid (CSF) rhinorrhea, intracranial injury, or skeletal disruption.

Under certain circumstances, a neurosurgeon may be required to elevate a frontal bone flap to provide intracranial access to the NOE fracture. Generally this is done specifically for neurosurgical indications, ie, a suspected major dural tear with a CSF leak, in the presence of compound or grossly displaced frontal bone fractures, or in the presence of intracranial injury requiring direct intervention. Concomitant intracranial exposure provides optimal access to the NOE complex and allows anatomical reduction of fractured segments of the supraorbital rims, glabella, and nasomaxillary processes.

12 Airway management

Intraoperative management of the airway in NOE fractures is dictated by the presence or absence of associated facial fractures. Isolated NOE injuries are preferably treated with the patient orally intubated. This allows unparalleled access to the NOE region and permits accurate reduction of associated nasal injuries. Even when associated with maxillary fractures, the endotracheal tube is placed orally in the retromolar area, thereby allowing restoration of premorbid occlusion.

However, when these injuries are associated with grossly disrupted maxillary or panfacial fractures, nasal intubation may be indicated. Nasal intubation will compromise reconstruction of nasal anatomy. Sometimes this can be overcome by an intraoperative switch from nasal to oral intubation or with a submandibular tube placement. In rare cases of combined maxillary and mandibular fractures with gross comminution, use of a tracheostomy may be necessary to facilitate surgical repair.

13 Perioperative and postoperative treatment

Preoperative and postoperative ophthalmologic examinations to detect additional intraorbital injuries, especially injuries to the globe and vision impairment, are strongly recommended. Perioperative antibiotics and eye-lubricating ointments are routinely used. Patient neurological status and vision are closely monitored in the first 48 hours following surgery.

The skin adjacent to the NOE bolsters is repeatedly assessed and transnasal wires are untwisted and loosened if edema is excessive. The bolsters are removed 10 days after surgery.

14 Complications and pitfalls

NOE contour irregularities, nasal deformities, disproportions, and asymmetries in periorbital morphology are the most commonly observed complications. Primary repair generally relies on the reapproximation and consolidation of multiple comminuted fracture segments and bone grafts. Bone resorption and surface contour irregularities commonly occur, particularly over the glabella and nasal root, but are rarely sufficiently deforming to necessitate subsequent hardware removal or recontouring procedures.

Posttraumatic nasal deformities are characterized primarily by deviations or inadequate projection of the nasal dorsum, particularly in the middle vault, and septal deviations associated with nasal airway obstruction. The hardware used in primary reconstruction precludes the use of nasal osteotomies. Secondary rhinoplasties therefore rely on the effective use of cartilage grafts to restore the midline and dorsal nasal projection.

Soft-tissue deformities are particularly obvious in the periorbital region, where minor discrepancies result in canthal dystopias and asymmetries in palpebral fissure height, width, or inclination. Previous critical reviews of periorbital morphology following fracture repair show that posttraumatic telecanthus is effectively corrected in the horizontal dimension by primary surgery. However, corrections of vertical canthal displacements are far less satisfactory. Mild degrees of asymmetry (> 2 mm) in medial canthal position in the vertical plane produce obvious deformities. In particular, vertical canthal displacements produce asymmetries in palpebral inclination which are readily apparent.

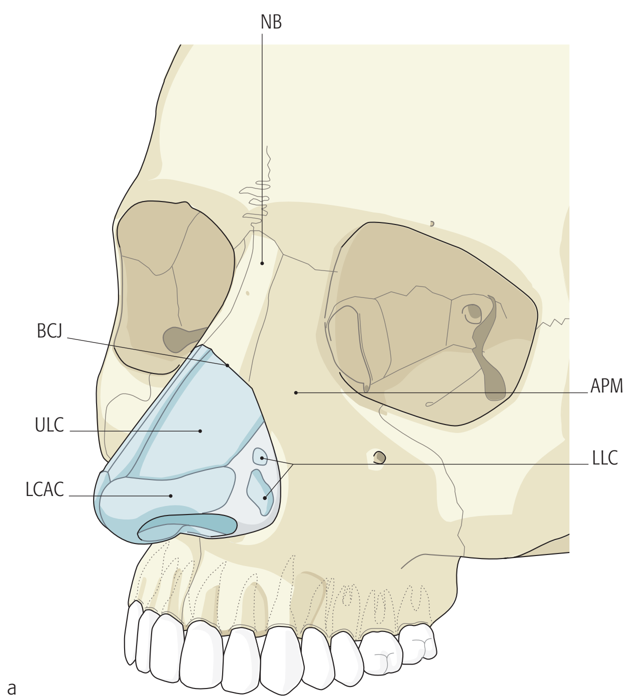
Authors Kevin A Shumrick, Jon B Chadwell

3.6 Fractures of the nasal skeleton

1 Anatomy and definition

The nasal skeleton is responsible for maintaining the nasal airway as well as providing one of the most prominent esthetic features of the face. Slight distortions of nasal architecture (from trauma) can adversely affect both nasal function and appearance.

The nasal skeleton is the only composite structure of the midfacial skeleton consisting of both bony and cartilaginous components (**Fig 3.6-1a–b**). The nasal skeleton consists of the paired nasal bones, the midline, septal cartilage and bone (vomer), the paired upper lateral cartilages which attach to the nasal bones, and the paired lower lateral cartilages. Finally, although not technically part of the nose, the ascending processes of both maxillae are frequently involved in nasal trauma and should be considered as basal support for the nasal skeleton.



