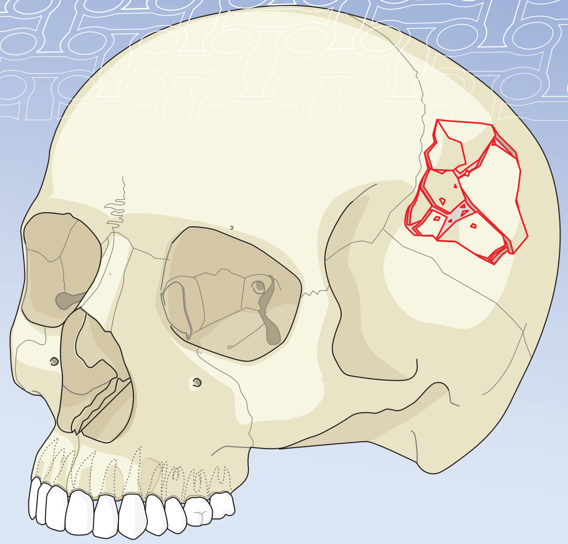
4 Skull and skull base fractures



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4.1 Frontal sinus, frontal bone, and anterior skull base

1 Definition

The frontal bone provides the convex contours of the forehead, the frontal bar, and the orbital roofs (**Fig 4.1-1a**). The frontal bar is the thickened bone that bridges the zygomaticofrontal sutures to form the superior horizontal (transversal) buttress of the facial skeleton. It gives structure and strength to the supraciliary and glabellar areas, and serves as a platform for the thin orbital plates projecting superiorly and posteriorly to separate the anterior cranial fossa from the orbits and ethmoid sinuses (**Fig 4.1-1b**). Medially, the orbital plates surround the crista galli and cribriform plate of the ethmoid bone. Posteriorly, the orbital plates, in combination with the cribriform plate, abut the lesser wings and planum of the sphenoid bone to complete the anterior skull base.

The frontal sinus is an epithelial-lined cavity within the frontal bone. The anterior table of the sinus typically defines the contours of the medial brow, glabella, and lower forehead. The posterior table forms part of the anterior cranial vault, and the floor corresponds to the medial orbital roof. The sinus as a whole is variable in size and is usually divided by a thin septum into two asymmetric sinuses, each of which is drained by a separate orifice located in the posteromedial aspect of the floor (**Fig 4.1-1b**). The drainage orifice lies protected behind the glabellar bone and the thick maxillary process of the frontal bone, and is most often a relatively large opening directly into the frontal recess of the nose or anterior ethmoid sinus, rather than a true duct (**Fig 4.1-2**).

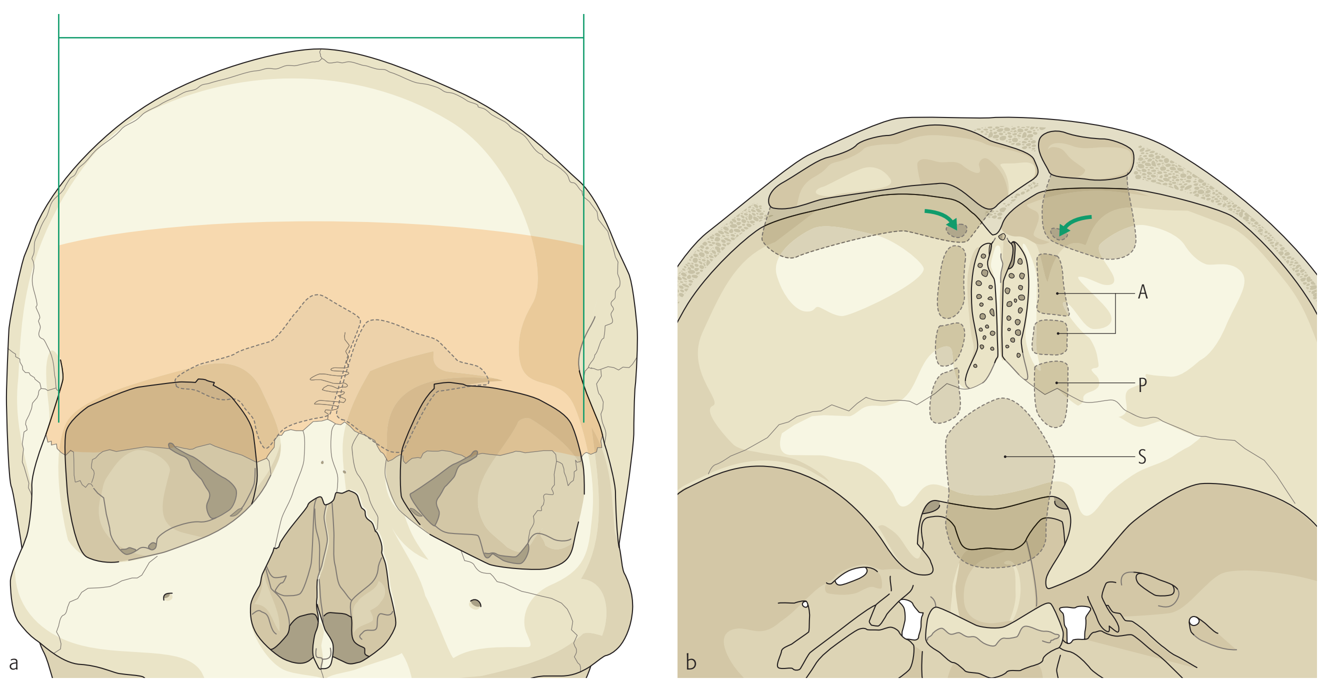

Fig 4.1-1a–b
a Anterior view of the frontal bone. The overlying frontal bar is the sturdy cornerstone of the forehead and anterior skull base.
b Anterior skull base from above. The relatively thin bone of the central third separates the cranial cavity from the nose and paranasal sinuses, extending from the frontal sinus anteriorly to the optic chiasm posteriorly. Arrows indicate the outflow tracts of the frontal sinus. A=anterior ethmoid, P=posterior ethmoid, S=sphenoid sinus.

The ethmoid sinuses are paired labyrinths of thin-walled respiratory epithelial-lined air cells, collectively referred to as sinuses, separating the nasal cavity from the orbits. These air cells open through many small orifices into the middle and superior meatus of the nose. The roof (fovea ethmoidalis) of an ethmoid sinus corresponds to the floor of the anterior cranial fossa adjacent to the cribriform plate. The olfactory bulbs and tracts are in close contact to the cribriform plate, and the dura is tightly adherent to bone in the olfactory groove. Underlying the cribriform plate is the olfactory mucosa of the upper nasal cavity.

Any fracture of the frontal bone may involve one or more walls of the frontal sinus, thus creating frontal sinus (wall) fractures. Extension of the fracture into or beyond the ethmoid sinuses and cribriform plate creates a frontobasilar fracture, a distinctly different and more complex injury.

2 Imaging

Plain skull x-rays may be of value in screening for fracture lines in the frontal bone or for air–fluid levels in the frontal sinus, but they provide insufficient information for definitive diagnosis and treatment planning. Thin-section axial and coronal (direct or reformatted) computed tomographic (CT) scans are required for accurate documentation of frontal, frontal sinus, and frontobasilar fractures following forehead trauma. Unfortunately, due to the ethmoid air cells surrounding the drainage orifices of the frontal sinus, the sensitivity and specificity of even high-resolution scans is insufficient to allow precise identification of each orifice and evaluation of the extent of injury. CT scans may suggest but do not provide direct evidence of potential outflow obstruction that could lead to infectious complications.

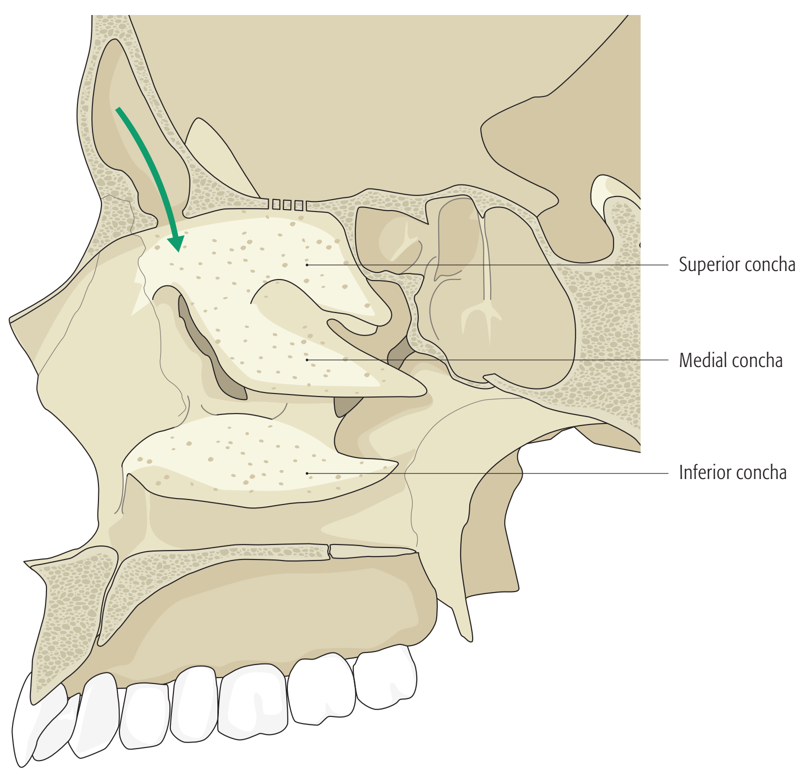

Fig 4.1-2 Sagittal section of the skull through the nose and nasal base. Arrow indicates pathway of the drainage of the frontal sinus into the frontal recess.

