Spectrum of Critical Imaging Findings in Complex Facial Skeletal Trauma[1]

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SA-CME

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LEARNING OBJECTIVES FOR TEST 1

After completing this journal-based SA-CME activity, participants will be able to:

- List the osseous buttresses of the facial skeleton.
- Describe common traumatic fracture patterns in the facial skeleton.
- Identify the imaging features of clinically and surgically relevant complications of facial trauma.

TEACHING POINTS

See last page

Multidetector computed tomography (CT) is the modality of choice for the evaluation of facial trauma because it helps accurately identify and characterize fractures and associated complications, thereby aiding timely clinical management and surgical planning. In particular, CT clearly depicts clinically relevant fractures in the eight osseous struts or buttresses that function as an underlying scaffold for facial structures. Information about the involvement of specific facial buttresses in a complex fracture is helpful for determining the type of fracture present and for identifying associated soft-tissue injuries that may require urgent care or surgery. Various kinds of complications can be expected to occur in Le Fort fractures, which affect the full thickness of the pterygoid plates, with resultant dissociation of part or all of the maxilla from the skull base; naso-orbitoethmoid complex fractures, which involve the medial orbital wall, nasal bone, ethmoid sinuses, and, often, the attachment site of the medial canthal tendon; zygomaticomaxillary complex fractures, which disrupt all four zygomatic sutures and may lead to enophthalmos due to increased orbital volume because of angulation of the lateral orbital wall; orbital “blowout” fractures, which may result in extraocular muscle herniation or entrapment and injuries to the globe or the infraorbital nerve; and fractures of the alveolar process, which are treated as open fractures because of their extension through the gingiva to the oral cavity and their resultant vulnerability to infection. Similarly, extension of a frontal sinus fracture through the posterior sinus wall creates a portal to the anterior cranial fossa and may lead to cerebrospinal fluid leakage, intracranial hemorrhage, or intracranial infection.

Abbreviations: CSF = cerebrospinal fluid, NOE = naso-orbitoethmoid

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Introduction

Facial fractures account for a large number of emergency department visits in the United States and are associated with substantial levels of morbidity and mortality due to damaged facial structures, associated complications, and trauma sustained by other parts of the body (1–3). Facial fractures are commonly caused by blunt or penetrating trauma sustained during motor vehicle accidents, pedestrian accidents, assaults, work-related accidents, and falls. Multidetector computed tomography (CT) is the modality most often used for imaging evaluation in such cases because the high image resolution available with thin-section acquisitions allows the detection of even subtle nondisplaced fractures of the facial skeleton. Multidetector CT provides better delineation of osseous and soft-tissue features, offers both multiplanar and three-dimensional image reconstruction, and can be performed more quickly than radiography, with easier patient positioning (4–7). Accurate description of facial fractures and complications is of paramount importance for surgical planning and appropriate management (8). The facial buttress concept elucidates the structurally meaningful skeletal struts that play a role in facial form and function and helps identify the regions that are likely to require surgical reconstruction (5,9–11).

The article first provides an overview of the facial skeletal anatomy and describes the system of facial buttresses. Next, the spectrum of fractures that may be seen in facial skeletal trauma is described with emphasis on the buttress or buttresses most likely to be affected by each fracture pattern. Critical features that may be seen at imaging and that are likely to have a bearing on the clinical management, surgical repair, and outcome of facial trauma are discussed. Last, surgically relevant complications that are predictable on the basis of the fracture pattern seen at imaging are reviewed according to the facial buttress affected by fracture.

Facial Anatomy

The facial skeleton is a complex structure formed by a combination of five paired bones and four unpaired bones. The complexity of the facial anatomy makes the characterization of facial fractures according to the bone or bones affected cumbersome. In addition, given the proximity of vulnerable soft tissues, it may be clinically more useful to describe facial fractures according to their location in relation to functionally relevant structures (eg, fracture of the medial orbital wall, fracture of the anterior maxillary sinus wall). The conceptual construct of facial buttresses underscores the functional relations between osseous components of the facial anatomy by simplifying the skeletal structure into four pairs each of horizontally and vertically oriented struts. The vertically oriented struts directly or indirectly connect the anterior facial skeleton to the posterior skull base. The greater thickness of bone in the facial buttresses, both horizontal and vertical, with respect to the remainder of the facial skeleton provides a rigid protective framework for the orbital contents, sinuses, teeth, and nasal cavity. Disruption of the facial buttresses can change facial dimensions and alter normal function, necessitating surgical fixation for restoration. Fixation is typically performed by using rigid titanium plates and screws anchored in the buttress, with or without bone grafts. Observation of the location of a fracture in relation to the facial buttresses does not supplant a precise description of the fractured anatomy but may be helpful for identifying the fracture pattern and predicting potential complications (Fig 1).

The upper transverse maxillary buttress originates at the level of the nasofrontal suture and proceeds along the inferior edge of the orbit across the zygomatic bone to the zygomaticotemporal suture. This buttress extends posteriorly as the orbital floor. The lower transverse maxillary buttress is oriented horizontally along the maxillary alveolar process and extends posteriorly to include the hard palate. The upper transverse mandibular buttress encompasses the mandibular alveolar process and extends from its posterior margin through the mandibular ramus to the posterior cortical margin of the mandible. The lower transverse mandibular buttress is the inferior margin of the mandible.

The medial maxillary buttress extends from the nasofrontal suture inferiorly along the lateral margin of the piriform aperture to the maxillary alveolar process. This buttress projects posteriorly to include the medial orbital wall and medial wall of the maxillary sinus. The lateral maxillary buttress begins at the zygomaticofrontal suture and projects inferiorly along the lateral orbital rim through the body of the zygomatic bone and across the zygomaticomaxillary suture to terminate in the maxillary alveolar process adjacent to the posterior maxillary molars. The posterior extensions of this buttress include the lateral orbital wall and lateral maxillary sinus wall. The posterior maxillary buttress is formed by the pterygoid plates, which connect the sphenoid bone (skull base) to the maxilla

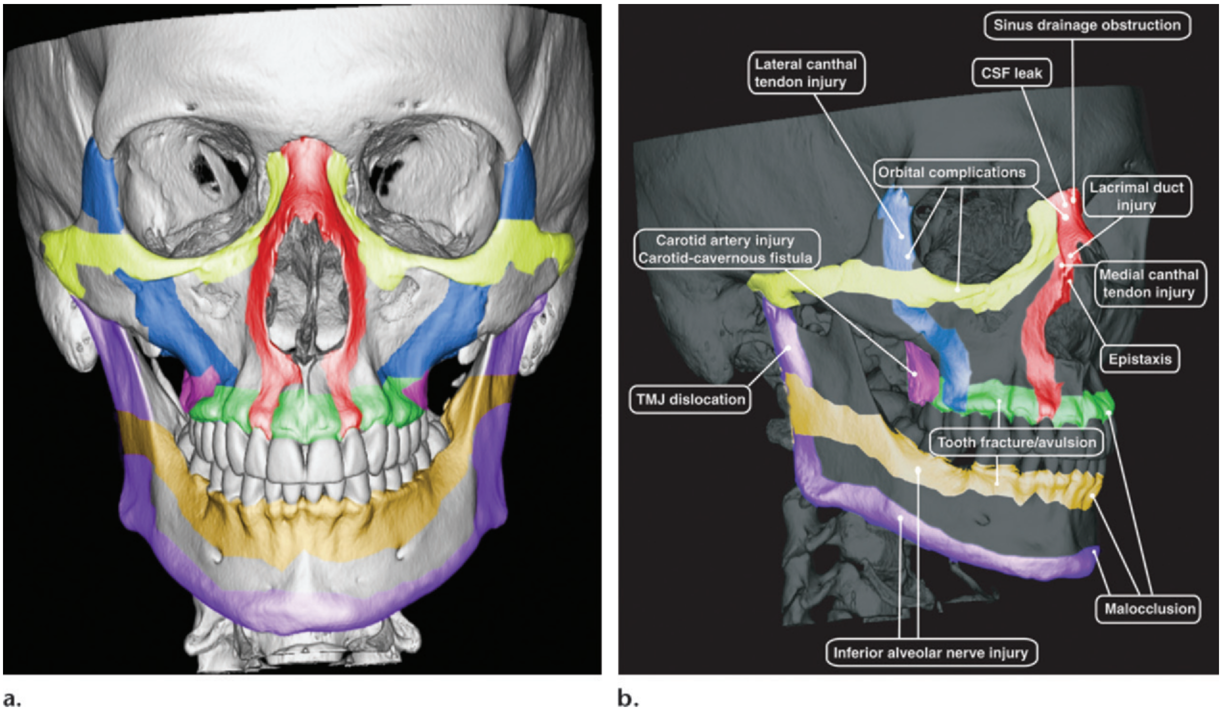
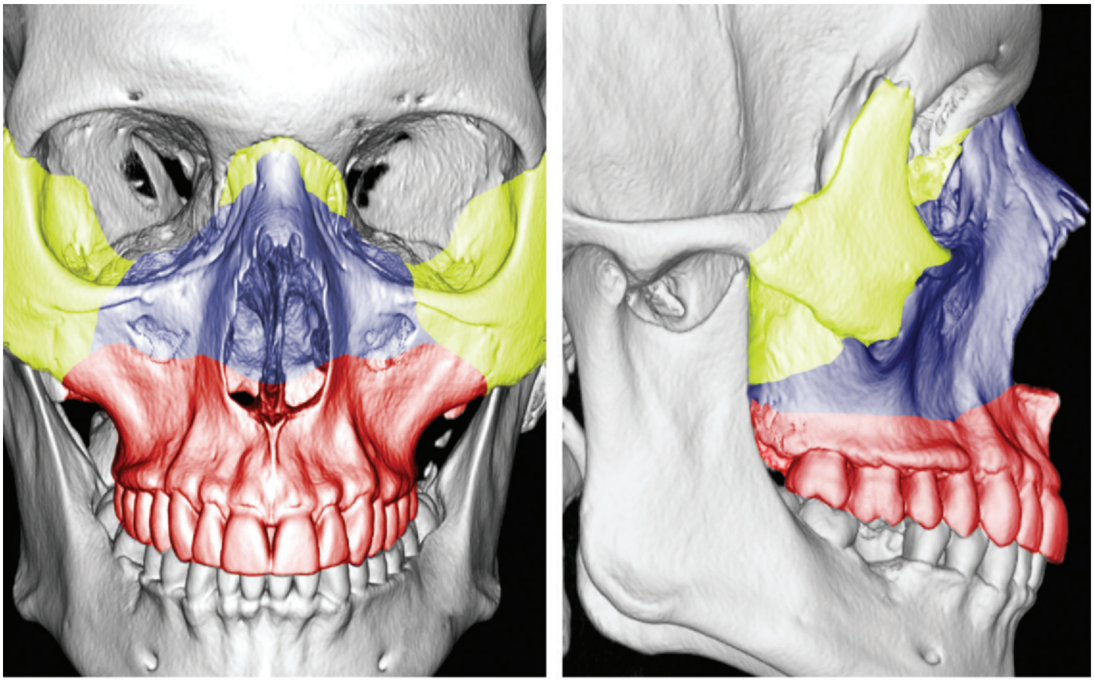


