



# Temporal bone trauma effects on auditory anatomical structures in mastoid obliteration

Aranka Ilea<sup>1</sup> · Anca Butnaru<sup>2</sup> · Silviu Andrei Sfrângeu<sup>2</sup> · Mihaela Hedeşiu<sup>3</sup> · Cristian Mircea Dudesu<sup>4</sup> · Bianca Adina Boşca<sup>5</sup> · Veronica Elena Trombitaş<sup>6</sup> · Radu Septimiu Câmpian<sup>7</sup> · Silviu Albu<sup>6</sup>

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## Abstract

**Purpose** The risk of temporal bone fractures in head trauma is not negligible, as injuries also depend on the resistance and integrity of head structures. The capacity of mastoid cells to absorb part of the impact kinetic energy of the temporal bone is diminished after open cavity mastoidectomy, even if the surgical procedure is followed by mastoid obliteration. The aim of our study was to evaluate the severity of lesions in auditory anatomical structures after a lateral impact on cadaveric temporal bones in which open cavity mastoidectomy followed by mastoid obliteration was performed, compared to cadaveric temporal bones with preserved mastoids.

**Methods** The study was carried out on 20 cadaveric temporal bones, which were randomly assigned to two groups. In the study group, open cavity mastoidectomy followed by mastoid obliteration with heterologous materials was performed. All temporal bones were impacted laterally under the same conditions. Temporal bone fractures were evaluated by CT scan.

**Results** External auditory canal fractures were six times more seen in the study group. Tympanic bone fractures were present in 80% of the samples in the study group and 10% in the control group ( $p = .005$ ). Middle ear fractures were found in 70% of the samples in the study group and 10% in the control group ( $p = .02$ ). Otic capsule violating fractures of the temporal bone were present only in the study group.

**Conclusions** Mastoid obliteration with heterologous materials after open cavity mastoidectomy increases the risk of fracture, with the involvement of auditory anatomical structures.

**Keywords** Temporal bone fracture · Mastoidectomy · Mastoid obliteration · Auditory anatomical structures · Cadaveric study

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Aranka Ilea and Anca Butnaru have an equal contribution as first authors of the article.

✉ Bianca Adina Boşca  
biancabosca@yahoo.com

<sup>1</sup> Department of Oral Rehabilitation, Oral Health and Dental Office Management, Faculty of Dentistry, “Iuliu Hațieganu” University of Medicine and Pharmacy Cluj-Napoca, Str. Victor Babeş, No 15, Cluj-Napoca, Romania

<sup>2</sup> Department of Radiology, Faculty of Medicine, “Iuliu Hațieganu” University of Medicine and Pharmacy Cluj-Napoca, Str. Clinicilor, No 1–3, Cluj-Napoca, Romania

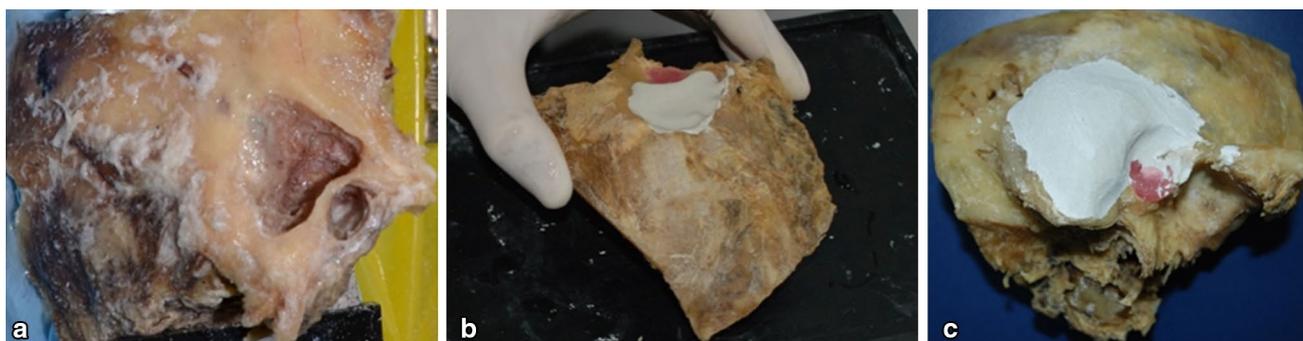
<sup>3</sup> Department of Dental Radiology, Faculty of Dentistry, “Iuliu Hațieganu” University of Medicine and Pharmacy, Cluj-Napoca, Str. Clinicilor, No 32, Cluj-Napoca, Romania

