Chapter 23: Maxillofacial Trauma

Robert B. Stanley, Jr.

Traditionally, fractures of the facial skeleton have been evaluated and treated in a segmentalized fashion, even if complex injuries were obvious on the initial evaluation. However, it has become increasingly evident that discussion of facial injuries in terms of fractures of the upper, middle, and lower thirds of the facial skeleton is illogical and most likely based on an arbitrary division of responsibilities among various surgical specialties that might consider treating such injuries. Although the segmentalized approach produced acceptable results in many injuries that were caused by "suburban" or low-velocity impact forces that might occur in sporting events or fist fights, similar success was often not achieved in victims of "urban" or high-velocity impact injuries seen with high-speed motor vehicle deceleration crashes or interpersonal violence involving blunt instruments and gunshot wounds. Unfortunately, in modern society, the ratio of "urban" to "suburban" injuries seen in both community hospitals and inner city trauma centers has been steadily increasing. Experienced maxillofacial trauma surgeons have recognized that suboptimal results cannot always be attributed to the severity of the injury itself but in some instances are due to a segmentalized approach to treatment.

Advances in the 1980s in diagnostic imaging, surgical instrumentation, and surgical techniques have confirmed that no facial fracture should be evaluated as an "isolated" bony injury and approached without regard to all surrounding structures. Not only do all bones of the face have numerous superficial articulations, but also all relate in some fashion directly with the skull base. Therefore the maxillofacial trauma surgeon must be familiar with the anatomy of the entire skull and be skilled in surgical procedures that involve bone immediately adjacent to the brain, eyes, cranial nerves, salivary glands, major vessels, oropharyngeal soft tissues, and teeth. In some cases a team approach may be required for management of injuries to these associated structures. However, treatment of the fractures should be coordinated by the surgeon who can best conceptualize the injuries to the parts as well as the whole of the facial skeleton.

Anatomy

Frontal bone

Superiorly, the frontal bone provides the gentle convex contours of the forehead, the very important frontal bar, and the orbital roofs (Fig. 23-1). The frontal bar is the thickened bone that bridges between the zygomaticofrontal (ZF) sutures to give structure and strength to the superciliary and glabellar areas. The frontal sinus orifices lie protected behind the glabellar bone and the stout maxillary processes of the frontal bar. The frontal bar receives masticatory forces directed from the mandible superiorly to the skull base through its zygomatic and maxillary processes, and it forms the superior-most horizontal buttress of the intricate lattice-like structure that maintains dimensions of the face and surrounds and protects the orbits, nasal cavity, paranasal sinuses, and oral cavity. The orbital roofs project superiorly and posteriorly from the frontal bar to separate the anterior cranial fossa from the orbits. Structural integrity of the frontal bar is therefore essential for reconstruction of fractures that involve the frontal bar, zygomata, orbits, nasoorbitoethmoidal (NOE) complex, and maxilla.

Maxilla

The maxilla is related superiorly to the frontal, ethmoid, and zygomatic bones and posteriorly to the pterygoid plates of the sphenoid bone within a system of relatively strong, vertically oriented struts or buttresses. These include the well-defined, paired nasomaxillary (NM), zygomaticomaxillary (ZM), and pterygomaxillary buttresses, which arise in the maxillary alveolar process and project superiorly to the skull base (Fig. 23-2) (Sicher and Dubrul, 1970). All of these buttresses have developed as a mechanical adaptation of the skull to masticatory forces. The greatest occlusal load appears to be borne by the ZM buttress, which originates in the lateral antral wall immediately above the first molar and continues superiorly through the zygoma to the ZF suture. Although the bone of the maxilla is quite thin overall, its lateral wall is formed by a V-shaped thickened area of compact bone that provides strength for the lower end of this strut.

The vertical buttresses are, for the most part, curved structures and must therefore be reinforced by horizontal struts. These reinforcing connections include the frontal bar, inferior orbital rims, the maxillary alveolus and palate, the zygomatic process of the temporal bone, and the serrated edge of the greater wing of the sphenoid bone. Posteriorly, the medial and lateral pterygoid plates are suspended from the body of the sphenoid at a 45-degree angle to each other, creating a reinforced "angle iron" configuration that resists horizontal movement at the level of the maxillary tuberosity (Toomey, 1981). Additionally the cranial base, which is almost at a 45-degree angle to the occlusal plane of the maxilla, is very resistant to horizontal compressive forces and thus acts as a horizontal buttress itself (Sicher and Dubrul, 1970).

Zygoma

The zygoma, which forms the cornerstone of the buttress system as well as provides the aesthetically important malar prominence, is related to the surrounding craniofacial skeleton through four superficial and two deep projections. The superficial projections contribute to two critical external arcs of contour (Fig. 23-3). The vertical arc defines the course of the ZM buttress, running from the zygomatic process of the frontal bone over the zygoma to the lateral antral wall. The longer horizontal arc runs from the maxilla in the area of the lacrimal fossa around the zygoma to the zygomatic process of the temporal bone. It is parallel to, but slightly below, the Frankfurt horizontal plane (Stanley, 1989). Because the height of contour of the malar prominence is also just at or slightly inferior to the Frankfurt plane (Powell et al, 1988), the point of intersection of these arcs of contour defines the position of the malar prominence (Fig. 23-3). The two deep projections are the sphenoid projection that articulates along the lateral orbital wall with the orbital plate of the sphenoid bone and the orbital projection that articulates with the orbital surface of the maxilla in the extreme lateral aspect of the orbital floor. The sphenoid and orbital projections lie beneath and perpendicular to the external arcs of contour in the area of the inferolateral orbital rim, thus greatly strengthening this portion of the rim.

Medial canthal complex

The bony prominences forming the superior, lateral, and inferior portions of the orbital rim are usually palpable and often visible through their soft tissue covering. No true medial rim exists in the area of confluence of the orbit, frontal process of the maxilla, and nasal dorsum. However, this critical area serves as the attachment point for the medial canthal tendon (MCT) and as the receptacle for the lacrimal collecting system. The tendon attaches in a tripartite configuration with horizontal and vertical components anteriorly and a deeper horizontal element posteriorly (Fig. 23-4) (Rodriguez and Zide, 1988). The anterior horizontal component is the strongest and is firmly attached to the anterior lacrimal crest, that is, the frontal process of the maxilla. The vertical component is less firmly attached along a line several millimeters above the insertion of the horizontal tendon. The posterior component has the weakest attachment to the posterior lacrimal crest. Although these three components surround the lacrimal sac within the lacrimal fossa, the palpable border of the ligament is actually over the bone of the anterior lacrimal crest, not the lacrimal sac. In the undisturbed state the medial canthal tendon anchors the eyelid structures to the medial orbital wall, thus maintaining the configuration of the palpebral opening, maintaining contact of the lids to the globe, and facilitating the lacrimal pump that ensures flow of tears from the lid puncta through the lacrimal system (Mathog, 1984).

Orbit

Within the orbit, the greatest diameter is found approximately 1.5 cm posterior to the inferior orbital rim. Here, the orbital roof has an upward convexity that places it approximately 5 mm above the superior orbital rim, and the orbital floor is concave with a depth of approximately 3 mm in relation to the inferior orbital rim. The globe itself rests within this concavity. Posteriorly the floor is convex, and posteromedially it slopes upward into the medial orbital wall without a sharp demarcation (Fig. 23-5). Laterally and posteriorly the floor is separated from the greater sphenoid wing by the inferior orbital fissure. The optic foramen actually lies posteriorly in the plane of the medial orbital wall, thus placing it medial and superior to the true orbital apex.

Mandible

The mandible is a rigid bone that has a U-shaped body that is extended at each end by vertically directed rami (Fig. 23-6). Since the body is cantilevered off the ramus, masticatory forces can create considerable structural demands on all parts of the mandible. A tension load exists at the upper border of the body and angle, and a compression load occurs at the lower border. The lower border of the body is smooth, round, and thickened by dense bone to help the outer and inner cortical plates resist these forces, but the lower border in the angle region becomes thinner and more irregular. Overall, the height of the mandible is the primary determinant of strength of the horizontal portion, particularly at the critical angle. Following extraction of the mandibular teeth, vertical height is lost as the alveolar process atrophies. Partially and fully edentulous mandibles therefore lose strength proportionate to this loss of bone.

The vertical rami, although relatively thin, are totally embedded in a muscle sling formed by the masseter and internal pterygoid muscles and are perfectly aligned with the compressive forces created by these muscles. The condylar neck is also a thin area and, like the angle, is not entirely protected by this muscle sling. It is fortunate that the trajectories of the masticatory and muscular stresses on the bony trabeculae of the mandible have caused the orientation of the trabeculae into crests, ridges, and lines of strength that provide additional reinforcement to the thin, unprotected angle and condylar neck regions (Sicher and Dubrul, 1970). It is unfortunate that, although these reinforcements resist the normal tension, compression, and rotational forces of mastication, they do not offer serious resistance to the lateral stress forces created by external blunt trauma.

Temporomandibular joint

The mandible articulates with the skull base through the ginglymoarthroidal (hinge and sliding) temporomandibular joints. The joint is formed by the condyle of the mandible, the glenoid fossa of the temporal bone, and an interposed fibrocartilaginous disc known as the meniscus. The meniscus divides the joint into two compartments, with the gliding motion occurring in the upper compartment and the hinge-like action occurring in the lower compartment. A ligamentous capsule surrounds the joint space and attaches around the condylar neck just below the head. When each condylar head is maximally seated against the joint meniscus in the bottom of the glenoid fossae, the mandible is in the centric relation position. This is a retruded position, and the teeth are not in maximal interdigitation. When the cusps of the maxillary and mandibular teeth are maximally interdigitated, the mandible is in the centric occlusion position, a position usually more than 1 mm anterior to centric relation (Ramfjord and Ash, 1969). Therefore the relationship of the condylar head to the glenoid fossa, and thus the relationship of the mandible to the skull base, has a normal range of variability. It is obvious that any form of jaw-to-jaw fracture fixation should be designed to place the jaws into the centric occlusion position.

Pathophysiology

Orbitozygomaticomaxillary (LeFort) fractures

The honeycomb construction of the middle third of the facial skeleton provides excellent stability as long as it is loaded in the application for which it was intended, to resist predominantly vertical masticatory forces, and as long as the lattice remains intact (Rahn, 1989). Although the relatively strong vertical buttresses bear the load of mastication, the "weaker" horizontal reinforcing buttresses must absorb external impact force centered over the lower forehead, orbits, zygomata, or maxilla. The initial disruption of a single buttress may weaken the entire lattice and lead to its collapse, but a random collapse under anterior or lateral impact forces is usually prevented by the strength of the horizontal buttresses combined with their relationship to the skull base (Stanley and Nowak, 1985). Instead, recurring fracture patterns are seen, and these tend to follow the three great weak lines of the midfacial skeleton, as described by LeFort in 1901 (see Fig. 23-2).

