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Original Article

Surgical Management and Hearing Outcome of Traumatic Ossicular Injuries

Stefan Delrue*, Nicolas Verhaert*, Joost van Dinther, Andrzej Zarowski, Thomas Somers, Christian Desloovere, Erwin Offeciers

Sint-Augustinus Hospital, European Institute for ORL-HNS, Wilrijk (Antwerp), Belgium (SD, JvD, AZ, TS, EO)
University Hospitals Leuven, Department of Otorhinolaryngology, Head and Neck Surgery, Leuven, Belgium (NV, CD)

OBJECTIVE: The purpose of this study was to investigate etiological, clinical, and pathological characteristics of traumatic injuries of the middle ear ossicular chain and to evaluate hearing outcome after surgery.

MATERIAL AND METHODS: Thirty consecutive patients (31 ears) with traumatic ossicular injuries operated on between 2004 and 2015 in two tertiary referral otologic centers were retrospectively analyzed. Traumatic events, clinical features, ossicular lesions, treatment procedures, and audiometric results were evaluated. Air conduction (AC), bone conduction (BC), and air-bone gap (ABG) were analyzed preoperatively and post-operatively. Amsterdam Hearing Evaluation Plots (AHEPs) were used to visualize the individual hearing results.

RESULTS: The mean age at the moment of trauma was 27.9±17.1 years (range, 2–75 years) and the mean age at surgery was 33.2±16.3 years (range, 5–75 years). In 10 cases (32.3%), the injury occurred by a fall on the head and in 9 (29.0%) by a traffic accident. Isolated luxation of the incus was observed in 8 cases (25.8%). Dislocation of the stapes footplate was seen in 4 cases (12.9%). The postoperative ABG closure to within 10 and 20 dB was 30% and 76.7%, respectively.

CONCLUSION: Ossicular chain injury by direct or indirect trauma can provoke hearing loss, tinnitus, and vertigo. As injuries are heterogeneous, they require a tailored surgical approach. In this study, the overall hearing outcome after surgical repair was favorable.

KEYWORDS: Middle ear ossicular chain, trauma, hydroxyapatite, ossiculoplasty

INTRODUCTION

As a musculoskeletal unity, supported by joints and ligaments, the ossicular chain of the middle ear is prone to dislocations and fractures. Traumatic injuries of the ossicular chain were already being reported in the 19th century [1]. With the introduction of the operating microscope and exploratory tympanotomy in the 1950's, these lesions were more frequently diagnosed [2, 3]. The first cases were treated by restoring the ossicles to their original position or with bone chips, sculpted incus autografts, or allografts [2]. While biocompatible prostheses were initially developed to improve hearing in chronic middle ear disease and otosclerosis, they also proved their usefulness in traumatic disease treatment [2-9]. A recent innovation is the application of hydroxyapatite bone cement, which appears to be a reliable technique to restore the energy transfer in a more physiological way [10, 11]. Ossicular dislocations are far more common than fractures. They may occur in any of the ossicular joints and can be subdivided into incudostapedial joint or incudomallear joint separations, and dislocations of the incus, stapes or incudomallear complex [12]. Dislocations may range from a slight subluxation to a complete disruption of the joint. Fractures may occur in all three ossicles and can be easily overlooked by their subtle clinical appearance. Hearing loss is purely conductive for traumas limited to the middle ear, or mixed in case of a stapediovestibular luxation or footplate fracture. In the latter, vertigo may coexist with a pneumolabyrinth as a radiological hallmark. Traumatic events can be either direct or indirect. A direct trauma is caused by direct contact to the ossicular chain due to a blast or a foreign body insertion through the ear canal. Indirect forces occur by acceleration-deceleration, like in a traffic accident, a fall from height, or a blow to the head. In these cases, forces are transmitted through the skull and cause an ossicular luxation or fracture, often associated with a longitudinal, transverse, or mixed fracture of the temporal bone. Longitudinal fractures run along the long axis of the petrous pyramid and are most common (70%–90%). In these cases, facial nerve injury occurs in 10%–25% and otic capsule involvement is rare. Transverse fractures have a course perpendicular to the long axis of the petrous bone. Bony labyrinth involvement is common and facial nerve injury is estimated up to 50% [13]. In high-income countries, more rigorous regulations, such as the compulsory use of a helmet or safety belt, resulted in a decline in traffic related head injuries. In developing countries, however, the number of injuries is still rising due to the increased use of motor vehicles [14]. The aim of this study was to review the etiological, clinical and pathological features of traumatic lesions of the ossicular chain and to evaluate hearing outcomes after surgery.