3 Approaches

In the absence of a large forehead laceration immediately over the bony injury, the coronal incision is standard for access to the entire spectrum of fractures, ranging from fractures isolated to the anterior table of the frontal sinus to extensive skull base disruptions. In contrast to the limited exposure provided by smaller local incisions, the coronal approach exposes the entire frontal area. This facilitates manipulation of fracture fragments, management of the internal components of a frontal sinus injury, and entrance into the cranial cavity if repair of dural injuries is required (see **Fig 3.2-5a–e**, page 196). The panoramic view afforded by the coronal approach includes adjacent intact structures that can be used as starting points for a more accurate reconstruction of the gentle frontal convex contours. In theory, the coronal incision leaves a more esthetic scar as it lies behind the hairline. In men with receding hairlines, a facial scar from an incision placed in a forehead crease or above or below the brows may be preferable; however, these incisions generally result in loss of forehead and anterior scalp sensation. Occasionally, a coronal incision can leave a very visible scalp scar in patients with shorter hair, particularly in the temporal areas, even when correctly performed. It is also more time-consuming than facial incisions. For those reasons, endoscopic brow-lifting instrumentation and techniques have been adapted to repair injuries for which a coronal incision might seem excessive. The operative field is viewed endoscopically through small incisions placed behind the hairline, and reduction and fixation is accomplished percutaneously through small stab incisions over the fractures, or the fracture depression is camouflaged using an onlay implant (solid or moldable). This type of approach appears suitable for treatment of fractures limited to the anterior table of the frontal sinus.

Management of the internal components of a frontal sinus fracture requires removal of the anterior table, either through elevation of depressed fragments or osteotomies of intact segments (**Fig 4.1-3**). Ideally, periosteal attachments are maintained, but this is usually neither possible nor even necessary for the survival of larger pieces of bone that are later repositioned. Smaller fragments can be replaced with bone grafts. Entrance into the cranial cavity for repair of dural injuries adjacent to the posterior table of the sinus can be accomplished by removing the relatively thin posterior table of the sinus. Additional osteotomies through the superior orbital rims, orbital roofs, and nasal bones, and removal of these segments, provide direct access to the floor of the anterior cranial fossa for repair of deeper injuries without the need for brain retraction. This subcranial approach provides access equivalent to a limited frontal craniotomy and allows evaluation and treatment of adjacent dural and parenchymal injuries. The approach can be easily converted to a formal frontal craniotomy if the injuries are found to extend over the convexities of the frontal lobes. Repair of frequently associated nasoorbitoethmoid (NOE) fractures is also facilitated by direct access to the internal aspects of the medial canthal attachments.

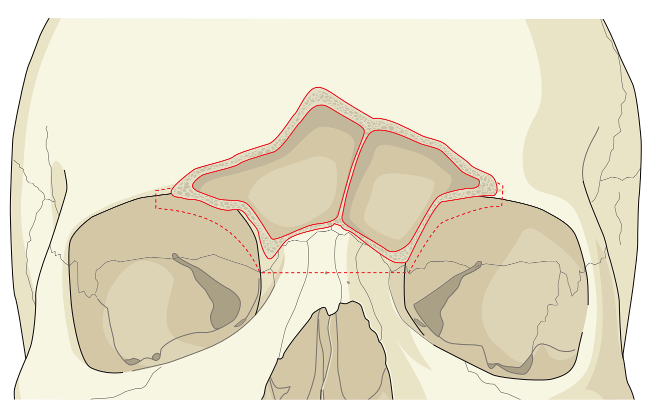

Fig 4.1-3 The anterior table of the sinus has been removed to expose the posterior table. The central third of the anterior skull base can then be exposed by gradual removal of the posterior table and block removal of the outlined segment of frontal bar, nasal bones, and medial orbits.

4 Special conditions influencing open reduction and internal fixation

Factors to be considered when evaluating the need for repair of frontal injuries fall into the following categories:

Loss of convex bony contours: External appearance soon after trauma may be inconsistent with the actual severity of fractures of the frontal bone, frontal sinus, and anterior skull base. Edema of the forehead and brow-area soft tissues may mask depressed fractures of the supraorbital ridges and anterior wall of the frontal sinus in particular. The surgeon must relate the amount of bony displacement seen on the CT scan to the flattening that will occur in these areas if the fractures are not realigned. In general, early open reduction and fixation is preferable to more complex delayed reconstructions that invariably involve osteotomies and bone grafting. A possible exception to this is an isolated, mildly depressed anterior table fracture that may or may not lead to noticeable forehead flattening. This type of defect should be amenable to delayed recontouring with an onlay graft, placed through either an open or endoscopic approach, if required.

Internal derangement of the frontal sinus: The typical frontal sinus orifice is, unless severely injured, large enough to maintain adequate drainage function during the acute phase of the injury, and subsequent cicatricial narrowing should not cause delayed dysfunction. This natural safety factor may explain the low incidence of reported infectious complications following both untreated and treated frontal sinus injuries. Unfortunately, the response of each orifice to trauma cannot be predicted, and the immediate proximity of the sinus to the orbit and cranial cavity means infection within the injured sinus wich may quickly lead to disastrous neurological complications. Fracture patterns most likely to involve the floor of the sinus, and thus one or both orifices, include anterior table fractures with accompanying impacted supraorbital rim or NOE fracture, and comminuted fractures of both the anterior and posterior tables. A fracture line in the posterior table is not an absolute indication for surgery unless it is displaced, or there are associated intracranial findings. Endoscopic evaluation of the orifices and posterior table by way of a small frontal sinus trephination may be helpful in cases with borderline indications for open repair.

Intracranial injuries: Pneumocephalus is often seen adjacent to fractures of the posterior table and anterior skull base. Although it does raise suspicion of a dural injury, pneumocephalus adjacent to a nondisplaced posterior table fracture does not demand surgery unless, in the unlikely event, serial CT scans fail to document resolution. In the absence of other indicators for surgery, a cerebrospinal fluid (CSF) leak through the frontal sinus is very unusual. Progressive pneumocephalus and CSF leaks are more likely to accompany fractures of the fovea ethmoidalis and cribriform plate, where the tight adherence of the dura to bone can lead to large tears with relatively small fracture displacements. These skull base injuries usually connect with posteriorfractures. Concurrent repair can be performed by way of an open approach through the frontal sinus, or via a subcranial approach if access back to the planum sphenoidale and optic canals is required. In very select cases where observation of the frontal sinus is appropriate, small to medium-sized defects in the skull base can be repaired using transnasal endoscopic techniques. Subdural and epidural bleeding in themselves should not effect the need for or type of repair of an injured frontal sinus. Indeed, an urgent frontal craniotomy may violate a sinus by adding the equivalent of a displaced posterior table fracture to traumatic injuries that may have otherwise been observed or treated less aggressively.

Associated maxillofacial injuries: A properly aligned frontal bar is required before reduction and fixation of fractures of the zygomas, orbits, NOE complex, and maxilla can be undertaken.

5 Sinus function and operative technique

It is generally agreed that depressed fractures limited to the anterior table of the sinus can be managed without concern for future obstruction of the drainage system, assuming that the sinus has been irrigated clear of debris (**Fig 4.1-4a–b**). Debate begins when anterior wall fractures are accompanied by a supraorbital rim or NOE fracture, and visual inspection at the time of repair of these fractures confirms injury of one or both orifices (**Fig 4.1-4c–d**). Most surgeons feel compelled at this point to treat the drainage system injury in order to prevent future episodes of sinusitis that would necessitate a second open surgery. Stenting has been favored by some, in the belief that sinus function can be preserved. However, lack of long-term success of stenting in cases of outflow obstruction due to chronic inflammatory disease has led many surgeons to avoid the use of stents to treat an acute injury. Instead, the trend has been to eliminate the sinus with an obliteration procedure. All vestiges of mucosa are removed from the sinus with a high-speed drill and progressively smaller burrs, and the orifices are occluded with muscle, fascia, or contoured bone grafts. The sinus is then filled with fat, cancellous bone chips, or a pedicled flap of pericranial tissue. Success with hydroxyapatite cement has also been reported, but its use in a potentially contaminated field remains controversial. Some have advocated leaving the sinus to obliterate itself through osteoneogenesis.

An appealing but so far unproven alternative for compliant patients with no evidence of a posterior table fracture has emerged with the advances in transnasal endoscopic sinus surgery, which has proven to be very effective in the treatment of chronic frontal sinus disease. The surgeon can now perform the necessary reduction and fixation of the fractures and manage the injury to the drainage system expectantly with follow-up CT scans, knowing that the few cases of outflow obstruction that will develop can be treated endoscopically rather than with an open procedure.

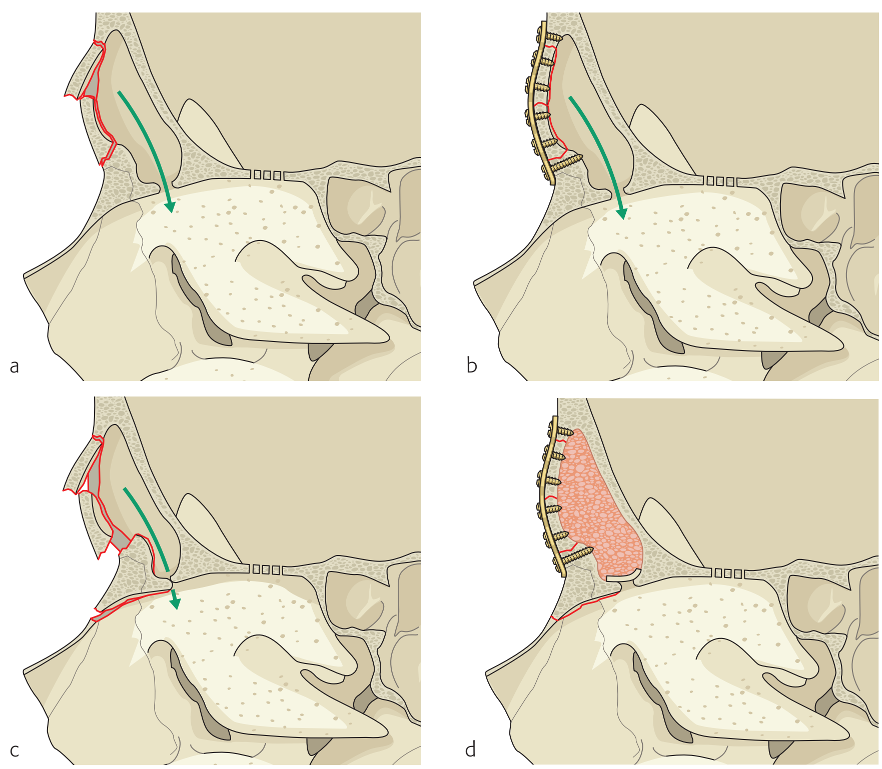

Fig 4.1-4a–j Injury patterns and recommended treatment.
a A displaced fracture limited to the anterior table should not affect sinus outflow.
b Reconstruction and fixation of the anterior sinus wall with non-load-bearing material.
c An accompanying NOE fracture predisposes to outflow obstruction.
d In case of outflow obstruction, sinus obliteration is the preferred option.