Anterior impact forces angled obliquely to the horizontal buttresses from above the Frankfurt plane usually produce a separation of the vertical buttresses from the skull base with inferior and posterior displacement of the maxilla. The maxilla may or may not be separated from the zygomatic bodies. Impacts directed at the same level, but head-on to the horizontal buttresses, not only may separate the buttresses from the skull base, but also nearly always produce fractures that cross the lower aspects of the buttresses at near right angles through the anterior and lateral walls of the maxillary antrum. This allows for a downward rotation of the anterior end of the maxilla around an axis approximating the lower end of the pterygoid plates. This organized collapse prevents total destruction of the orbits, nose, tooth-bearing segments of the maxilla, and skull base by high-velocity external impact forces (Stanley and Nowak, 1985).

Impact forces delivered to the face in motor vehicle accidents or interpersonal confrontations are usually not perfectly centered over the face, and LeFort fractures therefore usually occur in unpredictable combinations. Most often, the patterns are asymmetric, with the level of injury being higher on one side than the other (Manson, 1986). The spectrum ranges from isolated, minimally displaced LeFort I, II, or III fractures to multiple, widely displaced fracture-dislocations that cause gross malalignment of the buttresses. This malalignment will be evident clinically as a variable combination of maxillary retrusion and/or rotation, mid-facial elongation, and malocclusion. An actual reduction in midfacial height is a rare occurrence caused by a severe impact force that drives the mandible superiorly into the maxilla to shatter the vertical struts and shorten midfacial vertical dimension.

Orbitozygomatic fractures

Unlike anterior impact forces, lateral forces tend to be centered over a convenient target, the prominent convex outer surface of the zygoma. The sturdy zygoma is the main buttress between the maxilla and the cranium, and strong impact forces directed to the zygoma are usually absorbed by the fragmentation of the weaker bones with which the zygoma articulates at the inferior orbital rim, orbital floor, and lateral antral wall. The exceptions to this are the stout zygomatic process of the frontal bone, which is almost always spared by the typical clean separation of the ZF suture, and the zygomatic arch, which usually suffers either a single fracture near its midpoint or a double fracture that produces a displaced, large central fragment. Therefore fracture-dislocations of the zygoma may fragment both ends of the horizontal arc of contour and the lower end of the vertical arc. Restoration of the anterior and lateral projection of the cheek will require reconstruction of the horizontal arc, and restoration of the height of the malar prominence in relation to the Frankfurt plane will require reconstruction of the vertical arc (Stanley, 1989). The degree of disruption as well as the amount of displacement of the zygoma (and thus the complexity of the needed repair) depends on the velocity of the impact force. Even comminuted LeFort fractures can occur from the cross-facial transmission of very high-velocity lateral impact forces.

Deep orbital fractures

Within the orbit, impact forces are transmitted through the zygoma by way of the sphenoidal and orbital processes to the deeper structures. Any impact centered over the lateral orbital rim must be absorbed by the relatively weak sphenotemporal buttress that is formed by the zygoma, orbital plate of the greater wing of the sphenoid, and squamous portion of the temporal bone. If the ability of this buttress to absorb an impact force is exceeded, fracture-dislocations of the lateral orbital wall will result with impaction of the orbital plate of the sphenoid bone into the orbital apex or even into the middle cranial fossa. This impaction may cause injuries to the structures within the orbit, superior orbital fissure, and optic canal. Reduction of the bony injuries may therefore be necessitated not only by the need to restore the volume of the orbit and the contour of the orbital rim, but also by the need to remove bony impingement on vital neurologic structures (Funk et al, 1989).

Impact forces centered over the body of the zygoma are transmitted medially through the orbital process to the inferior rim and the floor of the orbit. Both structures will almost always suffer a comminuted fracture, the severity of which varies with the strength of the impact force. The floor fracture usually involves the concave central portion of the floor, starting at and extending medially from the groove/canal of the infraorbital nerve. High-velocity periorbital impact forces may be transmitted to the convex posterior floor and even to the medial wall, causing serious displacement of the bone in these areas. Although the globe itself rests anterior to the convexity, evaluation and reconstruction of this area and the adjacent medial wall are of equal importance to repair of the more accessible concave anterior portion of the floor (Manson et al, 1987).

The classic blow-out fracture of the orbital floor and the less common medial wall blow-out fracture have been the subject of numerous discussions in the maxillofacial trauma literature (Mathog, 1991). Both are thought to result from impact forces that are centered over the globe, producing a rapid increase in intraorbital pressure that "blows out" the thin bone of the concave portion of the orbital floor or the lamina papyracea. Although of historical importance, these isolated injuries appear to be occurring less frequently relative to other periorbital fractures in the this time of high-velocity impact injuries. Orbital roof fractures, on the other hand, are being seen more often and usually occur as part of a severe frontobasilar fracture caused by impact forces centered immediately above the orbit. These patients may have associated panfacial fractures, including unilateral or bilateral orbitozygomatic fractures.

The position of the globe is determined by the integrity of the orbital walls and the extensive network of ligaments that suspend it (Koorneef, 1982). Recession or depression of the globe within the orbit results from any injury that pushes one or more orbital walls outward and also damages the network of suspensory ligaments. The orbital soft tissues are then displaced by both gravitational forces and the remodeling forces of fibrous scar contracture. This usually changes the shape of the orbital soft tissues from a modified cone to a sphere, and the globe sinks backward and downward (Manson et al, 1986a). Probably the most common cause of this posttraumatic enophthalmus is the incomplete repair of a defect in the normally convex posterior aspect of the floor or failure to recognize and correct a medial wall component of the injury.

Nasoorbitoethmoidal fractures

NOE fractures are true orbital wall injuries that result from the unilateral or bilateral impaction of the frontal processes of the maxilla and the nasal bones into the orbital space, with secondary comminution of the ethmoid air cells and out-fracturing of the medial wall of the orbit (Sargent, 1991). The fractures may be associated with panfacial injuries caused by broad-surfaced impact forces that separate the middle third of the face from the skull base or, less commonly, with a narrow-impact force centered in the nasal or frontonasal area. The nasal dorsum will be flattened, but more importantly, the attachments of the three components of the MCT may be partially or totally disrupted. The resultant deformity of the inner canthus becomes progressively more obvious as the number of disrupted components increases. Loss of attachment of the posterior component allows anterior movement of the medial canthus; loss of attachment of the anterior horizontal component allows lateral movement; and disruption of the anterior vertical component allows inferior displacement. Symptoms and findings secondary to an MCT injury may therefore range from epiphora with minimal deformity, to noticeable telecanthus, to gross dystopia of the medial canthus with narrowing of the palpebral fissure (Rodriguez and Zide, 1988).

Mandibular fractures

The area of the mandible that fractures is determined by the interaction of the nature of the external force and the anatomic predispositions of the mandible to fracture at specific locations. A fracture may occur directly under the point of impact, or the force may be transmitted indirectly across the mandible to create a contralateral fracture. A blow to the body will usually cause an ipsilateral body fracture through the mental foramen (a naturally weak area) and either a contralateral angle fracture or a subcondylar fracture. The presence of a tooth at the angle seems to favor the fracture of the angle, and an unerupted third molar creates an even more favorable condition for fracture to occur (Wolujewicz, 1980). Ramus fractures occur much less frequently than condylar, angle, and body fractures, most likely because of the reinforcing ridges that naturally transmit forces through the ramus to the condylar neck and also because of the muscle sling that envelops the ramus and cushions direct blows. Impacts centered over the lower anterior alveolar ridge may cause alveolar fractures, leaving the lower incisors floating in the fragment of bone. Posterior alveolar fractures are much less common because of the longer, more stable posterior tooth roots and the increased amount of spongy bone in the posterior alveolus to absorb fracture forces.

The velocity of the impact force is also a factor. A low-velocity blow to the body usually causes a body fracture with little or no displacement at the point of contact and a contralateral subcondylar fracture. A high-velocity blow may cause a displaced, comminuted fracture at the point of impact but no contralateral fracture. A moderate blow to the symphysis may cause a parasymphyseal fracture or bilateral condylar fractures. A violent blow to the chin may create a flail mandible with a fracture of the symphyseal or parasymphyseal area combined with either bilateral angle or subcondylar fractures. This type of condylar fracture is actually a safety mechanism that prevents the condylar head from being driven into the middle cranial fossa or through the tympanic plate into the external auditory canal.

Displacement of the mandibular fragments is also influenced by two closely related facts, muscle pulls and direction of angulation of the fracture line. Muscle pulls are from the relatively weak anterior depressor group and the stronger posterior elevator group (Fig. 23-7). Direction and angulation of body and angle fractures have been used to classify these fractures as either favorable and unfavorable in relation to the muscle forces in the angle and body areas (Fig. 23-8). Displacement of fractures through the condyle or condylar neck is determined by the relationship of the fracture to the insertion of the lateral pterygoid muscle. This muscle inserts into the neck of the condyle as well as into the articular disk of the joint through the anterior wall of the joint capsule. A fracture above the insertion into the neck will cause little displacement of the condylar head because of the lack of muscle pull. On the other hand, a fracture below the muscle insertion, that is, a subcondylar fracture, will lead to displacement of the condylar head medially and forward because of the force of the lateral pterygoid muscle. If the segment is displaced entirely out of the joint capsule, it is called a dislocated fracture. Overall, forces generated by muscle pulls are thought to be more important in creating displacement of mandibular fractures than the direction and amount of force that cause the fracture (Archer, 1975).

Patient Evaluation

General considerations

Evaluation of the patient with facial trauma has been greatly enhanced with the use of computed tomography (CT). Axial and coronal scans can be used to demonstrate in graphic detail fracture lines through all aspects of the facial skeleton. It is now recognized that information gained from CT scans is of greater value than that gained from a combination of clinical examination and routine roentgenography for all facial fractures, with the exception of mandibular fractures in patients with no clinical evidence of other injuries (Manson, 1991). In these patients a panoramic roentgenogram, a form of tomogram of the mandible, adequately demonstrates the entire lower jaw from condyle to condyle. It accurately displays fractures of the condyle area and is particularly suited to the demonstration of most fractures of the ramus, angle, and body. In some instances parasymphyseal and midline mandibular fractures may be difficult to evaluate because of poor imaging of these areas associated with the mechanics of certain panoramic machines; however, these fractures are usually clinically very evident, and detailed roentgenographic analysis is not necessary.

