Chapter 160: Trauma to the Middle Ear and Temporal Bone

Sam E. Kinney

The middle ear and temporal bone are often involved in accidents involving trauma to the head. The accidents most frequently encountered are those involving motor vehicles; however, industrial and athletic injuries may also present potential lesions in the temporal bone and middle ear. Appropriate use of safety devices, both in automobiles and in industrial and athletic activities, to protect the skull and head from trauma may eliminate many of these problems; however, compliance with advised safety precautions is often not adequate.

The temporal bone and middle ear are composed of very dense bone. The source of the injury that may involve the temporal bone must be of rather intense force. Relativelly minor blows to the head would rarely effect a significant injury to the temporal bone and middle ear.

The type of injury seen with trauma to the head may be classified into two major categories: blunt trauma to the skull and penetrating trauma to the skull. The nature of the injury will vary considerablybased on the type of trauma delivered directly to the head.

Blunt Trauma

Blunt trauma to the skull most frequently occurs as the result of the head being thrown against a solid or semisolid object, or an object being thrown directly at the head. Soft tissue injuries of the external auditory canal may occur with blunt trauma, particularly trauma that is glancing in nature, that is, delivered in a sharp angle to the side of the head as opposed to a 90-degree injury. Fractures of the external auditory canal, middle ear structures, otic capsule, and structures surrounding the otic capsule may occur from blunt trauma. The most common form of temporal bone fracture, occurring from blunt trauma, is the longitudinal fracture of the temporal bone. It is estimated that 70% to 90% of temporal bone fractures are longitudinal (Cannon and Jahrsdoerfer, 1983; Dolan, 1989; Nelson, 1979). These fractures most commonly result from direct lateral blunt trauma to the skull in the parietal region of the head. In considering the effect of a fracture of the skull and its relationship to the temporal bone, it is helpful to think of the fracture occurring initially in a weaker portion of the calvarium, such as the squamous portion of the temporal bone, and the fracture line extending toward the temporal bone. Recognizing that the otic capsule is extremely dense bone, the fracture will course around the otic capsule, taking the course of least resistance. The course of least resistance usually involves major foramina in the skull base, the most common being that of the carotid artery and the jugular bulb. Fractures are frequently near the roof of the external auditory canal and run parallel along the petrous apex extending anteriorly to the foramen lacerum and the carotid artery. The line may also extend into the temporomandibular joint region (Fig. 160-1).

Longidutinal fractures

In a longitudinal fracture, the most frequent structures involved are the tympanic membrane, the roof of the middle ear, and the anterior portion of the petrous apex. The fracture line may involve a portion of the fallopian canal, most frequently in the tympanic portion, but may also occur in the mastoid portion (Grobman et al, 1989). The facial paralysis is most often delayed in onset, secondary to trauma and edema as opposed to direct interruption of the nerve.

Longitudinal fractures most frequently traverse at some point through the middle ear and commonly may cause disruption of the middle ear ossicles, creating a conductive hearing loss. Sensory neural hearing loss is a relatively uncommon finding with longitudinal skull fractures. Schuknecht (1974) has noted that minor sensory neural hearing loss, particularly involving high tone above 3000 to 4000 Hz, is seen in this type of injury. Sckuknecht believes that the loss is due to a concussive effect on the cochlea as opposed to direct involvement by fracture. The vestibular involvement of a longitudinal fracture is also relatively mild and is thought to be related to concussive effects as opposed to direct involvement of the vestibular labyrinth.

Bleeding in the middle ear presents with bleeding from the external canal in a longitudinal fracture as opposed to being confined behind the eardrum as is often seen in transverse fractures. Spinal fluid leak may occur in a longitudinal fracture but is less common than in a transverse fracture.

Transverse fractures

Transverse fractures of the temporal bone are far less common than the longitudinal fracture, accounting for approximately 20% to 30% of temporal bone fractures (Cannon and Jahrsdoerfer, 1983; Dolan, 1989; Nelson, 1979). These fractures most frequently occur by a severe blow to the occipital portion of the calvarium; however, they may also occur from a direct frontal blow. Because of the structures involved in the frontal portion of the head, the presence of a fracture through the temporal bone may not be recognized immediately because of the extensive injury that occurs in the frontal portion of the head from a severe blow in this area. The transverse fracture requires a far more intense blow to the skull. The fracture most often begins at the jugulare foramen and extends across the petrous pyramid to the area of the foramen spinosum and foramen lacerum. The fracture may actually traverse the otic capsule or may traverse the structures of the lateral most end of the internal auditory canal (Fig. 160-2).

The transverse fracture most often occurs in severely injured patients, and death from the blow itself may be immediate. The injury is most frequently accompanied by severe sensorineural hearing loss, and there may be loss of vestibular function. This loss may be to direct concussive injury to the inner ear or due to fracture through the otic capsule. It is estimated that facial paralysis, caused by interruption of the facial nerve, may exist in 50% of cases; it is noted immediately and may remain permanent unless corrected surgically (Lambert and Brackman, 1984).

In a transverse fracture there is often bleeding in the middle ear; however, the tympanic membrane is often intact and, therefore, a hemotympanum may be seen without bleeding to the exterior. Cerebrospinal fluid otorrhea is common in these injuries and most often is detected by clear fluid draining from the eustachian tube into the nasopharynx.

Mixed fractures

The anatomy of the skull base diminishes the likelihood for a pure longitudinal or transverse fracture. Mixed fractures, with the fracture line extending in almost any direction across the basal portion of the skull, may be seen (Dolan, 1989). Therefore, assumptions of injury cannot be made based on the fracture presentation, but a complete evaluation of the entire patient and the structures of the skull base are necessary to determine the extent of the injury.