Figure 1. System of facial buttresses. Three-dimensional CT images of an adult skull in frontal **(a)** and lateral oblique **(b)** orientations with color overlays show the superficial aspects of the horizontal and vertical facial buttresses and, in **b**, the sites of potential complications of fractures involving each buttress. The horizontal buttresses are the upper transverse maxillary (yellow), lower transverse maxillary (green), upper transverse mandibular (orange), and lower transverse mandibular (purple) buttresses. The vertical buttresses are the medial maxillary (red), lateral maxillary (blue), posterior maxillary (magenta), and posterior vertical mandibular (purple) buttresses.

Figure 2. System of facial partitions. Three-dimensional CT image of an adult skull with color overlays shows partition of the facial anatomy into upper (red), middle (blue), and lower (yellow) thirds, the system used by otolaryngologists to describe locations of fracture in the facial anatomy.

(midface) and which are an important site of craniofacial dissociation (Le Fort) fractures. The posterior mandibular buttress is the posterior margin of the mandible and includes portions of the angle, ramus, and condyle.

In a different system that is used by otolaryngologists, the osseous facial anatomy is divided into upper, middle, and lower thirds (Fig 2). The upper third of the face consists of the frontal bone (including the frontal sinuses) and is delineated from the middle third by the superior orbital rims and walls. The middle third of the face extends from the superior orbital rims inferiorly to the maxilla and thus includes the orbits; the nasal cavity; and the maxillary, ethmoid, and sphenoid sinuses. The middle third of the face is bounded posterolaterally by the zygomaticotemporal sutures, which connect the midface to the calvaria, and posteromedially by the pterygoid plates, which connect it to the skull base. The lower third of the



a. b.

Figure 3. Le Fort fractures. Three-dimensional CT images of an adult skull in frontal **(a)** and lateral **(b)** orientations with color overlays show the osseous facial structures that are typically affected by type I (red), type II (blue), and type III (yellow) Le Fort fractures.

face consists of the mandible. Classifying fractures by their location with regard to these facial thirds may be helpful for planning surgical access. For example, fractures involving the frontal sinuses (upper third) may be approached by using a coronal incision, whereas fractures involving the orbital floor (middle third) are approached by a transconjunctival incision of the lower eyelid (12).

Complex Fractures Involving Multiple Facial Buttresses

Le Fort fractures are complex facial fractures that result from a high-force impact on the midface structures and are characterized by a variable degree of craniofacial dissociation spanning multiple facial buttresses. These fractures were first described in the early 20th century by French surgeon René Le Fort, who conducted experiments in which blunt force was applied to the midface of cadavers. Le Fort described three common fracture patterns, each caused by a force of a different magnitude and all including a fracture through the pterygoid plates (Fig 3). Depending on the distribution of forces through the facial skeleton, multiple Le Fort fracture patterns may occur at the same time, and different combinations may occur on the two sides of the face (eg, type I and II fractures on the left side, and type II and III fractures on the right).

Teaching Point

A type I Le Fort fracture, also known as a Guérin fracture or "floating palate," results in separation of the hard palate (lower transverse maxillary buttress) from the remainder of the face and the skull base. This fracture pattern is horizontally oriented and spans the anterior, lateral, and medial maxillary walls, transecting the inferior margin of the piriform aperture and nasal septum and extending posteriorly through the pterygoid plates (Fig 4a, 4d, 4e). Because the fracture extends anteroposteriorly in the axial plane, it is typically best depicted on coronal and three-dimensional images.

A type II Le Fort fracture, also known as a "pyramidal" fracture, produces a pyramid-shaped maxillary fragment that may move independently of the rest of the upper midface and skull base. The apex of the pyramid is situated at or just inferior to the nasofrontal suture. The obliquely oriented fracture extends through the medial orbital wall, orbital floor, and zygomaticomaxillary suture, but spares the zygomatic bone (Fig 4b, 4d, 4e). This fracture spans the superior medial maxillary, inferior lateral maxillary,