Specific areas that should be thoroughly inspected with the high-resolution scans include the frontal bone, NOE complex, orbits, and entire craniofacial horizontal and vertical buttress system. Although all information necessary for evaluating most facial fractures can be seen on standard axial and coronal CT views, three-dimensional reconstructions may help less experienced surgeons conceptualize the overall injury. In addition, such reconstructions may prove valuable in patients who cannot be positioned for a coronal CT scan. Even in this time of cost-conscious medicine, the expense of CT evaluation of patients suffering almost all facial fractures, other than simple nasal fractures and mandibular fractures as described before, appears justified. It is no longer acceptable to adopt a wait-and-see attitude regarding possible delayed trauma sequelae such as enophthalmos, just as it is no longer acceptable to perform procedures such as orbital exploration simply to evaluate the status of the orbital floor and in so doing place the patient at risk for complications.

Frontal bone

External appearance as well as routine roentgenographic examination may be totally inconsistent with the actual severity of fractures of the frontal bone and supraorbital ridges. Because edema of the skin, subcutaneous tissue, and muscle overlying depressed fractures of the glabella and supraorbital areas may persist for several months, the surgeon must be able to relate the amount of bony displacement demonstrated by CT scan to the flattening that will subsequently become obvious if the fracture fragments are not properly realigned (Stanley, 1991). Although some of the depression may be camouflaged by variations in facial features (such as the position and density of the eyebrows; the skin thickness, texture, and color; and the size and overall bony configuration of the face), the forehead asymmetry may nonetheless be distressing to the patient. Early open reduction and internal fixation of the fractures are preferable to more complex delayed reconstructive techniques (Schultz, 1975), even if the decision to proceed with early surgery must by necessity be based on a somewhat subjective CT prediction of a future deformity.

Orbit

A detailed picture of the location of orbital fracture lines can be obtained with CT scans. Of greater importance, the scans also demonstrate the amount of displacement of the malar eminence and of the four walls, which might cause volume changes in the orbit. The choice of the most appropriate surgical approach for treatment of all but the most minimally displaced orbital or orbitozygomatic fractures can be made only if the integrity of the zygoma and the orbital walls is thoroughly evaluated. In particular, CT demonstration of comminution or dislocation of both ends of the horizontal arc of contour indicates that an exact reconstruction of the orbitozygomatic complex can be achieved only if the zygomatic arch is exposed and repaired (Fig. 23-9, A). Within the orbit itself, evaluation of the floor and medial wall is critical, especially in the areas of the convex posterior floor and the gentle slope of the floor into the medial wall. This evaluation requires either a true coronal CT scan or a three-dimensional reconstruction from an axial scan.

High-resolution studies have allowed for relatively accurate calculation of orbital volume changes related to specific defects of the orbital walls. Orbital injuries that can be identified as likely to produce enophthalmos are those in which the orbital floor disruption exceeds a total area of 2 cm^2, in which the bone volume changes exceed 1.5 mL (5% of orbital volume), and in which a significant amount of fat and soft tissue displacement has occurred (Manson et al, 1986b). Additionally, 3 mm of displacement of either the inferior or medial wall will cause an orbital volume change of 7% to 12%. These changes can produce from 2.5 to 4.0 mm of globe displacement if no change in orbital contents occurs (Parsons and Mathog, 1988).

The surgeon must always keep in mind that enophthalmos may not be seen acutely with even severe orbitozygomatic fractures because of orbital soft tissue swelling. In addition, if the body of the zygoma has remained intact, it may be impacted medially to compensate for the increased orbital volume caused by blow-out fractures of other walls, and the globe may appear to have normal anterior projection and vertical position. However, reduction of the zygomatic component of the injury to restore the malar prominence will unmask the traumatic increase in orbital volume and lead to "delayed-onset" enophthalmos if the other fractures are not treated. Careful review of the axial and coronal CT scans will prevent this error.

Nasoorbitoethmoidal complex

The diagnosis of NOE fracture may be made on physical examination alone if gross posterior telescoping of the nasal bones has occurred and the intercanthal distance has become greater than one half of the interpupillary distance (Rodriguez and Zide, 1988). In addition, a bimanual examination can be performed by placing a Kelly clamp intranasally beneath the frontal process of the maxilla and a finger directly over the MCT insertion. Any movement of the frontal process differentiates the injury from a simple comminuted nasal fracture (Paskert and Manson, 1989). However, edema may obscure posterior nasal telescoping and intercanthal widening. Also, bimanual palpation may not reveal the degree of fragmentation of the bones onto which the three components of the MCT attach, specifically the posterior lacrimal crest attachment of the posterior horizontal component. Both diagnosis and accurate portrayal of the extent of bone fragmentation are readily available with the CT scan. Although

MCT disruption cannot be seen on CT, indirect evidence exists if the bone in the area of attachment is found to be fragmented rather than a single displaced segment (Manson, 1991).

Craniofacial buttress system

This buttress system, particularly the vertical struts, must be systematically inspected preoperatively to document the degree of malalignment that has resulted from fracture displacement. Fracture lines themselves through the buttresses do not mandate open reduction, but comminution and gross malalignment strongly suggest the need for reduction of the fractures under direct visualization so that facial length and projection are accurately restored (see Fig. 23-10, A). The hard palate must also be examined for fractures (usually parasagittal) that might cause widening of the maxilla and prevent accurate interdigitation of the maxillary and mandibular teeth when the jaws are placed into maxillomandibular fixation (MMF). In addition, the CT scans will display fractures of the condylar head, condylar neck, and vertical ramus of the mandible (see Fig. 23-10, B). The status of these structures must be known before a patient with fracture-dislocations of the maxilla is placed into MMF. Although displaced fractures of the mandibular symphysis, body, or angle are usually readily apparent on clinical examination, displaced fractures closer to the temporomandibular joint may be overlooked in panfacial injuries because they are in areas not readily accessible for direct inspection and palpation. The status of these structures must be known before a patient with fracture-dislocations of the maxilla is placed into occlusion with MMF. A meticulous and time-consuming reconstruction of fractures extending from the frontal bar to the maxillary palatoalveolar complex may be totally inaccurate if condylar, condylar neck, or high ramus mandibular fractures are not recognized and appropriately addressed.

Ophthalmologic Considerations

General evaluation

A complete preoperative ophthalmologic evaluation of every victim of maxillofacial trauma who suffers a fracture in the orbitozygomatic area is an unrealistic expectation and by no means mandatory. However, the surgeon must always be sensitive to the possibility of direct ocular trauma and obtain proper consultation when indicated. A minimum preoperative examination should include testing of visual acuity (subjective and objective in both eyes), pupillary function, ocular motility, inspection of the anterior chamber for hyphema, and visualization of the fundus for gross disruptions. A decrease in visual acuity or any abnormality noted on the other phases of this screening examination warrants a more detailed examination by an ophthalmologist before reconstruction of the bony injuries is undertaken. The value of forced-duction testing for muscle entrapment has decreased with the increased use of CT to document the status of the orbital walls.

Orbital apex injuries

Located in the orbital apex are the optic canal and superior orbital fissure (SOF), both of which have a fairly protected position within the thick bone of the lesser sphenoid wing and sphenoid body (Paskert et al, 1988). Typically, impact forces centered over the orbital rims or globe are absorbed by fractures of the thin walls of the orbit itself before they can be transmitted to the posterior orbit. However, orbital trauma that does involve the optic canal usually causes an injury to the intracanalicular portion of the optic nerve and at least a partial loss of vision. Damage to the SOF and its neural contents is known to cause a syndrome consisting of ophthalmoplegia, ptosis, pupillary dilatation, and anesthesia of the upper eyelid and forehead (Ghobrial et al, 1986). A combined injury to the optic nerve and SOF contents is known as the orbital apex syndrome.

Treatment of intracanalicular optic nerve injuries remains controversial. Traditional teaching emphasizes that immediate loss of vision associated with an injury to the intracanalicular portion of the nerve is an irreversible injury, and thus surgical intervention to decompress the nerve in the optic canal is not warranted. Delayed or progressive loss of vision, on the other hand, implies that the nerve has remained viable after the initial insult and that decompression may prevent total necrosis of the nerve. Additionally, the response of the visual loss to massive doses of steroids has been advocated as an indicator for selective nerve decompression (Anderson et al, 1982). The steroids are given for a 12-hour period, and if no response is seen or if an initial response begins to deteriorate, decompression is performed. Recently, however, the morbidity associated with decompression of the intracanalicular portion of the nerve has been greatly reduced with the development of anterior surgical approaches through the paranasal sinuses (Ramsey, 1979; Sofferman, 1981), and restoration of vision has been described following decompression in a patient who suffered immediate total visual loss not responsive to 5 days of megadose steroid therapy (Spoor and Mathog, 1986).

Treatment of the injuries of the infraorbital portion of the optic nerve caused by impaction of orbital wall bone fragments into the orbital apex has been less controversial. If high-resolution CT documents the presence of an offending fragment in the orbital apex of a patient with diminished vision, early surgical reduction should be considered (Funk et al, 1989). Although the exact injury to the nerve caused by the impaction of such fragments is unknown, it is possible that a reversible compressive phenomenon (either incomplete ischemia or blocked axonal transport) is involved, and a certain time interval may exist before the transition to irreversible damage occurs. The role of steroid therapy in treatment of this type of optic nerve injury is undefined.

Typically patients with bone fragments impacted into the orbital apex will also have an SOF syndrome, and removal of the offending bone fragments may speed the resolution of the problem. However, it has been recognized that the chance for partial if not complete recovery of the motor and sensory components of any SOF syndrome is good, with or without surgical intervention (Zachariades et al, 1985). If surgery is undertaken, the lateral or temporal approach to the orbital apex offers a safe route that minimizes the chances of further damage to the optic nerve (Stanley, 1988). Although this procedure technically requires a mini-craniotomy, it is an extension of the approach to severe orbitozygomatic fractures that will be described in the upcoming section on surgical techniques.

Management Philosophy for Immediate Reconstruction

The goal of modern fracture management is total reconstruction of the bony architecture of the injured facial skeleton. Immediate reconstructions are generally less difficult and more successful than are delayed reconstructions. This is mainly because of cicatricial contraction of the facial soft tissue envelope if the underlying skeletal support collapses or is lost (Gruss et al, 1985b). During the acute phase of the injury, the soft tissues (although possibly injured themselves) are pliable enough to allow restoration of the underlying bony configurations with local bone fragments or autogenous bone grafts. If the soft tissues are allowed to contract into a bone defect, restoration of the supporting bone invariably produces a less desirable result. If revision surgery for minor residual bone defects or lacerations is required, this surgery too is greatly facilitated if the overall soft tissue envelope has been maintained in a normal position. These principles apply to most frontal orbitozygomatic, NOE, and maxillary injuries. Efforts should also be made to reconstruct mandibular injuries primarily (short of bone grafting) so that skin, lower lip, and tongue positions are maintained.