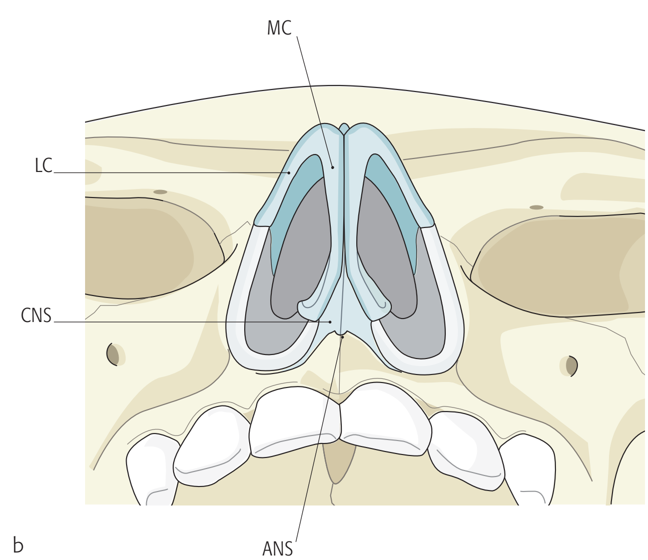


Fig 3.6-1a Anatomy of the nasal skeleton, 45° angle view.
NB Nasal bone
BCJ Bone cartilaginous junction
APM Ascending process of the maxilla
ULC Upper lateral cartilage
LLC Lower lateral cartilages
LCAC Lateral crus alar cartilage

Fig 3.6-1b Anatomy of the nasal skeleton, inferior view.
MC Medial crus
LC Lateral crus
CNS Cartilage nasal septum
ANS Anterior nasal spine

2 Imaging

The nasal skeleton is perhaps the only midface structure that is superficial enough to be largely assessed by physical and visual exam. While plain films of the nose are often performed during an emergency room visit for facial trauma, they are rarely helpful. Often, a fracture will be noted on the plain film, but the nasal appearance and function have not changed. Or, conversely, no fracture is seen on the film, but the nose is crooked. Definitive imaging of the nasal skeleton is performed by high-definition coronal and axial CT scans.

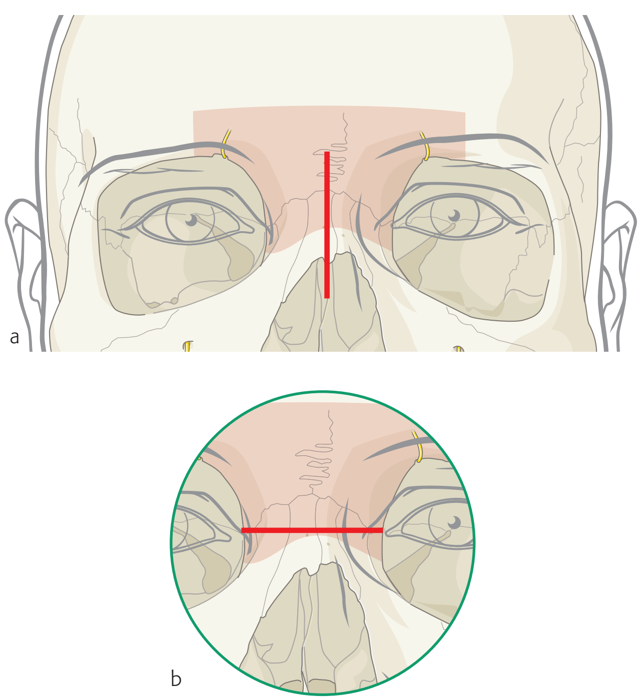


Fig 3.6-2a–b Horizontal and vertical incisions for transfacial access.

3 Approaches

Fortunately, the majority of nasal fractures can be managed with closed approaches. However, for more severe trauma an open approach may be required. Unfortunately, there is no single approach which will expose the entire nasal skeleton. Additionally, the fact that the nose is centrally positioned in the face presents few opportunities for camouflage of incisions and therefore, esthetic approaches to the nasal skeleton are challenging.

Exposure of the nasal skeleton may be achieved by several different approaches. In extensive trauma, a combination of approaches may be required.

3.1 Coronal approach

This approach provides excellent exposure of the nasal bones and their junction with the frontal bone down to the upper lateral cartilages, with sufficient exposure for plate and screw application (**Fig 3.2-5**, page 196). The coronal approach is rarely indicated for isolated fractures limited to the nasal skeleton. The most common use of the coronal approach is for fractures extending into the nasoorbitoethmoidal (NOE), nasofrontal, or frontal sinus regions.

3.2 The gull-wing approach

This approach should never be used. It is an incision across the nasion, extending laterally under or above the eyebrows. This approach provides excellent exposure of the upper two thirds of the nasal skeleton, but has the disadvantage of a very visible scar, and possible transection of the supratrochlear and supraorbital nerves.

There are two acceptable approaches (**Fig 3.6-2a–b**):

- The horizontal limb of the converse open-sky incision
- The vertical midline nasal incision over the nasal radix

These incisions can be used for isolated nasal or limited NOE fractures.

3.3 Lacerations

Occasionally, significant lacerations over the nose or central midface may provide sufficient exposure for reduction and repair of nasal injuries. Care should be taken when considering extending a laceration in order to avoid iatrogenic scarring or injury to the perinasal sensory nerves. It is rarely justified to extend a laceration in contrast to using standard incisions.

3.4 Sublabial approach

The sublabial approach through a gingival buccal incision (**Fig 3.1-4**, page 186) provides excellent exposure of the medial maxilla as it forms the piriform aperture and ascending portion of the maxilla. Although the maxilla is not technically part of the nasal skeleton, the nasal bones articulate with the ascending process of the maxilla. Fractures involving the medial maxilla frequently involve the nasal skeleton and may require an open approach with reduction and plating.

4 Classification of nasal skeletal fractures

There is no universally accepted classification system for nasal skeletal fractures. The following simple scheme deals with the most common clinical scenarios.