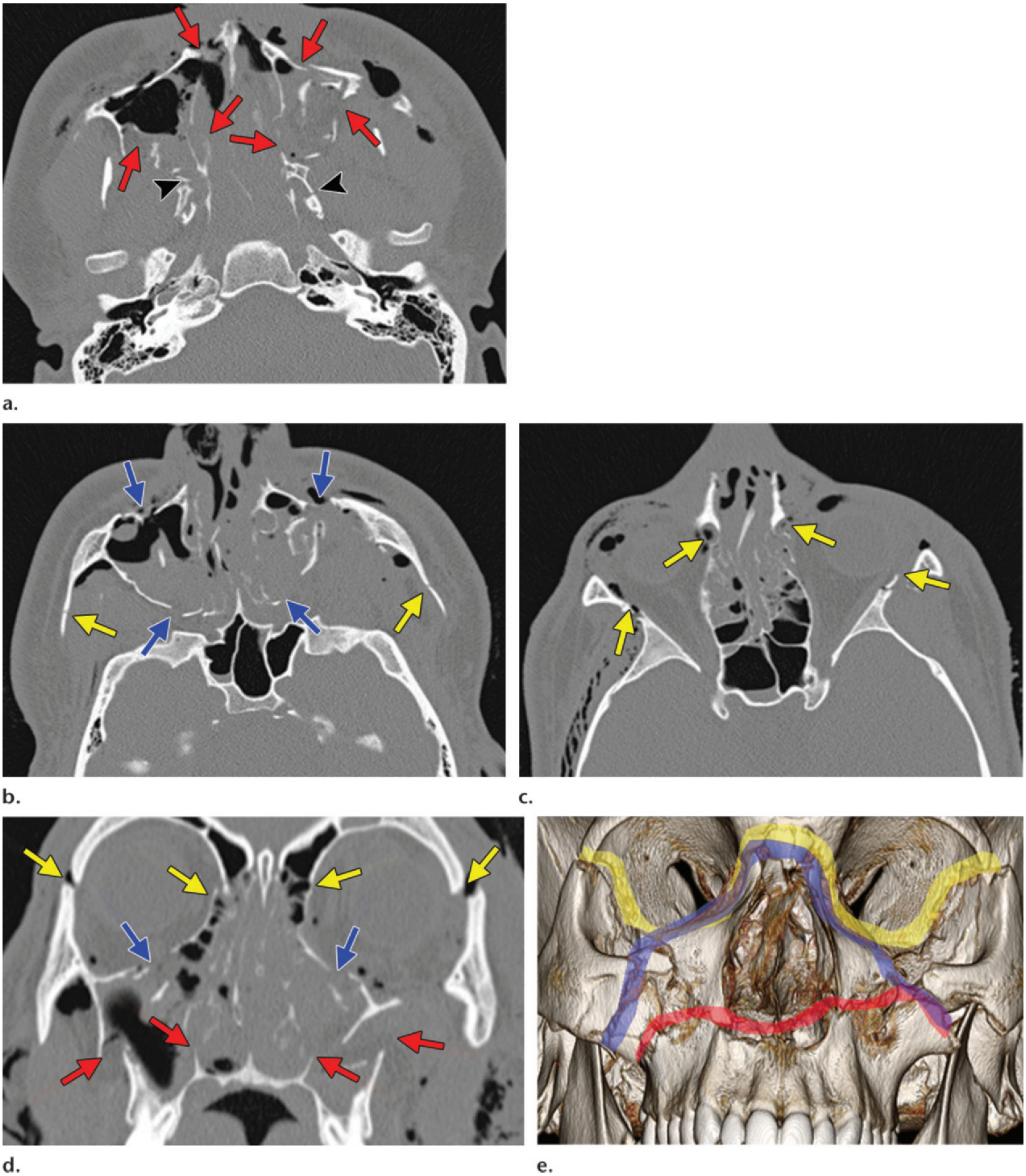
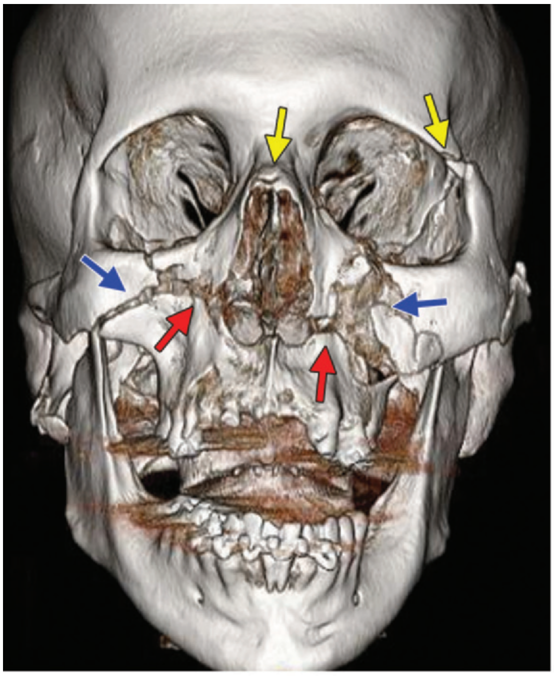
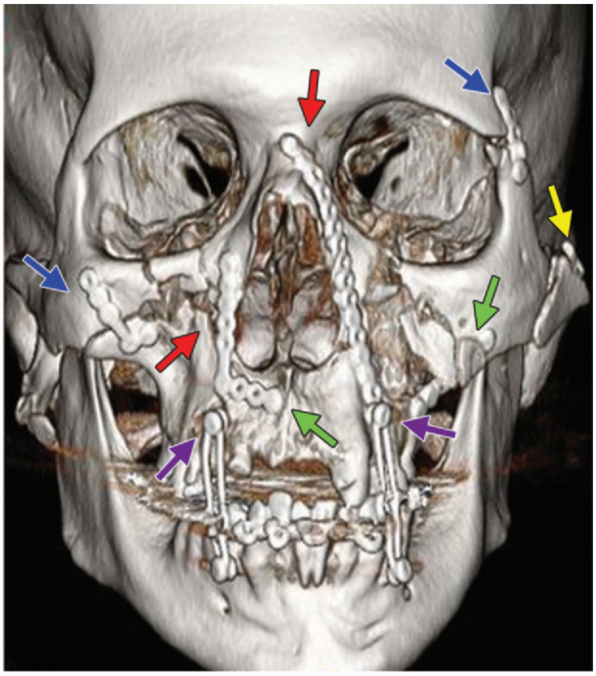


Figure 4. Multiple Le Fort fractures in the same patient. (Color keys correspond to the region affected by the fracture type shown with the same color in Fig 3.) **(a)** Axial unenhanced CT image at an inferior level of the maxillary sinuses demonstrates bilateral fractures through the pterygoid plates (arrowheads) and maxillary sinus walls (red arrows), findings indicative of type I Le Fort fractures. Pterygomaxillary dissociation due to fracture extension through the pterygoid plate is a criterion for Le Fort classification. **(b)** Axial unenhanced CT image at a superior level of the maxillary sinuses depicts fractures through the medial margins of the anterior and posterior maxillary walls, which are characteristic of type II Le Fort fractures (blue arrows), and nondisplaced fractures through the zygomatic arch, which are a component of type III Le Fort fractures (yellow arrows). **(c)** Axial unenhanced CT image at the level of the orbits shows fractures through the nasal bridge, medial orbital walls, and lateral orbital walls (yellow arrows), findings indicative of type III Le Fort fractures. **(d)** Coronal unenhanced CT image demonstrates type I Le Fort fractures of the inferior aspect of the maxillary sinus walls (red arrows), type II Le Fort fractures of the inferomedial orbital walls (blue arrows), and type III Le Fort fractures of the medial and lateral orbital walls (yellow arrows). **(e)** Three-dimensional CT image in frontal orientation delineates type I (red), II (blue), and III (yellow) Le Fort fractures.

Figure 5. Le Fort fractures before and after internal fixation. (Color keys in Fig 5a correspond to the fractured region with the same color in Fig 3; color keys in Fig 5b correspond to the buttress with the same color in Fig 1.) **(a)** Three-dimensional CT image of facial bones demonstrates bilateral type I (red arrows) and type II (blue arrows) and left-sided type III (yellow arrows) Le Fort fractures. **(b)** Three-dimensional CT image obtained after internal fixation of the fractures shows plates and screws spanning the medial maxillary (red arrows), lateral maxillary (blue arrows), right lower transverse maxillary (green arrows), and right upper transverse maxillary (yellow arrow) buttresses. Maxillomandibular fixation devices also are seen (purple arrows).



a.



b.

upper transverse maxillary, and posterior maxillary buttresses. Axial and coronal reformatted images are useful for visualizing the extension of a type II Le Fort fracture in an oblique plane through the medial and inferior orbital walls.

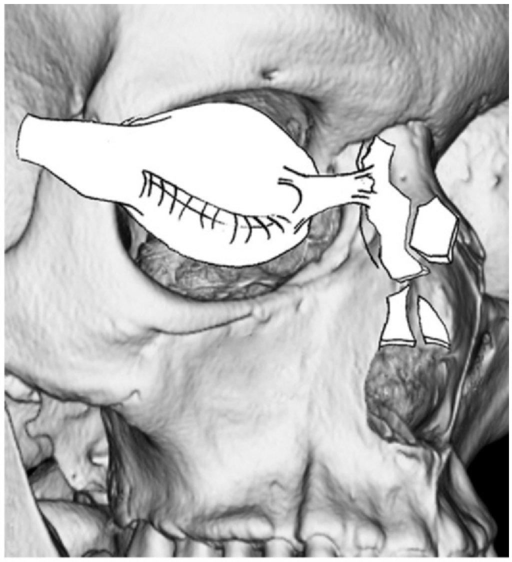
A type III Le Fort fracture, also known as craniofacial dissociation, causes complete dissociation of the face from the skull base, as the name implies. This fracture begins at the nasofrontal suture and travels laterally through the medial and lateral orbital walls and zygomatic arch; thus, a type III Le Fort fracture, unlike types I and II, involves the zygomatic bone (Fig 4b–4e). The facial buttresses affected by type III Le Fort fractures are the superior portions of the medial maxillary and lateral maxillary, upper transverse maxillary, and posterior maxillary buttresses. Identification of the extension of fracture to the lateral orbital wall and zygomatic arch on axial or coronal images of the face helps distinguish type III from type II Le Fort fracture, since involvement of the nasofrontal suture and medial orbital walls is common to both.

Surgical fixation of Le Fort fractures is achieved with rigid plates and screws placed along the fractured facial buttresses (Fig 5). The surgical procedure begins with restoration of the normal configuration of the medial and lateral maxillary buttresses to permit normal occlusion between the maxillary and mandibular teeth. Next, maxillomandibular fixation is performed to maintain dental occlusion during the rest of the repair procedure. Last, the anterior portions of the facial buttresses are repaired to restore facial dimensions and reestablish facial structural support, and the maxilla is rejoined to the calvaria (13).

Fractures of the naso-orbitoethmoid (NOE) complex are caused by a high-impact force applied anteriorly to the nose and transmitted posteriorly through the ethmoid bone. Severe comminution of both medial maxillary buttresses results in a pattern of fractures involving the nasal bones and septum, ethmoid sinuses, and medial orbital walls. Frequent complications caused by fractures of the NOE complex include exophthalmos due to a decrease in intraorbital volume, telecanthus due to medial canthal tendon injury, and cerebrospinal fluid (CSF) rhinorrhea due to fracture through the cribriform plate.

Figures 6, 7. **(6)** Three-dimensional CT images of an adult skull with graphic overlays depict the Markowitz and Manson classification system for classifying fractures of the NOE complex: type I NOE fracture **(a)**, characterized by a single large central fragment with attached medial canthal tendon; type II NOE fracture **(b)**, characterized by comminution without extension to the medial canthal tendon attachment; and type III NOE fracture **(c)**, characterized by comminution through the medial canthal tendon attachment, with resultant tendon avulsion. **(7)** Three-dimensional CT image of the left medial maxillary buttress in lateral oblique orientation shows a single fracture fragment that includes the lacrimal fossa at the expected insertion site of the medial canthal tendon, findings indicative of a type I NOE fracture. Fractures through the left frontal calvaria, lateral orbital rim, and zygomatic arch also are seen.

6a.