<sup>4</sup> Department of Mechanical Engineering, Faculty of Mechanics, Technical University Cluj-Napoca, B-dul Muncii, No 103–105, Cluj-Napoca, Romania

<sup>5</sup> Department of Histology, Faculty of Medicine, “Iuliu Hațieganu” University of Medicine and Pharmacy Cluj-Napoca, Str. L. Pasteur, No. 4, 400349 Cluj-Napoca, Romania

<sup>6</sup> Department of Cervicofacial and ENT Surgery, Faculty of Dentistry, “Iuliu Hațieganu” University of Medicine and Pharmacy Cluj-Napoca, Str. Gheorghe Bilascu Nr. 16–20, Cluj-Napoca, Romania

<sup>7</sup> Department of Oral Rehabilitation, Oral Health and Dental Office Management, Faculty of Dentistry, “Iuliu Hațieganu” University of Medicine and Pharmacy Cluj-Napoca, Str. Victor Babeş, No 15, Cluj-Napoca, Romania



**Fig. 1** Stages of the preparation of the mastoid neocavity and its filling. **a** Mastoid neocavity; **b** filling of the mastoid neocavity on the dental vibrating table. Wax was dropped in the external auditory canal to avoid the penetration of the filling material at this level.

The wax was subsequently removed mechanically before the lateral impaction of the samples; **c** setting of the filling material and manual finishing

## Introduction

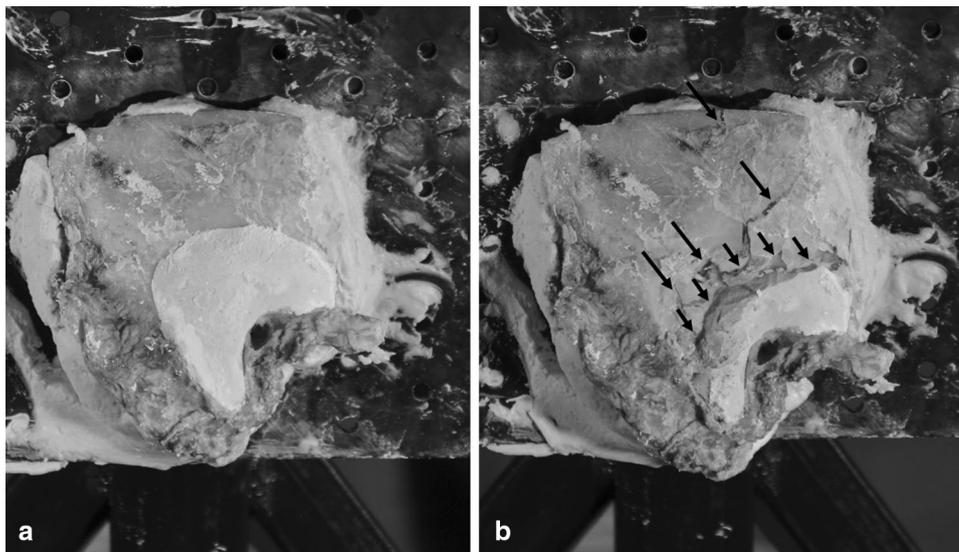
The important goals of mastoidectomy are a disease-free and dry ear, for a good hearing and disease recurrence management. Chronic otitis with or without cholesteatoma, benign or malignant tumors of middle ear and sensory deafness with cochlear implant rehabilitation represent the main indications for mastoidectomy associated or not with obliteration [1, 2]. The concept of mastoid obliteration was introduced by Mosher in 1911 with the aim of promoting the healing of post-mastoidectomy defects [3] with a real specificity for extensive temporal bone trauma, temporal bone resection in malignant tumors, congenital cranial base defect, cerebrospinal fluid leak, iatrogenic injuries, irradiation, chronic otitis with a recidivate cholesteatoma [4]. Mastoid obliteration has the following advantages: it