Laterally displaced fractures usually occur from a blow coming diagonally across the face. Typically, both nasal bones fracture at their nasomaxillary sutures or below, with the bone ipsilateral to the trauma being pushed medially and the contralateral bone being pushed laterally (**Fig 3.6-3a**). Additionally, there will usually be a fracture of the superior portion of the nasal septum (**Fig 3.6-3b**). This type of fracture may involve one or both nasal bones (depending on the amount of force involved) and sometimes the nasal process of the maxilla (**Fig 3.6-4**).

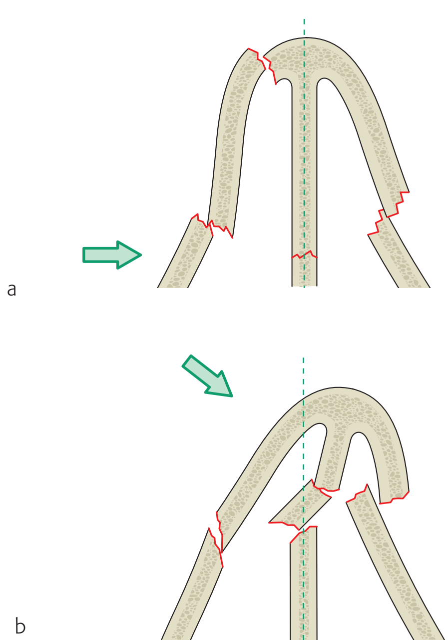


Fig 3.6-3a–b Lateral displacement of the nasal bones:
a Septum not displaced.
b With involvement of the superior portion of the nasal septum.

Fig 3.6-4 CT scan of a nasal fracture with involvement of both nasal bones.

Posteriorly depressed fractures occur from a "straight-on blow" over the nasal bones (**Fig 3.6-5**). Typically, the nasal bones are pushed posteriorly inside the ascending processes of the maxilla. There will also be a septal component for this type of fracture, which may be significant. Considerable force is required to cause a fracture of this type and it is common for these fractures to extend into the piriform aperture or NOE region.

Avulsion of upper lateral cartilage: With significant, localized, central third nasal trauma (such as striking the central nose on a steering wheel) the upper lateral cartilages may be avulsed from the nasal bones (**Fig 3.6-6a–b**). The avulsion may be either unilateral (from a side blow) or bilateral. This is an important diagnosis to be made because management of a cartilaginous injury is quite different from that of a bony injury. Additionally, the diagnosis of cartilaginous avulsion is made primarily by physical exam because a cartilaginous injury will typically not be appreciated on a CT scan.

Nasal septal fractures: In almost all nasal fractures the nasal septum will be involved to some degree (the exception being an isolated, unilateral distal nasal bone fracture). In most cases septal involvement requires intervention. With lateral trauma the septal fracture rarely realigns itself with external nasal bone repositioning and must be reduced separately. However, with direct anterior–posterior trauma there may be significant comminution of the nasal septum with loss of height. This comminution may result in nasal airway obstruction as well as an external dorsal nasal depression. This type of dislocation cannot be repaired or stabilized. It is managed by dorsal grafting (chapter 3.5 Nasoorbitoethmoidal (NOE) fractures).

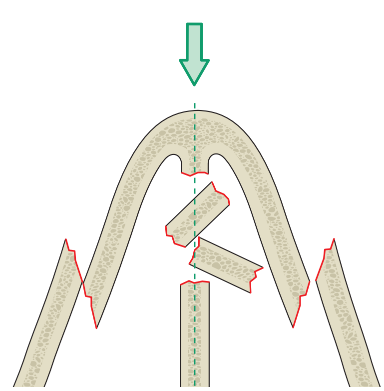
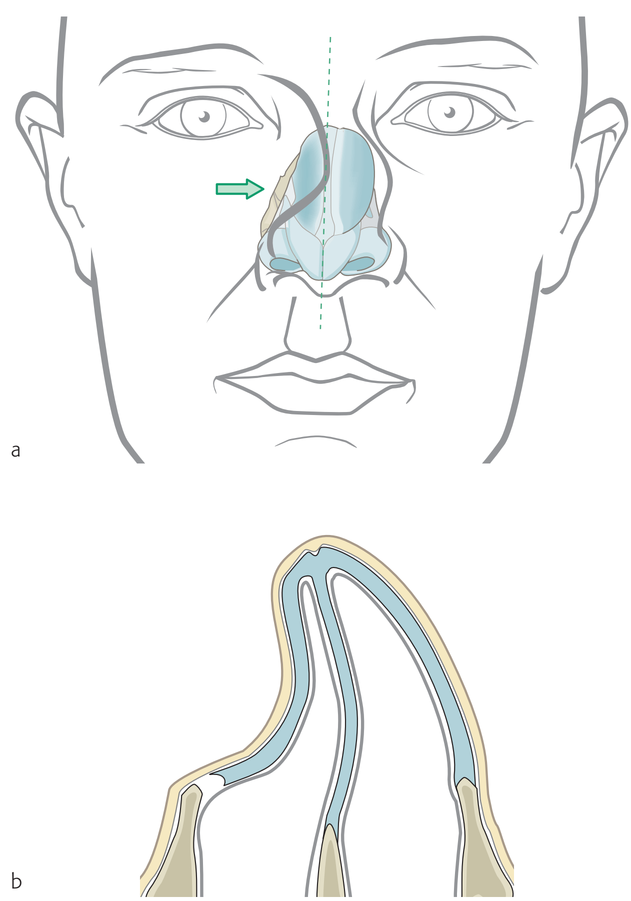


Fig 3.6-5 Centrally depressed nasal fracture. The nasal bones are pushed posteriorly inside the processes of the maxilla.



a

b

Fig 3.6-6a–b Upper lateral cartilage avulsion after significant localized central third nasal trauma.