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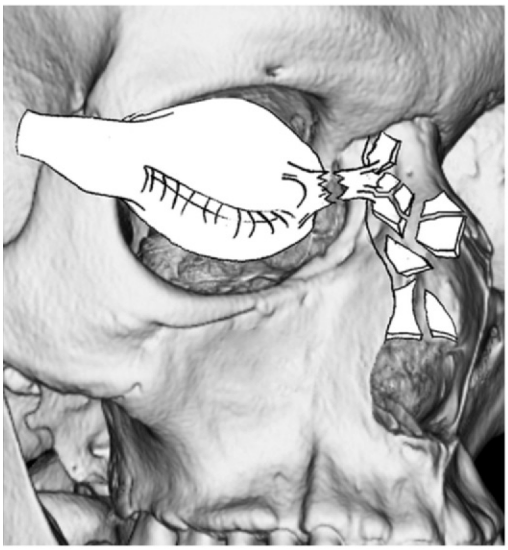
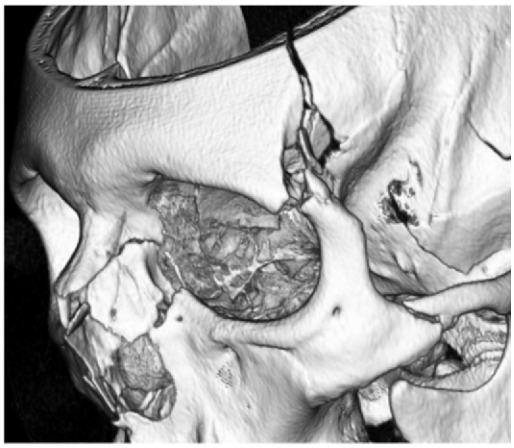


6c.

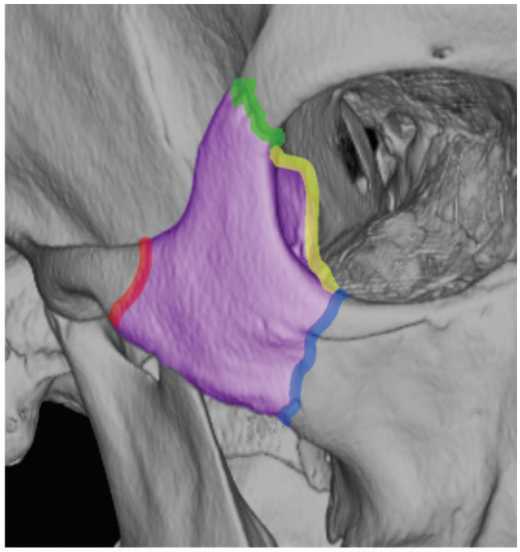


7.

The Markowitz and Manson classification system categorizes fractures of the NOE complex according to whether the medial canthal tendon is involved, as follows: In type I NOE fractures, the medial canthal tendon is intact and connected to a single large fracture fragment; in type II fractures, the fracture is comminuted, and the medial canthal tendon is attached to a single bone fragment; in type III fractures, comminution extends to the medial canthal tendon insertion site on the anterior medial orbital wall at the level of the lacrimal fossa, with resultant avulsion of the tendon (Figs 6, 7) (14). Although the tendon itself is not visible at multidetector CT, the radiologist's report of the degree of comminution of the medial orbital wall at the level of the lacrimal fossa may be helpful for surgical planning of medial canthal tendon repair.

Teaching Point

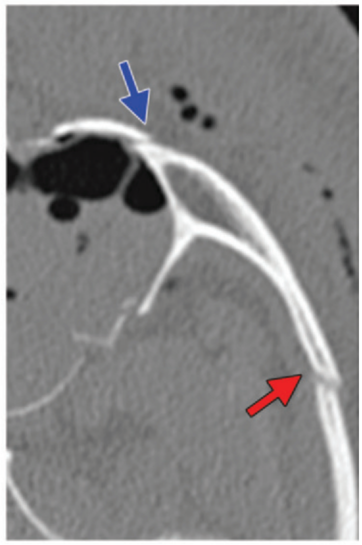
Figures 8, 9. **(8)** Three-dimensional CT image with color overlays delineates the osseous anatomy of the zygomaticomaxillary complex: the zygomaticofrontal (green), zygomaticosphenoid (yellow), zygomatico-maxillary (blue), and zygomaticotemporal (red) sutures surrounding the zygomatic bone (purple). **(9)** Fractures of the zygomaticomaxillary complex. (Color keys correspond to the location with the same color in Fig 8.) **(a–c)** Axial unenhanced CT images of the left orbital region show nondisplaced fractures through the left zygomaticofrontal (green arrow in **a**), zygomaticosphenoid (yellow arrow in **b**), zygomaticomaxillary (blue arrow in **c**), and zygomaticotemporal (red arrow in **c**) sutures. **(d)** Three-dimensional CT image of the upper left facial region shows a nondisplaced left zygomaticomaxillary complex fracture through the zygomaticofrontal (green arrow), zygomaticosphenoid (yellow arrow), zygomaticomaxillary (blue arrow), and zygomaticotemporal (red arrow) sutures.



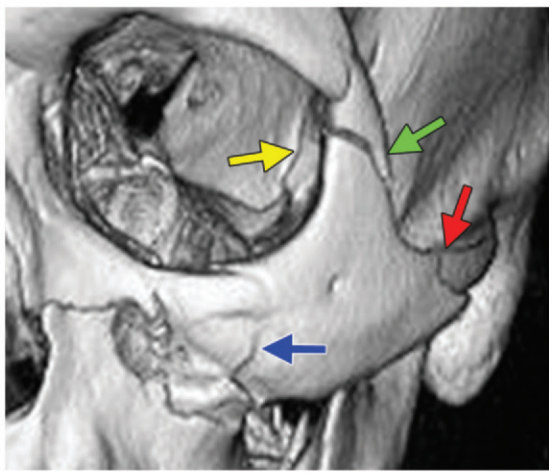
8.

9a.

9b.

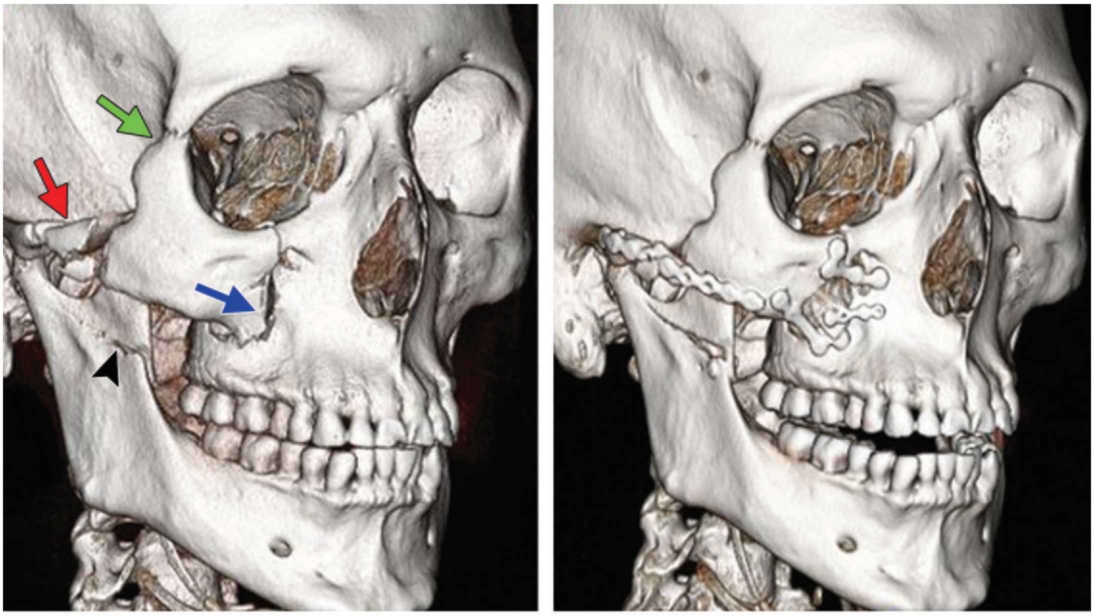


9c.



9d.

A fracture of the zygomaticomaxillary complex, also known as a tetrapod or quadripod fracture, is caused by a direct traumatic blow to the malar eminence, with resultant dissociation of the underlying zygomatic bone from the calvaria. The zygomatic bone constitutes part of the lateral orbital walls inferior to the frontal bone, the anterior and lateral maxillary sinus walls superior to the hard palate, and the zygomatic arch anterior to the temporal bone and is normally connected to the rest of the facial skeleton and the calvaria by four sutures. A zygomaticomaxillary complex fracture extends through these four sutures (Figs 8, 9). This fracture pattern was previously known as a tripod fracture because only three disrupted sutures (the zygomaticofrontal, zygomaticomaxillary, and zygomaticotemporal sutures) could be discerned at screen-film radiography. However, the fracture actually extends posteriorly through the



a. b.