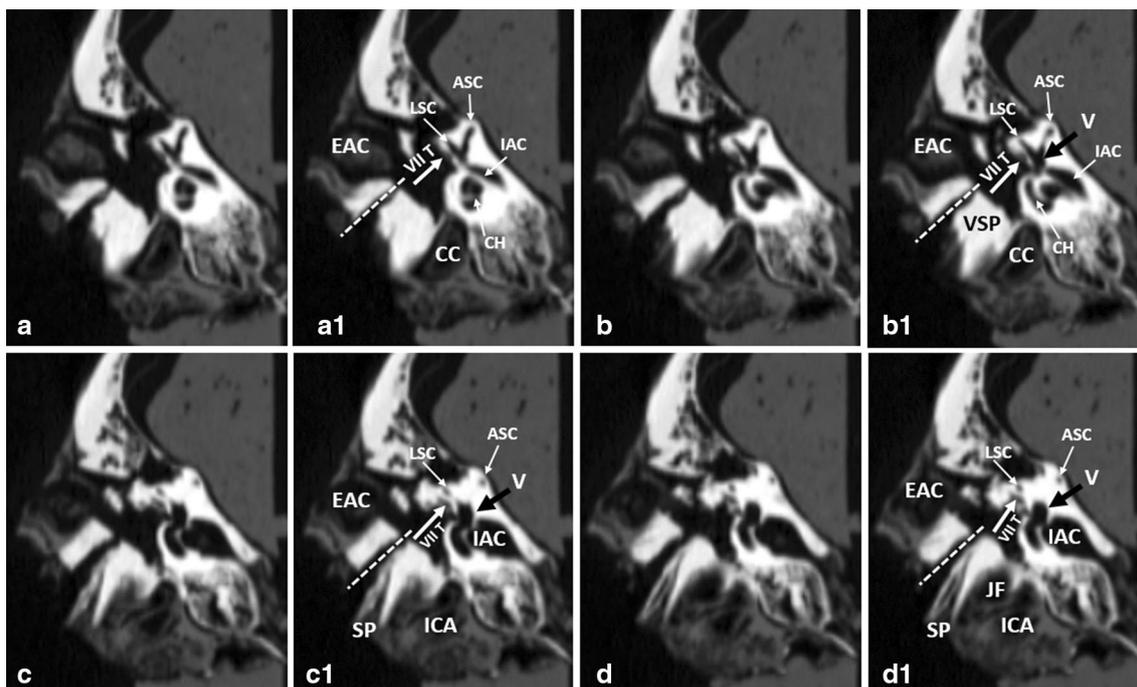
reduces the incidence of chronic discharge, prevents vertigo through exposure of semicircular canals to thermal agents from air and water, reduces the number of visits to the ENT specialist for cavity cleaning, allows hearing-aid implantation, and also improves esthetic appearance after meatoplasty [5].

Many studies have assessed the clinical, histological, imaging and sociological (patient quality of life) changes occurred after mastoid obliteration, but (to our knowledge) no study has described the consequences of temporal bone traumatic injuries after mastoid obliteration with heterologous materials.

The question we aimed to answer in this study is whether open cavity mastoidectomy followed by mastoid obliteration with heterologous materials increases the severity of temporal bone fractures with the involvement of auditory anatomical structures, compared to native mastoids, in the

**Fig. 2** A temporal bone sample in the study group before and after impaction. **a** Sample S1 fixed on a metal support with an irreversible elastic material (sodium alginate—an irreversible hydrocolloid impression material); **b** appearance and direction of fracture lines after impaction observed by examination of the external side; fracture lines in the temporal squama and at the junction with the mastoid (long black arrows); depressed fracture in the impact area (short black arrows)