Penetrating trauma

Penetrating trauma to the middle ear and temporal bone may be relatively minor, such as a laceration of the ear canal due to injury from the use of Q-tips, to rather severe, including gunshot wounds to the ear and temporal bone. If the gunshot does not cause instant death, there may be significant neurovascular injuries of the temporal bone and skull base.

The most common penetrating injury to the middle ear and temporal bone is a self-inflicted instrumentation of the ear canal, such as a Q-tip injury, or the introduction of a foreign object, such as a branch or other solid structure, such as a stone or other foreign body (Fig. 160-3). A not uncommon but therapeutically challenging injury is a hot spark or slag injury, which is occasionally incurred in industrial situations, such as welding.

The penetrating injury may create only a superficial flap laceration of the external canal, may penetrate the tympanic membrane, and may involve the ossicular chain in the middle ear. The external canal penetration may also involve the facial nerve in its tympanic portion and may effect direct injury to the auditory and vestibular system.

The effect of a gunshot injury to the middle ear and temporal bone depends on the mass and velocity of the bullet, the direction in which the bullet comes in contact with the skull and temporal bone, and the course that the bullet may take after it enters the temporal bone or the soft tissues of the skull base. The mass of the missile is important because the harder substances, such as a copper-jacketed bullet, tend to penetrate directly into the temporal bone and the soft tissues of the skull base or intracranially, where the softer lead bullets may tend to break up and become dispersed throughout the skull base. The angle of the trajectory of the missile is also important for a right-angle contact with the firm temporal bone may cause fracture, where a more angled trajectory may cause the bullet to ricochet, resulting in more of a soft tissue injury due to the course of the bullet after it has ricocheted off the harder temporal bone.

Evaluation

Immediate evaluation

Patients with blunt or penetrating injury involving the middle ear and temporal bone are often not evaluated initially in the emergency room because of other major systems injury. The most emergent aspect of major trauma it to maintain circulatory and respiratory function, and an evaluation of the head injury may be delayed. On the other hand, a relatively minor injury, particularly of a penetrating nature of the ear canal, may be the primary reason for the patient's visit to the emergency room, and therefore a complete evaluation may be accomplished when the patient is first seen.

The initial responsibility is to evaluate the total patient, both for cardiovascular and respiratory stability and for neurologic status. Assuming that these functions are satisfactory, an evaluation of facial nerve function is extremely important. A patient who is lying supine may have a total and complete interruption of a facial nerve and still appear to have adequate closure of the upper eyelid. If possible, presuming the patient is conscious, the patient is asked to make voluntary movements of the facial muscles, which then can be appropriately observed. If the patient's level of consciousness is somewhat depressed, one may observe facial nerve function by stimulating pain, as from applying pressure directly over the sternum, which will often cause the patient to grimace. Close observation of respiratory effort, particularly if the effort is strained, may reveal an asymmetry in the nasal flare, which may also be a clue that there has been a facial nerve injury.

Close observation should be made for a potential vestibular system injury; in particular, close observation of eye movements should be recorded. If the patient is conscious and complaining of severe vertigo, one must be suspicious of a potential otologic emergency, particularly in the case of what may seem to be limited penetrating injury of the external auditory canal.

Nystagmus should be evaluated carefully. It is conventionally recorded as being in the direction of the fast phase. The direction of the nystagmus will be toward the dominant vestibular labyrinth. If there is an irritative lesion due to trauma in the involved ear, the nystagmus should be toward that ear. However, if the nystagmus is directed toward the noninvolved ear, one should be suspicious of a destructive lesion in the involved ear. Observation of the nystagmus over time is important, for an initial injury may create an irritative lesion with the nystagmus toward the involved side, and the nystagmus then may revert to the opposite ear, indicating that an irritative lesion is now becoming a destructive lesion.

Direct evaluation of the ear and the external auditory canal and tympanic membrane is important. The external canal should be examined, both for lacerations and bony fracture (Fig. 160-4). It is important to have available some form of suction to adequately remove a blood clot from the external canal and to appropriately evaluate skin or bone injuries of the external canal. Bleeding from the external ear may be encountered in a patient who has sustained a direct blow to the symphysis of the mandible. This injury may cause the condyle of the mandible to be driven posteriorly, fracturing the anterior canal wall.

Longitudinal fractures of the temporal bone most often cross the tympanic ring, causing a tear in the tympanic membrane, and active bleeding from the middle ear may be observed. Close observation for possible cerebrospinal fluid leakage should also be made at this time. It is often difficult to determine if there is spinal fluid present, if there is fairly active bleeding. It may be helpful to take some of the fluid from the external canal and to place it directly on a piece of filter paper or tissue paper. Spinal fluid has a more rapid diffusion pattern, suggesting the presence of spinal fluid in addition to blood in the external canal. Collecting the clear fluid, when possible, allows laboratory assessment for glucose content. The use of sugar dip sticks, particularly in the presence of blood, has not been a reliable measure of sugar content in otorrhea.