Nasal septal hematoma: In case of inferior third nasal trauma when the cartilaginous septum is involved, disruption of the cartilaginous septum and its investing perichondrium may occur and may result in a septal hematoma (**Fig 3.6-7**). The natural history of a septal hematoma is for the hematoma to lift the perichondroma off the cartilage (depriving the cartilage of blood) and put significant pressure on the cartilage. This combination of pressure and loss of vascular supply may lead to infection, cartilage necrosis, and subsequent loss. The end result of an untreated septal hematoma is frequently the loss of a large portion of the septal cartilage with an inferior third nasal depression and the so-called "saddle nose deformity" of the external nose. Because of the severe sequelae of an untreated septal hematoma, it is recommended that all patients with significant nasal trauma undergo an endonasal examination in the early posttrauma period in order to rule out a developing hematoma.

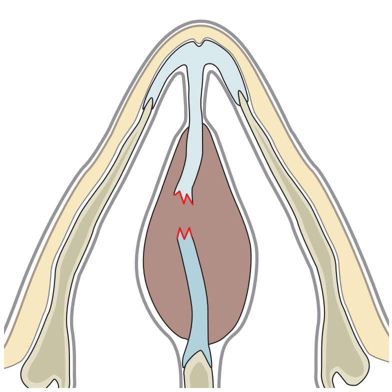


Fig 3.6-7 Septal hematoma after isolated septal fracture.

5 Management of nasal skeletal fractures

5.1 Medially and laterally displaced fractures

Laterally displaced fractures make up the bulk of nasal fractures and most can be managed by closed reduction. Obviously, with a closed reduction the fracture segments are not visualized and, therefore, an accurate diagnosis and proper technique is essential in order to assure a suitable outcome. Some surgeons recommend waiting 5–10 days prior to a closed reduction in order to allow some initial swelling to resolve. The type of anesthesia to be used is an important consideration. Local anesthesia with topical, intranasal cocaine and nasal sidewall infiltration with Xylocaine® may be sufficient anesthesia in selected patients, but it has several drawbacks. First, administration of the topical and injected anesthesia can be quite painful. Second, most patients will only allow one attempt at reduction of the fracture and, if this is unsuccessful or incomplete, patient discomfort will prevent a chance for further manipulation. Third, if there is any bleeding from fracture manipulation patients often become very uncomfortable and quite apprehensive. As an alternative to topical and injected anesthesia we prefer a brief general anesthesia with an endotracheal tube in order to minimize the chance of aspiration.

With the patient asleep, the nose is decongested with cottonoids impregnated with a topical decongestant (cocaine or oxymetazoline). Reduction is performed using a blunt elevator placed on the side of the depressed nasal bone (**Fig 3.6-8a–b**). A rough estimate of the distance from the nostril to the fracture site is measured with the elevator externally on the nose. The elevator is then introduced into the nostril on the side of the depressed nasal bone (side of traumatic impact). It is imperative that the elevator is as far anterior in the nasal cavity as possible, and under the nasal bone. Positioning the elevator under the nasal bone may be difficult because the depressed nasal bone may be lodged against the septum. Failure to make sure that the elevator is under the nasal bone will result in a failed reduction and considerable bleeding. The opposite hand wraps the fingers around the frontal temporal region (to provide countertraction) and the index finger is placed over the laterally displaced nasal bone. Reduction takes place by the simultaneous elevation of the nasal bone with the elevator, medial displacement of the laterally displaced nasal bone with the index finger, and countertraction applied by the fingers. Often a distinct click is heard as the fracture snaps into place.

5.2 Centrally depressed fractures

As noted, isolated centrally depressed fractures are relatively uncommon and the possibility of a NOE component should be ruled out by examination and CT scan because a closed reduction will not correct these more severe injuries. Centrally depressed nasal fractures require posterior to anterior elevation. Often the ascending processes of the maxilla are splayed laterally with the nasal bones inside them. Reduction requires elevation of the nasal bones anteriorly and then squeezing the ascending processes medially.

5.3 Avulsed upper lateral cartilages

Avulsed upper lateral cartilages require an accurate diagnosis to assure a satisfactory outcome. It is important to recognize that reduction of bony segments will not reposition the avulsed cartilages and a central depression will persist. In our experience, attempts at reattachment of the cartilages have been disappointing, even with direct visualization through a laceration. Attempts at suturing the cartilages back to the nasal bones have typically resulted in the sutures pulling through. We have found that accurate reduction of the bony fragments with crushed cartilage onlay grafting (either acutely or delayed) to fill the depression left by the avulsed cartilage provides the best result.