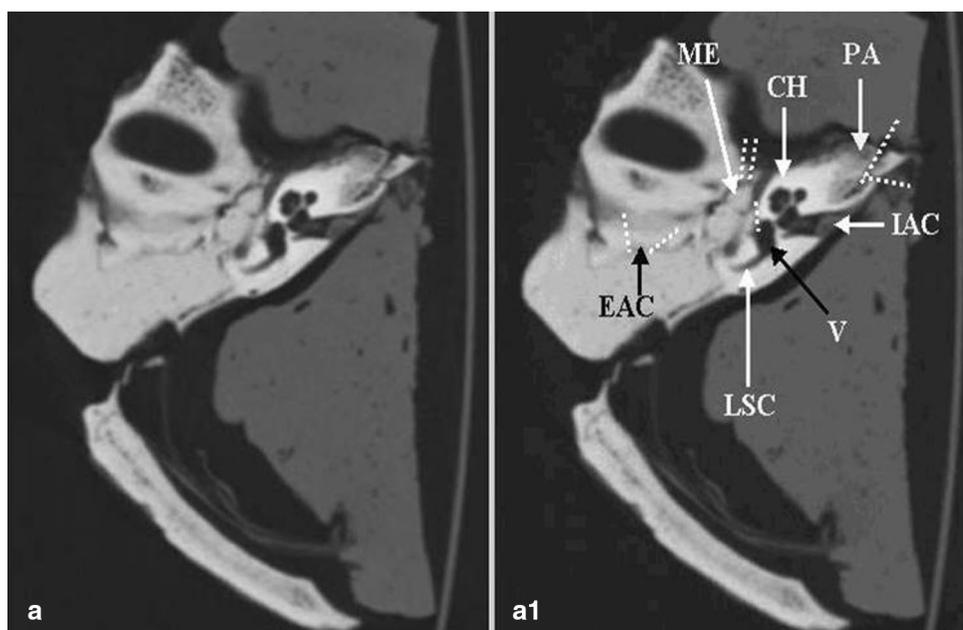


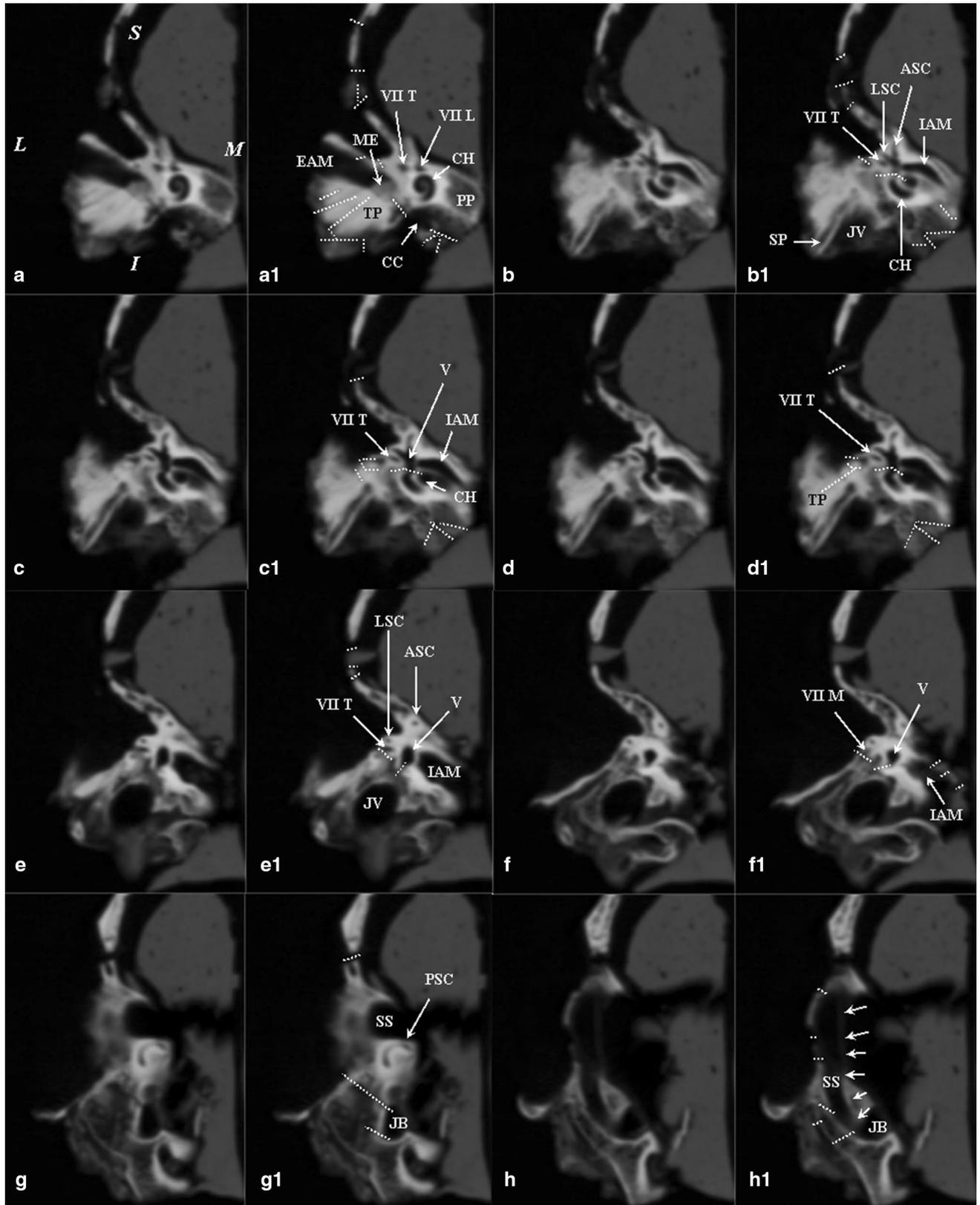


**Fig. 3** Tympanic bone fractures. **a–d** Successive coronal reconstructed CT sections in sample M1 along the tympanic segment of the facial nerve, in anteroposterior direction; the fracture lines in the tympanic bone are represented by an interrupted white line; **a, a1** tympanic segment of the facial nerve (VII T—thick white arrow) positioned below the lateral semicircular canal (LSC—thin white arrow); in the same section are found the cochlear apex (CH—thin white arrow), the anterior semicircular canal (ASC—thin white arrow) and a fragment of the internal auditory canal (IAC—thin white arrow); **b, b1** tympanic segment of the facial nerve (VII T—thick white arrow) positioned below the lateral semicircular canal (LSC—thin white arrow); in addition to the previous section, the cochlea with the apex

and the second spiral turn are evidenced (CH—thin white arrow); the vestibule is marked with a black arrow; **c, c1** si **d, d1** tympanic segment of the facial nerve (VII T—thick white arrow) positioned above the oval window that opens towards the vestibule (black arrow); in addition to the previous section, a fragment of the basal spiral turn of the cochlea and the internal auditory canal are evidenced; the lateral semicircular canal has a punctiform appearance above the facial nerve; VII T tympanic segment of the facial nerve, LSC lateral semicircular canal, ASC anterior semicircular canal, EAC external auditory canal, CC carotid canal, V vestibule, VSP vagina processus styloidei, SP styloid process, IAC internal auditory canal, ICA internal carotid artery (preforaminal, exocranial segment), JF jugular fossa

**Fig. 4** Middle ear fractures with extension to inner ear. **a, a1** Axial section at the level of the upper wall of auditory external canal and the epitympanum in sample S9; the interrupted lines are fracture lines positioned at the upper wall of the external auditory canal (EAC)—the squamous segment, at the level of the anterior wall of the middle ear (ME), at the anterior wall of the vestibule (V) and at the level of the petrous apex (PA); CH cochlea, IAC internal auditory canal, LSC lateral semicircular canal





