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Delayed surgical treatment of traumatic hearing loss due to ossicular disruption

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Abstract. *Delayed surgical treatment of traumatic hearing loss due to ossicular disruption. Objective*: Surgical treatment of dislocation and fracture of the middle ear ossicles is recommended to be carried out within months of the initial injury. Here we present 6 patients with traumatic ossicular injury whose surgery was delayed over 1 year. We evaluated the clinical and pathological changes that occurred over time and assessed the surgical outcomes in delayed cases.
Methodology: Histories of the causative traumas, computerized tomography (CT) and tympanometry findings, pre- and postoperative hearing thresholds, and ossicular damages assessed at the tympanotomies were evaluated.
Results: The time lapse between the trauma and the surgery varied from 1 to 6 years. The resultant hearing losses were moderate or moderately severe, conductive, mixed or sensorineural type. Tympanometry and CT revealed ossicular discontinuity in only two cases. In operations, various types of ossicular abnormalities in the form of absence, displacement, fracture and/or fixation were identified. Continuity and mobility of the ossicular chains were restored with various techniques. Air-bone conduction gap was brought to within 20 dBHL in all cases, and within 10 dB in 3 (50%) of the cases. Gains in the bone conduction were also notable.
Conclusion: Trauma to the middle ear may result in an elevation in the air and/or bone conduction thresholds due to ossicular disruption and fixation. Our findings confirmed that tympanotomy is superior to methods such as CT and tympanometry in delineating the type and extent of the traumatic ossicular damage, and usually gives favorable results even in delayed cases.

Introduction

Any trauma that involves the ear or temporal bone can lead to discontinuity or fixation of the middle ear ossicles. Traumatic ossicular disruption has been mostly associated with longitudinal or, according to contemporary nomenclature, "otic capsule sparing" temporal bone fractures. Less frequently observed transverse or "otic capsule violating" temporal fractures, blast, acoustic and baro-trauma, as well as traumas penetrating into the middle ear, are also responsible for traumatic ossicular injuries.[1,2] The ossicles can be separately affected from a traumatic force, most frequently observed in the incus, followed by the stapes and the malleus, two, or all three ossicles together.[2-4]

A posttraumatic conductive hearing loss of 50-65 dBHL,[5] or a hearing level measurement with an air-bone conduction gap (ABG) of approximately 40 dBHL following a trauma (for the cases with accompanying sensorineural losses), traumatic ossicular disruption must be considered.[3] Disruption of the ossicles behind an intact TM is usually characterized by a Type Ad tympanometric curve with an extremely deep or open ended peak that reflects "hyper-compliance".[6]

Surgical treatment of traumatic conductive hearing loss can be delayed by 6-12 weeks for the spontaneous resolution of the mucosal edema and hemotympanum, by which time the hearing loss itself may be resolved as well.[2,7,8] Treatment may also be delayed as treatment of serious medical problems, such as intracranial injuries, cerebrospinal fluid (CSF) leak or facial paralysis takes priority over the management of hearing loss.[4,9]

Material and methods

Our series included 5 patients with hearing loss with conductive component: 3 were conductive, 2 were mixed types and one patient had sensorineural hearing loss

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(SNHL) and was complaining of vertigo (n = 6). All of the hearing losses were unilateral and related to a trauma. The patients were admitted between 2003 and 2006. Following the collection of a detailed history, all patients underwent an otologic and oto-neurologic examination. An audiologic test battery of pure tone audiometry, speech threshold assessment, tympanometry and stapedial reflex testing with the use of a conventional probe tone of 226 Hz was administered to each patient, and a bithermal caloric test was performed in the patient with vertigo. Pure tone thresholds were determined by averaging the hearing thresholds at 0.5, 1 and 2 kHzs. Temporal bone CTs were taken in four patients. All patients underwent exploratory tympanotomy and various types of tympanoplasties under general anaesthesia through a transcanal approach. Postoperative pure tone hearing thresholds were recorded at least at bi-monthly intervals, and the final assessments were taken as the basis of this study.

Informed written consents were obtained from all patients for the use of their clinical data for scientific purposes.