Figure 10. Zygomaticomaxillary complex fracture before and after internal fixation. (Color keys correspond to the suture with the same color in Fig 8.) **(a)** Three-dimensional CT image of an adult face in oblique orientation depicts a right zygomaticomaxillary complex fracture with a nondisplaced zygomaticofrontal suture (green arrow), mildly displaced zygomaticomaxillary suture (blue arrow), and comminuted and displaced zygomatic arch extending through the zygomaticotemporal suture (red arrow); the zygomaticosphenoid suture was involved but is not depicted. A nondisplaced fracture of the base of the right coronoid process (arrowhead) also is seen. **(b)** Three-dimensional CT image in the same orientation demonstrates fixation of the zygomaticomaxillary and zygomaticotemporal sutures with plates and screws.

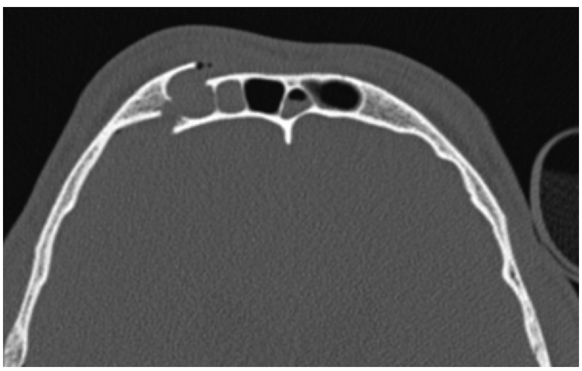


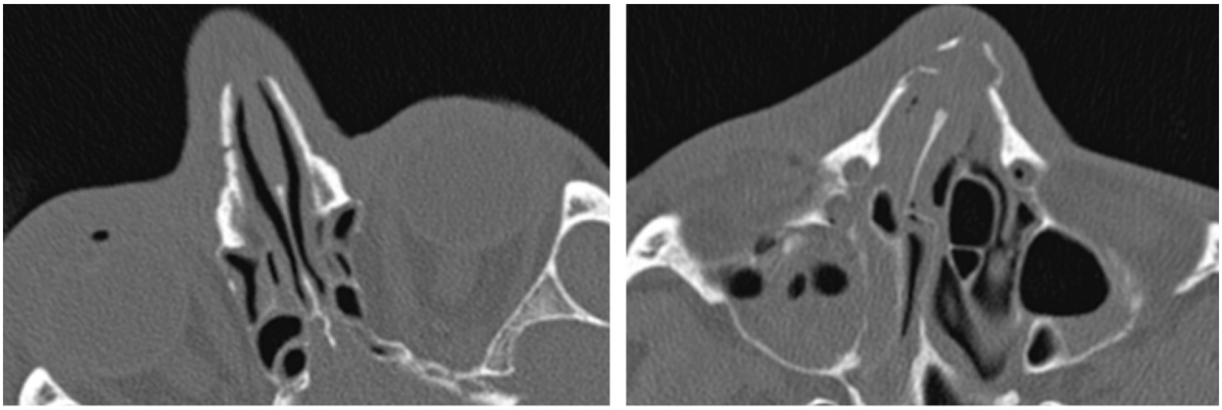
Figure 11. Frontal sinus fracture. Axial unenhanced CT image of the frontal bone demonstrates a mildly displaced fracture of the anterior and posterior walls of the right frontal sinus with associated opacification of the right frontal sinus and small foci of pneumocephalus.

zygomaticosphenoid suture, the fourth component. A zygomaticomaxillary complex fracture therefore disrupts both the lateral maxillary and upper transverse maxillary buttresses. Displaced zygomaticomaxillary complex fractures, which typically result from rotational forces applied on the zygomatic bone by the masseter muscle, may lead to difficulty in mastication because of infratemporal fossa occupation or increased orbital volume and resultant enophthalmos. Surgical repair involves rigid plate-and-screw fixation of the involved facial buttresses to reapproximate the disrupted sutures and restore facial symmetry and orbital volume (Fig 10).

Fractures Involving a Single Facial Buttress

Fractures of the upper third of the face typically affect the wall of the frontal sinus because the bone there is thinner than the rest of the frontal bone. Fractures may involve only the anterior sinus wall or extend into the posterior wall. Posterior wall extension creates a communication between the frontal sinus and the anterior cranial fossa, a condition that increases the likelihood of complications such as CSF rhinorrhea, brain herniation, and intracranial infection (Fig 11). A fracture along the medial aspect of the frontal sinus may extend into the nasofrontal duct, causing a mucocele that obstructs sinus drainage and necessitates surgical correction or frontal sinus cranialization.

RadioGraphics



a. b.

Figure 12. Nasal bone fractures. **(a)** Axial unenhanced CT image shows a nondisplaced type 1 fracture through the right nasal bone. Chronic dehiscence of the left orbital plate of ethmoid bone is incidentally seen. **(b)** Axial unenhanced CT image depicts mildly comminuted and displaced type 2 fractures through the bilateral nasal bones and nasal septum.

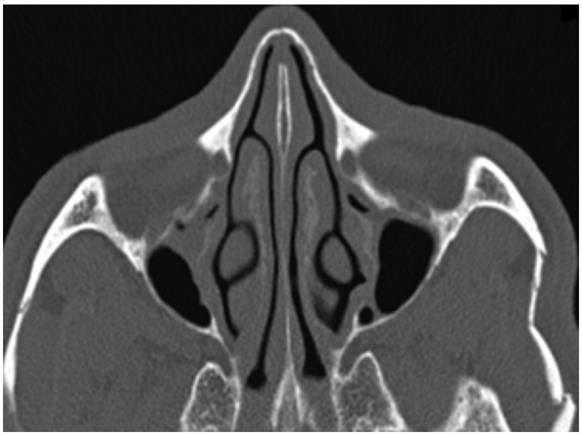


Figure 13. Zygomatic arch fracture. Axial unenhanced CT image demonstrates a comminuted and depressed fracture of the left zygomatic arch with resultant compression of the underlying temporalis muscle, a condition that could lead to trismus.

Figure 14. Fracture of the maxillary alveolar process. Axial unenhanced CT image depicts a fracture of the maxillary alveolar process, with resultant avulsion of the medial and right lateral maxillary incisors.

Nasal bone fractures are the most common of all facial skeletal injuries because of the superficial location of the nose and the relative thinness of the bone. Fractures of nasal bone typically result from blunt force applied from either an anterior or a lateral direction. They are classified according to the anatomic plane involved, as follows: Type 1 fractures are limited to the region beneath a plane extending from the caudal tip of the nose to the anterior nasal spine and do not involve the nasal septum; type 2 fractures involve the septum as well as the anterior nasal spine; and type 3 fractures involve orbital bone and, possibly, intracranial structures as well as the nasal bone and septum (Fig 12). A fracture that extends into the nasal cartilage may disrupt the perichondrium, causing a septal hematoma, with potential complications including impaired nasal breathing, abscess formation, and necrosis with resultant septal perforation.

Isolated zygomatic arch fractures may be found in patients with direct trauma to the posterior aspect of the upper transverse maxillary buttress. This fracture type is not to be confused with a zygomaticomaxillary complex fracture, which extends anteriorly to affect the lateral orbital wall. Given the ringlike structure of the zygomatic arch, the typical fracture pattern is segmental with mild comminution, occasionally involving the zygomaticotemporal suture, and, possibly, depression of bone fragments into the infratemporal fossa. Impingement of the temporalis muscle or adjacent mandibular coronoid process by displaced bone fragments may lead to trismus (Fig 13).

Alveolar process fracture, the most common maxillary fracture pattern, affects the lower trans-