Surgical Techniques

Frontal bone

Poor aesthetic results can be the result of a failure to recognize a fracture-dislocation within the frontal and supraorbital region, as well as a failure to achieve prompt reduction and stable fixation of fracture fragments. Problems with reduction and fixation have been lessened with the use of the coronal incision for access, rigid fixation devices (miniplates and screws), and autogenous bone grafts. Visualization of the entire frontal injury as well as surrounding intact structures through the coronal approach enables the surgeon to perform a more accurate reconstruction of the frontal contours than can be accomplished through smaller and less cosmetically acceptable facial incisions. Use of incisions placed above or below the brows should be restricted to men with unstable hairlines.

Once the fracture fragments have been realigned, maintenance of edge-to-edge contact and to a certain extent the convex contours of the forehead and supraorbital ridges can be achieved with interosseous wires. However, flattening caused by collapse of fragments across the forehead span (particularly across the span of the thin anterior wall of the frontal sinus) may occur when wire fixation alone is used. More stable fixation can be obtained with low-profile mini-plates and screws. If the frontal bone reconstruction is part of the overall repair of a panfacial injury, the frontal bar must be stabilized with a system that utilizes screws that are at least 1.5 mm in diameter. Anything less than this will most likely not give adequate stability to the frontal bar from which the reconstructed buttress system of the middle third of the face will be suspended. Although these relatively thick plates may be palpable, they are usually not visible unless they are placed beneath a full-thickness laceration from which the resulting scar outlines the plate under the skin. If this occurs, the plate can be easily removed at time of scar revision. If the frontal injuries are not accompanied by LeFort fractures, they may be stabilized with a micro plating system, that is, one that uses screws of 1.0 mm or less in diameter.

Small frontal bone fragments are more difficult to stabilize, even with miniplate fixation, and may be lost quickly to resorption processes. Larger, split-thickness cranial bone grafts can be used to replace numerous smaller fracture fragments, greatly facilitating fixation device application and providing a much thicker scaffolding that will better maintain soft tissue contour during remodeling and new bone formation.

Zygoma

The precise relocation of the displaced zygoma can be greatly simplified if the surgeon concentrates on reconstruction of the two main external arcs of contour. Restoration of the horizontal arc reestablishes anterior and lateral projection of the cheek, and restoration of the vertical arc reestablishes height of the malar prominence in relation to the middle third of the face. The repositioned zygoma can then be used as a framework for repair of any associated orbital wall fractures. Treatment required to attain multidimensional restoration of the position of the zygoma becomes increasingly complex as the injury to each arc of contour worsens.

Only those cases with absolutely no comminution of any of the projections of the arcs of contour should be treated with limited exposure reduction techniques such as the "Gillies' method with or without transzygomatic Steinmann pin fixation. If this technique is deem appropriate, it can be modified to give a more accurate assessment of reduction if a small sublabial incision is used for direct visualization of the lateral antral wall. If this is done, a single 26-gauge interosseous wire can be placed across the reduced fracture line in lieu of the transzygomatic pin to stabilize the zygoma against the downward pull of the masseter muscle. Because any type of limited access technique relies heavily on palpation and external visualization of the position of the zygoma and its projections, these procedures should be delayed for at least 7 days to allow for resolution of edema. Additionally, preoperative steroids may reduce intraoperative edema to further facilitate evaluation of the reduction. The repair should not be delayed more than 10 days, however, because the masseter muscle begins to shorten after this time, making elevation of the zygoma more difficult.

The lateral wall of the maxillary antrum will frequently be comminuted even if the other projections of the arcs of contour suffer simple fractures or separation of a suture line. In these cases, reconstruction of the lateral wall with wire fixation will be inadequate to resist the pull of the masseter muscle. However, a single miniadaptation plate attached across the comminuted area with 1.5 mm screws will be sufficient. Because the fixation device is not resisting heavy occlusal forces as would be the case with a LeFort fracture, only two screws into the body of the zygoma above and two screws into the maxilla below are required for stability. Additionally, the plate may be placed at an angle to the buttress to facilitate placement of screws below the fracture lines if there is concern for the root tips of the maxillary teeth.

An alternative site for placement of a single rigid fixation device for the less severe zygomatic injuries is the reduced ZF suture line. The thick bone above and below the suture lines makes screw placement easy and gives even greater stability to the reduction. However, this greater stability is unnecessary in most cases, and direct visualization of the suture line reduction gives little information regarding the overall position of the zygoma compared with direct visualization of the lateral antral wall. Additionally, the lateral brow incision required to expose the suture line may leave a noticeable scar.

The progression to more complex fractures usually involves comminution of both the lateral antral wall and the medial aspect of the inferior orbital rim, thus making traditional three-point reduction inadequate for accurate restoration of the position of the malar prominence. Typically, the prominence will be displaced posterior and lateral to its normal location and failure to recognize the amount and direction of the displacement at the time of reduction will leave a flattened cheek and a widened face. In these situations the fourth point of alignment, the zygomatic arch, must be used to accurately reposition the point of intersection of the arcs of contour (Stanley, 1989).

If the arch has been noted on CT scan to have a single displaced fracture or two greenstick fractures with bending of the arch, dissection may be carried out over the malar eminence through the subciliary incision to expose the fractures. If the arch has been noted to have a displaced central segment, access to the full length of the horizontal arc will be required, and a coronal, hemicoronal, or extended-pretragal incision will be necessary in addition to the standard subciliary incision. Dissection toward the lateral orbital rim and the zygomatic arch should be in a plane deep to the superficial layer of the deep temporal fascia so that the frontal and orbital branches of the facial nerve are elevated with the flap. The periosteum is then incised along the orbital rim and along the arch fragments deep to the attachment of the superficial layer of fascia. A subperiosteal dissection is carried over the body of the zygoma to connect with the subciliary dissection, and all of the components of the zygomatic arch are exposed.

Initial reduction of the zygoma is performed at the ZF suture line. This reduction is temporarily held in place with a single stainless steel wire through holes that are placed well away from the thick portion of the rim that will later be used for a rigid fixation implant. Because this temporary wire allows for rotational movement of the zygoma, the position of the malar prominence can be appropriately adjusted in the lateral and anterior dimensions. The zygomatic arch fragments are elevated and realigned, remembering that the bone of the middle portion of the arch is actually straight and must be reconstructed as such to properly reestablish anterior projection of the malar prominence (Fig. 23-9, B). Surprisingly, although the bone of the arch is thin, an accurate end-to-end realignment can usually be obtained to reconstruct the true length of the arch and thus the anterior projection of the malar prominence. Fixation is accomplished with 1.5 cm screws and plates. Final bending and attachment of the plates are done after the lateral projection of the prominence is established by realignment of the inferior rim fragments.

If the inferior rim fragments are too small to manipulate or are actually missing, lateral projection can usually be established by realigning the ZM buttress. If the bone fragments of the lateral antral wall are also too small or missing, restoration of the lateral projection of the prominence, like the anterior projection, must be based on the accurate restoration of the contour of the zygomatic arch. After the arch is totally reconstructed, a second plate is placed across the ZF suture. A third plate placed along the inferior rim or over the ZM buttress is usually not required because the arch and ZF suture plates appear to be adequate by themselves to resist the downward pull of the masseter muscle.

If extreme difficulty is encountered in mobilizing the zygoma to its correct position even with the extended access approaches, the masseter muscle can be detached from the zygoma and the arch. This is often necessary in those cases not treated within the recommended 7 to 10 days. This maneuver should not have long-term effects on jaw mobility or masticatory function, but the additional soft tissue trauma and subsequent scarring may cause accentuation of the prominence of the reconstructed arch. Accurate draping of the soft tissues over the reconstructed arch helps to prevent this. Simultaneous upward traction on the skin flap and incised temporal fascia allows for a tight closure that holds the periosteum in correct position over the arch and zygoma.

Maxilla

Traditional treatment of most fractures involving tooth-bearing segments of the maxilla includes the triad of closed reduction, MMF, and craniofacial or circumzygomatic suspension. However, bone fragments cannot be optimally repositioned, and maximum interfragmentary stability cannot be achieved using these techniques. Closed manipulation of the maxilla so that maximum interdigitation of the teeth is obtained before application of MMF should restore the position of the maxilla in the horizontal plane, if the mandible is correctly related to the skull base. However, it will not automatically reestablish midfacial height if the vertical buttresses have been disrupted by fracture-dislocations. Closed reduction and MMF are therefore adequate treatment for only less complex, minimally displaced maxillary fractures. MMF simply puts the jaws at rest for the 4 to 6 weeks required for fracture healing. Internal suspension wires play no useful role in the treatment of maxillary fractures and may introduce iatrogenic shortening of the midfacial vertical dimension. Internal suspension, which exerts a posteriorly and superiorly directed force, was designed to prevent elongation of the face after closed reduction of the maxillary fragments. However, clinical and experimental evidence has documented that elongation caused by muscle pulls does not occur following fracture reduction. Instead, internal suspension may actually telescope unstable maxillary segments on each other to shorten the vertical dimension of the middle third of the face (Joy et al, 1969; Sofferman et al, 1983).

Maxillary fractures that are demonstrated on CT scans to be displaced are best treated by extended-access approaches that allow for direct visualization and an anatomic reconstruction of the buttress system (Gruss and MacKinnon, 1986; Manson et al, 1980). The buttresses must be totally exposed through extended sublabial incisions that essentially deglove the maxilla. Although this frequently removes all residual external periosteal attachments to displaced maxillary fracture fragments, bony union should proceed in a timely fashion if the fragments are adequately stabilized and the periosteum is redraped over them. This is important, since clinical evidence now indicates that maxillary fractures heal by osseous rather than fibrous reunion (as once thought) (Thaller and Kawamoto, 1990). Adequate stabilization can be obtained with the use of multiple interosseous wires if the patient is also maintained in MMF for 4 to 6 weeks. This prolonged period of jaw immobilization can be eliminated if 2.0 mm screws and plates are used to stabilize the maxillary fracture fragments. Although the term rigid is used to describe the fixation achieved with these implants, it is somewhat inaccurate when applied to maxillary fractures. Rigidity sufficient to allow for removal of the MMF can be obtained but not sufficient to allow the patient to return immediately to a normal diet. Rather, the fixation devices will maintain the position of the maxillary dentoalveolar complex under the stresses of forces generated by mastication of very soft foods as well as deglutition.