If possible, the external canal should be cleaned of blood clots so that a direct assessment of the tympanic membrane can be completed. Traumatic injuries to the tympanic membrane may occur both as the result of direct penetration of the tympanic membrane and because of a compression injury of the external auditory canal. Such injuries usually occur from a slap on the ear, or sometimes after the ear directly strikes the water in a fall when water skiing. The most common locations for traumatic perforations of the tympanic membrane are the anterioinferior and posteroinferior quadrants of the tympanic membrane (Fig. 160-5). The injury may be linear and slitlike, triangular, or stellate, the last being from a compression or a blast type of external canal trauma. Close observation of the edges of a triangular-shaped or a stellate perforation may reveal a straight-line appearance, which suggests that at that point a portion of the tympanic membrane has folded on itself, most frequently toward the middle ear (Fig. 160-6). This observation is important and will be discussed further in treatment of penetrating injuries of the tympanic membrane.

If the traumatic perforation is in the posterosuperior quadrant of the tympanic membrane, one must be suspicious of possible ossicular chain involvement in the injury. This observation demands close evaluation of the patient for nystagmus. An injury of the posterosuperior quadrant of the tympanic membrane in the presence of nystagmus demands immediate otologic surgical attention and should be noted immediately to the appropriate otolaryngologic physician. An injury in the posterosuperior quadrant of the tympanic membrane, accompanied by facial nerve weakness oor paralysis, also suggests a direct injury to the facial nerve in the tympanic portion requiring immediate attention by an otologic surgeon.

Intermediate evaluation

Radiologic evaluation

Once a patient has stabilized from an acute injury, a full evaluation of the structures in the temporal bone should be undertaken. High resolution computed tomography (CT) scanning, using a bone algorithm, is the radiologic study of choice to evaluate potential fractures of the skull base (Fritz et al, 1989). The radiologist should be informed as to the nature of the lesion, so that the appropriate cuts can be made to identify fractures in all of the involved areas. High-resolution CT demonstrates that multiple fracture lines often course through the skull base. Unless there is a suspected intracranial involvement, there is no need to use contrast in the high-resolution CT study (Fig. 160-7).

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Magnetic resonance imaging (MRI) scans are excellent to evaluate intracranial injuries, but are not useful for fracture identification.

An evaluation of the vascular structures of the temporal bone and skull base is often necessary. Gunshot wounds to the skull base can occlude major vascular structures. This occlusion may not be clinically evident at the time of initial evaluation. The technique of digital subtraction angiography is most useful and may be accomplished with a venous injection; however, an arteriogram may be more accurate. With the continued improvement of MRI, contrast injections may not be required in the future to evaluate vascular lesions. The most common vascular lesion of the skull base is occlusion of the jugular bulb and the lateral sinus usually due to direct involvement of the dural sinus itself. However, fractures and gunshot wounds to the skull base may also cause occlusion of the internal carotid artery system, which can be identified using digital subtraction angiography. Occasionally, a traumatic aneurysm of the internal carotid artery or an arteriovenouos malformation, secondary to trauma, may be suspected. These lesions are often clinically evident on the basis of auscultation in and about the skull base and the ear. Intraarterial digital subtraction angiography may be useful to clearly identify an aneurysm or an arteriovenous malformation.

Nuclear medicine evaluation

The evaluation of a potential cerebrospinal fluid leak often may be accomplished using nuclear medicine techniques. Intrathecal injection of fluorescein or a radioactive carrier substance may be useful when spinal fluid is thought to be leaking directly from the external canal. Fluorescein may be visualized under ultraviolet light, or an absorbable packing can be placed in the external auditory canal for 24 hours and the packing then examined by a scintillation counter to determine whether radioactive uptake is in the sponge.

If a leak is suspected to be traversing the eustachian tube, either fluorescein dye or a radioactive carrier substance can be injected intrathecally in the lumbar area. Cotton pledgets may be carefully placed, tagged, and labeled in the area of the eustachian tube. These pledgets can then either be examined under black light or studied using scintillation counters foor presumptive evidence of a leak of spinal fluid.

Audiologic evaluation

When the patient's condition is satisfactory, complete audiologic studies should be performed. This evaluation would include pure tone air and bone conduction and speech discrimination scores. Acoustic reflex testing should also be performed in cases where there is a faciial nerve injury to help in topographic diagnosis.

Vestibular studies

Vestibular studies should also be performed using the technique of electrooculography and recording of eye movements should be accomplished. The presence of a peripheral vestibular lesion may be either direct or concussive and may also suggest the possibility of a central vestibular lesion. Separate electroneurography (ENG) leads for each eye as well as a vertical channel may help to delineate further a central lesion or may demonstrate the presence of cranial nerve injury involving eye muscle function.

The slow harmonic acceleration rotary chair test may also be performed. An abnormality of phase lag may indicate a permanent peripheral vestibular damage, and an asymmetry of preponderance may indicate the level of central compensation for an altered peripheral vestibular lesion. Baseline vestibular studies are useful to monitor the patient's level of compensation for a significant peripheral vestibular lesion.

Facial nerve function evaluation

In those patients with a partial or complete facial nerve paralysis following skull base trauma, a full evaluation of facial nerve function should be undertaken. Initial testing should include topographic testing to try to locate the level of the lesion in the temporal bone. As noted in the audiologic section, tympanometry with reflex testing may indicate the presence or absence of stapedial muscle function. Schirmer's tear testing should also be undertaken. A significantly reduced tearing function would suggest a lesion at the level of the geniculate ganglion. Taste testing is not considered accurate and is only suggestive of a lesion proximal to the take off of the chorda tympani nerve.