Results

The patients were young males between the ages of 20 and 24 (Table 1). The traumas that lead to their hearing losses were reported as occurring 1-6 years (average 2.1 years) prior unilaterally, and described as being the "blunt" type; the traumas varied from hitting, falling, traffic accidents to a sport accident. Only two of the patients had a history of posttraumatic hemorrhagic otorrhea. Although unilateral hearing loss appeared to be the common presenting symptom for all patients, one was additionally complaining of occasional vertiginous bouts that had started immediately after the trauma, which occurred 1 year prior. Tympanic membranes were intact in all of the cases. A groove along the longitudinal axis of the bony ear canal in one patient, and irregularity around the Rivinus notch in another were noted. Hearing loss was moderate to moderately severe (Table 1). Tympanograms were type-C (peaking between -100 and -40 daPa region) in 3 patients, normal or type-A (peaking between 0 to -100 daPa) in 1, and type-A (normal peaks with smaller amplitude) in 2 of the cases. A tympanometric

Table 1

History and physical, radiological and audiometric findings of the patients with traumatic ossicular disruption (*EAC: external auditory canal, **Hearing loss levels: moderate: 40-55 dBHL, moderately severe: 55-70dBHL)

PATIENT (AGE)	SYMPTOMS	HISTORY	OTOPSCOPIC FINDINGS	TYMPANO-GRAMS (Types)	HEARING LOSS TYPE and LEVEL	TEMPORAL CT FINDINGS
E.Y. (21)	Right hearing loss	Traffic acident, 2 years prior, posttraumatic hemorrhagic otorrhea	Groove in the bony EAC*, manibrium could not be identified	A	Moderately severe**, mixed type	Longitudinal temporal fracture line
C.A. (21)	Left hearing loss	Fall, 5 years prior	Dull TM	As	Moderate**, mixed type	
S.D. (22)	Right hearing loss	Hitting, 3 years prior	Normal	C (Bifid)	Moderate, conductive type	
S.A. (21)	Right hearing loss, dizzy spells, black-outs	Blow, 1 year prior	Normal	C	Moderately severe, sensorineural type	
H.E. (21)	Right hearing loss	Traffic acident, 6 years prior	Contour changes in the posterior and superior end of the EAC bony wall	As	Moderate, conductive type	Dislocation in the incus-malleus block
M.A. (24)	Left hearing loss	Hitting, 1 year prior (during wrestling), posttraumatic hemorrhagic otorrhea	Normal	C	Moderate, mixed type	Normal

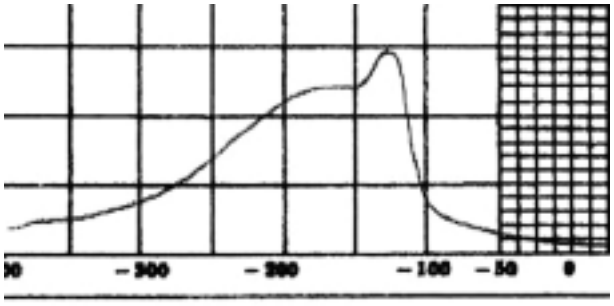

Figure 1
Bifid peaked tympanometric curve indicating an abnormality in ossicular continuity (Case 3).

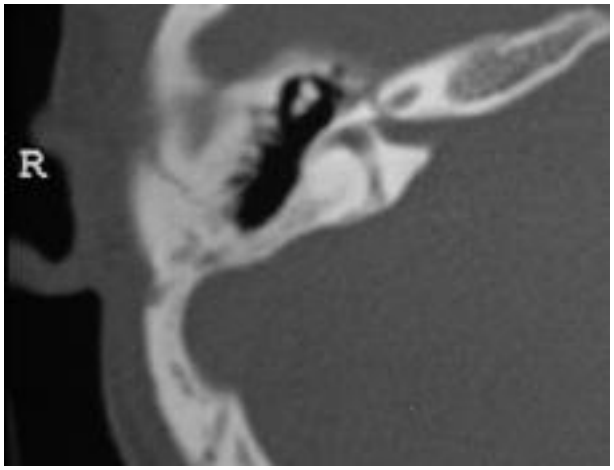

Figure 2
Right longitudinal fracture line (old) (Case 1)

curve with open ended or a deep peak (type Ad tympanogram), one of the pathognomonic findings of ossicular discontinuity, was not recorded in any of the patients; however, bifid tympanogram (also type-C) was taken in one of the cases (Figure 1). Stapedial reflex could not be elicited in any of the affected ears. Bi-thermal caloric test indicated canal paresis on the affected side in the patient with vertigo and SNHL. A fissure line, indicating a sustained temporal fracture, was identified in only one patient (Figure 2), and displacement of the incus-malleus block, consistent with a suffered middle ear trauma, was found in another case.