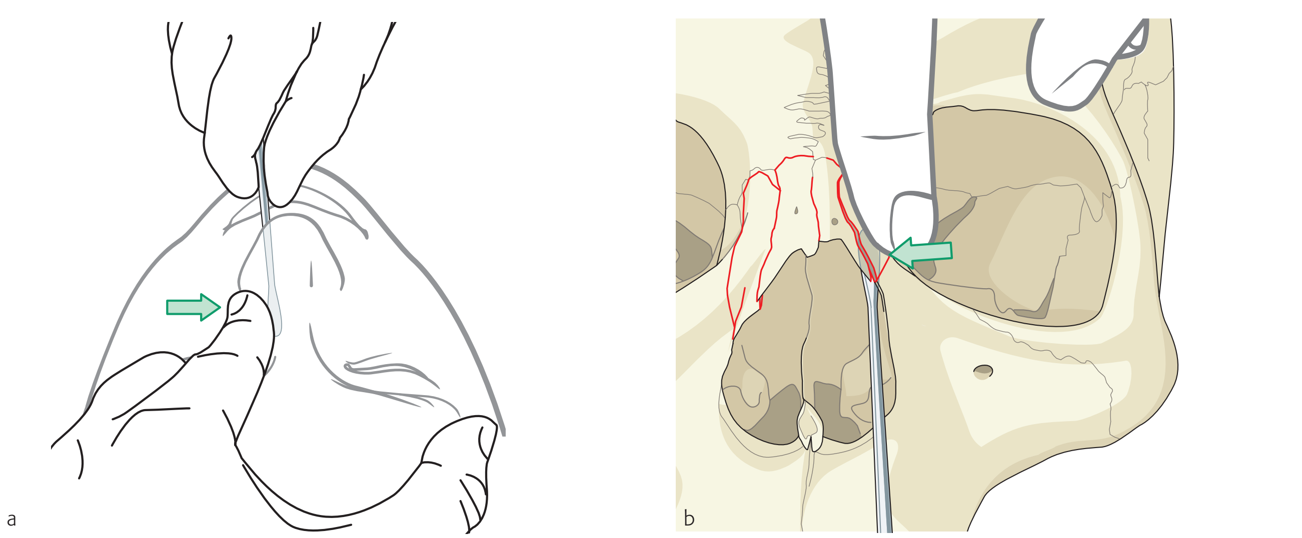


Fig 3.6-8a–b Reduction and position control of the laterally displaced left nasal bone fracture with an elevator inside the nose and index finger outside the nose.

5.4 Comminuted nasal fractures

Comminuted nasal fractures are often associated with significant lacerations. These lacerations can be quite helpful for reduction and stabilization. The fractures are visualized using a combination of approaches (such as open rhinoplasty and coronal), the fractures are aligned, and then plated with a low profile plating system. The microplate 1.0 system is preferred, but 1.3 is also acceptable.

5.5 Septal fractures

Management of septal fractures depends largely on symptoms and physical findings. As noted, there will almost always be a septal fracture with any displaced nasal fracture, but reduction is always indicated using forceps. Indications for open surgery are 1) septal hematoma, 2) septal deviation with nasal airway obstruction, 3) protrusion of bone or cartilage through septal mucosa (which will preclude healing and give rise to recurrent epistaxis). Septal hematoma is managed by incision, drainage, and transseptal mattress sutures. Displaced septal fractures can be treated with a closed approach or with an open septoplasty approach. In our experience, in severe fractures an open septoplasty approach with preservation of septal cartilage and removal of comminuted bone gives the most predictable results. Optimal timing for septal repair seems to be within 5 days. With significant delay in repair of a septal fracture, scarring and fibrosis will develop and make a straightforward septoplasty a major ordeal.

6 Perioperative and postoperative management

For simple, uncomplicated nasal fractures, which have been reduced in a closed fashion, an external splint is applied for 5–7 days simply to protect the nose from inadvertent trauma in the early postoperative period. When applying a nasal splint following a closed reduction, it is important to remember that the fracture is not fixated and if the splint is crimped too tightly, it can displace the fracture (**Fig 3.6-9**). If the septum has been repaired, then the septal mucosal flaps will be coapted with either transseptal mattress sutures or the nose is packed overnight with rolled, nonabsorbent gauze. There is no significant advantage to leaving the packing in longer than one night and it is a source of considerable discomfort for the patient. There have been reports of using nasal packing to hold an unstable nasal bone in place, but it is questionable whether intranasal packing is reliable for maintaining a nasal bone in reduction. Internal splint septum stabilization, such as Doyle splints, can also be used.

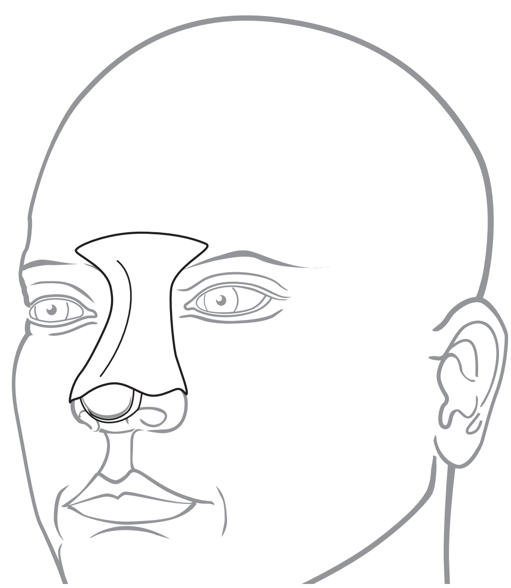


Fig 3.6-9 An external splint can be used for stabilization in simple and uncomplicated nasal fractures.

7 Complications and pitfalls

The two major complications of nasal skeletal fractures are nasal airway obstruction and external deformity. The major cause of nasal obstruction is either a deviated nasal septum or a medially displaced lateral nasal sidewall. They actually look different: in one the septum is dislocated laterally, in the other the turbinate and sidewall are dislocated medially. A CT scan may be helpful in differentiating between a septal deflection versus a sidewall fracture.

Correction of a deviated nasal septum secondary to a septal fracture can be quite difficult when performed on a delayed basis. It should be noted that the chances of a postoperative septal perforation increase when repairing a delayed septal fracture because mucosa is often trapped in fracture lines and dissection will result in mucosal disruption.

Correction of residual external nasal deformities requires an accurate diagnosis as to which nasal components are responsible for the deformity. Lower third dorsal depressions are commonly caused by avulsed upper lateral cartilages (unilateral or bilateral). These residual depressions are best managed by crushed septal cartilage onlay grafting utilizing either an endonasal or open rhinoplasty approach. Upper third deviations are usually the result of unreduced nasal bone fractures. Additionally, these deformities are often accompanied by dorsal irregularities. Once 4–6 weeks have passed, attempts at closed reduction are rarely successful. The most reliable method of managing bony nasal deflections (with or without dorsal irregularities) is with a rhinoplasty technique resecting the dorsal hump, if indicated, and performing lateral osteotomies. Attempts at recreating the original fracture by performing simple lateral osteotomies, without resecting the dorsal hump, often fails to completely straighten the nose or relieve the hump.