Electrodiagnostic studies of facial nerve function remain imprecise, but may be helpful in the rehabilitation of facial nerve function in temporal bone trauma. The most widely used test is percutaneous electrostimulation of the facial nerve. Threshold determination for minimal and maximal movement of faciial musculature is determined and compared to the opposite or normal side. Percutaneous testing is valid only after 4 days from the onset of the facial nerve injury. The absence of response on the involved side to percutaneous stimulation immediately after an accident may be presumptive evidence of a complete interruption of the facial nerve. In most instances, however, the peripheral facial nerve will continue to be ablve to be stimulated for up to 4 days after direct facial nerve interruption. After the 4-day period, repeat percutaneous stimulation will indicate grossly the levelof facial nerve function. If the level of stimulation remains within the range for the contralateral side, the prognosis for return of function is excellent. Evoked electromyography or EMG may also be used as a prognostic evaluation of facial nerve function as described by Esslen (1977). A reduction in amplitude of the evoked electromyographic potential from a percutaneous electrode of greater than 95% indicates a poor prognosis and may suggest the advisability of surgical intervention to evaluate the integrity of the facial nerve (see also Chapter 149).

Late evaluation

If a patient is seen late after skull base trauma, a full evaluation of facial nerve function, vestibular function, and auditory function should be undertaken. When evaluating facial nerve function, the time course of events after the accident is important. If there has been no evidence of return of function within 30 days of the accident, one can assume that degeneration of the facial nerve has occurred. This degeneration certainly could be on the basis of direct interruption of nerve (neurotmesis); however, the nerve sheaths may still be intact with complete degeneration (axonotmesis). If there has been complete degeneration, one would not expect to begin to see return of function until approximately 3 to 4 months after the onset of the accident. If the patient is seen at 4 months from the time of the accident and there is no evidence of return of function clinically, a suspicion of significant interruption of the facial nerve must be entertained.

Electromyographic studies of facial nerve function may be undertaken to determine the presence of regeneration potentials. These potentials may become evident before there appears to be clinical return of facial motor function.

Vestibular studies should be completed, both to evaluate the vestibular status of the involved ear and to evaluate the potential for recovery of vestibular function in the involved ear. Total loss of vestibular function in the involved ear may suggest the translabyrinthine approach to accomplish the appropriate surgical rehabilitation of the facial nerve. Studies should include electronystagmographic recording of bithermal caloric tests and, if possible, rotational vestibular testing. As noted earlier, the rotational test may be helpful to determine if there is a permanent change in vestibular function and also if the central mechanisms of compensation have been effective.

Audiologic studies are important. As noted by Tos (1971) in a study of 248 petrosal fractures, 26 of which were transverse and 222 longitudinal, all patients with a transverse fracture had anacusis in the involed ear. In no cases did this loss of hearing later improve. In the patients with longitudinal fractures, the primary hearing loss was in the frequencies of 500 to 2000 Hz and was within normal limits in 24% of cases. In 67% of cases, hearing was reduced by more than 20 dB at these frequencies. Of this group of patients with hearing loss, 59% had a conductive hearing loss, 4% had a sensorineural loss, and in 4% had a mixed loss. Three to 6 weeks after the trauma, the hearing returned to normal in 63% of cases. The final hearing results in long-term follow-up indicated that in longitudinal fracture, 80% of cases had hearing within the normal range. Of the 20% that had persistent hearing loss in long-term follow-up, 13% had dislocation or fractures of the ossicles, 4% had a mixed loss of hearing, and 4% had a purely perceptive hearing loss of all tones.

Treatment of Middle Ear and Temporal Bone Trauma

Immediate treatment

Immediate treatment is defined as the treatment rendered most often in the emergency room in the immediate period after the incident. In patients who have sustained blunt trauma to the skull or temporal bone, the most criticalfactor is to stabilize the patient's cardiovascular respiratory system and to assess and stabilize the patient's neurologic status. If there appears to be a significant laceration of the external canal, this canal should be stented with a pack to attempt to prevent stenosis of the ear canal. If there is a significant fracture dislocation of the ear canal, a useful procedure is to place a small infant nasal speculum firmly down into the bony external canal. Gentle opening of this canal will often relocate the bony fragments into their anatomic position, and these then can be stabilized using the appropriate external canal packing. Any attempt to correct an ear canal stenosis as the result of trauma will be a most useful adjunct, for once scar formation has occurred in this area, stenoses become difficult to correct.

If the assessment suggests the presence of a spinal fluid leak, whether through the external auditory canal or out the eustachian tube into the nasopharynx, management decisions must be made in the immediate period, usually in consultation with neurosurgical colleagues. There are disputes in the literature as to the efficacy of using prophylactic antibiotics in the presence of a cerebrospinal fluid leak. Some physicians will argue that the prophylactic

antibiotics may prevent the occurrence of meningitis. Others will argue that prophylactiic antibiotics are usually given in a dose that is not adequate to treat meningitis. If the meningitis occurs, therefore, it becomes difficult to assess the nature of the infection and the involved organism and to institute appropriate antibiotic therappy. As noted by Canniff (1971) in a large seriies of 1800 cases of head injury, the incidence of cerebrospinal fluid otorrhea was only 1.4%. Of this group, 20% went on to contract meningitis.

If prophylactiic antibiotics are administered, a broad-spectrum antibiotic with the capacity to cross the blood-brain barrier is given intravenously. Most studies indicate that the spontaneous closure of a spinal fluid leak should occur within 4 to 5 days of the onset. If there is no clinical evidence to suggest the presence of meningitis, the use of temporary lumbar subarachnoid drainage may facilitate the spontaneous closure of the cerebral spinal fluid leak. If the spinal fluid leak persists, surgical intervention may be indicated.