Corresponding Address: *Stefan Delrue and Nicolas Verhaert have contributed equally to this paper. E-mail: delrue.stefan@gmail.com - nicolas.verhaert@kuleuven.be

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MATERIALS and METHODS

The study was performed in two tertiary-referral otologic centers. 30 consecutive patients with traumatic ossicular injuries, operated on between 2004 and 2015, were retrospectively analyzed. One patient had a bilateral lesion. Traumatic events, signs and symptoms, ossicular injuries, treatment procedures, and hearing outcomes were collected from the medical records. Both cases with posttraumatic conductive as well as mixed hearing loss due to inner ear trauma were included. Each case was treated according to the specific nature of the lesion. Surgeons could choose between ossicular remodeling techniques, allografts (malleus or incus), hydroxyapatite bone cement (OtoMimix; Walter Lorenz Surgical, Inc., Jacksonville, FL, USA), total or partial titanium replacement prostheses, and stapes prostheses. Sealing of the oval window was performed with connective tissue, perichondrium, or fascia, in combination with fibrin glue. Preoperative and postoperative air conduction (AC), bone conduction (BC), and air-bone gap (ABG) were calculated for the 0.5, 1, 2 and 3kHz hearing thresholds according to the guidelines of the Committee on Hearing and Equilibrium [15]. If not separately measured at 3kHz, the pure-tone air and bone conduction threshold results for 2 and 4 kHz were averaged. Individual audiological results were presented in Amsterdam Hearing Evaluation Plots (AHEPs), in the same way as it is used to report the individual results in stapes surgery [16].

Statistical Analysis

The normality of the data distribution was checked with a Shapiro-Wilk normality test. Pre- and postoperative hearing results were compared using the non-parametric Wilcoxon Signed rank test. Statistical analysis was performed on IBM SPSS Statistics version 22 software (SPSS; Chicago, IL, USA). Multi-detector and high-end cone beam CT-devices were used for temporal bone imaging. All patients gave their written informed consent for the surgical interventions. The principles outlined in the Declaration of Helsinki were followed. As a retrospective chart study, no separate ethical committee approval was needed. The study only collected and analyzed outcome data in an otherwise standard patient population.