During the tympanotomy procedure, see Table 2, one or more ossicular abnormalities were identified in all of the ears, most common of which was incudo-stapedial joint (ISJ) disarticulation. Less frequently we found limited mobility of stapes due to secondary changes. A "mini" perilymph fistula was identified in the stapes footplate in the case with NSHL and vertigo, in addition to multiple ossicular pathologies (Table 2).

Various techniques were used to restore ossicular chain continuity and mobility. For the ISJ reconstruction, perichondrium-cartilage grafting was performed in 3 of the cases, in which part of the lenticular process was missing. Stapes mobilizing interventions were performed in 2 of the patients. In one case, the incus was transposed between the stapes and the malleus, and a Teflon piston was placed between the remaining mobile footplate and the incus through a small hall in another one. The fistula in the footplate was plugged with grafts of fat and overlying perichondrium (Table 2).

We achieved an average hearing gain of 28.17 dBHL in air conduction and 20.34 dBHL in ABG through the above-mentioned operations. Air-bone conduction gaps were brought to within 10 dB in 50% of the patients. Fairly significant improvements were also achieved in the bone conductions (average 7.83 dBHL) (Table 2). Bone conduction improvement was achieved in 5 of the 6 cases (one case with 1 dB improvement was excluded). In addition to postoperative improvements in the hearing levels, the patient with labyrinthine fistula described improvement of his complaints of vertigo.

The average follow-up period was 5 months with increasing intervals. The final two audiometric measurements confirmed stabilization of the surgical results.

Discussion

Hearing loss is a common complication of ear or temporal bone traumas. Conductive or mixed type hearing loss has been reported to occur early (within days) after temporal bone fractures in 37-66% of the patients,[4,10] whereas hearing losses with conductive component appear to persist later in life in only 10-20% of the temporal bone trauma cases, most likely due to spontaneous resolution of the hemotympanum or re-attachment of the ossicles by fibrous bands in the majority of the cases.[3,7] In recent years, the widespread use of advanced imaging that enables more accurate description of the damage has facilitated alternative categorizations of temporal bone fractures[9,11,12] in place of the classic

Table 2
Preoperative findings, description of the operations and postoperative results (hearing gains)

PATIENT	PREOPERATIVE FINDINGS	DESCRIPTION of OPERATIONS (Type of tympanoplasties)	HEARING GAINS (Ac/Bc; dBHL) (*thresholds, **air-bone gaps)		
			Preoperative thresholds	Postoperative thresholds	Hearing gains
E.Y.	Eroded and dislocated incus, absence of malleus	Type-II, cartilage oto-grafting between malleus and incus	55/18* (37)**	24/17 (7)	31/1 (30)
C.A.	Fractured stapedial crura	Type-III, Teflon piston placement between footplate and incus	53/20 (33)	25/13 (12)	28/7 (21)
S.D.	ISJ (incudo-stapedial joint) separated, fractured lenticular process	Type-II, cartilage oto-grafting between malleus and incus	43/10 (33)	13/5 (8)	30/5 (25)
S.A.	ISJ separated, sklerosis in stapedial tendon, fixed footplate, perilymph fistula	Stapedial tendon transection, footplate mobilization, fistula repair	65/55 (10)	50/37 (13)	15/18 (-3)
H.E.	Enlargement of epitympanum, rotated incus-malleus block	Type-II, incus interpositon	60/15 (45)	13/10 (3)	47/5 (42)
M.A.	Fibrous bands around stapes, limited stapes mobility	Debridement, stapedial tendon transection, stapes mobilization	43/20 (23)	25/12 (13)	18/8 (10)
AVERAGE			**53.17/23 (30.17)**	**25/15.67 (9.33)**	**28.17/7.33 (20.83)**