Initial treatment

Immediate treatment of a penetrating ear canal injury may be expectant or may require immediate surgical intervention. The most common injury is a laceration of the skin of the ear canal, most commonly from a Q-tip injury. Careful examination of the external canal and removal of any blood clots against the drum may reveal only a laceration with an intact tympanic membrane. These lesions can be handled expectantly without stenting and, in particular, should not be treated with the instillation of liquid drops into the ear canal.

A perforation of the tympanic membrane should be observed closely under the microscope to determine the extent of this injury. In general, a slitlike perforation has the potential for spontaneous healing in 24 to 48 hours. Usually, no treatment is necessary. As noted earlier, however, if one can identify a straight line of a triangular or stellate laceration, there may be a rotational flap of the tympanic membrane most frequently into the middle ear. If the patient is seen early after the injury, there may be anesthesia in the margins of this perforation, and a small-angled pick can be used to gently tease this flap back into its anatomic position. This procedure may be supplemented by a single injection of local anesthetic into the vascular strip. Once the flap has been rotated back into its anatomic position, it may hold in position with a small amount of local blood. However, this area may also be stented by taking a small patch made out of fine paper, such as cigarette paper, or a fine synthetic materiial, which is applied directly over the injury on the surface of the drum. The use of an antibiotic ointment on the undersurface of this patch facilitates its being held firmly in place. The patient is cautioned to avoid blowing the nose or putting undue pressure in the middle ear until time has passed to allow healing. Most important, the patient should not instill any type of liquid antibiotic corticosteroid drop into the ear canal of a dry, clean, traumatic perforation of the tympanic membrane.

In some instance, the etiology of the traumatic perforation of the tympanic membrane is water, such as a water skiing accident or an accident resulting from vigorous irrigation of the impacted cerumen from the ear canal. In this case, there may already be active infection present when the ear is first examined. The use of an antibiotic corticosteroid drop preparation to control this superficial infection may then be indicated; a paper patch is of little use if moisture is coming from the middle ear space.

Earlier articles in the literature have suggested immediate repair of traumatic perforation of tympanic membrane using more extensive tympanoplastic techniques. This approach is not necessary because the spontaneous closure rate, with or without stenting, is approximately 90% in traumatic perforations of the tympanic membrane.

The management of traumatic perforations of the tympanic membrane should include full audiometric studies and close evaluation for possible nystagmus. a compressive-type injury in particular may have an associated spontaneous round or oval window membrane rupture associated with the traumatic perforation of the tympanic membrane.

Surgical intervention

Dislocation of an ossicle associated with traumatic perforations of the tympanic membrane requires a careful assessment of the patient for the presence of nystagmus or vertigo. This assessment may include the electronystagmographic recording of eye movements. If there is indication of injury to the labyrinth, then the repair of ossicular damage should be delayed from immediate treatment to a more intermediate period. In most instances, there is considerable blood and disturbance of the normal mucosal lining of the middle ear associated with an acute injury of the middle ear. As this area heals, there will be continued distortion of middle ear and ossicular function. Most surgeons believe that it is appropriate to allow this immediate problem to resolve before undertaking elective repair of a specifici ossicular injury.

If a patient presents with a traumatic perforation of the tympanic membrane, particularly a perforation in the posterosuperior quadrant that has associated complaints of severe vertigo and the presence of nystagmus, immediate otologic surgical consultation and intervention are indicated. Severe injury to the stapes, including dislocation of the stapes into the vestibulae of the labyrinth, may exist. The only hope for salvage of inner ear function is immediate exploration of the middle ear and correction of the injury.

The most common injury would be fracture dislocation of the stapes. If this injury is identified at the time of surgery, an appropriate repair should be undertaken. The most expeditious and safe repair is to extract the remainder of the stapes without injury to the vestibule and to close the oval window with a tissue graft, such as vein, fascia, or perichondrium. At the time of the initial procedure, a reconstruction using a stapedectomy prosthesis or ossicular reconstruction and immediate repair of the tympanic membrane may be undertaken. This procedure most often can be carried out through a transcanal approach but may require general anesthesia because of the acute nature of the vestibular injury.

If a partial or complete facial paralysis is identified from direct penetration of the tympanic membrane in the posterosuperior or anterosuperior quadrant of the tympanic membrane, a decision about immediate exploration of the facial nerve can be based on the patient's general status.

At the time of surgery, the ear should be prepared for both a transcanal and a postauricular transmastoid facial recess approach for exploration of the facial nerve. Decompression of the facial nerve on both sides of the injury may be all that is necessary to relieve the direct compressive effect of an injury to the facial nerve. If more than 50% of

nerve tissue loss has occurred, however, it is necessary to obtain an appropriate nerve graft from the great auricular nerve of the neck to be used as an interpositional graft. At the time of exploration, the appropriate reconstruction of the ossicular chain can also be accomplished.

Immediate treatment of gunshot wounds to the skull base or temporal bone first involvfes stabilization of the patient's cardiovascular and neurologic status. A complete neurologic evaluation should be completed, including an evaluation of all of the lower cranial nerves, in particular the fifth through twelfth cranial nerves. The anatomic structures are tightly compacted in the area of the temporal bone and skull base, and involvement of one structure may suggest the involvement of another structure. As an example, a vocal cord paralysis indicating an injury to the vagus nerve most assuredly indicates the possibility of an injury to the carotid artery or jugular vein. Therefore, close attention to the cranial nerve structures is important. Complete radiologic evaluation should be obtained, including high resolution CT scans and digital subtraction angiography. A laceration and eventual thrombosis of the jugular bulb due to a temporal bone lesion often are not recognized until the time of surgery, particularly true if the patient has been shot behind the ear where the bullet most frequently would course across the mastoid and injure the sigmoid sinus or jugular bulb. A suspected lesion of the carotid artery in the temporal bone should be observed carefully. The neurologic status of the patient can change precipitously if there is an expanding vascular lesion at the skull base or neck. Consultation with the neurosurgical service is indicated and a combined decision on the necessity for vascular exploration can be made. Facial nerve injuries associated with gunshot wounds will eventually need surgical intervention for rehabilitation. However, there is no great urgency for surgery of the facial nerve injury and stabilization of the patient's acute injury must take precedence.