RESULTS

The average ages at the moment of trauma and surgery were 27.9±17.1 years (range, 2–75 years) and 33.2±16.3 years (range, 5–75 years), respectively. Mean delay between trauma and surgery was 5.5±9.2 years (range, 0–28 years). The male-to-female ratio was 1.5. 10 (32.3%) ossicular lesions were caused by a fall on the head and 9 (29.0%) by a traffic accident. An overview of the traumatic events and their incidence is provided in Table 1. In one patient (3.3%) ossicular injury occurred bilaterally after a fall on the head. In 4 patients (13.3%) the exact traumatic event could not be determined, but a clear traumatic injury (fracture or dislocation) was discovered during middle ear exploration. Hearing loss was an overall symptom, reported by all patients. Non-pulsatile tinnitus occurred in 13 patients (43.3%) and vertigo in 4 (13.3%). The vertigo varied from global instability to positional vertigo and vertigo elicited by pressure changes. CT imaging showed a temporal bone fracture in 16 cases (51.6%). Fourteen (45.2%) of these were longitudinal and two (6.5%) were mixed. Facial nerve palsy was observed in two cases (6.5%) and both were associated with a longitudinal fracture of the temporal bone. A perforation of the tympanic membrane was found in 4 cases (12.9%) and healed spontaneously in 3 (9.7%) of these. Isolated luxation of the incus (discontinuity of both the incudostapedial and incudomallear joint) was encountered in 8 ears (25.8%) and was the most frequent lesion. In 3 of these cases (9.7%), the own incus could be retrieved and used as a sculpted interposition graft. A summary of all ossicular lesions and treatment modalities is shown in Table 2. Hydroxyapatite bone cement was used to bridge ossicular discontinuity (fractures and dislocations) in 12 cases (38.7%) and to stabilize a titanium partial ossicular replacement prosthesis in 1 (3.2%) case. A sculpted allograft incus was used in 6 cases (19.4%): in 4 (12.9%) as an interposition between malleus handle and the stapes suprastructure, and in 2 (6.5%) between the stapes footplate and original incus. Stapediovestibular dislocation occurred in 4 cases (12.9%) and was caused by the insertion of a foreign body in the external auditory canal in 3 of them. To prevent inner ear trauma by pressure on a mobile footplate, the ossicular chain of one patient was left interrupted after repositioning of a dislocated stapes out of the vestibule. By doing so, the BC threshold of 15.0 dB HL could be preserved. Surprisingly, the postoperative AC threshold in this patient was 28.1 dB HL and no further intervention was scheduled. Fixation of the stapes footplate was observed in 2 cases (6.5%), both with a fracture of the stapes crura. In these cases, a stapedotomy was performed. Of the two cases with facial nerve palsy, one had a bony spicule compressing the nerve at the geniculate ganglion. Removal of this spicule was followed by a complete facial nerve decompression from the internal auditory canal up to the stylomastoid foramen. The facial nerve function recovered from a House-Brackmann grade VI to grade II. The other patient presented with a facial nerve palsy grade III with spontaneous recovery to grade I within 4 weeks after trauma. During surgery, a partially denuded, but otherwise normal, facial nerve was found. One case with a preoperative near deafness (AC 103.5 dB HL) due to a longstanding perilymphatic fistula caused by the insertion of a cotton swab could not be treated and was therefore not included in the audiometric analysis. Standard postoperative audiometry was performed after six months up to 1 year. Mean follow-up time was 11.5 months. Individual hearing outcomes are presented in AHEPs (Figure 1). These graphs allow for a visual representation of the hearing results of each individual. The 2 diagonal lines in Figure 1a enclose the area within the BC that did not change over more than 10 dB. The full diagonal line (x=y) in Figure 1b represents complete ABG closure. Hearing results above the dotted line (n=4) represent changes in the AC insufficient to close the gap between the postoperative AC and the preoperative BC to 20 dB or less. The mean preoperative and postoperative AC pure-tone thresholds were 46.4±13.7 dB HL and 28.2±15.2 dB HL, respectively. The mean BC pure-tone threshold was 14.2±8.3 dB HL preoperatively and 13.3±9.7 dB HL postoperatively. The BC did not change significantly ($p>0.05$). The average BC deteriorated more than 10 dB (12.5 dB) in only one patient. This was a case of a fracture of both stapes

Table 1. Distribution of traumatic events (n=31)

Traumatic event	Number of cases
Fall on the head	10
Traffic accident	9
Penetrating trauma through ear canal	5
Unknown	4
Removal of finger from ear canal	2
Blow to the head	1

Table 2. Treatment procedures according to ossicular lesions (n=31)

Lesion	Number of cases	Treatment (Number of cases)
Incus luxation	8	Autologous incus interposition (3)
		Allograft incus interposition (3)
		HA cement bridging of incudomalleolar and incudostapedial joint (1)
		PORP + fixation of prosthesis with HA cement (1)
Incudostapedial dissociation	5	Incudostapedial bridging with HA cement (3)
		Autologous incus interposition (2)
Malleus fracture	4	HA cement bridging (4)
Incudomallear dissociation	3	HA cement bridging (2)
		Autologous incus interposition (1)
Incus luxation + stapediovestibular dislocation + PLF	2	Stapes repositioning* (1)
		Footplate repositioning and sealing + allograft incus (1)
Stapes suprastructure fracture	2	Allograft incus: columellar reconstruction between footplate and original incus (2)
Stapes suprastructure fracture + footplate fixation	2	Stapedotomy (2)
Incus fracture	1	HA cement bridging (1)
Incus luxation + stapes fracture (capitulum)	1	Autologous incus interposition (1)
Stapediovestibular dislocation + incudostapedial dissociation	1	Stapes repositioning + incudostapedial bridging with HA cement (1)
Stapes suprastructure fracture (anterior crus) + PLF	1	Sealing footplate (1)
Stapediovestibular dislocation (lateralization of footplate) +PLF	1	Sealing footplate (1)