3.7 References and suggested reading

Alpert B, Gutwald R, Schmelzeisen R (2003) New innovations in craniomaxillofacial fixation: the 2.0 lock system. *Keio J Med;* 52(2):120–127.
Alvi A, Carrau RL (1996) The bicoronal flap approach in craniofacial trauma. *J Craniomaxillofac Trauma;* 2(2):40–55.
Antonyshyn O, Gruss JS, Galbraith DJ, et al (1989) Complex orbital fractures: a critical analysis of immediate bone graft reconstruction. *Ann Plast Surg;* 22:220–233.
Antonyshyn O, Weinberg M, Dagum A (1996) Use of a new anchoring device for tendon reinsertion in medial canthopexy. *Plast Reconstr Surg;* 98:520–523.
Buitrago-Téllez CH, Schilli W, Bohnert M, et al (2002) A comprehensive classification of craniofacial fractures: postmortem and clinical studies with two- and three-dimensional computed tomography. *Injury;* 33(8):651–668.
Carlin CB, Ruff G, Mansfeld CP, et al (1998) Facial fractures and related injuries: a ten-year retrospective analysis. *J Craniomaxillofac Trauma;* 4(2):44–48.
Caron G, Paquin R, Lessard MR, et al (2000) Submental endotracheal intubation: an alternative to tracheotomy in patients with midfacial and panfacial fractures. *J Trauma;* 48(2):235–240.
Champy M, Lodde JP, Kahn JL, et al (1986) Attempt at systematization in the treatment of isolated fractures of the zygomatic bone: techniques and results. *J Otolaryngol;* 15(1):39–43.
Chen CH, Wang TY, Tsay PK, et al (2008) A 162-case review of palatal fracture: management strategy from a 10-year experience. *Plast Reconstr Surg;* 121:2065–2073.
Coleman JR Jr (2001) State of the art in facial trauma repair. *Curr Opin Otolaryngol Head Neck Surg;* 9:220–224.
Converse JM, Smith B, Obear MF, et al (1967) Orbital blowout fractures: a ten-year survey. *Plast Reconstr Surg;* 39(1):20–33. Review.
Cooter RD, Dunaway DJ, David DJ (1996) The influence of maxillary dentures on mid-facial fracture patterns. *Br J Plast Surg;* 49(6):379–382.
Dawar M, Antonyshyn O (1993) Long-term results following immediate reconstruction of orbital fractures: a critical morphometric analysis. *Can J Plast Surg;* 1:24–29.
Dolan R, Smith DK (2000) Superior cantholysis for zygomatic fracture repair. *Arch Facial Plast Surg;* 2(3):181–186.
Dufresne CR (1992) The use of immediate grafting in facial fracture management: indications and clinical considerations. *Clin Plast Surg;* 19(1):207–217.
Ellis E III, Reddy L (2004) Status of the internal orbit after reduction of zygomaticomaxillary complex fractures. *J Oral Maxillofac Surg;* 62(3):275–283.
Ellis E III, Zide MF (1995) Maxillary vestibular approach. *Ellis E III, Zide MF (eds), Surgical Approaches to the Facial Skeleton.* 1st ed. North Providence: Lippincott Williams & Wilkins, 114–120.
Ellis E III, Zide MF (1995) *Surgical Approaches to the Facial Skeleton.* Baltimore: Williams & Wilkins.
Eppley B (2000) Zygomaticomaxillary fracture repair with resorbable plates and screws. *J Craniofac Surg;* 11(4):377–385.
Forrest CR, Philips JH, Prein J (1998) Le Fort I-III fractures. *Prein J (ed), Manual of Internal Fixation in the Cranio-Facial Skeleton.* Berlin: Springer-Verlag, 108–126.
Fox AJ, Tatum SA (2003) The coronal incision: sinusoidal, sawtooth, and postauricular techniques. *Arch Facial Plast Surg;* 5(3):259–262.
Girotto JA, MacKenzie E, Fowler C (2001) Long-term physical impairment and functional outcomes after complex facial fractures. *Plast Reconstr Surg;* 108(2):312–327.
Glassman RD, Manson PN, Vanderkolk CA, et al (1990) Rigid fixation of internal orbital fractures. *Plast Reconstr Surg;* 86(6):1103–1111.
Gruss JS (1986) Complex nasoethmoid-orbital and midfacial fractures: role of craniofacial surgical techniques and immediate bone grafting. *Ann Plast Surg;* 17(5):377–390.
Gruss JS (1985) Naso-ethmoid-orbital fractures: classification and role of primary bone grafting. *Plast Reconst Surg;* 75:303–317.
Gruss JS, Bubak PJ, Egbert MA (1992) Craniofacial fractures: an algorithm to optimize results. *Clin Plast Surg;* 19(1):195–206.
Gruss JS, Mackinnon SE (1986) Complex maxillary fractures: role of buttress reconstruction and immediate bone grafts. *Plast Reconstr Surg;* 78(1):9–22.
Gruss JS, Phillips JH (1992) Rigid fixation of Le Fort maxillary fractures. *Yaremchuk MJ, Gruss JS, Manson PN (eds), Rigid Fixation of the Craniomaxillofacial Skeleton.* Stoneham, Mass: Butterworth-Heinemann, 245–262.
Gruss J, van Wyck L, Phillips J, et al (1990) The importance of the zygomatic arch in complex midfacial fracture repair and correction of posttraumatic orbitozygomatic deformities. *Plast Reconstr Surg;* 85(6):878–890.
Hackl W, Fink C, Hausberger K, et al (2001) The incidence of combined facial and cervical spine injuries. *J Trauma;* 50(1):41–45.
Hallikainen D, Lindqvist C, Söderholm AL (2002) Radiographic evaluation of the craniomaxillofacial region. *Greenberg AM, Prein J (eds), Craniomaxillofacial Reconstructive and Corrective Bone Surgery: Principles of Internal Fixation Using the AO/ASIF Technique.* New York: Springer-Verlag, 210–219.
Hammer B (1995) *Orbital Fractures: Diagnosis, Operative Treatment, Secondary Corrections.* Göttingen: Hogrefe & Huber.
Hammer B, Prein J (1995) Correction of post-traumatic orbital deformities: operative techniques and review of 26 patients. *J Craniomaxillofac Surg;* 23(2):81–90.
Haug RH, Bradrick JP, Morgan JP (1997) Complications in the treatment of midface fractures. *Kaban LB, Pogrel MA, Perrot DH (eds), Complications in Oral and Maxillofacial Surgery.* Philadelphia: WB Saunders, 147–163.
Hendrickson M, Clark N, Manson PN, et al (1998) Palatal fractures: classification, patterns, and treatment with rigid internal fixation. *Plast Reconstr Surg;* 101(2):319–332.
Hernandez Altemir F (1986) The submental route for endotracheal intubation. *J Maxillofac Surg;* 14(1):64–65.
Hollier LH, Thornton J, Pazmino P, et al (2003) The management of orbitozygomatic fractures. *Plast Reconstr Surg;* 111(7):2386–2393.
Jackson IT (1989) Classification and treatment of orbitozygomatic and orbitoethmoid fractures. The place of bone grafting and plate fixation. *Clin Plast Surg;* 16(1):77–91.
Jaquiéry C, Aeppli P, Cornelius CP, et al (2007) Reconstruction of orbital wall defects: critical review of 72 patients. *Int J Oral Maxillofac Surg;* 36(3):193–199.
Klotch DW, Gilliland R (1987) Internal fixation vs. conventional therapy in midface fractures. *J Trauma;* 27(10):1136–1145.
Knize DM (1995) A study of the supraorbital nerve. *Plast Reconstr Surg;* 96(3):564–569.