Intermediate treatment

Facial nerve injury

After the initial stabilization process following a blunt head trauma injury to the temporal bone, a complete evaluation of the auditory and vestibular functions as well as facial nerve function is accomplished. A planned course of treatment may then be outlined. The facial nerve injury frequently requires the greatest judgment regarding recommendation for surgical intervention. A clear observation of good facial nerve function followed by gradual paresis or paralysis with excellent indications of electrical activity in the peripheral facial nerve can be treated appropriately with expectant observation. However, the history and observations at the onset of the facial nerve injury often are cloudy, and the surgeon must all information available to determine whether surgical intervention is indicated. As noted earlier, longitudinal fractures without severe cochlear and vestibular deficits most frequently do not include interruption of the continuity of the facial nerve. Continued observation of the lesion is appropriate, depending on the time that has elapsed since the injury occurred. If the patient is being evaluated 4 months after the accident, with no evidence of return of function, surgical intervention is indicated. However, if the patient is seen 1 month after the accident, the decision for surgery becomes more difficult, for the patient could be in the phase of regeneration, and surgery would not add a great deal to the status of the patient's final outcome.

Surgical intervention

Facial nerve exploration. In those cases where transverse fractures have occurred there is severe loss of auditory and vestibular function, the likelihood of a mechanical disruption of the facial nerve is much greater, and the need for surgery is clearer. These patients have a significant chance for direct communication to intracranial spaces from a middle ear infection. This further necessitates surgical intervention to seal possible routes of intracranial spread of infection.

If an option to offer surgery for repair of a facial nerve lesion has been given to the patient, the facial nerve may be approached and repaired in a variety of ways.

A patient with intact cochlear and vestibular function should undergo an exploration of the facial nerve through a mastoid, middle ear, and middle fossa approach. It is important to remember that temporal bone fracture lesions often involve the facial nerve in more than one location. The most frequent location of involvement is in the area of the geniculate ganglion; therefore, the surgeon must be prepared to fully evaluate and correct a lesion in that area. The patient is prepared and draped for postauricular mastoid surgery and possible middle fossa surgery. After a postauricular incision is made, a complete mastoidectomy is accomplished, and the facial nerve is identified in its vertical segment. The nerve may be identified inferior to the horizontal semicircular canal by thinning the external auditory canal, or it may be identified at the stylomastoid foramen by following the digastric ridge forward until the nerve is identified. The facial recess is opened widely and the status of the ossicles are assessed. The facial nerve is then observed in its middle ear portion up to the level of the cochleariform process. The nerve may also be observed medial to the ossicles through the epitympanum and followed the cochleariform process to the geniculate ganglion. In rare instances, one may be able to expose the most distal portion of the labyrinthine segment of the facial nerve across the superior semicircular canal. However, the limitations of room to evaluate the entire nerve at the area of the geniculate ganglion through the transmastoid route usually do not give adequate exposure to repair the nerve properly. Therefore, the incision can be carried superiorly, a middle fossa craniotomy performed, the middle fossa dura elevated, and the facial nerve identified in its labyrinthine segment to the internal auditory canal.

Fisch (1974) has noted that when the facial nerve has not regained function over a considerable period after an accident, the lesion is frequently at the level of the geniculate ganglion. The facial nerve may be attempting to regrow through the greater superficial petrosal nerves. Fisch recommends separating the superficial petrosal nerve from the geniculate ganglion, skeletonizing the superior semicircular canal, and rerouting the facial nerve from the labyrinthine portion to the tympanic portion with a direct end-to-end anastomosis if the nerve has been severed at the geniculate ganglion.

If the facial nerve has not been disrupted, the nerve sheath can be decompressed 180 degrees of its circumference. In the case of a traumatic faciial nerve injury, it is advisable to open the neural sheath of the facial nerve at the point of injury to make sure that fibrous scarring of the nerve sheath is not preventing neuronal regeneration. When there is actual fibrous scar formation of the nerve sheath and interruption of the neuronal pathways, a resection of the portion of the nerve with interposition nerve graft is indicated. Repair of the nerve in the temporal bone is often facilitated by providing a bony groove in which to lay the

nerve on nerve graft. It is important when using an interposition graft to use a graft that is somewhat longer than the space to be occupied. The results of the grafting procedure will be far better if there is no tension or potential separation of the suture lines.