Characteristic of most fractures involving the anterior and posterior table of the frontal sinus are comminution with displacement of the bone fragments of both tables, and extension across the floor of the sinus damaging the drainage orifices (**Fig 4.1-4e–f**). Despite the increased risk of intracranial spread should infection occur in the sinus, some surgeons have again advocated reconstruction of the sinus walls and stenting of the orifices in order to preserve sinus function. Most surgeons, however, now choose to eliminate the sinus with either an obliteration procedure or cranialization of the sinus. The sinus is obliterated as previously described if the posterior table fragments are sufficiently intact to be easily realigned, and there are no underlying dural lacerations that require repair. The sinus is cranialized if the posterior wall is severely fragmented, or the presence of CSF in the sinus signals a need to inspect and repair the dura (**Fig 4.1-4g–h**). Cranialization differs from obliteration in that the posterior table is removed so that the once epithelial-lined sinus cavity becomes part of the intracranial cavity. The new intracranial space is left to be filled by fibrous tissue and expansion of the frontal lobes —a process that may take several months. Therefore, a pedicled flap of pericranium should be rotated intracranially to reinforce the occlusion of the drainage orifices and the dural repairs. Cranialization of the sinus is also a key component of the subcranial approach to more extensive skull base injuries (**Fig 4.1-4i–j**).

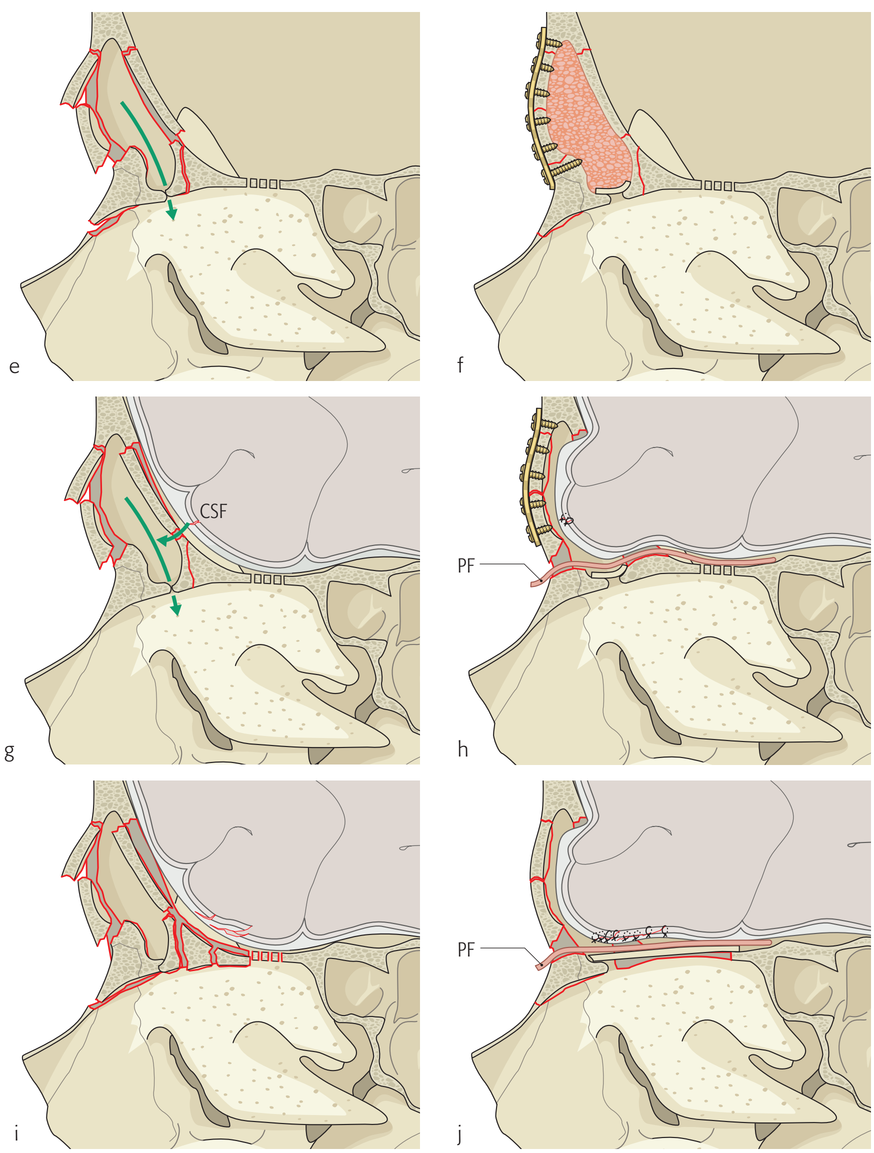

Fig 4.1-4a–j (cont) Injury patterns and recommended treatment.

- **e** Combined anterior and posterior table fractures also predispose to outflow obstruction.
- **f** Obliteration is the preferred option if the posterior table is relatively intact and there is no evidence of a dural injury.
- **g** When the posterior table is comminuted, as often seen with an accompanying NOE fracture, the dura will usually be lacerated and a cerebrospinal fluid (CSF) fistula may develop.
- **h** The posterior table fragments should be removed to allow repair of the lacerations and cranialization of the sinus. A pericranial flap (PF) enhances the seal of the floor of the sinus.
- **i** The subcranial approach should be considered for more extensive injuries with disruption of the central third of the anterior skull base.
- **j** A pericranial flap (PF) is essential for reinforcement of fascial grafts used to repair the dura and bone grafts covering the skull base defect.

6 Osteosynthesis techniques

Once the fracture fragments have been realigned, edge-to-edge contact and the convex contours of the forehead and supraorbital ridges can be maintained with plates and screws from the 1.0, 1.3, or corresponding Matrix systems (**Fig 4.1-5**). Restoration of the convexities will produce a self-reinforcing reconstruction adequate to resist the physiological loads that are transmitted to the frontal bar. Thicker miniplates are more likely to be outlined under the forehead skin and are unnecessary from a biomechanical point of view, even when the frontal bone reconstruction is part of the overall repair of a panfacial injury. It is also unnecessary to use long screws that penetrate beyond the diploic space of the frontal bone. Small bone fragments are difficult to stabilize, even with very small plates, and may be quickly lost to resorption. Small bone fragments therefore should be replaced by cranial bone grafts to facilitate placement of the plates and screws, and provide a more substantial scaffolding to maintain soft-tissue position during remodeling and new bone formation. Alternatively, comminuted fractures of the anterior wall of the frontal sinus can be reconstructed using titanium mesh, possibly reducing the need for bone grafts.

Fixation of posterior table fractures is usually not performed. If the posterior table injury allows for an obliteration procedure, exact edge-to-edge realignment of large bone fragments is not mandatory. Displacement that allows for insertion of a malleable retractor just under the thin bone actually lessens the chances of an iatrogenic injury of the dura during removal of the mucosa adjacent to the fracture lines with high-speed burrs. The material then used to obliterate the sinus will stabilize the fragments until fibrosis or new bone formation closes the gap. Fibrosis can be enhanced in a sinus obliterated by fat if a fascial graft is applied over the posterior wall injuries. Fixation is also not usually required when bone grafts are used to bridge defects of the cribriform plate and fovea ethmoidalis. The subcranial approach should provide exposure adequate to create opposing ledges of the orbital plates of the frontal bone and planum sphenoidale that will support the grafts. The bone grafts support a fascial graft or, preferably, a pedicled pericranial flap that actually seals the skull base under pressure from the frontal lobes. Fibrin glue may also be used to hold the flap in place in the early postoperative period. Fixation is required to maintain the shape of the orbit if the orbital plate is fragmented and unstable. Large in-situ fragments or grafts can be cantilevered from the frontal bar with the 1.3 system, or plates 1.5 and screws if the bridging segment extends all the way to the posterior orbit. The uppermost level of the convexity of the orbital roof must be restored to prevent downward displacement of the globe (**Fig 4.1-6a-b**).

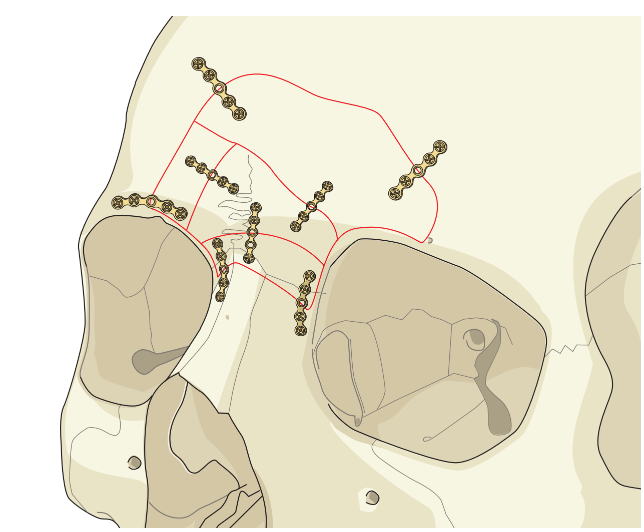

Fig 4.1-5 Reconstruction of the lower forehead and NOE complex. Small miniplates are particularly useful in the glabellar and frontonasal areas where surface to apply the plates might be limited.