**Fig. 5** Otic capsule violating fractures of the temporal bone—coronal image of sample S1. **a–h** Coronal reconstructed CT sections using the MPR (multiplanar reconstruction) technique in the areas of interest of the otic capsule, positioned in anteroposterior direction from the cochlea to the posterior semicircular canal in sample S1; the main fracture lines adjacent to the area of interest are marked with interrupted white lines; the first image **a** contains spatial positioning elements marked as follows: *L* lateral, *M* medial, *S* superior and *I* inferior, which correspond to all images **b–h**; **a, a1** coronal section of the external acoustic meatus, middle ear and cochlea (upper portion), evidencing a portion of the labyrinthine and tympanic segment of the facial nerve; the evidenced fracture lines are located in the tympanic portion, in the inferior and superior wall of the middle ear, in the superior wall of the external auditory canal, on the inferior side of the petrous portion adjacent to the carotid canal and in the squama portion; *EAM* external acoustic meatus, *TP* tympanic portion, *CC* carotid canal, *ME* middle ear, *CH* cochlea, *PP* petrous portion, *VII T* tympanic segment of the facial nerve, *VII L* labyrinthine segment of the facial nerve; **b, b1** coronal section of the basal cochlear coil, emergence of anterior and lateral semicircular canals, anterior portion of the internal acoustic meatus and the styloid process; the evidenced fracture lines are located in the superior and posterior wall of the middle ear, in the medial wall of the middle ear extending to the cochlea, on the inferior side of the petrous portion adjacent to the carotid canal and in the squama portion; *SP* styloid process, *JV* jugular vein, *CH* cochlea, *VII T* tympanic segment of the facial nerve, *LSC* lateral semicircular canal, *ASC* anterior semicircular canal, *IAM* internal acoustic meatus; **c, c1, d, d1** coronal sections immediately posterior to image **b**; in addition, the vestibule and multiple fracture lines are evidenced at the superior margin and on the posterior side of the petrous part; *V* vestibule, *VII T* tympanic segment of the facial nerve, *IAM* internal acoustic meatus, *CH* cochlea, *TP* tympanic part; **e, e1, f, f1** coronal section of the posterior portion of the vestibule, anterior and lateral semicircular canals and internal acoustic meatus; the evidenced fracture lines are located in the temporal squama, the proximal descending segment of the facial nerve, in the inferior vestibular wall and posterosuperior wall of the internal acoustic meatus; *JV* jugular vein, *VII T* tympanic segment of the facial nerve, *LSC* lateral semicircular canal, *ASC* anterior semicircular canal, *IAM* internal acoustic meatus, *VII M* mastoid segment of the facial nerve, *V* vestibule; **g, g1** coronal section of the posterior semicircular canal; fracture lines adjacent to the jugular vein bulb and temporal squama; *JB* jugular bulb, *PSC* posterior semicircular canal, *SS* groove for sigmoid sinus; **h, h1** coronal section evidencing the groove for sigmoid sinus (the medial margin is marked with white arrows); the fracture lines are evidenced on the lateral margin; *JB* jugular bulb, *SS* groove for sigmoid sinus

case of lateral trauma applied to temporal bones isolated from human cadavers.

## Materials and methods

The study was approved by the Ethics Committee, No. 250/22.02.2011. The study protocol was described by the team of authors in a previous paper [6] and consisted of the use of 20 temporal bones harvested from human cadavers, of which ten represented the study group (S1–S10), and the other ten remained native and formed the control group (M1–M10). In the study group, mastoid cells were removed by an external approach, and the resulting neocavities were

filled with a mixture of calcium carbonate, white gypsum (semihydrated calcium sulfate) and hydroxyapatite in a proportion of 10:10:1—see Fig. 1.

The samples were harvested so as to avoid any fracture or deterioration. All the harvested samples were right temporal bones. The temporal bones of cadavers with a history of oromaxillofacial diseases, otomastoiditis, and head trauma were excluded from the study.

All samples were impacted at a mean speed of  $3.35 \text{ m/s} \pm 0.013$  and a mean kinetic energy of  $50.50 \pm 0.39 \text{ J}$  using a rigid arm pendulum [6]. The impact area was the same in all samples, being situated on the exocranial surface of the temporal bone, at the junction of the mastoid with the temporal squama—see Fig. 2.