PLF: perilymph fistula; PORP: partial ossicular replacement prosthesis (titanium); HA: hydroxyapatite
*without further ossicular reconstruction because of unstable footplate. In this case an anterior tympanic membrane perforation was also closed.

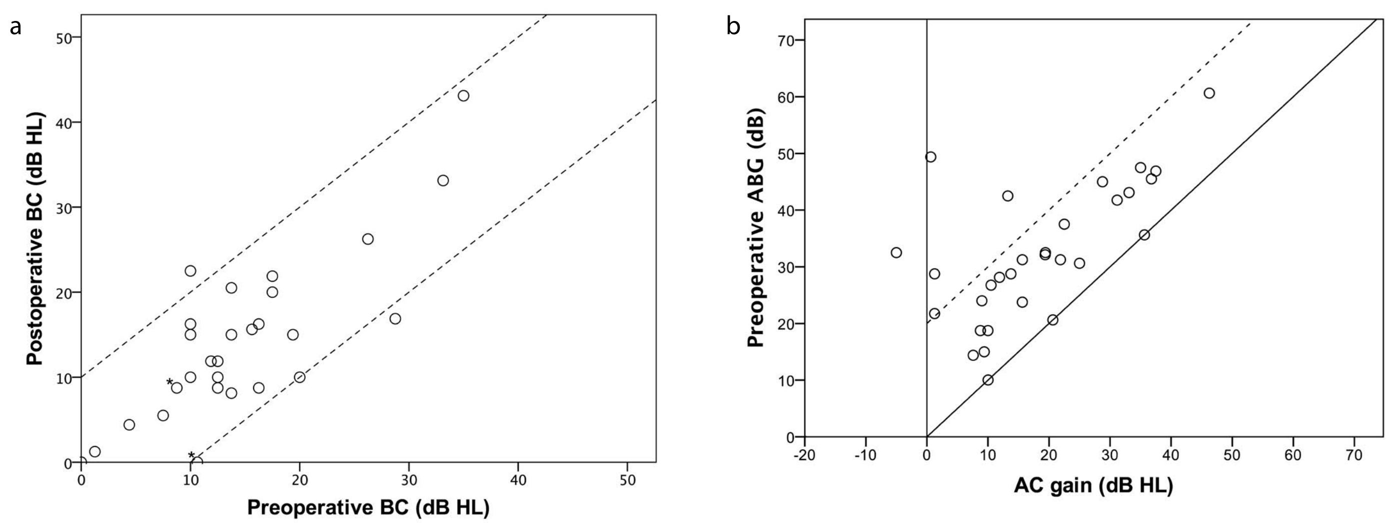

Figure 1. a, b. Individual audiometric results (n=30) shown in AHEPs. (a) Pre-operative BC is plotted against postoperative BC for each operated ear. The 2 dashed lines confine the area in which the BC did not change over more than 10 dB. Asterisk indicates two cases with identical BC values. (b) Postoperative AC gain is plotted against the preoperative ABG for each operated ear. The solid line indicates a total closure of the ABG after surgery. Hearing results above the dotted line represent changes in AC insufficient to close the gap between postoperative AC and preoperative BC to 20 dB or less

crura, in which a columellar reconstruction of a malleus allograft on the stapes footplate was used. The mean ABG was 32.2±12.0 dB preoperatively and 14.8±9.8 dB postoperatively. The postoperative ABG closure to within 20 and 10 dB was 76.7% and 30%, respectively. The Wilcoxon Signed rank test showed a significant improvement of AC (Z=−4.7; p<0.001) and ABG after surgery (Z=−4.7; p<0.001). The box and whisker plots of the audiometric results are shown in Figure 2.