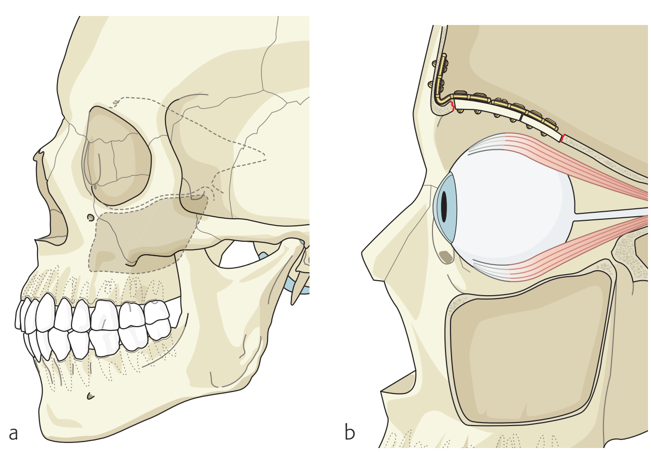

Fig 4.1-6a–b
a The orbital roof is convex superiorly behind the frontal bar. Bone grafts used to reconstruct the roof must remain tangential to the convexity to prevent downward displacement of the globe.
b Bone grafts are cantilevered in an arched configuration to maintain the convexity.

7 Perioperative and postoperative treatment

Because of the proximity to the nasal cavity, fractures that extend into the frontal sinus or central area of the anterior skull base are considered by most surgeons to be contaminated. Therefore, a therapeutic course of an intravenous broad spectrum antibiotic is empirically started upon admission and continued for 3–7 days postoperatively. Surgery must be performed in a timely fashion so that infection with resistant organisms does not result from an excessively prolonged course of the antibiotic.

Lumbar drains are not used routinely, in an attempt to limit the duration of postoperative CSF leaks. However, a drain should be considered when extensive loss of skull base bone in a specific area indicates a tenuous reconstruction in the presence of profuse CSF rhinorrhea. An example of this would be the posterior orbit/planum sphenoidale where even with fibrin glue a seal might not be obtainable without excessive pressure from the bone grafts and pericranial flap on the optic nerves and chiasm.

8 Complications and pitfalls

Early postoperative wound infections are uncommon in correctly managed cases, even when multiple nonvascularized grafts are placed. A CSF leak is the most likely early complication to be seen, occurring in up to 10% of patients with frontobasilar fractures. Management should be with a lumbar drain for 7–10 days before re-exploration is considered. Most leaks are through the skull base rather than the frontal sinus, and may be amenable to transnasal endoscopic repair if the site of the leak is small and definitely identified to be through the cribriform plate, fovea ethmoidalis, or planum sphenoidale. Postoperative meningitis occurs less frequently, and may or may not be related to a predisposing CSF leak.

Delayed postoperative complications, though known to occur years later and therefore frequently unknown to the original surgeon, are relatively uncommon. Most are related to the obstruction of a drainage orifice in a frontal sinus that was preserved, or ingrowth of mucosa from the frontal recess through an inadequately occluded orifice into a sinus that was obliterated. A mucocele or mucopyocele with pressure symptoms or perhaps chronic infection may develop in the sinus and require reoperation. Only rarely do these delayed infections spread intracranially, but the potentially fatal consequences of such spread emphasize the need for appropriate initial management. Failure to permanently occlude an orifice during a cranialization procedure creates a direct opening from the frontal recess into the cranial cavity. All patients must understand that they are at lifelong risk of delayed complications following any procedure to treat frontal sinus and frontobasilar fractures.

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4.2 Lateral skull base fractures

1 Introduction

Fractures of the lateral skull base have long challenged surgeons dealing with the management of facial nerve injuries. In addition to the facial nerve, the temporal bone contains the vestibular and cochlear nerves, the complex structures of the inner and middle ear, as well as critical vascular and nerve structures. Management of lateral skull base fractures requires a particularly careful approach.

2 Definitions

2.1 Anatomy of the lateral skull base

The lateral skull base includes the greater wing of the sphenoid and the temporal bone. The rich and complex neurovascular content of the lateral skull base and temporal bone are the reason for morbidity associated with trauma to this region. The lateral skull base foramina and their respective contents include: the foramen lacerum and carotid canal with the internal carotid artery and nerve plexus, the foramen ovale and the mandibular nerve (CN V3), the foramen spinosum and the middle meningeal vessels, the foramen rotundum and the maxillary nerve (CN V2), and the pterygoid canal through which passes the vidian nerve and artery (**Fig 4.2-1**). Also intimate with the lateral skull base are cranial nerves III through XII and vascular structures including the sigmoid sinus and jugular bulb. The muscular attachments to the lateral skull base include the temporalis, medial and lateral pterygoids, masseter, digastric, sternocleidomastoid, tensor and levator veli palatini, strap muscles of the neck, and the paraspinal muscles of the neck.

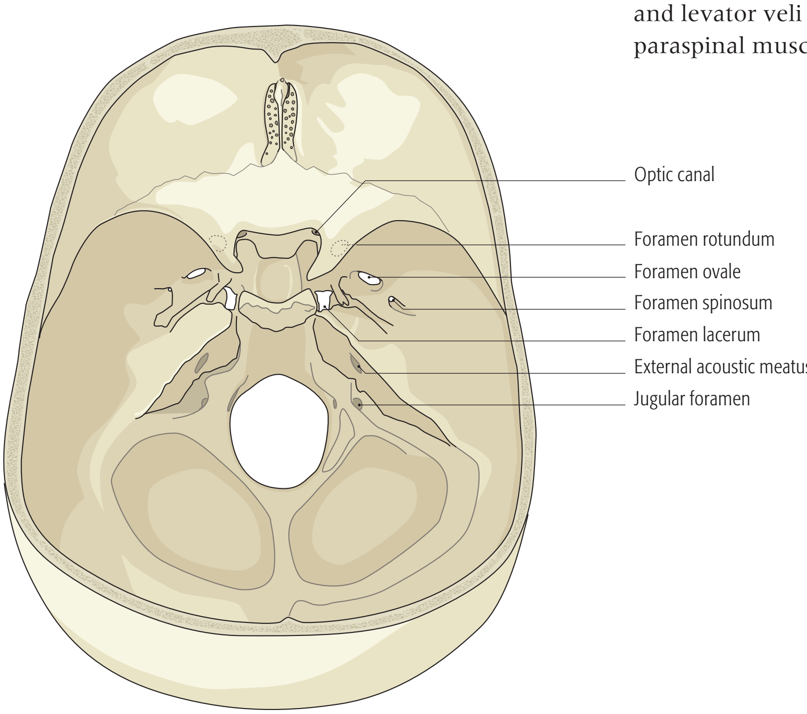

Fig 4.2-1 Skull base and most important foramina.

The temporal bone is composed of the squamous, mastoid, tympanic, and petrous portions, and the styloid process. Contained within the temporal bone are the vestibulocochlear apparatus, the facial nerve, the ossicular chain, the endolymphatic sac, and the origin of the eustachian tube.

Injury to the facial nerve can cause significant morbidity (**Fig 4.2-2**). The facial nerve passes from the brainstem into the temporal bone, entering through the internal auditory canal. The nerve courses through the meatal segment (8–10 mm) and the labyrinthine segment (2–4 mm) to the geniculate ganglion. At this point it turns into the tympanic or horizontal segment (11 mm). It then courses to the second genu where it turns again, becoming the mastoid or vertical segment (12–14 mm) which exits at the stylomastoid foramen. The intermediate nerve, which travels with the facial nerve, provides branches which include the chorda tympani and greater and lesser superficial petrosal nerves. The geniculate ganglion is the most common site of traumatic injury to the facial nerve.

2.2 Demographics of temporal bone injury

Causes of temporal bone injuries include motor vehicle accidents (MVA), all-terrain vehicle accidents, motorcycle accidents, bicycle accidents, falls, assault, gunshot wounds, equestrian accidents, sports injuries, and others. The peak age for temporal bone injury is 21–30 and there is a 3:1 male to female preponderance. Pediatric temporal bone fractures occur most commonly due to MVA, falls, bicycle accidents, and blows to the head, with bimodal age distribution peaks at age 3 and 12.

2.3 Accompanying injuries

Any of the contents of the lateral skull base and temporal bone can be injured by trauma to this region. Otological complications following lateral skull base fractures include deafness (24–42%), vertigo (20%), cerebrospinal fluid (CSF) otorrhea (18%), facial nerve palsy (4–7%), tinnitus (2%), and chorda tympani dysfunction (2%). The most common surgically correctable lateral skull base fracture complication is thought to be ossicular discontinuity, with the most com-

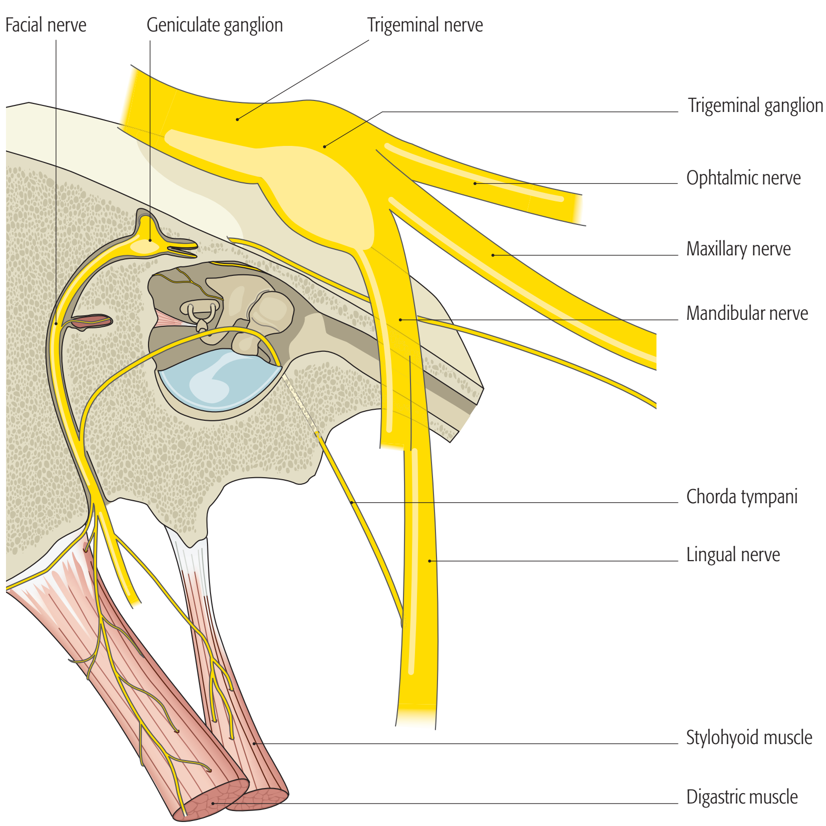

Fig 4.2-2 Course of the facial nerve (VII) within the petrous portion of the temporal bone and its relation to the inner ear.

mon site of injury being the incudostapedial joint. Fractures involving the otic capsule are more commonly associated with sensorineural hearing loss (100%), facial nerve injury (48%), and CSF fistula (31%) than otic sparing fractures. However, sensorineural hearing loss may be seen in extralabyrinthine fractures due to cochlear concussion, disruption of the membranous labyrinth not seen on imaging, or intralabyrinthine hemorrhage seen as hyperintensity on T-1 weighted MRI.