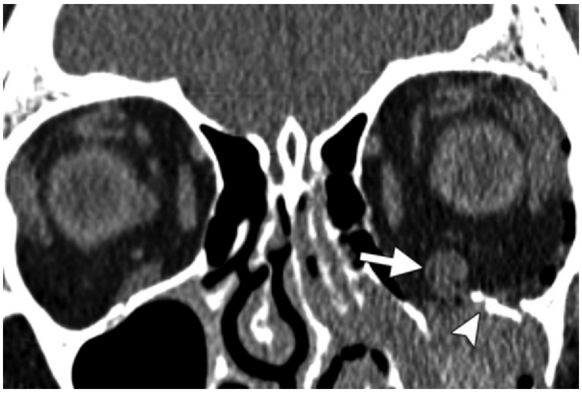
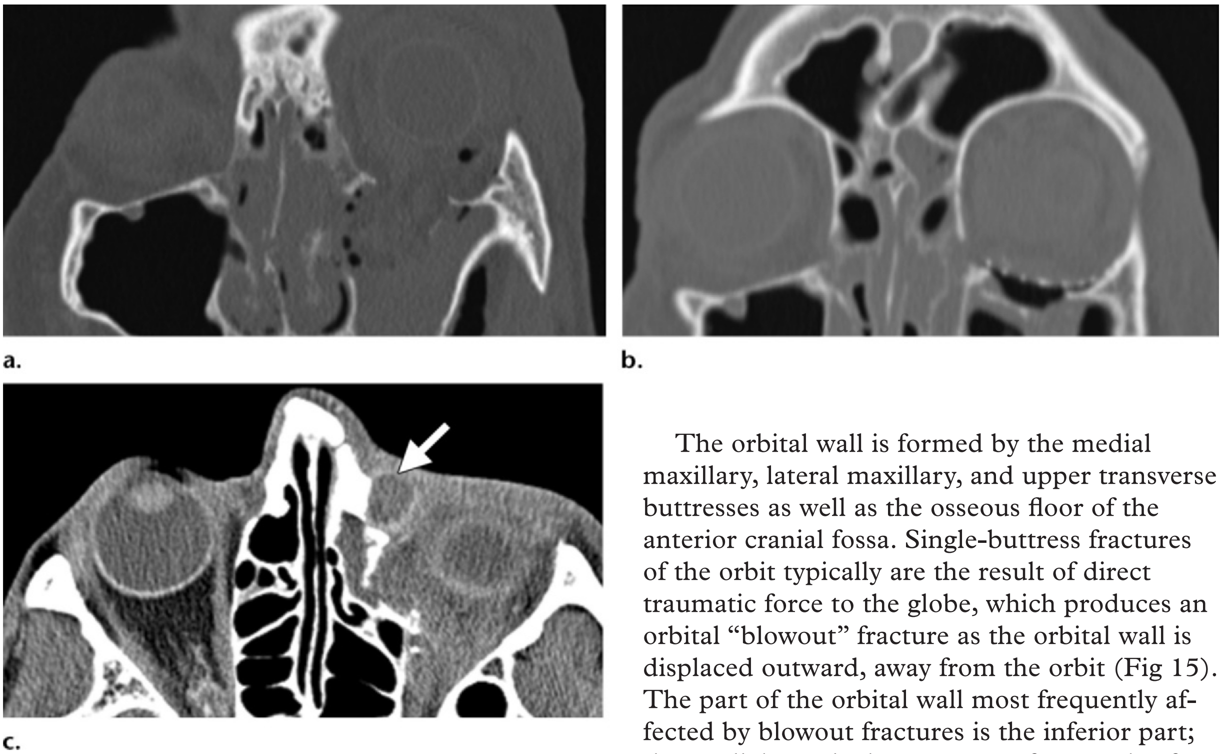


Figure 15. Orbital blowout fracture. Coronal unenhanced CT image shows a displaced blowout fracture of the left inferior orbital wall with resultant entrapment of the inferior rectus muscle (arrow), which appears rounded in comparison with the normal right inferior rectus muscle. The fracture extends through the inferior orbital canal (arrowhead).

Figure 16. Orbital blowout fracture before and after fixation. **(a)** Coronal unenhanced CT image demonstrates a left inferior orbital blowout fracture with herniation of intraorbital fat and the inferior rectus muscle. **(b)** Coronal unenhanced CT image obtained after surgical fixation depicts metallic surgical mesh placed along the inferior orbital wall fracture. The position and appearance of the left inferior rectus muscle are normal. **(c)** Axial contrast-enhanced CT image obtained at follow-up shows dilatation and rimlike enhancement of the left lacrimal duct (arrow), findings indicative of dacryocystitis secondary to lacrimal duct obstruction, a complication of either fracture or surgical fixation.



verse maxillary buttress. This type of fracture may result from direct force applied to the alveolar process or from indirect force transmitted from the underlying teeth via the base of the dental crown, which acts as a fulcrum. Because of the abundance of bacteria in the mouth, a fracture of the alveolar process is treated as an open fracture in which there is a breach of the overlying mucosa necessitating surgical débridement and prophylactic antibiotics. Potential complications of alveolar process fractures include dental root avulsion, crown or root fracture, dental intrusion or extrusion, and malocclusion (Fig 14) (15).

The orbital wall is formed by the medial maxillary, lateral maxillary, and upper transverse buttresses as well as the osseous floor of the anterior cranial fossa. Single-buttress fractures of the orbit typically are the result of direct traumatic force to the globe, which produces an orbital "blowout" fracture as the orbital wall is displaced outward, away from the orbit (Fig 15). The part of the orbital wall most frequently affected by blowout fractures is the inferior part; the medial part is the next most frequently affected. Complications of orbital blowout fractures include extraocular muscle herniation and entrapment, intraorbital hemorrhage, globe injury, and injury to the infraorbital nerve in the presence of an orbital floor fracture. Internal fixation of orbital blowout fractures typically involves replacement or reinforcement of the fractured part of the orbital wall with a mesh material to restore orbital volume and provide a barrier against the herniation of intraorbital contents into the maxillary sinus (Fig 16).

Figure 17. Orbital roof fracture. Coronal unenhanced CT image demonstrates mild inferior displacement of a right orbital roof fracture with an adjacent extraconal hemorrhage.

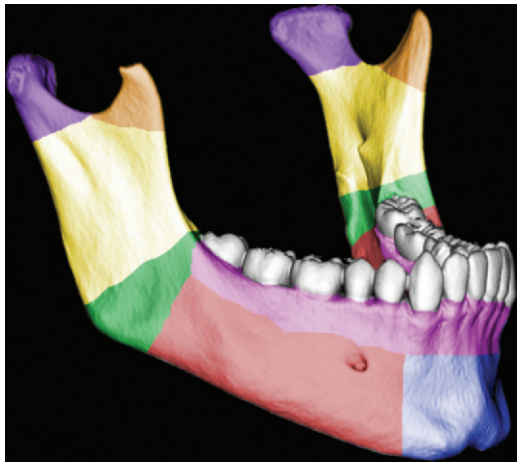


Figure 18. Three-dimensional CT image with color overlays shows the parts of the mandible in lateral orientation: the alveolar process (magenta), parasymphyseal region (blue), body (red), angle (green), ramus (yellow), coronoid process (orange), and condyle (purple).

Two other types of orbital wall fracture are the orbital roof fracture and the pediatric "trapdoor" fracture. The orbital roof is the only part of the orbital wall that separates the anterior cranial fossa from the intraorbital contents. A fracture through the orbital roof can result in a dural tear, with resultant CSF leakage or brain herniation (Fig 17). The trapdoor fracture is an inferior orbital blowout fracture in which the inferior rectus muscle herniates into the underlying maxillary sinus before the fractured fragment returns to its original position, entrapping the muscle. This type of fracture typically occurs in children. On coronal multidetector CT images, the inferior rectus muscle is seen inferior to the orbital floor, with or without visualization of the fractured fragment of the inferior orbital wall.

Teaching Point

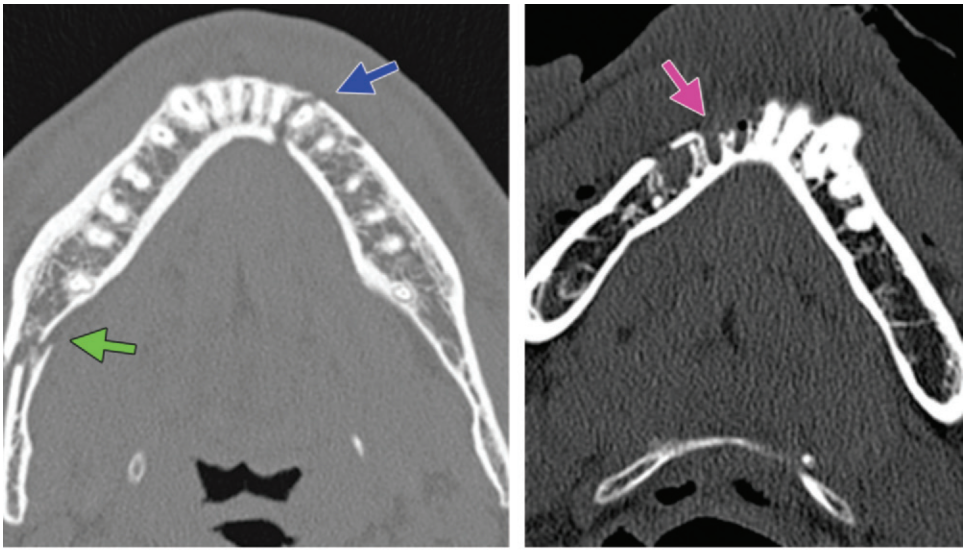
The mandible is a U-shaped bone that is connected to the calvaria through the temporomandibular joints, creating a ringlike structure (Fig 18). Because of this ringlike configuration, a traumatic blow to the mandible typically produces at least two discrete fractures. The appearance of a single fracture of the mandible at imaging is likely the consequence of a fracture-dislocation complex (similar to the Galeazzi and Monteggia fracture-dislocation complexes of the forearm) with subsequent relocation of the temporomandibular joints before imaging. Fractures of the mandible are characterized according to their location (Fig 19), the degree of comminution, and the presence of displaced fragments. Fractures involving the mandibular canal, which traverses the mandibular ramus, angle, and body, may result in injury to the inferior alveolar nerve. Surgical techniques for the management of mandibular fracture include external fixation (eg, maxillomandibular fixation) and/or open reduction with internal fixation to restore dental occlusion and allow healing of the bone by transferring the forces generated by mastication from the mandible to rigid titanium plates and screws (Fig 20) (16,17).