DISCUSSION

Hearing loss after head trauma is common and is mostly a temporary discomfort caused by a hemotympanum or a tympanic membrane perforation. Ossicular injury should be considered when conductive hearing loss persists several weeks after trauma and exceeds 30 dB. Posttraumatic vertigo is often caused by concussion, which can be treated conservatively. Vertigo provoked by changes in pressure or

Table 3. Overview of traumatic ossicular injury case series

Author	Number of ears	Incus involvement (%)	Footplate injury* (%)	Surgical Technique	ABG closure
Wright et al. (5)	21	20 (95.2)	4 (19.0)	Wire/gelfoam stapedectomy, ossicular repositioning, autograft ossiculoplasty, bone graft	66.7% within 10 dB°
Hough et al. (2)	31	?	?	Bone graft interpositioning, repositioning, wire prosthesis, autograft ossiculoplasty	78% within 10 dB°
Cremin (3)	16	12 (75.0)	0	Teflon wire piston, polythene/Nylon tubing, fat wire prosthesis, myringostapediopexy (lowering ear drum)	75% within 10 dB°
Spector et al. (6)	28	20 (71.4)	5 (17.9)	Ossicular repositioning, autograft ossiculoplasty, fat/wire prosthesis, polythene sheet/strut, stapedectomy	66% within 10 dB° 82% within 20 dB°
Yetiser et al. (8)	32	29 (90.6)	2 (6.3)	Ossicular repositioning, autograft ossiculoplasty, hydroxyapatite cement, Fluoroplastic piston prosthesis, TORP, PORP	37.6% within 10 dB^ 71.9% within 20 dB^
Basson et al. (7)	16	15 (93.8)	0	Autograft ossiculoplasty, cartilage/bone graft interpositioning, TORP, PORP	Average postop ABG 15 dB° (2 patients lost to follow-up)
Ghonim et al. (9)	42	30 (71.4)	?	Stapedotomy, ionomeric cement, autograft ossiculoplasty, bone graft interpositioning	71.4% within 10 dB^ 90.5% within 20 dB^
Delrue et al. (18)	31	21 (67.7)	4 (12.9)	Autograft / allograft ossiculoplasty, stapedotomy, stapes repositioning/sealing PORP, hydroxyapatite cement	30% within 10 dB^ 76.7% within 20 dB^,

*Fracture of stapes footplate or stapediovestibular dislocation; °Calculated for frequencies 0.5, 1, 2 kHz; ^Calculated for frequencies 0.5, 1, 2, 3 kHz; ABG: air-bone gap; TORP: total ossicular replacement prosthesis; PORP: partial ossicular replacement prosthesis