In Brodie's review of 820 temporal bone fractures, 24% sustained hearing loss (21% conductive hearing loss, 57% sensorineural, 22% mixed). Facial paralysis was seen in 7%, and was immediate (27%) or delayed (73%). Complete paralysis was seen more frequently in patients with immediate weakness (47%) than delayed weakness (22%). All patients with incomplete paralysis and 97% of the patients with delayed onset paralysis had complete recovery. CSF fistulas may manifest as otorrhea, rhinorrhea, or both. Most CSF fistulas close spontaneously within 9 days (78%). The incidence of meningitis increases with CSF leaks that persist longer than 7 days.

Benign paroxysmal positional vertigo (BPPV) is a well-described entity known to occur following trauma. Therapeutic maneuvers such as the Epley maneuver have been shown to be successful in the management of most cases of BPPV. Epley and modified Epley maneuvers are sequential physiotherapeutic measures to reposition otolithic debris. Other causes of posttraumatic vertigo include traumatic perilymphatic fistula and posttraumatic Ménière's disease.

Posttraumatic cholesteatoma is another well described complication of temporal bone fracture that may occur even later than 10 years after the incident. Periodic long-term follow-up may be useful in monitoring for this complication.

Acute intracranial complications that may accompany temporal bone trauma include cerebral midline shift, subarachnoid hemorrhage, subdural hemorrhage, cerebral edema, ipsilateral and contralateral temporal lobe contusion, and often require emergent neurosurgical management.

Internal carotid artery injuries as a result of blunt head trauma are unusual. They occur typically due to shearing forces anywhere along the length of the vessel, and include dissection, intimal tear, spasm, thrombosis, occlusion, transaction, dissecting aneurysm, pseudoaneurysm, arteriovenous fistula, and carotid-cavernous fistula. Massive bleeding may require packing and angiography with embolization or common carotid ligation with middle fossa craniotomy to control back bleeding.

Pediatric injuries have a higher incidence of hearing loss and intracranial complications. Facial nerve injuries, however, are less common in pediatric trauma.

Penetrating temporal bone injury, as seen in gunshot wounds, carries an increased risk of life-threatening vascular compromise. Vessels at risk from gun shot wounds involving the lateral skull base include the facial artery, lingual artery, internal maxillary artery, superficial temporal artery, vertebral artery, jugular vein, and internal carotid artery. Angiography should be included in the evaluation of penetrating injuries to this region, and embolization may be useful in the stabilization and management of these injuries.

2.4 Classification of temporal bone fractures

Traditional classifications of temporal bone fractures describe the relationship of the fracture to the petrous ridge and otic capsule: longitudinal (**Fig 4.2-3a–d**), transverse, and mixed (**Fig 4.2-4**). Early reviews described longitudinal fractures as the most common type (70–90%). These tend to occur secondary to a temporal or parietal blow and run along the length of the petrous pyramid anterior to the labyrinthine capsule and are often associated with tympanic membrane perforation, external auditory canal skin rupture, and ossicular chain disruption. Facial nerve injury occurs in 10–20%. Transverse fractures are less common (10–30%) and occur from a frontal or parietal blow and course perpendicular to the long axis of the petrous pyramid, passing through the labyrinthine capsule. They are associated with sensorineural hearing loss, vertigo, nystagmus, and facial nerve injury in up to 50% of cases.

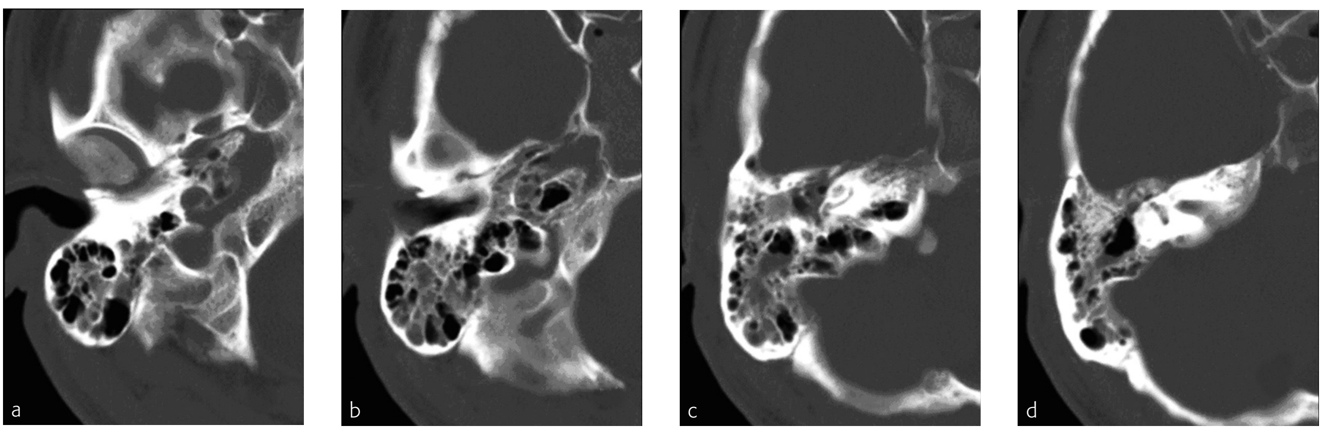

Fig 4.2-3a–d Head CT of patient with a right longitudinal temporal bone fracture and delayed onset, incomplete right facial palsy.
The fracture line involved (a) the glenoid fossa, (b) the external auditory canal, and (c) the middle ear space, and it approximated but did not violate the otic capsule (d).

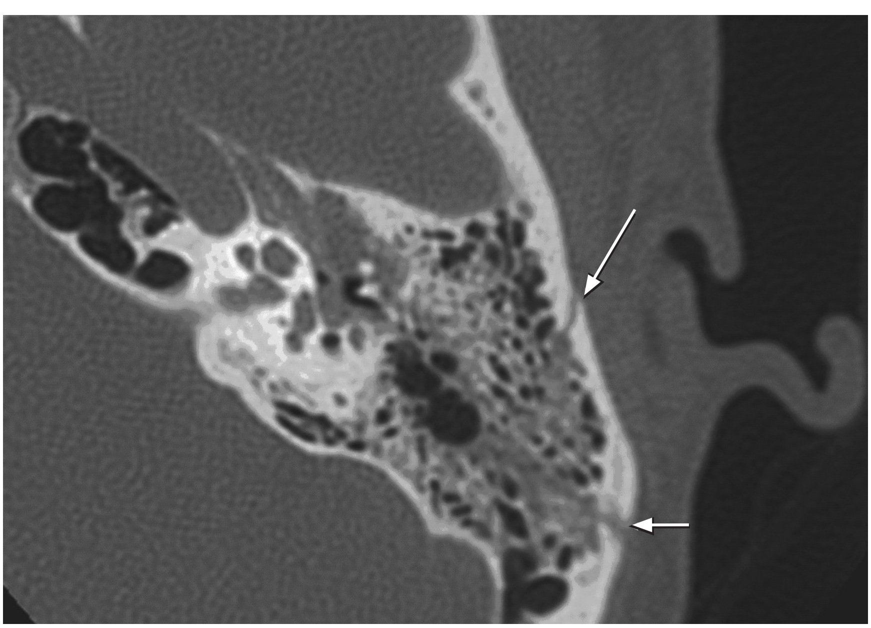

Fig 4.2-4 Temporal bone CT of patient showing a complex temporal bone fracture with both longitudinal (short arrow) and transverse (long arrow) components.

Recently, new efforts at classification of temporal bone injuries have looked to modify the classification of fractures into groups with greater clinical significance. Studies comparing high resolution computed tomography (HRCT) of the temporal bone and clinical course have found little correlation between the traditional classifications of fractures and patient complications. Kelly and Tami proposed a temporal bone fracture categorization system based upon the status of the otic capsule. Yanagihara et al describe a classification system based upon 97 fractures evaluated with surgical exploration: Yanagihara types 1–4.

Type 1 (6%) fractures traverse the mastoid process. They do not involve the facial canal. Type 2 fractures (43%) cross the mastoid process into the external auditory canal; they involve the vertical portion of the facial nerve. Type 3 fractures (18%) include a type 2 that extends to the pyramidal or horizontal portion of the facial nerve. Type 4 (31%) fractures extend through the tegmen, the antrum, the facial nerve between labyrinthine segment and horizontal segment, and cross the geniculate ganglion. Type 4A fractures spare the inner ear and internal auditory canal while type 4B fractures, traditionally a transverse fracture, violate either structure. Yanagihara felt that this grading system, when compared to the traditional system, more accurately correlated fracture type with associated injuries, complications, and intraoperative findings. Dahiya et al reviewed 90 patients with temporal bone fractures and found that when compared to fractures that spare the otic capsule, fractures that violate the otic capsule are more frequently associated with facial paralysis (2x), CSF leaks (4x), profound hearing loss (7x), and intracranial complications such as epidural hematoma and subarachnoid hemorrhage. Subsequently, Ishman and Friedland reviewed CT scans of 148 temporal bone fractures and found that the traditional classification system showed poor prediction of facial nerve weakness, CSF fistulas, and hearing loss. However, facial nerve injuries and CSF leaks were significantly more prevalent in fractures that involved the petrous bone than in nonpetrous bone fractures, and conductive hearing loss was more common in the nonpetrous fractures involving the middle ear.