Restoration of the pretrauma relationships of the tooth-bearing segments of the maxilla to the mandible and skull base requires reestablishment of the occlusal relationship that existed in the patient before the injury. Few people have perfect occlusion. The patient must be asked about preexisting occlusal abnormalities such as a premature occlusal contact that caused the patient to "slide" into maximum interdigitation or an anterior open-bite or posterior cross-bite. Evaluation and matching of corresponding wear facets of the maxillary and mandibular teeth will demonstrate where the preexisting occlusion of that patient is achieved.

If the mandible is also fractured, the lower dental arch must first be stabilized and accurately related to the skull base, with proper alignment of the mandibular condyles in the glenoid fossae an absolute requirement. The anteroposterior position of the maxilla can then be set by occluding the teeth in stable MMF. The midfacial vertical dimension is stabilized by reduction and fixation of any fracture line between the palatoalveolar complex and the frontal bone. In those cases with subcondylar or condylar head fractures that cannot or should not be treated with open reduction, the midfacial buttress system can be reconstructed first, thus using the maxilla to establish the proper vertical and horizontal position of the occlusal plane. Although this sequence may not restore the relationship of the occlusal plane to the skull base with the same accuracy as that achieved if it is related to an intact or totally reconstructed lower arch, it is the preferred sequence if mandibular vertical ramus height cannot be accurately restored because of a condylar head injury.

The stepwise repair of the buttress system begins with an accurate anatomic reconstruction of the frontal bar, if necessary, including the zygomatic processes of the frontal bone, the supraorbital rims, and the glabellar region (Gruss and Phillips, 1989). Once this has been accomplished, the orbitozygomatic complexes can be reattached to the lateral ends of the bar, and reconstruction is continued inferiorly to the palatoalveolar complex, deep into the orbit, and medially to the nose and NOE complex. Although not a part of the maxilla, each zygoma must be accurately repositioned and stabilized before reattachment of the maxilla to the upper ends of the vertical buttresses. Often, zygomatic fractures associated with LeFort fractures of the middle third of the facial skeleton require open reduction and internal fixation of the zygomatic arch to position the zygoma correctly before reattachment of the maxilla. This is particularly critical in those cases in which mandibular condyle fractures necessitate reconstruction of the upper jaw first. Failure to recognize and correct the amount and direction of the displacement of the zygoma at the time of reduction in these cases not only will leave a flattened cheek and widened face, but also may produce a rotated and possibly tilted maxilla when it is reattached to a malpositioned zygoma. It should be reemphasized that the bone of the middle portion of the zygomatic arch is actually straight and must be reconstructed as such to properly reestablish anterior projection of the maxilla when it is reattached to the zygomata.

In addition to the accurate repositioning of both zygomata before final positioning and fixation of the maxillary segments, the integrity of the palate must be reestablished if necessary. Palatal fractures, most commonly parasagittal splits, must be reduced anteriorly at the inferior rim of the piriform aperture, as well as posteriorly, so that a solid, structurally accurate dentoalveolar complex can be related to the mandibular teeth. Open reduction and internal fixation of the anterior extent of a palatal fracture can be accomplished through the same extended gingivobuccal incision that is used to expose and repair the vertical buttresses. The bone above the anterior teeth is thick enough to place a miniadaptation plate with multiple screws. Occasionally, a small amount of bone can be removed immediately below the anterior nasal spine to facilitate placement of the plate, with a flat contour under the upper lip and base of columella.

The posterior extent of a palatal fracture can usually be reduced in a closed fashion if the overlying palatal mucoperiosteum is intact. However, difficulty may be encountered if it is necessary to overtighten the MMF wires to pull the lingual cusp tips of the maxillary molars and premolars into the central fossae of the mandibular teeth. In these cases an incision can be made over the posterior end of the palatal fracture and a transosseous wire placed across the fracture. This wire will not serve as a point of rigid fixation of the palatal fracture, but rather it will serve just to reduce the fracture gap posteriorly when it is tightened. Stable fixation is obtained from plates and screws placed across the anterior extent of the palatal fracture and across both ZM buttress areas (Fig. 23-10, C through E).

Palatal fractures that are exposed in a laceration of the mucoperiosteum are almost always widely separated and impossible to reduce without using a transosseous wire to pull the palatal shelves together posteriorly. If this method of reduction is not used, but rather tightening of the MMF wires is used to pull the teeth into occlusion, the maxillary teeth will most likely be lingually tipped or left in a posterior cross-bite deformity. The exposure through the laceration may be adequate to allow for placement of a plate across the split palate; however, this may be technically difficult, and these plates frequently become exposed in the mouth later and have to be removed.

Acrylic palatal splints are an essential adjunct for stabilization of teeth in a segment of maxillary bone separated from the palate by an alveolar fracture. Even if a rigid fixation device cannot be used to attach the isolated alveolar segment to the surrounding maxillary bone, the combination of a sturdy buccal arch bar, a palatal splint, and circumdental wires to cinch the involved teeth between the bar and the splint usually provides stability sufficient to allow for removal of MMF and a soft diet.

Only when the zygomatic and palatal fractures have been repaired can the maxillary complex be reattached superiorly. The reattachment should begin with the ZM buttress that has the less severe injury. Unlike the anterior wall of the maxilla, which is often severely comminuted, the ZM buttress is often traversed by a single fracture line that can be easily reduced or it has a single free-floating fragment that can be accurately related to the zygoma above and the lower maxilla below. Usually, at least one ZM buttress can be reduced in this fashion to set the correct vertical dimension of the middle third of the face. Following stabilization of this buttress, reduction and fixation of the other ZM buttress and the NM buttresses can proceed.

Comminution of the lower ends of the vertical buttresses severe enough to require bone grafting for stabilization is fortunately uncommon, although occasional cases will be seen in which gaps of 1 to 2 cm of missing bone will occur. Onlay split cranial bone grafts can be attached across these gaps with lag screws to serve the same function as a plate across reduced fracture lines. Naturally, reconstruction of vertical dimension cannot be done with the same precision in these cases as in those in which edge-to-edge approximation of fracture fragments is achieved. Reconstruction of the NM buttresses may facilitate reestablishment of vertical dimension in some cases. However, if the ZM buttresses are comminuted, the NM buttresses are invariably even more fragmented and difficult to realign.

Stability of the reattachment of the maxillary complex is similarly gained mainly through the reconstruction of the ZM buttresses. Reconstruction of the NM buttresses may provide some supplementary vertical stability to the overall reconstruction, but only if the upper confluence of these struts, that is, the NOE complex, is relatively intact. If plates and screws are used for fixation and the patient is allowed to function early, a delicate NOE repair should not be depended on to transmit occlusal forces to the skull base to strengthen fixation of the maxillary complex. Instead, the ZM buttress reconstructions must be relied on to hold the repositioned maxilla in place during healing. Plates must be positioned to overlie the ZM buttresses as closely as possible, and three screws should be used to anchor the plate to the zygoma above and the maxilla below. Placement of screws into the lower end of a plate or a bone graft may be difficult if the fracture line closely parallels the apices of the molar and premolar teeth. This problem can usually be overcome by using L-shaped plates that allow for placement of more screws close to, but not through, the root tips. Bone grafts can be contoured and positioned to allow for similar placement of lag screws.

Rigid fixation is a nonforgiving technique that will not allow for postoperative adjustment of the position of the maxilla by the patient's own muscle pulls or with orthodontic traction on arch bars. Therefore any error in adaptation or application of the plates and screws to the bone will permanently fix the maxilla in an undesirable relationship to the skull base superiorly and the mandible inferiorly (Stanley and Funk, 1988). This may lead to occlusal and cosmetic disturbances unless recognized and revised immediately. Assuming that the correct interdigitation of the teeth is established by the temporary MMF, malunion of maxillary fractures treated with rigid fixation devices may result from either inaccurate adaptation of the plates to the midfacial bony contours or failure to have one or both mandibular condyles seated in the glenoid fossa in the correct centric occlusion position when the plates are applied. If the plates are not perfectly adapted to the bone, tightening of the screws may produce torque in the system, and the fragments may move to produce a malocclusion when the MMF is removed. This potential problem has been all but eliminated with the replacement of the stiff, hard to bend stainless steel plates with more malleable, easier to adapt plates such as the 2.0 mm AO/ASIF titanium craniofacial plates.

The potential problem of inaccurate condylar seating in the glenoid fossae must be considered by the surgeon in all cases. Patients with complex maxillary injuries may suffer a deranged occlusal relationship that is difficult to correct. Invariably, one or both mandibular condylar heads will be displaced from their normal centric occlusion position in the glenoid fossae if the MMF is used to "pull the patient into occlusion". In such a case, even though the plates are accurately adapted to the malpositioned maxillary fragments, a malocclusion will develop when the MMF is removed and the patient's normal muscle balances return the mandible to its correct position (see Fig. 23-11). Even if a gross malocclusion does not result and the patient learns to function in this altered position, chronic joint discomfort is likely to develop.

An altered relationship within the temporomandibular joint may also be a problem in patients who have associated mandibular injuries. Edema, effusion, or hematoma may be present within the joint structures, displacing the condylar head to an abnormal position. This produces a risky situation in the use of rigid fixation on the maxillary fractures. In cases where doubt exists regarding the position of the condylar heads within the glenoid fossae, plates and screws should be used to rigidly fix any LeFort III or zygomatic fractures, and then wire osteosynthesis should be used for the LeFort I and II components. Although the patient must endure MMF for 4 to 6 weeks, the semirigid fixation at the maxillary level of the buttresses allows a shift of the occlusal plane into a proper relationship with the skull base during the early postsurgical period.

Orbital walls

Reconstruction of the orbital walls can begin only after total reconstruction of the zygoma and any other injuries of the horizontal and vertical buttress system. This includes an accurate anatomic reconstruction of the frontal bar. Orbital roof fractures are repaired with the surgeon keeping in mind a key difference regarding fracture reduction in other sites. Whereas the goal for reconstruction of the lateral, inferior, and medial walls of the orbit is an exact reconstruction of contour and position, the goal for reconstruction of the roof is to position it higher than its pretrauma level. The normal upward convexity of the roof is difficult to duplicate, and a reconstructed roof that appears to be at the correct level often will be too flat later, thus pushing the globe inferiorly. This problem is avoided if the rebuilt roof is attached to the frontal bar at a level approximating the maximum height of the convexity of the roof, rather than the lower level at which it normally attaches anteriorly.