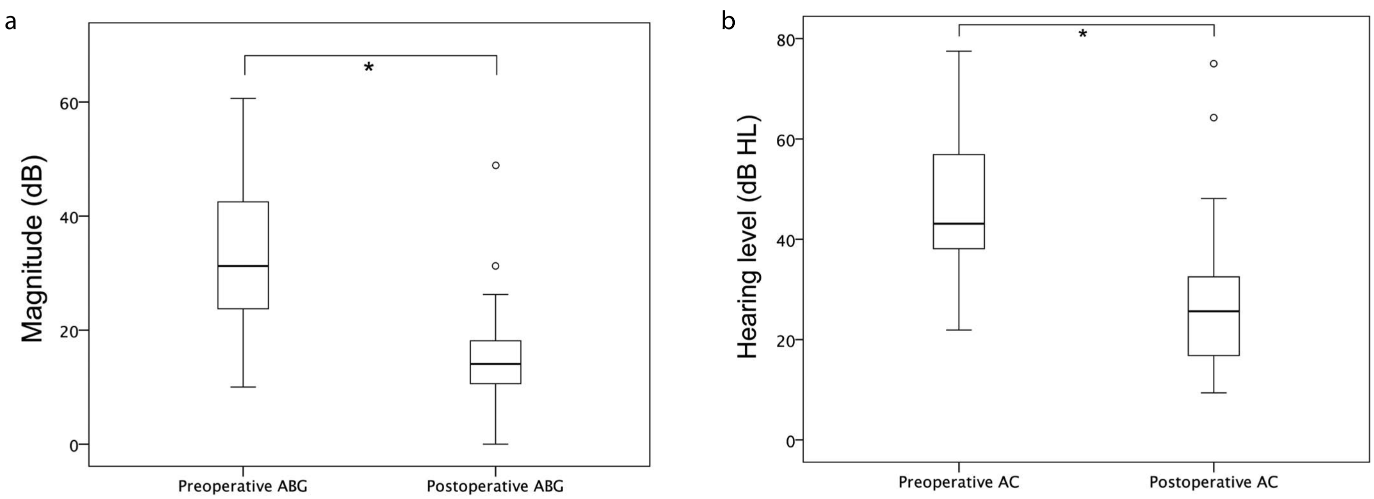

Figure 2. a, b. Box and whisker plots of the audiometric results (n=30). Pre- and postoperative ABG (a) and pre- and postoperative AC (b). Lines indicate median, ends of the whiskers lowest and highest value within 1.5 interquartile range of lower and upper quartile, circles represent outliers and *p<0.001

loud noises, sensorineural hearing loss, and nystagmus must raise the suspicion of vestibulocochlear involvement and a perilymph fistula (PLF). The oval window is a common place of PLF through disruption of the annular ligament or fracture of the stapes footplate. Since most of the attention is primarily focused on stabilizing a patient's overall condition after trauma, a time gap between the accident and diagnosis of an ossicular injury often occurs. The mean delay of 5.5 years in our series is comparable to other studies with average intervals ranging from 5.7 to 8.2 years [4, 6-9]. The higher incidence of indirect traumas to direct traumas also corresponds to previously published data [5, 7-9]. Remarkably, four of our patients had a clear traumatic ossicular lesion, but could not remember the preceding trauma. This ignorance was noted by several authors, who presumed that the traumatic event was neglected or dated from early childhood [2-4].

On the other hand, some patients attribute hearing loss to a traumatic event while chronic middle ear disease eventually turns out to be the cause [2]. Our knowledge about the pathophysiology of traumatic ossicular injuries of the middle ear cleft is largely based on the observations of Hough [17]. A combination of different interfering mechanisms is described: tissue weakening due to the explosive effect of concussion, inertia of the ossicular chain during acceleration and deceleration, tetanic contraction of the intra-tympanic muscles, and a torsion effect of a skull fracture causing shifting of the middle ear contents [17]. All three ossicles are prone to trauma, but because of its lack of a muscular attachment and by its fragile connection with the stapes suprastructure, the incus is by far the most vulnerable [2, 5]. This corresponds to the observations in our study. Fractures are less common than dislocations. We had one case of an incus fracture. This le-