3 Imaging

Lateral skull base trauma is most frequently seen in patients with significant, often life-threatening, concurrent injuries. Work-up of the lateral skull base injury must often wait until primary assessment and resuscitation have been completed. Evaluation of these injuries begins with a history, often limited, and physical examination. Signs and symptoms of lateral skull base injuries may include neuropathy of cranial nerves III–XII, hematotympanum, bleeding from the external auditory canal, tympanic membrane perforation, otorrhea, rhinorrhea, hearing loss (sensorineural or conductive), horizontal nystagmus with the fast phase toward the uninjured ear, or postauricular ecchymosis (Battle's sign). Battle's sign is thought to be due to mastoid emissary vein rupture or extravasation of blood along the postauricular artery.

In patients with suspected lateral skull base injury, additional evaluation may include imaging, electrodiagnostics, vestibular testing, and audiometrics. Audiometric evaluation at the initial evaluation, from tuning fork examinations to audiogram, can help determine the nature of hearing loss and extent of temporal bone injury. With conductive hearing loss, the most common injury is middle ear hemorrhage, and follow-up audiometry at 6–7 weeks after injury can help differentiate hemorrhage from ossicular chain injury. Auditory brainstem response studies in the initial evaluation may also provide complementary information on neuro-otologic integrity.

The most commonly used electrodiagnostic test for evaluation of acute facial paralysis is electroneurography (ENOG). Maximum electrically evoked stimulus with amplitude measurement of facial muscle compound action potential allows for objective calculation of neural degeneration through comparison of the affected and unaffected sides of the face. Most authors agree that degeneration of greater than 90–95% seen on ENOG is associated with a greater amount of neurotmesis and subsequent Wallerian degeneration and, therefore, a decreased possibility of favorable recovery. Electromyography (EMG), with evidence of voluntary action potentials versus fibrillation potentials, may provide additional information on the status of an injured nerve when performed three weeks after the onset of complete facial paralysis.

The development of HRCT and enhanced MRI has allowed precise localization and description of lateral skull base and temporal bone injuries. The use of these studies in the evaluation of patients with these injuries remains somewhat controversial. Some authors report that temporal bone CT is important in diagnosis and treatment plan development while others question the clinical utility of routine temporal bone imaging. Kahn et al reviewed 105 patients with clinical suspicion for temporal bone injury and subsequent HRCT and found poor correlation between CT findings and clinical course or management decision. They recommended the selective use of HRCT to complement decision making when surgery is planned, clinical examination is unreliable, or the clinical course is unusual. HRCT has been shown to identify temporal bone injuries that may be obscured by more serious neurological injury and to identify occult vascular injuries such as carotid canal fracture. In a prospective review of 350 consecutive patients with head trauma evaluated with HRCT, Exadaktylos et al found that of the 38 fractures identified on imaging, 12 were missed on clinical examination. In light of the 12% complication rate seen in their patients, they recommend routine HRCT in all patients with a suspicion for temporal bone injury.

In patients where surgical intervention is warranted, authors agree that imaging is useful in preoperative planning. HRCT and MRI have been shown to be useful in identifying ossicular injury in patients with conductive hearing loss, localization of the site of nerve injury in patients with facial paralysis, and in identifying concomitant intracranial injury helping the surgeon tailor the timing and nature of surgical intervention.

4 Treatment strategies and approaches

Indications for surgery

After reviewing literature on traumatic facial nerve injury, Chang and Cass proposed the following algorithm for management of facial nerve injury due to temporal bone trauma. Facial nerve injury that is delayed in onset should be observed because of the excellent prognosis for normal to near-normal recovery seen in this group. Patients with acute onset of incomplete facial injury which, with observation, does not progress to complete paralysis should also be observed and complete recovery is expected. Patients with acute onset of complete paralysis or acute onset of incomplete injury which progresses to complete paralysis should receive serial ENOG until greater than 95% degeneration within 14 days from injury is seen, qualifying this group for surgical exploration. Otherwise, observation is recommended with a good outcome expected. Subsequent authors have made similar recommendations. After review of 115 patients with traumatic facial paralysis, 65 of which were treated surgically, Darrouzet et al recommended surgery for patients with total paralysis of immediate onset and evidence of denervation seen on EMG. Nosan et al prospectively followed 35 patients with temporal bone fracture associated facial paralysis and recommended surgery for patients with greater than 90% degeneration seen on ENOG, regardless of the time of onset from injury. As previously described, Brodie found that patients with delayed or incomplete paralysis rarely required surgery to obtain excellent recovery.

Facial nerve decompression: approach and extent

The approach to decompress the facial nerve and the extent of facial nerve decompression required are topics of debate that have persisted over the past 30 years. The most common site of injury to the facial nerve is the perigeniculate area, with published frequencies ranging from 66–93%, though multiple sites of injury are not uncommon. Because of this, most authors agree that extensive decompression of the nerve is usually required, though the extent and approach described by each author has varied. May described a transmastoid supralabyrinthine approach to decompressing the region of the geniculate ganglion. Fisch described utilizing a translabyrinthine approach for transverse fractures with sensorineural hearing loss and a combination transmastoid middle cranial fossa approach for longitudinal fractures with intact hearing.

Most recent recommendations have been modifications of the approaches described by May and Fisch. Yanagihara found that with a modification of the technique described by May, a transmastoid supralabyrinthine approach with disarticulation of the incus, the geniculate ganglion could be decompressed in 36 of 41 patients, with the remaining 5 requiring a middle cranial fossa approach. Some authors have described the use of topographic tests, such as the Schirmer test, to determine if the lesion is proximal or distal to the geniculate ganglion, and tailoring the extent of the dissection based upon the site of the lesion. Pulec argued that most cases require decompression only to the cochleariform process and described another modification of the May transmastoid supralabyrinthine approach in which the incus is left intact. This approach is combined with a middle cranial fossa or retrolabyrinthine approach if more proximal decompression is required.

Chang and Cass, in their review, made the following recommendations. Since most injuries are in the perigeniculate region and proximal degeneration occurs after nerve trauma, facial nerve decompression should include the meatal foramen through the stylomastoid foramen. In patients with no residual hearing the translabyrinthine approach provides adequate access for decompression and repair. In patients with residual hearing they felt that the supralabyrinthine approach is inadequate for exposure and recommended a combined transmastoid middle cranial fossa approach. They recommended bony decompression without nerve sheath slitting, as nerve sheath slitting puts the nerve at risk of iatrogenic injury and no study has shown a benefit to this step. They recommended nerve repair only if there is total or near-total transection, with delayed repair if spontaneous nerve recovery accounting to grade 3 or 4 of the House-Brackmann facial nerve grading system is not attained.

Darrouzet described the use of a geniculectomy in facial nerve decompression. He describes the cauterization of the distal ends of the ganglionic content and proximal petrous nerves to prevent crocodile tear syndrome with errant secretory fiber regrowth within the petrous nerves.

Other surgical interventions

Management of hearing loss following temporal bone injury may require surgical intervention. Conductive hearing loss following temporal bone injury is most frequently due to middle ear hemorrhage. However, conductive hearing loss of greater than 30 dB that persists longer than 6–7 weeks after injury increases the likelihood of ossicular injury and warrants exploration and repair of the ossicular chain. In cases with profound sensorineural hearing loss secondary to temporal bone fracture, cochlear implantation has been described for patients with bilateral hearing loss or hearing loss in only one ear.

Surgical intervention may be useful for the management of vertigo seen in temporal bone trauma. Benecke described the use of transmastoid labyrinthectomy in patients with vertigo following temporal bone trauma and recommended it for patients with symptoms of long duration, diagnostic testing showing peripheral and not central disease, and failed medical management. Posttraumatic perilymphatic fistulas require surgical intervention with middle ear exploration and patching of the fistula. Posttraumatic vertigo is often multifactorial and surgical intervention may have suboptimal results.

Posttraumatic CSF fistulas management may also benefit from surgical intervention. Though most posttraumatic CSF fistulas close spontaneously, in those that do not close within 7–10 days there is a decreased incidence of spontaneous closure and an increased incidence of meningitis. Surgical closure is therefore recommended.

5 Preoperative and postoperative treatment

Medical management of temporal bone injuries, like many of the issues addressed above, remains controversial. This includes the use of antibiotics in patients with CSF fistulas to prevent meningitis, and the use of steroids in facial nerve injury to increase the likelihood of good recovery. Two meta-analyses looked at the efficacy of prophylactic antibiotics in temporal bone and basilar skull trauma. Villalobos et al reviewed 12 studies with 1,241 patients with basilar skull base fractures and found no reduction in meningitis with antibiotic prophylaxis, including those patients with CSF fistulas. Brodie reviewed six studies with 324 patients with posttraumatic CSF fistulas and found that none of these studies demonstrated a reduction in the incidence of meningitis with antibiotic prophylaxis. However, analysis of pooled data from these studies revealed that prophylactic antibiotic treatment significantly reduced the incidence of meningitis.

The use of steroids in the treatment of incomplete or delayed facial paralysis has been described, but no study has looked at the efficacy of steroids in the management of posttraumatic facial paralysis. Based on the pathophysiology of facial nerve injury and the anti-inflammatory properties of steroids, Chang and Cass argue that a short course of steroids, being inexpensive and of minimal risk to the patient, may lead to an improved outcome in these injuries.

6 Conclusion

Lateral skull base and temporal bone trauma complications range from subtle changes in hearing, to debilitating vertigo, to life-threatening blood loss and intracranial injury. Care for these patients requires a physician knowledgeable in the diagnosis and skilled in the management of this common and potentially complex group of injuries. Unfortunately, literature on the management of these injuries is controversial and inconclusive. Current recommendations in the literature include the following:

- HRCT scans of the temporal bone may not be necessary in the diagnosis of temporal bone fractures but may be useful in surgical planning.
- Traditional classifications of temporal bone fractures (longitudinal versus transverse) may yield little clinical utility. Evaluation of the otic capsule, however, may help predict complications and guide the clinical course.
- Conductive hearing loss of > 30dB 7–8 weeks postinjury requires surgical evaluation of the ossicular chain.
- Facial nerve paralysis that is delayed or incomplete should be observed, with good expected outcome.
- CSF leaks that persist for more than 7–10 days and post-traumatic vertigo consistent with perilymphatic fistula may benefit from surgical exploration and repair.
- Immediate and complete facial nerve injury with an ENOG revealing 90–95% degeneration within 14 days from injury should be treated with total nerve decompression as soon as possible.
- Decompression of the meatal foramen through the stylomastoid foramen will decompress the most common site of nerve injury (perigeniculate region) and any concurrent injury sites. This may be accomplished through a translabyrinthine approach in the non-hearing ear or through a combination transmastoid and middle cranial fossa approach in the hearing ear.