division of longitudinal and transverse fractures.[1,13] A more hearing oriented classification divides the temporal bone fractures into "otic capsule sparing" and "otic capsule violating" types.[11] The proportions of the fracture types also vary depending on the classification used. According to classical knowledge, the longitudinal fractures make up 70-90% of the temporal bone fractures, with the majority resulting in conductive hearing loss,[1,13] while recent studies demonstrated that most of the temporal bone fractures are actually of mixed or oblique types.[4,9] Likewise, in a series of 90 temporal bone fracture cases, only 38% of the identifiable fracture lines were pure longitudinal.[4] On the other hand, any trauma to the region may lead to conductive hearing loss without any fracture or dislocation by causing laceration, contusion and effusion in the middle ear, which progresses into fibrosis and ossification, and thus fixation of the ossicles.[14]

Our findings also support these two characteristics, as only one of four CTs showed a fracture line, and in the 2 ears analyzed, ossicles were intact and showed continuity, but their movements were limited. Presence of stapes fixation and fibrous adhesions in the middle ear space in these cases suggested the occurrence of direct injuries to the middle ear structures, causing hemorrhage and exudation that organized into scar tissue and eventually hindered movements of the ossicles. These signs also reflect the long-standing maturation process of the posttraumatic scar tissue.

The most common type of traumatic ossicular damage is ISJ disarticulation (53-82%), followed by fracture of lenticular process and incus dislocation.[7,10,15] Relatively poor ligamentous support of the incus is believed to render this ossicle more vulnerable to external forces compared to the malleus and stapes.[16] The fracture of the stapes footplate and crura are seen less often, and may be accompanied by perilymph fistula and oval or round window membrane tears.[2,15] On the other hand, isolated malleus fractures and dislocations rarely occur, and are usually in the form of manubrium fractures or extrusion of the whole malleus, which are caused by great traumatic pressures directly delivered through the external auditory canal.[5,15] In our case with absent malleus, the ossicle might

have extruded in the same fashion, or dislocated and de-vitalized over time.

We assessed a postoperative improvement of over 5 dBHL in bone conduction in 5 of our cases, and stapes mobilizing interventions were carried out in two of these cases. The elevation of the BC threshold in the middle ear pathologies was first pointed out by Carhart, who reported a BC threshold dip around 2 kHz in otosclerosis, which is now referred to as "Carhart's notch".[17] Bone conduction threshold elevation in middle ear pathologies is partly explained by the lack of "inertial motion" of the ossicles at higher frequencies. Inertial motion of the middle ear ossicles, one of the physical phenomena involved in BC stimulation, is enabled by the spring-like action of the ligaments and tendons that attach the ossicles to the bony tympanic walls and cause "in phase" movement of the ossicles with the skull vibration in lower frequencies. However, during the vibration of the skull at higher frequencies, this mechanism is overridden, and thus relative motion of the ossicles to the bony tympanum results in cochlear fluid displacement and sound perception. Discontinuity of the middle ear ossicles, therefore, causes a relative threshold elevation between 1.5 kHz, which corresponds the resonant frequency of stapes footplate, and 3 kHz,[18] and this would explain the BC gain we achieved in our cases in which ossicular chain continuity has been restored.

Type-Ad tympanogram, known to be characteristic for ossicular discontinuity, was not observed in any of our patients. However, a tympanogram with a bifid peak, which can also be interpreted as ossicular discontinuity,[18] was observed in one patient. This may have been due to the fact that our patients were "delayed" cases, and fractured or dislocated ossicles were most likely gradually attached or fixed to the surrounding tissues by adhesions. A 16 case series with ossicular disruptions confirmed that static admittance measurement with a 226 Hz probe tone has limited predictive value in identifying tympano-ossicular pathologies, as opposed to a 678 Hz probe tone (43% vs. 88%).[19] Indeed, we did not find any hyper-mobile or free ossicles or ossicular fragments during the operations; on the contrary, some ossicles had to be mobilized, as explained above.