Kunz CN, Sigron GR, Jaquiéry C (2012) Functional outcome after non-surgical management of orbital fractures – the bias of decision-making due to defect size: critical review of 48 patients. *Br J Oral Maxillofac Surg.* (submitted)
Lee CH, Lee C, Trabulsy PP, et al (1998) A cadaveric and clinical evaluation of endoscopically assisted zygomatic fracture repair. *Plast Reconstr Surg;* 101(2):333–345.
Le Fort R (1901) Etude expèrimentale sur le fractures de la machoire supèrieure. *Rev Chir;* 23:201, 360, 479.
Linnau KF, Stanley RB Jr, Hallam DK, et al (2003) Imaging of high-energy midfacial trauma: what the surgeon needs to know. *Eur J Radiol;* 48(1):17–32.
Luce EA (1992) Developing concepts and treatment of complex maxillary fractures. *Clin Plast Surg;* 19(1):125–131.
Luhr HG (2000) [The development of modern osteosynthesis]. *Mund Kiefer Gesichtschir;* 4 Suppl 1:84–90. German.
Luhr HG (1988) A micro-system for cranio-maxillofacial skeletal fixation. Preliminary report. *J Craniomaxillofac Surg;* 16(7):312–314.
Luhr HG (1987) Vitallium Luhr systems for reconstructive surgery of the facial skeleton.*Otolaryngol Clin North Am;* 20(3):573–606. Review.
Manson P (1999) Computed tomography use and repair of orbitozygomatic fractures. *Arch Facial Plast Surg;* 1(1):25–26.
Manson PN, Clark N, Robertson B, et al (1999) Subunit principles in midface fractures: the importance of sagittal buttresses, soft-tissue reductions, and sequencing treatment of segmental fractures. *Plast Reconstr Surg;* 103(4):1287–1306; quiz 1307.
Manson PN, Clifford CM, Su CT, et al (1986) Mechanism of global support and posttraumatic enophthalmos, I: the anatomy of the ligament sling and its relation to intramuscular cone orbital fat. *Plast Reconstr Surg;* 77(2):193–202.
Manson PN, Crawley WA, Yaremchuk MJ, et al (1985) Midface fractures: advantages of immediate extended open reduction and bone grafting. *Plast Reconstr Surg;* 76(1):1–10.
Manson PN, Glassman D, Van der Kolk C, et al (1990) Rigid stabilization of sagittal fractures of the maxilla and palate. *Plast Reconstr Surg;* 85(5):711–717.
Manson PN, Markowitz B, Mirvis S, et al (1990) Toward CT-based facial fracture treatment. *Plast Reconstr Surg;* 85(2):202–214.
Manson PN, Shack RB, Leonard LG, et al (1983) Sagittal fractures of the maxilla and palate. *Plast Reconstr Surg;* 72(4):484–489.
Markowitz BL, Manson PN, Sargent L, et al (1991) Management of the medial canthal tendon in nasoethmoidal fractures: the importance of the central fragment in classification and treatment. *Plast Reconstr Surg;* 87(5):843–853.
Marx RE (1994) Clinical application of bone biology to mandibular and maxillary reconstruction. *Clin Plast Surg;* 21(3):377–392.
Mast G, Ehrenfeld M, Cornelius CP (2012) [Maxillofacial fractures: midface and internal orbit; Part 2: therapeutic options]. *Unfallchirurg;* 115(2):145–164. German.
Mathog RH, Hillstrom RP, Nesi FA (1989) Surgical correction of enophthalmos and diplopia: a report of 38 cases. *Arch Otolaryngol Head Neck Surg;* 115(2):169–178.
Michelet FX, Deymes J, Dessus B (1973) Osteosynthesis with miniaturized screwed plates in maxillo-facial surgery. *J Maxillofac Surg;* 1(2):79–84.
Moss CJ, Mendelson BC, Taylor GI (2000) Surgical anatomy of the ligamentous attachments in the temple and periorbital regions. *Plast Reconstr Surg;* 105(4):1475–1490.
Ng M, Saadat D, Sinha UK (1998) Managing the emergency airway in Le Fort fractures. *J Craniomaxillofac Trauma;* 4(4):38–43.
Noffze MJ, Tubbs RS (2011) René Le Fort 1869-1951. *Clin Anat;* 24(3):278–281.
Patel PC, Sobota BT, Patel NM, et al (1998) Comparison of transconjunctival versus subciliary approaches for orbital fractures: a review of 60 cases. *J Craniomaxillofac Trauma;* 4(1):17–21.
Pearl RM (1987) Surgical management of volumetric changes in the bony orbit. **Ann Plast Surg; 19**(4):349–358.
Perrot DH (1997) Complications associated with the use of rigid internal fixation in maxillofacial surgery. *Kaban LB, Pogrel MA, Perrot DH (eds), Complications in Oral and Maxillofacial Surgery.* Philadelphia: WB Saunders, 223–235.