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4.3 Cranial vault fractures

1 Anatomy, fracture patterns, and pathophysiology

The cranium is at first unicortical and partially cartilaginous in its vault and base, becoming bicortical in the 5–10 year age period. The frontal sinus is rudimentary until after age 10, when it begins to enlarge into the frontal bone to assume its adult shape (**Fig 4.1-1a–b**, page 261).

Generally, depression of the frontal region may create an unpleasant cosmetic deformity. Depressed fractures are usually broader in area at the inner table than they are at the external table. Therefore, a burr hole and widening of the external table area of fracture must frequently be accomplished to free the entrapped skull fragment. A cranioplasty must then be employed to achieve a smooth skull.

However, the primary consideration in depressed, closed, or open skull fractures is the brain and the meninges. Depression of the inner table more than a few millimeters has the potential to lacerate the dura, creating a cerebrospinal fluid (CSF) leak. If the fracture and the leak are in communication with the sinuses, CSF may drain into the nose or pharynx (CSF rhinorrhea). If the leak is in communication with the structures of the ear and temporal bone, otorrhea may be produced. The leak may also occur in the orbit, producing a leak into a confined, potentially closed space unless the medial (ethmoid) portion of the orbit is fractured. In that situation, the leak ultimately drains into the nose. A CSF leak may be perceived by documenting clear fluid draining from the nose or ear. Initially, the fluid may be blood tinged. When absorbed onto a paper towel, such bloody fluid produces a double ring sign with the clear fluid extending outside the blood tinged central ring. Pneumocephalus may also occur. Rarely, a "ball valve" obstruction may produce tension that builds up inside the skull from air blown inside the cranial vault by a struggling patient and a tension pneumocephalus may be produced which requires decompression in order to prevent brain compression. If a skull fracture is not repaired and has lacerated the dura, the pressure and expansion of the pulsating brain over months may be sufficient to slowly erode the bone creating pseudogrowth of the skull fracture. This is a phenomenon which occurs in children and can be detected by follow-up x-rays at 6 months and 1 year to determine any widening of the fracture. If widening occurs, an intracranial repair of the dura is necessary.

If the cortex of the brain is damaged, surgery may be indicated for debridement of dead tissue. Intracerebral hematoma or extracerebral hematoma may require evacuation if pressure is produced. The pressure may increase as the hematoma begins to dissolve due to osmotic effects of the dissolving clot. An extradural collection of blood may occur from a ruptured middle meningeal artery producing acute brain compression from extradural hematoma. Such emergent conditions require immediate operative intervention.

Generally, cranial vault fractures begin in one of the skull areas and are located initially between cranial sutures, "buttresses of the skull" (**Fig 4.3-1**). Fractures may extend to

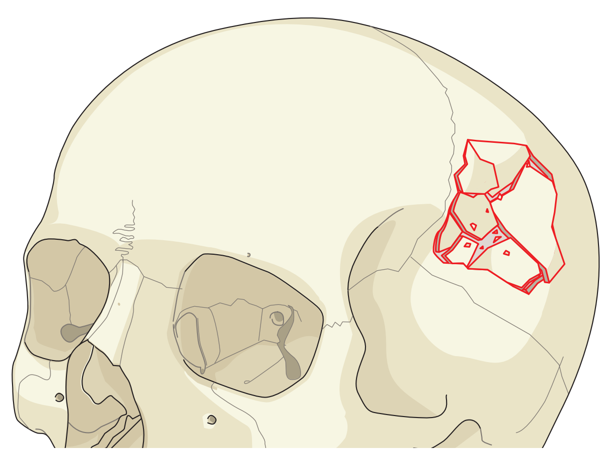

Fig 4.3-1 Impression fracture of lateral cranial vault.

penetrate an adjacent anatomical area (again delineated by sutures) and the initial linear fracture then spreads in a stellate fashion, giving rise to comminution with increasing force. One- and two-area cranial vault fractures are common, such as the lateral frontal temporal orbital fracture. Occasionally, three-area skull fractures occur involving both lateral frontal temporal orbital areas and the central region. It must be noted however, that subtle fractures may begin in the cranial base even with blows to the vault, then extend into the vault with increasing force, and then comminute the calvarium (**Fig 4.3-2a–c**).

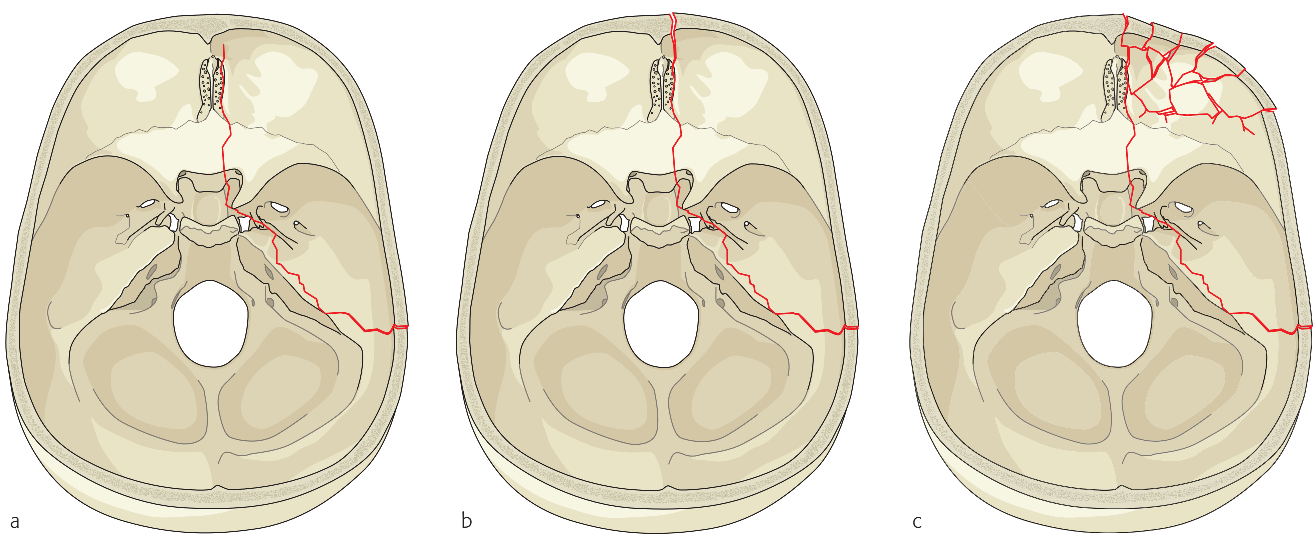

Fig 4.3-2a–c Frontobasal fractures, type I–III.
a Frontobasal fracture type I. Longitudinal fracture of the cranial base, initially paralleling the cribriform plate and extending to separate the anterior and middle fossa from the posterior fossa.
b Frontobasal fracture type II. Linear fracture of the frontal bone extending into the cranial base.
c Frontobasal fracture type III. Comminution of the entire frontal bone segment on the right involving the lateral and central area, along with comminution of the orbital roof and extension into the cranial base.

2 Imaging

A complete cranial and midface CT scan including the skull vault and base, the orbits, sinuses, and the temporal bones should be obtained with both bone and soft-tissue (brain) windows. Ideally, both axial and coronal scans are necessary to detect and analyze all the fractures in different planes, and to confirm the degree of displacement and the extent of the fracture. Since the base changes in level with each slice, neither the length nor the direction of skull base fractures can be fully reflected in a single "cut" of a CT scan.

Soft-tissue conditions such as extradural hematoma and pneumocephalus are detected. Depending on the degree of displacement of supraorbital fractures, the eye may be dislocated downward and forward as the supraorbital area collapses, expanding into space normally occupied by the globe.

Isolated fractures of the orbital roof can occur with or without supraorbital fractures, and parallel fracture patterns seen in orbital floor fractures in that single hinge, double hinge and "punched-out" fractures occur. The displacement of orbital roof fragments may either be superior or inferior, depending on the contour of the fracture and the deforming forces.

Fractures of the skull may also be seen in plain skull films, but CT scan documentation is superior and preferred. Plain x-rays may reveal an area of chronically infected bone as a radiolucent region. Plain x-rays are no longer routinely used since the advent of CT scans, because they do not provide 3-D information including soft tissues.

CT scans should be utilized to determine the area, extent, and displacement of the fractures and potential to compromise structures such as the orbit, the function of the ethmoidal and frontal sinuses, mastoid region, and adjacent soft tissues.

A 3-D reconstructed CT scan may be obtained which shows larger fractures, asymmetry, and the position of the individual segments and is helpful for evaluating position and asymmetry problems, especially involving the orbits.

MRI examination is standard for determining the specifics of soft-tissue injury including the brain.

Postoperatively, the study of the cranial bone with bone scans or CT scans may help to detect areas of chronic inflammation. Perfusion studies may also detect areas of dead bone.

3 Treatment strategies

Nondisplaced fractures of the cranial vault generally require no operative intervention. However, even nondisplaced fractures can have late sequelae such as frontal sinus nonfunction (obstruction). If the fracture extends into the frontal sinus area and compromises the function of the nasal frontal duct, or creates laceration of a mucous membrane which heals as a mucocele, lesions caused by pressure will be created (chapter 4.1 Frontal sinus, frontal base, and anterior skull base). A linear cranial vault fracture may also tear the dura, producing resorption of the bone and pseudogrowth of skull fractures. This occurs mostly in children.

Fractures may be open or closed in terms of communication with the outside environment through the skin. Fractures that enter the sinuses are considered open because of communication with the oral and nasal environment. Fractures may also be open to the skin through a laceration. A subcutaneous hematoma may require drainage despite the simplicity of the fracture if there is sufficient accumulation. Again, the presence of an epidural hematoma requires consideration for evacuation.