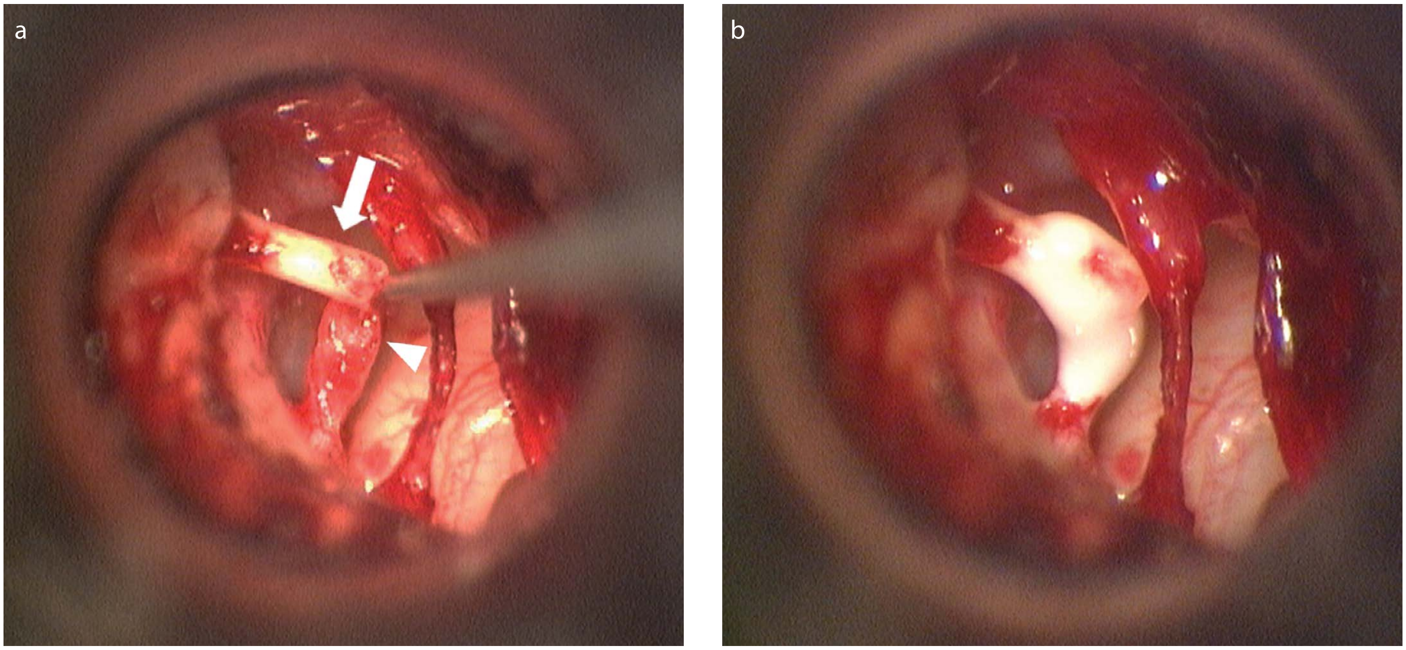

Figure 3. a, b. Avulsion of the lenticular process of the incus (right ear) caused by a bicycle accident. Intraoperative view after elevation of the tympanomeatal flap and mobilization of the chorda tympani. Arrow indicates long process of the incus, arrowhead capitulum of stapes (a). Bridging of the gap with hydroxyapatite cement (b)