The zygomatic contribution to the lateral orbital wall most often remains attached to the body of the zygoma and is correctly rearticulated to the greater sphenoid wing with proper reduction of the zygoma. In the unlikely event of a displaced sphenoid wing fracture, the intact lateral wall component of the zygoma can be used as a landmark for repositioning the orbital plate of the sphenoid bone. Only rarely will an alloplastic or autogenous graft be needed to reconstruct a lateral wall defect to correct herniation of orbital soft tissues into the temporal and infratemporal fossae. However, if a high-impact injury does produce comminution and displacement of the lateral orbital wall, a split calvarial graft is the ideal choice for graft material. Because a lateral approach must be used to safely expose these retrobulbar bone injuries, the calvarial donor site is already in the surgical field. Additionally, a relatively flat area of skull can usually be found to produce a graft that closely matches the contour of the lateral orbital wall. Once inserted, the graft can be stabilized to the frontal bone or the zygoma with fine-gauge, stainless steel wire.

The orbital floor projection of the zygoma usually remains intact and is also restored to a normal position when the zygoma itself is repositioned. The medial floor (orbital plate of maxilla) can then be reconstructed using the intact lateral floor as a stable landmark. Reconstruction of a defect involving only the concave anterior aspect of the floor can usually be adequately accomplished with an alloplastic implant. Dissection of the floor must expose the entire circumference of the defect so that a 360-degree ledge is present to support the implant. Of the various alloplasts available, Marlex mesh has many properties that make it an ideal choice. It is readily available, is easily trimmable, and can be inserted in a layered fashion to create additional strength. Most importantly, clotted blood and eventually fibrous tissue fill the mesh to prevent implant migration, without the need for fixation of the implant to the orbital rim or residual floor.

Reconstruction of defects of both the concave anterior and convex posterior floor requires an implant with rigidity greater than that offered by Marlex. This is due to the frequent lack of a ledge of residual floor to stabilize the implant posteriorly or medially, even when the orbital floor dissection is carried well into the posterior third of the orbit. A split calvarial graft is ideally suited for reconstruction of these larger defects. This bone is easily contoured to match most large floor defects, and its rigidity eliminates the need for medial and posterior support. The graft may be stabilized by attaching it to the orbital floor projection of the zygoma with one or two lag screws or to the reconstructed orbital rim with miniplates and screws. It should be emphasized that the calvarial bone graft will not restore accurate position of the globe if the surgeon is hesitant in floor dissection and does not venture the sometimes necessary 35 to 40 mm into the posterior third of the orbit to allow for maximal reconstruction of the convex posterior floor (see Fig. 23-5).

Reconstruction of defects that involve the concave anterior floor, convex posterior floor, and medial orbital wall (lamina papyracea) offer the greatest challenge. Although these severe orbital injuries are usually seen as part of a panfacial fracture, they may occur with isolated orbitozygomatic injuries. Complete exposure of the medial wall of the orbit is mandatory and is best accomplished through a coronal incision. Reconstruction is made difficult by the need to restore not only the integrity of walls themselves but also the exact relationship of the medial wall to the floor. Cranial bone grafts are often too rigid for use in this situation because they cannot be bent without fracturing. Although it is possible to use two calvarial grafts joined together by a miniplate to re-create a relatively correct medial wall-to-floor relationship, an alternative way to achieve the desired contour is to use one or two split rib grafts. These grafts can be bent to the desired contour with the use of Tessier rib benders or multiple ostectomies without loss of rigidity sufficient to support the orbital soft tissues. The rib grafts may be stabilized laterally by attaching them to the orbital projection of the zygoma with lag screws or to the reconstructed orbital rim with miniplates and screws. Medially, the ends of the split ribs can be wedged against any remaining medial orbital wall for stabilization. In cases with severe injuries to the lamina papyracea, the ribs may have to extend superiorly to the frontal bone to completely fill the defect. A recent innovation that may simplify this type of reconstruction is the prefabricated titanium orbital floor plate that acts as a cradle for bone implants, thus greatly facilitating placement and stabilization (Glassman et al, 1990).

Nasoorbitoethmoidal complex

Repair of NOE fractures requires reconstruction of the medial orbital area and nasal dorsum in preparation for redraping the overlying soft tissues and reattachment of the MCT. The reattachment of this complex tendon with its delicate functional and aesthetic roles is not a simple matter of realigning bony fragments and grossly reattaching the end of the tendon to its approximate site of insertion. It must be remembered that in the undisturbed state the MCT has three components that surround the lacrimal sac in the lacrimal fossa and that each component has a different vector of attachment. Disruption of each vector adds a different feature to the resultant dysfunction of the MCT, particularly in its aesthetic role. Although it is impossible to reattach each component individually, understanding of the vector analysis of the MCT will allow the surgeon to design compensatory maneuvers to more precisely restore the appearance of the medial canthal area (Rodriguez and Zide, 1988).

Impact velocity appears to be a major determinant of the severity of the NOE injury and the needed repair (Manson, 1991). Low-velocity injuries will often be unilateral and create a minimally to moderately displaced large fragment composed of the frontal process of the maxilla, lacrimal bone, and anterior-most portion of the lamina papyracea (Fig. 23-12). The attachments of all three components of the MCT should therefore remain intact, and repair consists of realignment and fixation of the bone fragment. The approach to the injury usually requires only a subciliary incision, but a sublabial incision may be necessary to allow for application of instrumentation needed to completely rotate the fragment into position.

Occasionally, transnasal wiring will be necessary to pull the posterior edge of the fragment into exact alignment. Fixation can be accomplished with fine-gauge, stainless steel wire or a microplating system (screws 1.0 mm or less in diameter). Application of microplates in this area often proves to be much simpler than the passing of multidirectional wires because of the maze of soft tissue structures and bony fragments around and through which the wires must be passed. Closed reduction and external splint stabilization are often all that are needed for the nasal bone aspect of the NOE fracture.

Medium-velocity injuries may be unilateral but more often are bilateral and will similarly create a moderately displaced large fragment in the area of the MCT attachment. However, this fragment will usually be composed of only the frontal process of the maxilla and a portion of the lacrimal fossa, with the site of attachment of the posterior horizontal component of the MCT destroyed (see Fig. 23-12, C). The anterior horizontal and vertical components will usually remain attached to the frontal process of the maxilla, but a partial avulsion is common. Realignment and fixation of the bony fragments require a combination of subciliary, sublabial, and coronal incisions. Local incisions are used only when lacerations have occurred in the area or in males with an unstable hairline. Fixation is again accomplished with either fine-gauge wire or microplates and screws.

Although reduction and fixation at this point should have returned two of the three components of the MCT to their correct positions, the posterior horizontal component detachment still has not been addressed. If no further MCT repair is performed, the inner canthus will be left slightly forward of its normal position and it may have a noticeably blunted appearance. Also, the medial-most aspect of the lower eyelid may stand away from the lacrimal lake. The vector of pull of the posterior horizontal component is re-created with a transnasal 28-gauge wire that is initially passed around the anterior horizontal component of the tendon (see Fig. 23-12, C). Access to the tendon is obtained through a small skin incision made 2 mm medial to the inner canthus (Rodriguez and Zide, 1988). A small curved needle is then used to carefully pass the wire above and below the tendon to loop the tendon just medial to the lacrimal sac. Both ends of the wire are then passed transnasally through a spinal needle that has been pushed through a hole drilled with a long 2.0 mm or 2.7 mm drill bit. The drill is aimed from the superomedial aspect of the contralateral orbit across to the presumed pretrauma location of the ipsilateral posterior lacrimal crest. The spinal needle is removed, and both ends of the wire are pulled equally taut. While the position of the medial canthus is being directly visualized, the ends of the wire are tied around a 1.5 mm screw placed into the thick cortex of the nasal process of the frontal bone, just above the passage hole of the transnasal wires (Fig. 23-13).

Bilateral injuries are treated in the same fashion, with the transnasal wire from each side being anchored independently in the contralateral orbit. This greatly facilitates tightening of the wires and eliminates the possible need to redo both repairs if one transnasal wire is broken during the tightening process. Of course, the tightening of these wires is not done until reconstruction of the deeper aspect of the medial orbital wall is completed. Closed reduction and external splint stabilization are usually sufficient for the nasal bone injuries in these cases. However, severe comminution of these bones combined with posterior telescoping of the nasal septum can be present, necessitating placement of a dorsal nasal bone graft that can be cantilevered from the frontal bone with lag screws or a microplate and screws.

High-velocity force will produce severe comminution of the entire NOE complex with unilateral if not bilateral detachment of all three components of each MCT (see Fig. 23-12, D). Repair is started with reconstruction of the frontal processes of the maxilla and medial orbital walls with available bone fragments or bone grafts if necessary. In these cases, microplates and screws facilitate the repair and provide greater stability for the subsequent MCT repair than do multiple interosseous wires. A hole is left in both medial walls immediately above and behind the normal location of the posterior lacrimal crest. The location of these holes is determined by the vector analysis of a completely detached MCT complex, which shows that the tendon must be repositioned posterior and superior to its location in the undisturbed state to simulate the combined pull of the three components (see Fig. 23-4) (Rodriguez and Zide, 1988). Transnasal wires are used to pull the tendons into the holes (see Fig. 23-12, D through F). Because the force of the pull on these tendons will be greater than on partially de-tendons, the wires should be tied rather than simply looped around them. This helps to prevent the wire from sliding medially along the tendon away from the lacrimal sac. Each wire should be anchored in the contralateral orbit while the medial canthal areas are being observed for symmetry. It is virtually impossible to overcorrect a totally detached MCT complex (Sargent, 1991). In fact, a patient who appears to be properly positioned in the operating room will frequently appear undercorrected when the edema resolves. Bone grafts cantilevered from the frontal bone may be used in these cases to reconstruct the frontonasal angle and nasal dorsum.

lacrimal collection system injury with subsequent dysfunction is a surprisingly uncommon sequela of all but the most severe NOE fractures. If such an injury is suspected or recognized at the time of the initial fracture reduction and fixation, repair is probably best delayed in favor of the optimum MCT repair that can be achieved (Gruss et al, 1985a). An attempt at simultaneous lacrimal system repair will invariably lead to a compromised MCT repair. A secondary reconstruction of the MCT complex is usually more difficult and less successful than a primary repair, whereas secondary lacrimal repairs have proven to be very efficacious. Iatrogenic injury to the lacrimal sac is a possibility, but a thorough understanding of the tripartite structure of the MCT and its relationship to the medial orbital wall should prevent this.