4 Symptoms requiring operation

Depressed fractures must be evaluated for correction based on esthetic and functional considerations. Functional considerations requiring operative intervention are compression of the brain through fragments or hematoma formation, compromise of a sinus or interference of space normally occupied by the orbit, impaction into the structures in the superior orbit such as the levator, or extension into the superior orbital fissure with the superior orbital fissure syndrome (partial or complete interference with function of cranial nerves):

- Olfactory nerve (central cranial base fractures), cranial nerve I
- Optic nerve (medial orbit), cranial nerve II
- The structures in the superior orbital fissure, cranial nerves III–VI, produce interference with levator and extraocular muscle function, and altered sensation in the frontal branches of the trigeminal nerve.

5 Approaches

Approaches to cranial vault fractures include lacerations and surgical incisions. Coronal incisions can generally be reflected with less retraction pressure the farther they are brought forward in the scalp. However, the anterior position of the incision is more visible with a forward location. Generally, a midcoronal incision which can be either straight or zigzagged (called the stealth incision) is preferable. The latter is camouflaged by its varying angulation within the hair (**Fig 3.2-5a–e**, page 196).

The coronal incision provides panoramic exposure and is optimal for access to the entire anterior portion of the skull. Even in the presence of a cutaneous forehead laceration the vascular supply is usually preserved despite damage to some of the anterior blood supply. Local incisions should not generally be extended for frontal sinus exploration.

Lacerations can be used for very limited fractures. Local approaches or lacerations usually permit only limited visualization and generally do not provide exposure for bilateral exploration, control of bleeding, or management of other dural or intracerebral injuries.

Management of a torn sagittal sinus is usually difficult. It can either involve acute repair or ligation of the sinus (which is an injury rarely tolerated in an adult). Depressed skull fragments can be left, if there is no bleeding at operation, but this delays an onlay cranioplasty in situations where cosmetic considerations require cranial vault repair.

6 Surgical technique including reduction

Cranial vault fractures may be elevated most safely by burr holes remote from the fracture and approaching the fracture area after dissecting the dura free. The fragments of bone produced by drilling the burr holes should be captured (drill-hole shavings) with a small strainer with the curve of its lip designed to fit the curve of the skull so that the bone can be utilized in repair. They are reserved in saline on a back table until required. The shavings are placed into areas of bone defect, such as fracture sites, osteotomies, or burr holes.

Calvarial skull fracture fragments are removed in sequence, marked for orientation and position, and a diagram drawn with brilliant green or marking pencil to identify by labeling where the fracture fragment came from and what its orientation was. This pattern assists reassembly.

Any intracranial neurosurgery such as dural repair, removal of any dead or damaged brain, and control of hemorrhage is performed. Any weak area of the dura, especially along the cranial base, should be reinforced with a dural patch. Autogenous material (fascia lata) or alloplastic material (alloderm) or Duragen® may be utilized. Appropriate aerobic and anaerobic cultures are obtained. The fracture fragments are then reassembled by the reconstructive surgeon on a back table while intracranial surgery is in process, and then may easily be replaced into the defect. Gaps occur at osteotomies and fracture lines in fracture treatment, and may be filled with calvarial or iliac shavings as previously described.

Occasionally, fragmentation is so extensive that a bone graft should replace the fractured cortical fragments. The bone graft may be taken by harvesting noninvolved full thickness skull and splitting it with a right angle saw or chisels. A calvarial bone graft may be split through the diploë with chisels. The bone graft can be used to plug the frontal sinus and nasofrontal duct, fill dead space, reconstruct portions of the cranial vault, or seal communication of the anterior cranial base with the nose. Larger cranial bone pieces should be stabilized with fixation. In some cases, a periosteal or galeal frontalis flap should be used in the anterior cranial base as an additional soft-tissue seal between the cranial base of the frontal sinus and the nose. These flaps thin the frontal skin, and caution must be used in their application.

Sometimes, extensive brain edema and swelling do not allow immediate reconstruction of the cranial vault. In these cases the bones should nevertheless be reassembled to preserve orientation, after which the bone is deep-frozen and stored for secondary use.

7 Types of fixation

Fixation of calvarial fragments can involve long spanning plates, or fragments can be serially united to each other with smaller plates (**Fig 4.3-3a**). The latter type of fixation was called "chain link" fixation when interfragmentary wires were utilized. It would seem that a stronger fixation is provided by the long spanning plate, and the author prefers this technique, although no data are available to prove its superiority. Yet another option is the fixation of these fractures with a mesh (**Fig 4.3-3b**). Other areas of the cranial vault can be used for bone graft harvesting. Gaps between fragments can be filled with bone grafts or shavings (**Fig 4.3-4**).

Cranial vault shapes are more easily reconstructed with plate and screw fixation, particularly when compared to wires. The use of wires shortens the distance between the bone fragments and creates asymmetry compared with the contour of the other side because of loss of bone at fracture gaps. With rigid fixation and bone grafts, the proper anatomy of the bone is reestablished. Bone grafts are also used to replace comminuted bone segments. Generally, plates 1.3 or corresponding Matrix plates provide sufficient stability for the (almost) nonloaded cranial vault and forehead. In general, thicker plates such as miniplates 1.5 and 2.0 are not necessary and often yield visible plate silhouette, especially in the forehead area if the skin has been thinned by injury or flap harvest.

Bone flaps are often required to provide intracranial exposure for dural or cerebral injury management. Plate and screw fixation can be helpful to stabilize these bone flaps. Burr holes should be covered either by specially contoured plates or filled with bone graft material to avoid noticeable depressions. Alternatively, burr hole covers can be used.

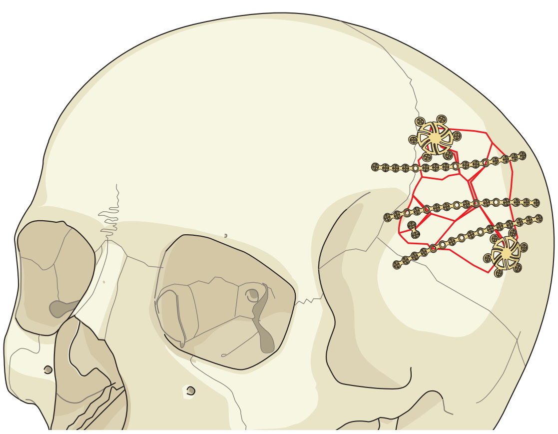

Fig 4.3-3a Fixation of a lateral cranial vault fracture after reduction using short and long mini- and/or microplates and burr hole covers.

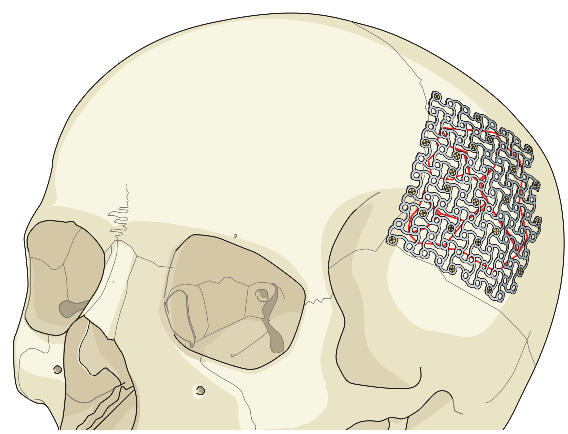

Fig 4.3-3b Fixation of a lateral cranial vault fracture with a mesh.

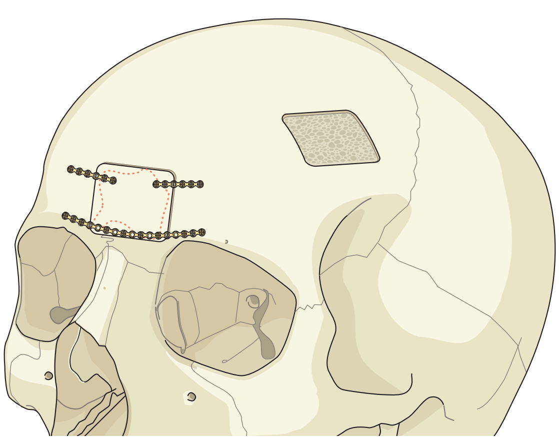

Fig 4.3-4 When the anterior table is excessively comminuted, the esthetic result is improved by use of a bone graft to reconstruct the entire anterior sinus wall. It is stabilized with miniplates.

8 Side effects of treatment and complications

A consequence of harvesting a galeal-frontalis forehead flap is thinning of the forehead skin. Sometimes the skin is so thin that late postoperative plate exposure occurs, or there is a visible permanent deformity. This kind of deformity can only be improved with thin free tissue transfers (fat transfer followed by secondary liposuction). “Plate silhouette” also occurs when replaced frontal bone partially resorbs, revealing a plate that stands on a ridge above the bone. This may require hardware removal and recontouring.

The “take” of replaced calvarial bone is generally in the region of 50%. This may cause contour deformities which are managed by late onlay cranioplasty. In each case, the smooth contour of the forehead should be reestablished with minimally profiled contoured plates, either applied to the bone surface or in a small inset created to avoid “plate silhouette.”

Coronal incisions occasionally result in hypertrophic scars but are rarely keloidal. The keloid variant occurs mostly in patients with non-white skin and is very difficult to treat. Certainly, a minimally displaced frontal sinus fracture where duct function is intact would produce far less deformity than a keloid occurring in a coronal incision.

Infections after raising cranial bone flaps for access to intracranial structures or infections in comminuted cranial vault areas are rare. They may present as acute soft-tissue infections such as abscess formation requiring incision and drainage. Late sequelae can be due to chronic bone infections such as osteomyelitis, which is treated either surgically, with hyperbaric oxygen, or with a combination of the two. Antibiotic prophylaxis is indicated in all cases with intracranial dural repair, drainage of hematomas, or major bone surgery. All patients with postoperative infections are treated with antibiotics as well.

9 Conclusion

In the last 10 years, treatment options and outcomes of frontal sinus and cranial vault fractures were studied and short- and long-term complications noted. These data suggest that an aggressive complete initial management strategy produces the best esthetic and functional results minimizing complications such as dural fistula and sinus obstruction.

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5 Panfacial fractures