Expected Complications of Fracture

Upper Transverse Maxillary Buttress Fractures

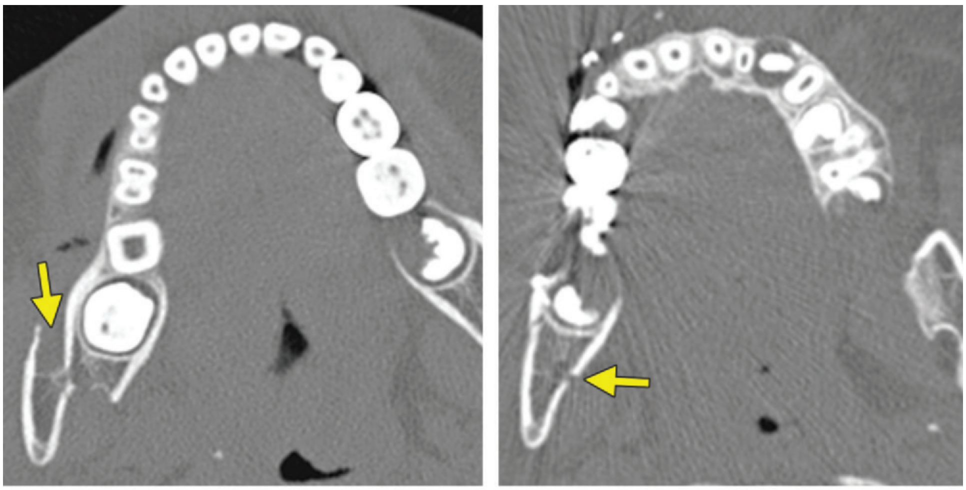
Because the upper transverse maxillary buttress forms the orbital floor, fractures of this buttress may cause various orbital complications, including inferior rectus muscle tears, globe rupture or impingement, optic nerve injury, and orbital hematoma. Superior orbital fissure syndrome is caused by extension of the fracture through the superior orbital fissure, with resultant injury to cranial nerves III, IV, V_1 (the ophthalmic branch of the trigeminal nerve), and VI as they traverse the fissure into the orbit, thus causing ophthalmoplegia or diplopia (extraocular muscle paralysis) and ptosis (paralysis of the levator palpebrae superioris, which is supplied by cranial nerve III). Additional injury to the optic nerve (cranial nerve II) at the orbital apex results in orbital apex syndrome, with uniocular visual loss added to the list of signs and symptoms. Orbital apex syndrome is a surgical emergency because prompt intervention is necessary to prevent permanent blindness. Rupture of the globe due to traumatic rupture of the cornea, sclera, or full thickness of the eye (sclera, choroid, and retina), which also may result in blindness, is depicted at CT as deformity of the globe ("flat tire" sign); however, a more subtle disruption of the globe might be identifiable only at ophthalmologic examination.

Teaching Point

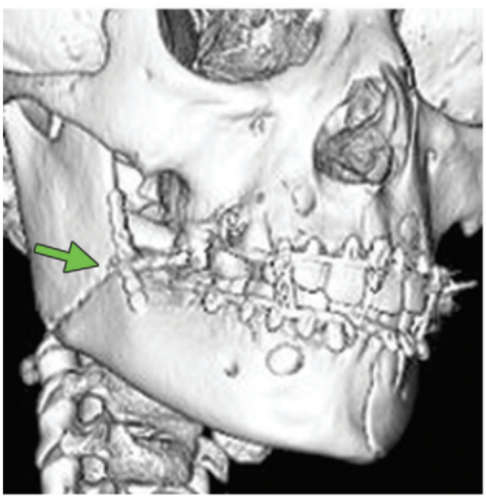


a. b.

Figure 19. Mandibular fractures. (Color keys correspond to the mandibular region with the same color in Fig 18.) **(a)** Axial unenhanced CT image of the mandible depicts a nondisplaced left parasymphyseal fracture (blue arrow) and mildly displaced fracture of the right mandibular body (green arrow) with distraction of the mandibular canal. **(b)** Axial unenhanced CT image demonstrates a fracture of the right alveolar process (magenta arrow) with multiple missing teeth.



a. b.



c.

Figure 20. Mandibular fractures before and after internal fixation. (Color keys correspond to the mandibular region with the same color in Fig 18.) **(a)** Axial unenhanced CT image of the mandible demonstrates a displaced fracture of the right mandibular angle with distraction of the mandibular canal (yellow arrow). **(b, c)** Axial **(b)** and three-dimensional **(c)** unenhanced CT images of the mandible after internal fixation of the right posterior aspect of the upper transverse mandibular buttress across the mandibular angle fracture (green arrow in **c**) and maxillomandibular fixation shows reapproximation of the right mandibular body fracture fragments and mandibular canal (yellow arrow in **b**).

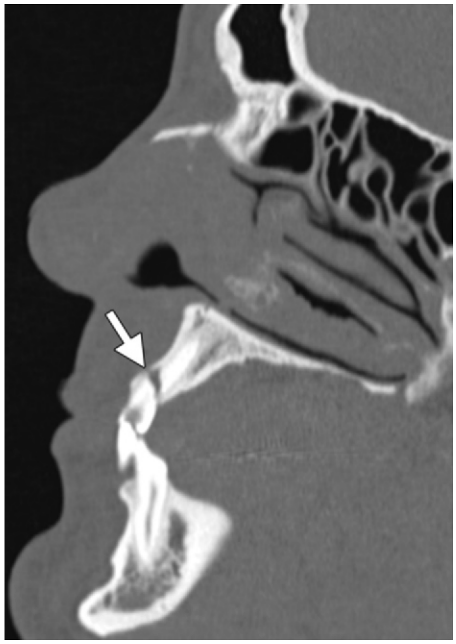


Figure 21. Dental fracture as a complication of lower transverse maxillary buttress fracture. Sagittal unenhanced CT image of the facial midline demonstrates a maxillary alveolar process fracture that extends through the right medial maxillary incisor root (arrow).

The inferior rectus muscle can herniate through a fracture defect, tear, be avulsed from the globe, or be entrapped (Fig 15), leading to ophthalmoplegia and diplopia. Teaching Point Although entrapment of the inferior rectus muscle is diagnosed on the basis of clinical manifestations, herniation may be suggested by a rounded appearance of the normally flattened ovoid muscle belly on cross-sectional images. Injury to the infraorbital nerve (cranial nerve V_2, a branch of the maxillary division of the trigeminal nerve) as it traverses the orbital floor within the infraorbital nerve canal is a common complication of orbital blowout fracture and type II Le Fort fracture and can result in temporary or permanent hypesthesia of the ipsilateral cheek and maxillary gingiva. Fractures involving the lateral aspect of this buttress may cause trismus secondary to injury or impingement of the temporalis muscle in the infratemporal fossa.

Lower Transverse Maxillary Buttress Fractures

Potential complications of fractures involving the lower transverse maxillary buttress include dental fracture (Fig 21), avulsion, and devitalization as well as malocclusion. Soft-tissue infection due to oral flora invading damaged tissues adjacent to the fracture is another potential complication; for this reason, alveolar process fractures are managed as open fractures, with prophylactic antibiotic therapy.

Upper and Lower Transverse Mandibular Buttress Fractures

The complications of an upper transverse mandibular buttress fracture are similar to those of a lower transverse maxillary buttress fracture, since both fracture patterns involve the alveolar process. Most mandibular fractures extend through both the upper and the lower mandibular buttresses. Fractures through the mandibular canal may damage the inferior alveolar nerve, a branch of the mandibular division of the trigeminal nerve (cranial nerve V_3), where it traverses the mandibular ramus, angle, and body from the mandibular foramen to the mental foramen (Fig 20a). Damage to the inferior alveolar nerve may result in anesthesia of the ipsilateral lower lip, chin, anterior tongue, and mandibular teeth.

Medial Maxillary Buttress Fractures

The medial maxillary buttress encompasses the lateral walls of the ethmoid sinuses, medial walls of the orbits, and medial walls of the maxillary sinuses, which are in close proximity to a multitude of vulnerable structures, including the intraorbital contents, frontal recess, sphenoethmoid recess, ostiomeatal complex, lacrimal duct and sac, and medial canthal tendon. The radiologist's detection of complications such as sinus drainage obstruction, orbital complications, medial canthal tendon injury, epistaxis secondary to injury to the anterior or posterior ethmoid arteries, CSF rhinorrhea, and lacrimal duct and sac injury allows appropriate surgical planning and management. Extension of medial maxillary buttress fractures through the cribriform plate (Fig 22) can cause a tear in the underlying dura, allowing CSF leakage into the paranasal sinuses and nasal cavity. Fracture extension to the paranasal sinuses may create a communication that allows bacteria to spread into the normally sterile environment of the anterior cranial fossa, with resultant infection (eg, meningitis, epidural abscess, cerebral abscess). Obstruction of the frontal recess by bone fragments (Fig 23a) may result in frontal sinus mucocele formation, an indication for surgical cranialization of the frontal sinus. Injury to the lacrimal duct and/or sac may cause dacryocystitis, which must be surgically corrected (Fig 23b). Medial canthal tendon injury, a frequent complication of NOE complex fractures, results in telecanthus and must be surgically repaired (Fig 24). Uniocular blindness may be caused by a number of orbital complications, including optic nerve injury (Fig 24), globe rupture, and orbital apex syndrome.

Figure 22. CSF leakage as a complication of medial maxillary buttress fracture. Coronal unenhanced CT image of the face depicts a comminuted fracture through the cribriform plate (arrow), a condition that may lead to CSF rhinorrhea. Fractures of the bilateral orbital roofs, which could cause dural tears, also are seen.

a. b.