Mandible

Traditional treatment of most fractures of the mandible has included a 6-week period of total jaw immobilization with MMF. This was true whether the fracture was considered to be favourable and nondisplaced (thus not requiring open reduction) or unfavorable and displaced (thus requiring open reduction and probably fixation with a transosseous wire) (Clark and Bailey, 1984). Because the mandible resembles the long bones of the extremities in that it is a sturdy, bicortical structure, it was only natural that rigid fixation techniques used for long bone fractures would eventually be adapted for mandibular fractures (Spiessl, 1976). Initially, relatively thick plates and large (2.7 mm) bicortical screws (with a minimum of two screws on both sides of the fracture) were used to provide a very stable and rigid form of fixation for the mandible. In addition, the fixation devices were most often designed so that compressive forces between the bone ends would be generated through a specifically engineered interaction of the screws with the plates. This compression allowed the bone to share the functional forces with the metallic devices and thus reduced the chances of implant failure. Because these compression plates by anatomic necessity had to be placed on the lower border (compression side) of the mandible, it was necessary to maintain additional fixation along the upper border to prevent separation of the fracture. This additional fixation was either an arch bar (tension band splint) attached to the teeth across the fracture line if the fracture occurred between the teeth or a smaller plate (tension band plate) if it occurred posterior to the teeth. This form of fixation facilitated primary bone healing and allowed for immediate removal of MMF, thus allowing the patient to function with the stabilized mandible in the early postoperative period.

A subsequent modification of the rigid fixation technique has featured the use of smaller, more easily bendable plates and smaller (2.0 mm) screws, sometimes placed in a monocortical fashion. This less rigid form of fixation is often used in conjunction with a 2- to 4-week period of MMF. Also, lag screws across the fracture line have been used for certain strategically located fractures, providing adequate stability to allow for immediate mobilization of the mandible (Ellis and Ghalli, 1991a; Niederdellmann and Shetty, 1987). It is well recognized that no matter which rigid fixation technique is used, the incidence of complications, including infection, nonunion, malunion, and malocclusion, will increase disastrously if the surgeon is not thoroughly trained in the indications, techniques, and instrumentation of the technique.

Treatment of isolated mandibular fractures, whether with closed reduction or open reduction and internal fixation, is greatly facilitated by an intact maxilla. As previously mentioned, with two-jaw injuries, the variable position of the condylar heads in the glenoid fossae comes into play, and MMF does not guarantee that maximal intercuspation of the teeth will restore the occlusal plane to its correct relationship to the skull base. This is particularly problematic when the mandibular injuries include fractures of the head or neck of one or both condyles. However, with an intact maxilla, the relationship of the occlusal plane to the skull base remains undisturbed, and MMF wires *can* indeed be used to "pull the patient into occlusion". Again, a knowledge of the pretrauma occlusion is very helpful so that inadvertent and time-consuming attempts to correct preexisting malocclusion will not occur.

Because of the importance of MMF in setting and maintaining occlusion, application of a secure set of arch bars is critical. A malleable bar must be firmly attached to both dental arches using prestretched 25-gauge circumdental wires. If possible, a ligature should be placed around each first molar, premolar, and canine. If teeth are missing, the bars can be extended posteriorly so that second molars can be ligated or the incisors can be used. Use of the incisors to resist MMF pulls on a long-term basis is not advisable, because the slender, conical, uniroot incisor structure predisposes the maxillary lateral incisors and all mandibular incisors to loosening in their sockets. Circumdental attachment of the arch bars can be greatly reinforced with circummandibular wires and piriform aperture suspension wires (Fig. 23-14) if rigid fixation is not being used and the patient will remain in MMF for 6 weeks. The MMF, whether wire itself or orthodontic elastics, can be applied around the curved hooks of the arch bars, but the actual resistance to the MMF forces is carried out by the circummandibular and piriform wires. This will maintain very solid jaw-to-jaw fixation even in a partially edentulous situation.

If rigid fixation is to be used and MMF will be only a temporary intraoperative condition, application of a stable set of arch bars is still essential. During fixation of the fractures with plates and screws, the interocclusal relationship set by the temporary MMF must remain undisturbed if iatrogenic occlusal discrepancies are to be avoided. Ivy loops and Essig wires may be excellent means for temporary stabilization of the jaws before surgery, but they do not offer adequate stability during surgery.

In most instances the arch bars can be applied and all circumdental wires tightened before exploration of the fracture site. However, occasionally the fracture fragments will be locked in a displaced position by overlapping bone edges or interposed soft tissue, and closed reduction to allow for alignment of the occlusal plane is not possible. Exposure of the fractures to allow for direct manipulation of the fragments before final application of the arch bars and MMF will therefore be necessary in these cases. Such simultaneous intraoral and external open manipulation of a mandibular fracture has been thought to increase the risk of wound infection and nonunion of the fracture. However, all mandibular fractures involving the tooth-bearing body are already contaminated through lacerations in the gingiva and periodontal ligaments of involved teeth. Also, fractures can be widely exposed and repaired through transoral approaches without increased risk of infectious complications. Therefore, although infectious complications usually involve oral organisms, contamination of the wound at time of surgery is usually not the principal cause, but rather a delay in treatment (both antibiotic and surgical) or failure to adequately stabilize the fracture fragments is primarily responsible for infections.

Broad-spectrum antibiotic therapy (penicillin or a cephalosporin) should be started and a form of jaw immobilization (preferably arch bars and MMF) should be applied as soon after the injury as possible. Nondisplaced, favorable fractures treated with closed reduction can then be managed on an outpatient basis, with a follow-up panoramic tomogram to be obtained 1 week later to confirm that fracture alignment has been maintained. Patients with displaced fractures are best treated as inpatients with intravenous antibiotics begun immediately and definitive open reduction with a form of internal fixation accomplished within 3 to 5 days. Longer delays, especially in patients with severely comminuted fractures and large oral lacerations, greatly increase the chances that the fracture sites will become infected, with a resultant increase in the difficulty of the surgery and a higher complication rate.

A tooth in fracture line and teeth immediately adjacent to the fracture must be evaluated and treated individually. It must be determined whether the root of the tooth is fractured, whether it is still firmly attached to one of the bone fragments by residual periodontal ligament, and whether the tooth will aid in reduction and immobilization of the fracture. A single molar tooth in a posterior fragment may be essential to prevent superior displacement by the elevator muscle group. The canine tooth, positioned at the corner of the dental arch, may be essential in stabilizing parasymphyseal and anterior body fractures. A tooth that is salvageable, possibly with endodontic therapy, and that will be an important factor in stabilizing the fracture reduction should be retained. A tooth that has a questionable prognosis, even with immediate or delayed endodontic therapy and with minimal contribution to stabilization, should be considered nonessential. Such teeth probably should be removed if the extraction can be performed without seriously distracting the fracture (Stanley, 1984). The need for extraction must be assessed for each patient and placed in the context of the likelihood that the patient will actually seek out and receive the dental care necessary for the long-term preservation of the tooth (Dierks, 1991).

Once nonsalvageable teeth have been extracted and stable MMF established, a decision must be made regarding the use of an intraoral or extraoral approach to the fracture. Fractures that occur in the anterior mandible between the mental foramina are ideal for reduction and fixation through a transoral approach. Although fractures in this area do not fit into the favorable/unfavorable classification system for lateral fractures, most should be considered unstable because of the bilateral muscle pulls to which they are subjected. Internal fixation is therefore usually indicated. An incision is made several millimeters below the junction of the attached and free gingiva, low enough to leave sufficient tissue attachment to bone to accommodate sutures when the mucoperiosteal flap is repositioned, but high enough to prevent damage to the buccal sulcus. The entire anterior surface of the mandible can be exposed with direct visualization of both mental nerves possible (Fig. 23-15).

Fixation can be obtained with an interosseeous wire (and 6 weeks of MMF) or with a compression plate placed along the lower border using bicortical 2.7 mm screws. Successful fixation allowing for immediate jaw mobilization has also been reported with long lag screws (Ellis and Ghali, 1991a) and smaller plates attached with monocortical 2.0 mm screws (Champy et al, 1978). These latter two techniques are made possible because the fixation devices are being attached to the mandible anterior to the mental foramina, and therefore the inferior alveolar neurovascular bundles are not at risk for damage. The level of attachment can be moved superiorly on the mandible to lie within the tension zone of fracture distraction, and therefore less sturdy devices can be used. A knowledge of the average root length of each anterior mandibular tooth (available in all dental anatomy texts) is required to safely perform these techniques.

The transoral approach to anterior fractures eliminates the need for a submental incision and also the risk of damage to one or both marginal nerves if the incision must be extended into the submandibular triangle area for adequate exposure. However, treatment of fractures near or through the mental foramen by way of the intraoral approach presents the increased risk of damage to this sensory nerve from excessive traction or direct trauma during drilling, tapping, and screw insertion. The status of this nerve must be documented before surgery, and the patient must be warned to expect a transient decrease in function postoperatively if sensation has remained intact following the fracture.

The transoral approach also prevents direct inspection of the lingual surface of the mandible. Therefore a butterfly type of fracture with a single linear defect in the buccal cortical plate and a large free-floating fragment in the lingual cortical plate may be overlooked, and attempts to insert bicortical screws for attachment of a compression plate may actually produce fracture line displacement or inadequate fixation stability. If a comminuted fracture is recognized, a compression plate cannot be used, but a more rigid reconstruction type of plate must be applied if immediate mobilization is desired. A second limitation of the intraoral approach is the difficulty of inspecting the lingual cortex adequately to ensure the accuracy of reduction. If the patient is only partially dentulous and the number of stable occlusal contacts limited, or if there are associated maxillary and palatal fractures, failure to close the lingual cortical displacement may produce a widening of the face at the level of the mandibular angles. However, with these possible problems in mind, the surgeon should find with experience that the transoral approach to anterior fractures is preferable to an external approach in most patients. The application of plates across fracture lines is actually easier than complex figure-of-eight wiring because a lingual dissection and retrograde passing of the wire are avoided.

A second type of fracture that should be considered for a transoral approach is the minimally to moderately displaced angle fracture. This fracture can usually be adequately exposed, reduced, and stabilized through a vertical incision along the anterior border of the ascending ramus of the mandible, extending for a short distance down the lateral oblique line of the buccal surface of the body. Subperiosteal dissection is carried over the buccal surface of the proximal and distal fracture edges, and soft tissue is freed from the fracture line. A bone-holding forceps can be applied to the ramus and the fracture pulled into reduction. Third molars in the line of fracture are evaluated and managed by the previously described criteria. Fixation can be obtained with an upper border buccal wire through the third molar socket if the tooth is extracted (along with 6 weeks of MMF), a long lag screw (Ellis and Ghali, 1991b; Nierderdellmann and Shetty, 1987), or small plates attached along the ascending ramus and oblique line with 2.0 monocortical screws (Champy et al, 1978). Controversy exists whether patients treated with the smaller plates should be allowed to function immediately or whether a shortened (2 to 4 weeks) period of MMF is needed. Larger compression plates can also be placed transorally along the lower border of the mandible with 2.7 mm screws in conjunction with a smaller upper border tension-hard plate to allow for immediate mobilization. However, this technique should not be attempted by inexperienced surgeons because the screws must be placed transbuccally and the lower border plate may be difficult to position properly. This greatly increases the risk of placing a screw through the inferior alveolar neurovascular bundle.