The temporal bone fractures were assessed by CT scan (OPTIMA CT660 128SL WITH ASiR) using spiral acquisition mode with 350 mAs values (automatic modulation), 120 kV, collimation 0.65, pitch 0.8, reconstructed sections of 0.62–0.65 mm, with bone filter and multidetector device (General Electric) with 64 detector rows. The fracture lines assessment was performed by three independent radiologists. Only those recognized by all three investigators were taken into account. The fracture lines being very fine and small were considered if they were found on all three sectional planes: axial, sagittal and coronal. Otic capsule violating fractures of the temporal bone were evaluated, according to the classification of Kang et al. [7], by the involvement of inner ear structures, respectively, the bone labyrinth formed by the cochlea, the vestibule and the three semicircular canals. Petrous bone fractures were assessed in relation to the following components: middle ear, otic capsule, internal acoustic meatus, petrous apex and arteriovenous canals/foramina.

Statistical data processing was performed using the Kolmogorov–Smirnov test for normal distribution. The Student test was used for comparison of the means in the case of two independent samples if the probability distribution was normal. If variables did not have a normal distribution, the Mann–Whitney test was used for comparison of the ranks. The Chi-square test or Fisher’s exact test was used in the case of qualitative variables. For the linear relationship between two discrete quantitative variables, the Pearson correlation coefficient ( $r$ ) was used, and for the non-linear relationship between two discrete quantitative variables, the Spearman correlation coefficient ( $r$ ) was used. The significance threshold for the tests was  $\alpha = 0.05$ . Statistical calculations were performed using SPSS 15.0 and Microsoft EXCEL applications.

## Results

### External auditory canal and tympanic bone fractures

External auditory canal (EAC) fractures were six times more seen in the study group. Tympanic bone fractures were only present in 10% of the samples of the control group compared to 80% in the study group ( $p = .005$ )—see Fig. 3. Comminuted fractures of the tympanic bone were found only in the study group and represented 87.5% of all fracture lines in this group. Statistically significant differences were obtained between the two groups for vertical tympanic bone fractures ( $p = .01$ ) and oblique fractures ( $p = .005$ ).

### Middle ear fractures

Middle ear fractures were present in 70% of the study samples compared to control samples, of which only 10% had middle ear fractures ( $p = .02$ ). In the control group, only one sample showed fractures, and these were located in the epitympanum, the lateral and upper tympanic walls. Statistically significant differences between the two groups were obtained in the following fracture locations: epitympanum ( $p = .02$ ), mesotympanum ( $p = .011$ ) and the anterior wall of the tympanic cavity ( $p = .003$ )—see Fig. 4.

### Inner ear fractures

Otic capsule violating fractures of the temporal bone were present only in the study group and represented 40%—see Fig. 5. The otic capsule was spared in the control group. In the study group, otic capsule violating fractures occurred in the vestibule (in 40% of the samples), the posterior semicircular canal (in 10% of the samples) and the lateral semicircular canal (in 20% of the samples). No statistically significant differences between the two groups were evidenced regarding otic capsule violating fractures—see Table 1.

## Discussion

The prevalence of temporal bone fractures in major head trauma is not negligible, and according to the literature data, it ranges between 3 and 22% [8–10].

Our study conducted on cadaveric specimens shows that temporal bone fractures (with the involvement of auditory anatomical structures) under conditions of mastoid obliteration with heterologous materials are more severe than in the case of unaffected mastoid cavities. Clinical implications may be multiple. External auditory canal fractures can be followed by conductive hearing loss and bloody otorrhea [7]. Middle ear fractures are more frequently associated with conductive hearing loss and may be due to hemotympanum, tympanic membrane perforation, ossicular dislocations or fractures. In inner ear