sion was bridged with hydroxyapatite cement as illustrated in Figure 3. Meriot et al. [12] reported among ossicular injuries a prevalence of 4% incus fractures, almost all affecting the long or lenticular process. Compared to the incus, the stapes is more securely anchored to the middle ear by its annular ligament and stapedial tendon and muscle. Stapedial lesions in traumatic middle ear disease are mainly fractures of the stapes crura. These lesions are generally caused by torsion of the incus during a high velocity trauma, or more seldom by insertion of a foreign body in the external auditory canal. Several authors noted the association between a fracture of the crura and a fixation of the stapes footplate [2, 5]. This can be due to pre-existing otosclerosis or due to posttraumatic ankylosis. Fixation of the footplate makes the stapes more vulnerable for fractures due to the loss of elasticity in the annular ligament, which could otherwise accommodate a part of the shearing forces. Dislocations of the stapediovestibular joint and fractures of the stapes footplate are mainly caused by direct penetrating events. Since the stapes is often protected by the scutum, these lesions are rare. In our series, three out of four stapediovestibular dislocations were caused by the insertion of a foreign body in the ear canal. Finally, the malleus is firmly attached to the tympanic membrane and is supported by its ligaments and the tensor tympani muscle. Due to the strong double saddle joint, malleus dislocation is nearly always associated with involvement of the incus [5]. A special entity is the isolated fracture of the malleus handle, encountered in 4 cases within the present study. Negative pressure in the ear canal by digital manipulation is the prototypical cause. It may, however, occur without a clear traumatic event [1, 18]. High-resolution CT imaging is useful in the preoperative work-up, but may fail to describe the exact ossicular abnormality. In a large radiological series of 166 cases by Meriot et al. [12], incudomallear joint separation was observed as the most common posttraumatic abnormality. However, the prevalence of incudostapedial joint dissociation is radiographically underestimated because a hemotympanum often masks an interruption, especially when the ossicular ends are still aligned in their normal position. The first reports of surgical repair of traumatic ossicular injuries date back to the 1950s [19]. Although several biocompatible prostheses are now available, we are convinced that ossicular autografts or allografts are still useful, mainly because of a lower risk of extrusion. To treat incudostapedial discontinuity in a conservative way, Cremin [3] described a method with a polythene tube to reconnect the incus and stapes. A variant of this method is an incudostapedial joint splint made from a silicone grommet, as proposed by Mills et al. [20]. These techniques can now be replaced by ossicular bridging with hydroxyapatite bone cement. Biocements have proved their value in otologic surgery as they have ideal adhesive and osseointegrative characteristics [10]. A major advantage is the fact that the ossicular chain can be restored in a more physiologic way and with only minimal manipulation. While good results were reported with glass ionomers, inflammatory reactions may take place when in contact with soft tissue of the middle ear or, more dangerously, with the dura mater [21]. Hydroxyapatite does not cause these effects, as it is a natural component of the living bone. Yetiser et al. [8] reported in a series of 32 ossicular injuries, two cases treated with hydroxyapatite bone cement: a fracture of the incus long process and a fracture of the malleus. In our study, hydroxyapatite cement was used for both fractures and dislocations. Compared to other traumatic ossicular injuries, stapediovestibular dislocation seems the most difficult to treat. Although a PLF may spontaneously resolve and lead to recovery of hearing, progressive or persisting vestibulocochear symptoms require middle ear exploration [22]. Sealing can be performed with fascia, fat, connective tissue, or a vein graft, in combination with fibrin glue. Whether to leave a dislocated footplate in the vestibule, lift it out, or remove and replace it with a stapes piston is still a subject of controversy and depends on the individual case [23]. In order to adequately show the audiometric results, we used the AHEPs. The concept of these plots was introduced by de Bruijn et al. [16] to report the outcome of stapes surgery. It allows an easy recognition of both favorable and unfavorable results of individual cases, as well as cochlear damage due to the procedure or the postoperative course. Table 3 provides an overview of published case series. Our results are comparable to those of Yetiser et al. [8]. A large retrospective study by Pedersen et al. [4], reporting 122 patients, was not included in this table as the audiometric results of ossicular injuries were mixed with pure tympanic membrane perforations, so without ossicular involvement. Remarkably, there is an important variability between reported hearing outcomes in terms of ABG closure. This reflects the diversity of lesions, but may also be due to methodological differences between studies. Inclusion criteria were not always specified and higher frequency (3 and 4 kHz) thresholds were not measured in the publications of the 1960s and 70s. Nevertheless, our overall hearing outcome is favorable and supports (early) surgical intervention after trauma.

CONCLUSION

Traumatic ossicular injuries are heterogeneous, and therefore, require a tailored surgical approach. Our data show that the overall audiometric outcome after surgery is favorable. With the introduction of hydroxyapatite bone cement, an ossicular gap can be bridged with only minimal manipulation. For larger interruptions, ossicular interposition is still needed. The combination of favorable hearing outcome and more precise radiological imaging (i.e., cone beam CT) endorses an attitude toward faster surgical middle ear inspection procedures after major head trauma.

Ethics Committee Approval: As a purely retrospective chart study no formal number/ID of approval was needed from our institutional ethics committee.

Informed Consent: All patients gave their written informed consent for the operations described in this paper.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - N.V., J.V.D.; Design - S.D., N.V., J.V.D..; Supervision - N.V., J.V.D., E.O.; Resources - N.V., J.V.D., A.Z., T.S., C.D., E.O.; Materials - N.V., J.V.D., A.Z., T.S., C.D., E.O.; Data Collection and/or Processing - S.D., N.V., J.V.D.; Analysis and/or Interpretation - S.D., N.V.; Literature Search - S.D.; Writing Manuscript - S.D., N.V.; Critical Review - N.V., A.Z., E.O.

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