Reduction of moderately to severely displaced angle fractures can also be problematic through the transoral approach. An external approach offers greater access to the fragments in these cases and greatly facilitates correct application of large compression plates. Access to the angle can be achieved through a standard Risdon approach or through a modified Risdon approach (Fig. 23-16) (Ardrary, 1989). The combination of the two approaches creates a gently curving incision that follows natural skin lines to produce wide exposure of the ascending ramus, angle, and posterior body of the mandible. During deep dissection, the anterior border of the sternocleidomastoid muscle is identified and the tail of the parotid gland is retracted forward. The lateral aspect of the platysma is incised well away from the lower border of the mandible, and the marginal branch of the facial nerve is therefore retracted upward with the gland and upper cervical flap.

Elevation of the masseter muscle is necessary for drilling the holes and placement of a transosseous wire or a compression plate. Dissection in the lingual surface of the mandible is unnecessary if plates and screws are to be used, other than a finger dissection over the major vessels to allow for placement of a protective malleable retractor. After fixation is completed, the masseter muscle is reattached with slowly absorbing sutures placed through its lower border and carried around the mandible to the fascia of the lateral pterygoid muscle. A small drain that can be attached to bulb suction is positioned in the depths of the wound in each case and brought out through a small separate stab incision. A meticulous layered closure of the wound is then carried out.

Displaced, unfavorable fractures of the body of the mandible posterior to the mental foramen usually require an external approach. Although it is possible to apply even large compression plates to fractures in this area by way of a transoral approach combined with the transbuccal insertion of screws, the location of the mental nerve places it exactly in the way of visualization, manipulation, and stabilization of the fragments. An external approach greatly facilitates repair of body fractures, and it is typically done through a transverse upper neck incision placed approximately 2.5 cm below the lower border of the body, centered below the fracture site. The marginal mandibular nerve is protected during elevation of the upper skin flap either by using the facial nerve stimulator during the subplatysmal dissection or by maintaining the level of the dissection immediately on the lateral surface of the submandibular gland up to the lower border of the mandible. A longer incision will be required for application of a compression plate than for insertion of a figure-of-eight wire across the fracture site. Closure and drainage are accomplished in the same fashion that was described for angle fractures.

Treatment of condylar neck fractures has remained the most complex and controversial issue in mandibular fracture management. Although there is general agreement about conservative, closed management with early mobilization for intracapsular, that is, condylar head, fractures, numerous series now argue against the across-the-board use of this management for all extracapsular, that is, condylar neck, fractures (Klotch and Lundy, 1991). Open reduction and internal fixation are usually indicated when there is (1) displacement of the condylar head from the glenoid fossa, (2) mechanical obstruction of jaw opening caused by a displaced condylar head, (3) telescoping of the proximal and distal fragments with loss of vertical ramus height resulting in malocclusion, and (4) displaced bilateral subcondylar fractures with malocclusion (Ardrary, 1989). Of note, these indications make no mention of attempting to prevent future dysfunction within the temporomandibular joint itself, with the possible exception of the condylar head completely displaced from the fossa. To date, there is no proof that any form of surgical therapy to realign a fractured condylar neck decreases the incidence of future degenerative problems within the joint, and in fact surgical exploration of the joint may worsen the damage if done injudiciously.

The standard treatment for most unilateral condylar neck fractures is a short period of MMF (10 to 14 days) followed by progressive mobilization with placement of elastics at night for an additional 2 weeks. Rigid fixation techniques should be applied to any accompanying body or angle fractures to ensure that early mobilization is possible. Four specific situations in which open reduction with internal fixation of condylar neck fractures should be considered are (1) a unilateral or bilateral condylar fracture with severely comminuted midfacial fractures (see discussion of maxillary fractures); (2) a comminuted symphysis fracture and condyle fracture, with associated tooth loss; (3) a displaced condyle fracture in mentally retarded or medically compromised adults (that is, those for whom MF would not be desirable) with evidence of open bite or retrusion; and (4) an edentulous or partially edentulous mandible with posterior bite collapse and a displaced condyle (Zide, 1989).

The approach to the condylar neck, when indicated, is through the incision used for an angle fracture, although it does not have to be carried as far inferiorly. The submasseteric dissection must be carried higher on the ramus to allow adequate exposure of the proximal fragment, but specific identification of the main trunk of the facial nerve (Klotch and Lundy, 1991) is usually not necessary. The mandible may be grasped at the angle and pulled away from the condyle with a bone-holding forceps or with a transosseous wire to facilitate identification and mobilization of the condylar neck segment. Plate and screw (2.0 mm) fixation offers the most effective method of holding an anatomic reduction, and the patient should be able to mobilize the mandible immediately. As with all rigid fixation implants, a minimum of two screws must be placed above and below the fracture line. Therefore preoperative evaluation must establish that the fracture is not as high as the level of attachment of the joint capsule to the condyle neck. Occasionally a percutaneous transparotid approach may be required for placement of the screws into the proximal fragment. If plate and screw fixation is done with careful, blunt dissection through the parotid and appropriate transbuccal instrumentation, there should be little risk of injury to the branches of the facial nerve.

Comminuted fractures of the mandible, whether the result of blunt trauma or gunshot wounds, usually are associated with serious intraoral soft tissue injuries. Therefore these fractures are at greatest risk for infection, sequestration, and nonunion. This is particularly true for body fractures, whereas angle/ramus and parasymphyseal comminuted fractures tend to do well.

Angle/ramus comminuted injuries are particularly well suited for open reduction and internal fixation with a sturdy reconstruction plate if the proximal condylar segment is large enough to accommodate two 2.7 mm screws. This is ideal treatment for gunshot wounds with associated injury to the muscles of mastication, since early mobilization will usually avoid trismus later (Fig. 23-17). Facial nerve injuries can be repaired concurrently. Sequestration of devascularized fragments of the ascending ramus usually does not occur, because they are covered by the masticatory muscle sling and are not in a dependent area that will be bathed by saliva if the oral wound closure dehisces. Comminuted parasymphyseal fractures also tend to do well although they are in a dependent area. There are numerous muscle attachments in the area that usually remain closely adherent to the bone fragments to maintain some vascularity. Also, the most severe comminution generally involves the alveolus, which is usually vigorously debrided to reduce the chances of sequestration and infection.

Comminuted body fractures, however, usually contain large devascularized fragments with vital molar or premolar teeth. An attempt should be made to salvage all the fragments if possible, knowing that some may later sequester and require debridement. Reduction of these fragments requires an open approach, and fixation with plates and screws may actually carry less risk of further devascularization than does the placement of transosseous wires. Less additional devascularization occurs because the lingual periosteum does not have to be elevated for insertion of screws. Therefore a sturdy reconstruction plate that bridges across the comminuted area from stable proximal segment to stable distal segment is the preferred way to manage these injuries. The plate will maintain the dimensions of the mandible even if some bone is eventually lost and a secondary reconstruction is required.

Edentulous mandible

Fractures of the edentulous mandible are often treated with closed reduction and immobilization using the patient's dentures or a preformed Gunning splint. The dentures or splints are attached to the mandible with circummandibular wires and to the maxilla with piriform or circumzygomatic wires. MMF is then established between the dentures or splints. Although this form of treatment leads to successful healing in most cases, it may be very uncomfortable and severely restricts oral intake in patients who may already be nutritionally compromised. Open reduction and internal fixation using compression plates with 2.7 mm screws have been demonstrated to be successful in jaws with a vertical height of at least 2 cm (Levine, 1987). Atrophic mandibles less than 2 cm in height can also be treated with rigid fixation, but longer reconstruction plates with more screws to resist distractive forces should be used. Also, simultaneous bone grafting to augment the atrophic mandible should be considered if no violations of the oral mucosa have occurred.

Pediatric Fractures

Fractures of the jaws in children are usually best treated with closed reduction and 2 to 3 weeks of MMF. The accelerated healing patterns in children and the short period of required MMF, as well as the presence of unerupted teeth in the body of the mandible and lower maxilla, argue against open reduction and internal fixation in patients with primary and mixed dentition. Also, a minor degree of malalignment with occlusal discrepancy is tolerable in these patients, since growth and possible preventive orthodontic care will usually correct tooth malposition and malocclusion. Open reduction in children should be reserved for severely displaced maxillary and mandibular fractures. Unilateral condylar fractures require only rest and a soft diet, whereas bilateral condylar fractures may require a 2-week period of MMF with elastics to bring about a correct lower jaw position. The pediatric condyle is famous for its ability to remodel and assume a near-normal appearance with conservative management. However, the parents must be alerted to potential growth disturbances that can lead to underdevelopment of one hemimandible with deviation of the chin to the side of the condylar injury.

The philosophy of management for frontal, orbitozygomatic, and NOE fractures is the same as that for adults. The micro-plating systems now available are ideal for stable fixation in these patients (Crockett and Funk, 1991). Again, the parents must be warned that growth disturbances, mainly maxillary retrusion, may occur secondary to severe nasoseptal and maxillary injuries.

Summary

The intent of treating fractures of the facial skeleton is to restore the aesthetic appearance and function. The use of newly developed diagnostic and surgical methods does not automatically ensure improved results and may indeed increase the risk of iatrogenic injuries if they are incorrectly applied. The surgeon must be skilled in the selection and use of both traditional techniques and the newer rigid fixation methods for all types of fractures. A surgeon may be hesitant to perform the extended access approaches in hopes that any facial asymmetry resulting from incomplete fracture reduction will be imperceptible. However, the range of imperceptible asymmetry is small, and the surgeon should not accept suboptimal results that may have been improved with a more aggressive reconstruction.

Reduction and fixation of each individual fracture line or fracture-dislocation should not be viewed in a segmentalized fashion, but rather as a step in the progressive reconstruction of the entire facial skeletal complex. It is of prime importance that the trauma surgeon possess an ability to conceptualize the reconstruction three dimensionally as it is proceeding and to work safely around all of the vital soft tissue structures contained within this complex skeletal unit.