**Table 1** Fractures of auditory anatomical structures in control and study group

Fractures at auditory anatomical structures level	Control group: M1–M10		Study group: S1–S10		Statistical significance <i>P</i> value
	Number of fractures line	Percentages of pieces (%)	Number of fractures line	Percentages of pieces (%)	
<b>External ear</b>					
External auditory canal	1	10	6	60	0.057
Tympanic bone	1	10	3 and 14 multiple fractures	80	<b>0.005</b>
<b>Middle ear</b>					
Epitympanum	2	10	25	70	<b>0.02</b>
	Lateral wall—1	10	Lateral wall—3	70	<b>0.02</b>
	Medial wall—0		Medial wall—4		
Mesotympanum	Anterior wall—0		Anterior wall—7	60	<b>0.011</b>
	Posterior wall—0		Posterior wall—2		
Hypotympanum	Upper wall—1	0	Upper wall—5	40	0.087
	Lower wall—0		Lower wall—4		
<b>Otic capsule</b>					
Cochlea	0	0	7	40	0.211
Vestibule	0	0	0	0	–
Anterior semicircular canal	0	0	4	40	0.087
Posterior semicircular canal	0	0	0	0	–
Lateral semicircular canal	0	0	1	10	1.00
			2	20	0.474

Statistically significant values are in bold

fractures, sensorineural hearing loss and vertigo are more frequently found.

The new classification of temporal bone fractures that takes into consideration otic capsule violating or sparing provides better clinical prediction of the severity of lesions than the traditional classification (longitudinal, transverse or oblique fractures) [11]. Otic capsule violating fractures of the temporal bone are more frequently accompanied by sensorineural hearing loss, cerebrospinal fluid leak, epidural hematoma and subarachnoid hemorrhage than otic capsule sparing fractures [8, 11].

There are many mastoidectomy techniques for chronic middle ear or mastoid diseases. In our study, we conducted the canal wall-up mastoidectomy technique. This consists of making a mastoid neocavity but preserves the ear canal. The access to the pathological processes is less easy than in the canal wall-down technique, but the effectiveness could be similar and the postoperative ear care is managed very well by the patient [12, 13]. To reduce these inconveniences, mastoid obliteration is performed. In our study, for mastoid obliteration we used a mixture of heterologous materials similar to the bone mineral structure. Over the years, various autologous materials have been used, such as conchal or tragal cartilage [5], crushed cortical bone chips [14], bone pate [15], muscle and musculoperiosteal flaps [16] or abdominal adipose tissue [17]. The disadvantages of autografts are variable resorption, donor area defect, limited amount for harvesting (except for abdominal adipose tissue) and risk of cholesteatoma reimplantation when bone pate is used. Several types of heterologous materials have been used for mastoid obliteration, such as hydroxyapatite (granules or cement),  $\beta$ -tricalcium phosphate and polyphosphate [12], biphasic calcium phosphate ceramics mixed with fibrin sealant [18], glass ionomer bone cement [19, 20], silicone blocks [21] or bioactive glass [22].

The limitations of our study are related to the following aspects: a small number of samples included in the study; experiments conducted on isolated temporal bones, not on cephalic extremities, which would have allowed a different type of distribution of the impaction force and kinetic energy absorption. The results of our study provide clinicians and patients useful information related to the risk of fracture located in the anatomical structures of the auditory system. The clinical situations in everyday practice are slightly different: the possibility of absorption of kinetic energy by head structures during temporal bone trauma; different mechanical–physical characteristics of the multiple types of materials used in practice for mastoid obliteration (some of them can stimulate osteogenesis in the months following surgery in live patients), compared to the heterologous material used in this study.

## Conclusion

Mastoid obliteration with heterologous materials after open cavity mastoidectomy produces a weakening of the skull base that increases the risk of fracture, with the involvement of auditory anatomical structures, in the case of lateral trauma applied to the junction of the mastoid with the temporal squama in temporal bone pieces.

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## Compliance with ethical standards

**Conflict of interest** The authors declare no conflicts of interest with respect to the authorship and/or publication of this article.

**Ethical approval** All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee (Ethics Committee of “Iuliu Hațieganu” University of Medicine and Pharmacy Cluj-Napoca, Romania, No. 250/22.02.2011) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

**Informed consent** The study was conducted on temporal bone harvested from human cadavers donated to the “Iuliu Hațieganu” University of Medicine and Pharmacy Cluj-Napoca, Romania.

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