Translabyrinthine decompression and repair. In the case of a transverse fracture with total loss of auditory and vestibular function, a translabyrinthine decompression and repair of a facial nerve injury may be accomplished. In this case, the patient must be made aware that there will be total loss of auditory and vestibular function with no potential for recovery. The procedure is performed under general anesthesia, with the patient supine and the ear prepped and draped for postauricular surgery. After a postauricular incision, a complete mastoidectomy is performed, leaving the external auditory canal intact. The facial nerve is identified either at the junction below the horizontal semicircular canal or at the stylomastoid foramen. The nerve is decompressed to the middle ear and geniculate ganglion. A complete labyrinthectomy is performed, removing the semicircular canals and the contents of the vestibule. The facial nerve can then be traced from the geniculate ganglion through its labyrinthine portion to the lateral end of the internal auditory canal at the dural reflection. As in longitudinal fractures, a frequent area of involvement of the nerve is the area of the geniculate ganglion. The proximal segment of the nerve in the labyrinthine portion can be decompressed, although the bony fallopian canal at this point is extremely narrow. One should take care to decompress the nerve to the internal auditory canal fully because the narrowest point of the fallopian canal is at the point of the fallopian canal's entrance from the lateral end of the internal auditory canal.

Care should be taken not to completely free the nerve from its dural reflection at the lateral end of the internal auditory canal. At this point, the intracranial segment of the facial nerve no longer has a nerve sheath, and if the nerve is no longer attached at the dural reflection, it may significantly retract into the cerebellar pontine angle and no longer be accessible for grafting. If retraction does occur, the posterior fossa dura can be opened providing direct access to the cerebellar pontine angle. When performing a translabyrinthine facial nerve decompression, the facial nerve may be completely elevated out of the fallopian canal from the geniculate ganglion distally to the stylomastoid foramen. This maneuver gains length on the distal segment of the facial nerve and may allow direct end-to-end anastomosis to the labyrinthine portion at the internal auditory canal. In most cases, one or two sutures directly into the neural sheath is enough to stabilize the nerve. If one must graft directly to the intracranial portion of the facial nerve where there is no neural sheath, it is often difficult to get a suture to stay implanted in the proximal segment of nerve, and the graft may need to be stabilized with an adherent substance, such as Avitene.

Root entry zone injury. There is a traumatic injury to the facial nerve that is not readily amenable to surgical intervention. In some cases of severe closed head injury, the injury may occur at the root entry zone of the facial nerve into the brainstem. These patients are most frequently unconscious for a period of time after their accident, and at the time of initial evaluation, they not only have facial nerve injury, but also have evidence of brainstem injury, including hemiparesis or paralysis. These deficits frequently will recover, but the facial nerve injury may never recover. If one is exploring a long-standing facial nerve injury and does not identify a lesion throughout its peripheral course to the internal auditory canal, one should be suspicious that the injury occurred at the point of the root entry zone. There is little prospect for recovery of this type of lesion.

Patient counseling. Preoperative and postoperative counseling of patients and patients' families should include suggestions that the period of recovery of facial nerve function can vary considerably. Whereas one expects regeneration of an uninterrupted nerve to occur at the rate of 1 mm a day or 1 inch a month, in the case of a direct anastomosis or an interposition graft, the rate at which the nerve will bridge these gaps cannot be predicted. Patients are cautioned that recovery is not expected to occur before 6 months, but it would certainly be expected to show evidence of regeneration by 1 year. Continued recovery can be anticipated up to 18 to 24 months after repair.

Vestibular injuries

Vestibular injuries after head trauma are most generally treated with expectant observation. The recovery of a patient from this type of vestibular injury depends on the stability of the peripheral vestibular lesion. If the lesion is permanent and stable, the patient should experience a vestibular crisis with gradual improvement and satisfactory compensation. If the lesion is fluctuating and nonstable, however, the patient will continue to be symptomatic.

Fluctuating vestibular injury. The most common cause of a fluctuating vestibular injury is perilymphatic fistula. The history of a traumatic event is the most reliable indicator of a perilymphatic fistula. Fistula testing using ENG and ear canal pressure or with posturography may be helpful, but is not diagnostic of this type of fistula.

Exploratory tympanotomy. Exploratory tympanotomy for perilymphatic fistula can be generally accomplished under local anesthesia using the transcanal tympanomeatal flap route. Exposure is gained so that the entire round window and oval window can be examined. The round window bony nitch may have to be gently removed with a small diamond burr to completely visualize the round window membrane. Care should be taken to also observe the entire annular ligament of the stapes in the oval window. In cases of head trauma, one should also look carefully in the area of the fossula of cochlear window where there may be a congenital cartilage rest through which one may see a leak of perilymph. If a fistula is identified, the repair is accomplished by denuding the mucosa and applying an autologous tissue graft over the area of fistula. This graft can be lobular ear fat, perichondrium from the area of the tragus, or possibly temporalis fascia or vein. If the fistula from the round window is rather profuse, it is helpful to close this window with a tissue graft and then construct from the tragal cartilage a cartilage strut that will fit directly from the hypotympanum or the bony anulus down into the round window firmly holding the tissue against the round window membrane. In the case of an oval window fistula, the tissue often can be supported by packing it through the crura of the stapes; or, if there is a significant injury to the stapes itself, including fracture of the foot plate, a formal stapedectomy with tissue and a prosthesis reconstruction can be accomplished. It is often difficult to close a fistula through the area of the fossula of cochlear window. The use of a small diamond burr directly on this area will impact tissue down into the leak and cause it to stop. This leak should then be covered by a tissue graft, such as fat or perichondrium.

Vestibular neurectomy. If there has been a significant vestibular injury, which is fluctuating, and there is useful hearing in the ear, but the patient has not recovered from the vestibular injury after 1 year of expectant observation, a vestibular neurectomy through the

middle fossa or retrolabyrinthine approach could be considered. If there appears to be persistent minimal vestibular function that is creating a fluctuating lesion, and there is nonfunctional hearing in the ear, a formal postauricular labyrinthectomy with or without eighth nerve neurectomy could also be considered after an appropriate period of expectant observation.