Peter H, Freihofer M (1980) Experience with transnasal canthopexy. *J Maxillofac Surg;* 8(2):119–124.
Philipps JH, Gruss JS, Wells MD, et al (1991) Periosteal suspension of the lower eyelid and cheek following subciliary exposure of facial fractures. *Plast Reconstr Surg;* 88(1):145–148.
Pollock RA (1992) Nasal trauma: pathomechanics and surgical management of acute injuries. *Clin Plast Surg;* 19(1):133–147.
Posnick JC, Goldstein JA, Clokie C (1992) Advantages of the postauricular coronal incision. *Ann Plast Surg;* 29(2):114–116.
Prein J, Hammer B (1988) Stable internal fixation of midfacial fractures. *Facial Plast Surg;* 5(3):221–230.
Putterman AM, Stevens T, Urist MJ (1974) Nonsurgical management of blow-out fractures of the orbital floor. *Am J Ophthalmol;* 77(2):232–239.
Rhee JS, Posey L, Yoganandan N, et al (2001) Experimental trauma to the malar eminence: fracture biomechanics and injury patterns. *Otolaryngol Head Neck Surg;* 125(4):351–355.
de Roche VR, Kuhn A, de Roche-Weber P, et al (1996) [Development of a resorbable implant: experimental reconstruction of the orbits with polylactate membranes. Animal model and preliminary results]. *Handchir Mikrochir Plast Chir;* 28(1):28–33. German.
Rohner D, Tay A, Meng CS, et al (2002) The sphenozygomatic suture as a key site for osteosynthesis of the orbitozygomatic complex in panfacial fratures: a biomechanical study in human cadavers based on clinical practice. *Plast Reconstr Surg;* 110(6):1463–1471.
Romano JJ, Iliff NT, Manson PN (1993) Use of Medpor porous polyethylene implants in 140 patients with facial fractures. *J Craniofac Surg;* 4(3):142–147.
Romano JJ, Manson PN, Mirvis SE, et al (1990) Le Fort fractures without mobility. *Plast Reconstr Surg;* 85(3):355–362.
Rudderman RH, Mullen RL (1992) Biomechanics of the facial skeleton. *Clin Plast Surg;* 19(1):11–29.
Sargent LA (2007) Nasoethmoid orbital fractures: diagnosis and treatment. *Plast Reconstr Surg;* 120(7 Suppl 2):16S–31S.
Schilli W, Ewers R, Niederdellmann H (1981) Bone fixation with screws and plates in the maxillo-facial region. *Int J Oral Surg;* 10(suppl 1):329–332.
Stanley RB (1999) Use of intraoperative computed tomography during repair of orbitozygomatic fractures. *Arch Facial Plast Surg;* 1(1):19–24.
Stanley RB, Sires BS, Funk GF, et al (1998) Management of displaced lateral orbital wall fractures associated with visual and ocular motility disturbances. *Plast Reconstr Surg;* 102(4):972–979.
Stoll P, Schilli W, Joos U (1983) The stabilization of midface-fractures in the vertical dimension. *J Maxillofac Surg;* 11(6):248–251.
Sullivan WG (1991) Displaced orbital roof fractures: presentation and treatment. *Plast Reconstr Surg;* 87(4):657–661.
Tessier P (1972) The classic reprint: experimental study of fractures of the upper jaw. I and II. *Rene Le Fort, M.D., Lille, France. Plast Reconstr Surg ;* 50(5):497–506.
Tessier P (1972) The classic reprint: experimental study of fractures of the upper jaw. III. *René Le Fort, M.D., Lille, France. Plast Reconstr Surg;* 50(5):600–605.

Uemura T, Jinnai T, Yokoyama T, et al (2001) C-shape extended transconjunctival approach for the exposure and osteotomy of traumatic orbitozygomaticomaxillary deformities. *J Craniofac Surg;* 12(6):603–607.
Wolfe SA (1982) Application of craniofacial surgical precepts in orbital reconstruction following trauma and tumor removal. *J Maxillofac Surg;* 10(4):212–223.
Wright DL, Kellman RM (2002) Craniomaxillofacial bone infections: etiologies, distributions, and associated defects. *Greenberg AM, Prein J (eds), Craniomaxillofacial Reconstructive and Corrective Bone Surgery: Principles of Internal Fixation Using the AO/ASIF Technique.* New York: Springer-Verlag, 76–89.
Yamamoto K, Matsusue Y, Murakami K, et al (2011) Maxillofacial fractures in older patients. *J Oral Maxillofac Surg;* 69(8):2204–2210.
Zingg M, Laedrach K, Chen J, et al (1992) Classification and treatment of zygomatic fractures: a review of 1025 cases. *J Oral Maxillofac Surg;* 50:778–790.