Timing of the surgery for traumatic ossicular disruption is widely accepted to be no sooner than 4-6 weeks in order to allow spontaneous resolution of hemotympanum, healing of mucosal tears and possible re-attachment of ossicles.[8,20] Some authors encourage longer waiting periods, and in many cases, ossicular chain reconstructions are successful years after the trauma. Seven weeks to 6 months is now considered to be the period of spontaneous repair.[20] Few reports describe the correlation between the time of the surgery and surgical results of ossicuplasties for traumatic ossicular disruption. Pedersen and Johansen[21] report that of a large retrospective traumatic ear lesion series, the 11 patients whose postoperative hearing remained unchanged or worsened had a history of long delay of treatment. Likewise, in a relatively homogenous middle ear trauma series, Strohm[20] found that although auditory gain is greater, residual hearing was decreased in delayed surgical cases. Yetişer *et al*.[22] also attributed their moderate 37.6% rate of 10 dB ABG closure to delayed surgeries. These findings confirm the observation that the process of ossification or fibrosis and consequent fixations of the ossicles following middle ear trauma continue for years. On the other hand, exploration of tympanum is also indicated for definitive diagnosis of ossicular disruption when posttraumatic conductive or mixed hearing loss persists for over 6 weeks.[8,20] Our series is not large enough to extract a definitive conclusion of the correlation between the timing of surgery and surgical outcome, although ABG was brought to within 20 dB in all of our cases in which surgery was delayed for more than a year. Nevertheless, we suggest that the surgery should not be postponed for more than 6 months once posttraumatic hearing loss with conductive component has been suspected. Even if the delay would not considerably affect the surgical outcome, there is no conceivable reason to deprive the patient of the potential benefit of the surgery.

Conventional ossiculoplasty techniques were adhered to in restoration of the mobility and continuity of the ossicles for our cases[2,3]: cartilage grafts were used for ISJ reconstruction, as part of the lenticular process was missing in all of those cases, incus transposition was used in the case of incus dislocation, and a Teflon piston was inserted into the mobile footplate through a small hall for the fractured stapes suprastructure. A less than 20 dBHL ABG, which has been accepted as the criterion of successful ossiculoplasty, was achieved in all of our cases, and in

3 (50%) of the patients, an ABG within 10 dBHL was achieved. Wennmo and Spandow[8] and Hough and Stuart[23] reported high success rates for traumatic ossicular disruption surgery, as they achieved an ABG of 10 dB or better in 78% and 67% of their cases, respectively. The former authors also reported <20 dBHL ABG in 89% of their patients. According to the "20 dB ABG" criteria, Pedersen and Johansen[21] reported a 78% success rate in their retrospective 122 case series, while Yetişer *et al*.[22] attained this criteria in 71.9% of their 32 patients. Although the timings of the surgeries were not so favorable and the number of cases was fewer, our results are comparable to theirs. On the other hand, success rates (<20 dB gap) range from 50 to 66% in the series of ossiculoplasty for the chronic otitis media-related ossicular damages.[24,25] This is possibly because of the recurrences of the disease or proliferation of a widespread fibrous tissue following the interventions aimed at clearing out the diseased mucosa, which eventually displace the repositioned ossicles.[25] In contrast, middle ear mucosa in the traumatic ossicular disruption is mostly healthy to facilitate the stabilization of the surgical results.

Conclusion

Any trauma affecting the middle ear and causing traumatic ossicular disruption can result in a hearing loss typically with conductive component (conductive or mixed). However, bone conduction may also deteriorate when integrity and/or mobility of the ossicles are affected, or a pathologic connection between the middle and inner ear (fistula) occurs. Type-Ad tympanogram or hyper-compliance, characteristic tympanometric finding of ossicular discontinuity, may not be found in delayed cases due to fibrosis and fixation. Exploratory tympanotomy appears to be the method of choice in the assessment of the extent of the traumatic ossicular damage. Hearing results after traumatic ossicular disruption surgery, as long as inner ear remains intact and general principles of ossiculoplasty are followed, are usually favorable even in cases whose surgery was delayed, such as ours.

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