Auditory Injuries

Auditory injuries of the sensorineural type can only be treated with expectant observation unless one suspects the presence of a perilymphatic fistula. The most common auditory injury, other than a sensorineural injury, is ossicular dislocation. Hough and Stuart (1968) presented a classic article on the evaluation and correction of middle ear ossicular dislocation secondary to trauma. They speculate that the reason for the severe dislocation might be the explosive concussive effects that weaken the ligamentous structure and the rapid deceleration on impact that may cause the ossicle to violently disrupt at the instant of separation of the fracture line.

If, on the basis of audiometric testing and tympanometric findings, one suspects an ossicular dislocation, elective repair can be undertaken. As noted earlier, it is advisable to allow the acute irritative effects of a middle ear injury, particularly blood in the middle ear, to resolve before elective surgical intervention for an ossicular dislocation. These problems can be approached most appropriately through the transcanal route under local anesthesia using a tympanomeatal flap. The most common ossicular dislocation is separation of the incudostapedial joint with or without dislocation of the body of the incus from the articulation with the malleus head. A fibrous strand that attaches the capitulum of the stapes to the lenticular process of the incus is often found. This strand may present a greater conductive hearing loss in the high tones than in the low tones. This lesion may be repaired by the appropriate ossicular resculpturing and interposition or possibly by the use of an incus replacement prosthesis.

The second most common injury of the ossicular chain is fracture of the stapes crura. This lesion is identified most frequently by the preoperative audiometric evaluation. A crural fracture is suspected in a patient in which there is a significant conductive hearing loss, tympanometric findings suggestive of an ossicular disruption with an intact stapedius reflex test. Only a disruption of the ossicular chain medial to the attachment of the stapedius tendon, such as a crural fracture, could allow this type of audiologic pattern. Stapes crural fractures may be repaired most expeditiously by performing a formal stapedectomy.

Penetrating trauma of the middle ear may require surgical intervention. As noted earlier, injuries of penetration of the posterosuperior quadrant may effect immediate facial nerve injury, either partial or complete. Partial injuries may be completely evaluated and treated expectantly based on the outcome of the evaluation and the electrical studies. If a significant direct traumatic injury of the facial nerve is identified, transmastoid facial nerve decompression and repair are indicated. This lesion can be treated on a delayed basis without risking anesthesia in a patient with a compromised neurologic state. As noted earlier, an injury to the posterosuperior quadrant accompanied by severe vertigo, nausea, and nystagmus is an otologic emergency. Immediate middle ear exploration and repair of direct injury to the vestibule are essential. A patient who sustains a perilymphatic fistula from the round window

or oval window membranes would be treated in a manner similar to that described earlier.

Auditory involvement from a penetrating lesion of the external auditory canal most frequently involves the tympanic membrane or the ossicular chain. In the case of a penetrating traumatic injury to the tympanic membrane, at least 3 months should be allowed to pass before considering surgical repair of the lesion. The perforation sometimes will be persistent at 1 month, but at 3 months it may have completely healed. If the lesion persists beyond 3 months, conventional myringoplasty or tympanoplasty should be entertained to repair the hole in the tympanic membrane. Hot spark slag burns to the tympanic membrane create a much more difficult problem for surgical repair. These lesions most frequently do not repair spontaneously and eventually require surgical intervention. Scarring of the mucosa of the middle ear and the promontory are common and cause difficulty in the repair of these lesions. Graft failures from conventional myringoplasty and tympanoplasty are not uncommon in slag injuries. It becomes apparent at the time of surgery that the thermal injury to the tympanic membrane involves a much greater portion of the middle layer of the tympanic remnant than would be estimated on the basis of the perforation's size.

Surgery for gunshot wound injuries to the middle ear and temporal bone is most commonly indicated because of facial nerve injuries. As noted earlier, the patient must be evaluated carefully to observe for concomitant injuries to other cranial nerves and vascular structures. When exploring a facial nerve after a gunshot wound, preparations are made to obtain a graft from the great auricular nerve in the neck. Often a significant segment of the nerve has been destroyed by the missile and a rerouting of the facial nerve, as demonstrated earlier in the translabyrinthine decompression, or an interposition great auricular nerve graft is indicated. Auditory repair after gunshot wounds is reserved for ossicular and tympanic membrane abnormalities because injury to the vestibular and auditory components of the inner ear generally are not recoverable unless the cause is a perilymphatic fistula.

Late treatment

The surgeon may be asked to evaluate a patient with a persistent facial nerve injury who has sustained blunt or penetrating trauma to the temporal bone. Expectant return of function of a facial nerve injury would be expected 4 to 6 months after injury. If there has been no return of function by then, a presumptive diagnosis of total block or interruption of the facial nerve should be entertained and a proposal considered for total facial nerve exploration and repair of the facial nerve lesion either by direct anastomosis or interpositional graft.

A second late complication of blunt or penetrating trauma of the external auditory canal may be stenosis or atresia. The stenosis can create significant problems for the patient, including retention of cerumen and keratin debris behind the stenosis with potential cholesteatoma formation. They also may create a significant auditory deficit. The late stenosis of the external auditory canal from trauma must be approached in a manner similar to congenital aural atresia. If the stenosis must be resected 360 degrees to obtain an appropriate canal, the use of local skin flaps, full-thickness postauricular skin grafts, or split-thickness skin grafts obtained from the buttocks, thigh, or anterior arm are necessary to reline the canal.