Figure 23. Sinus obstruction as a complication of fracture of the nasolacrimal canal (medial maxillary buttress fracture). **(a)** Coronal unenhanced CT image demonstrates a blowout fracture of the left medial orbital wall with fracture fragments obstructing the left frontal recess (arrowhead), a condition that could lead to mucocele formation, which is not present in this case. **(b)** Axial unenhanced CT image at the level of the maxillary sinuses shows a minimally displaced fracture through the nasolacrimal canal (arrow), which could lead to disruption of the nasolacrimal duct.

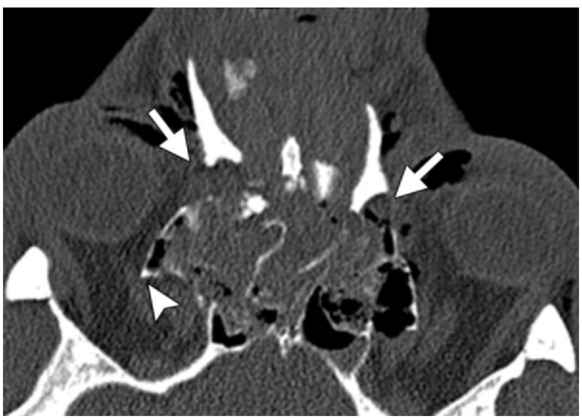
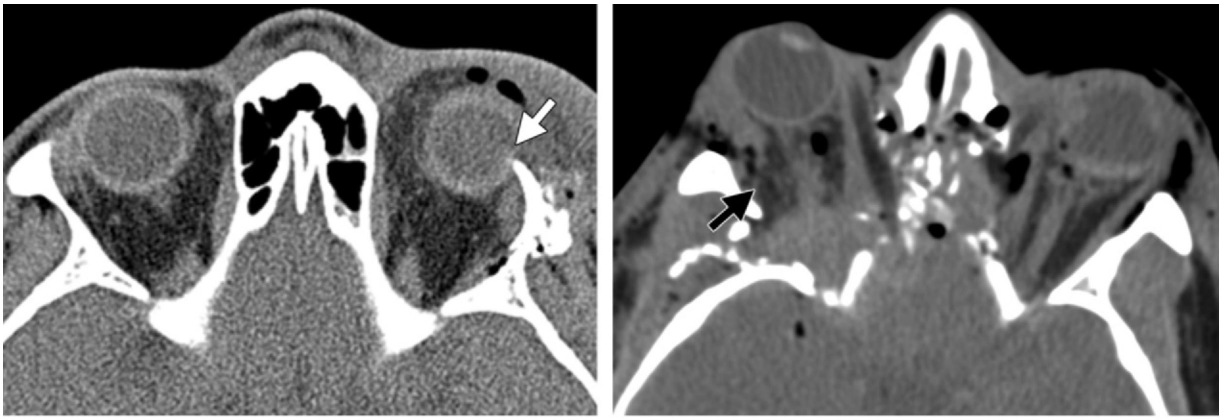


Figure 24. Telecanthus and optic nerve injury as complications of medial maxillary buttress fracture. Axial unenhanced CT image demonstrates a comminuted fracture of the NOE complex with telecanthus and involvement of the bilateral lacrimal fossae (arrows), findings indicative of a type III fracture of the NOE complex with medial canthal tendon avulsion. A fragment of the fractured right medial orbital wall impinges on the right optic nerve (arrowhead).



a. b.

Figure 25. Lateral rectus muscle avulsion and globe injury as complications of lateral maxillary buttress fracture. **(a)** Axial unenhanced CT image depicts an angulated left lateral orbital wall fracture with a fragment impinging on the left globe (arrow). **(b)** Axial unenhanced CT image shows discontinuity in the right lateral rectus muscle (arrow), a finding indicative of a full-thickness tear.

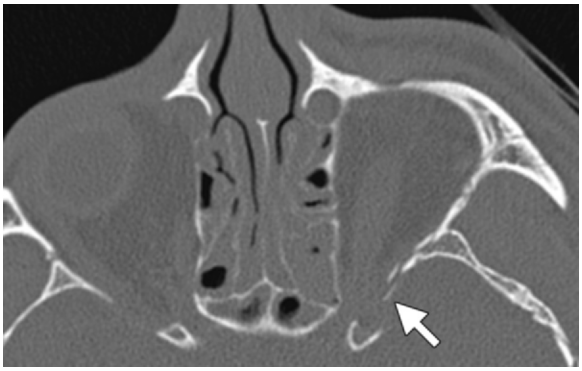


Figure 26. Involvement of the superior orbital fissure in a lateral maxillary buttress fracture. Axial unenhanced CT image demonstrates a mildly comminuted and displaced fracture of the left lateral orbital wall with extension to the superior orbital fissure (arrow). This finding, when combined with palsy of cranial nerves III, IV, V_1, and VI, is indicative of superior orbital fissure syndrome.

Lateral Maxillary Buttress Fractures

Orbital complications such as globe injury (Fig 25a), extraocular muscle injury (Fig 25b), optic nerve injury, and orbital hematoma may occur when fractures involve the lateral orbital wall. Fractures through the lateral maxillary buttress also may extend to the superior orbital fissure (Fig 26) or orbital apex, potentially leading to superior orbital fissure syndrome or orbital apex syndrome, respectively. The lateral canthal ligament may be injured at the site of its attachment to the lateral orbital wall.

Posterior Maxillary and Posterior Mandibular Buttress Fractures

Involvement of the pterygomaxillary junction (part of the posterior maxillary buttress) is the common element in all Le Fort fractures. Extension of a posterior maxillary buttress fracture posteriorly into the sphenoid bone may result in carotid artery injury, carotid-cavernous fistula, or both; extension of the fracture into the skull base may affect other foramina, such as the foramen ovale, in which cranial nerve V_3 is located (Fig 27).

A posterior mandibular buttress fracture, especially when associated with a displaced fracture of the condylar process or dislocation of the temporomandibular joint, can cause malocclusion and trismus.

Summary

Accurate classification of facial fractures and identification of related complications by the radiologist permit prompt surgical management and

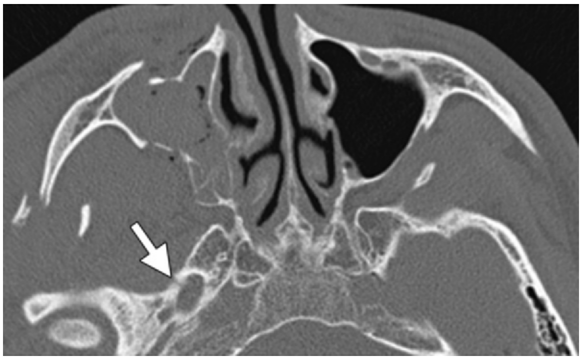


Figure 27. Complication of a posterior maxillary buttress fracture. Axial unenhanced CT image depicts comminuted fractures of the right anterior and posterior maxillary sinus walls and zygomatic arch. Extension of the fracture through the right foramen ovale (arrow) is suggestive of possible injury to the indwelling cranial nerve V_3.

an improved clinical outcome of these common traumatic injuries. This article reviews the pertinent facial anatomy with emphasis on the facial buttress system and on multidetector CT imaging features of common facial fracture patterns. Surgical management of fractures and their associated complications is reviewed according to the specific facial buttress involved.

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Spectrum of Critical Imaging Findings in Complex Facial Skeletal Trauma

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Le Fort described three common fracture patterns, each caused by a force of a different magnitude and all including a fracture through the pterygoid plates (Fig 3). Depending on the distribution of forces through the facial skeleton, multiple Le Fort fracture patterns may occur at the same time, and different combinations may occur on the two sides of the face (eg, type I and II fractures on the left side, and type II and III fractures on the right).

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Although the tendon itself is not visible at multidetector CT, the radiologist's report of the degree of comminution of the medial orbital wall at the level of the lacrimal fossa may be helpful for surgical planning of medial canthal tendon repair.

Page 14

The mandible is a U-shaped bone that is connected to the calvaria through the temporomandibular joints, creating a ringlike structure (Fig 18). Because of this ringlike configuration, a traumatic blow to the mandible typically produces at least two discrete fractures.

Page 14

Superior orbital fissure syndrome is caused by extension of the fracture through the superior orbital fissure, with resultant injury to cranial nerves III, IV, V_1 (the ophthalmic branch of the trigeminal nerve), and VI as they traverse the fissure into the orbit, thus causing ophthalmoplegia or diplopia (extraocular muscle paralysis) and ptosis (paralysis of the levator palpebrae superioris, which is supplied by cranial nerve III). Additional injury to the optic nerve (cranial nerve II) at the orbital apex results in orbital apex syndrome, with uniocular visual loss added to the list of signs and symptoms. Orbital apex syndrome is a surgical emergency because prompt intervention is necessary to prevent permanent blindness.

Page 16

Although entrapment of the inferior rectus muscle is diagnosed on the basis of clinical manifestations, herniation may be suggested by a rounded appearance of the normally flattened ovoid muscle belly on cross-sectional images.