



# Gusher in stapes surgery: a systematic review

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## Abstract

**Objective** The aim of this study is to perform a systematic literature review on the occurrence of gusher during stapes surgery, to understand its surgical management and outcomes.

**Methods** The PRISMA standard was applied to identify English, Italian or French-language studies, related to stapes surgery and mentioning gusher or perilymphatic leak. Full-texts lacking information on the management of gusher and/or the post-operative hearing outcome were excluded.

**Results** Twenty-four articles were eventually included. Seventy-six patients were involved in the qualitative synthesis. The management of gusher mostly consisted in covering the oval window and/or filling the tympanic cavity, with absorbable and autologous graft materials. Packing of the external auditory canal was reported in 51 patients (67%). Gusher was related to complete/profound loss of hearing in 25% of the cases and to a worsening of hearing function in 31% of patients. In 19% of patients an improvement in hearing tests was reported; in 28% the hearing function was unchanged. Post-operative vestibular symptoms were reported in 7 patients, and were mainly mild and transient. The absence of vestibular symptoms was underlined in 9 cases, while in 79% of the patients the authors did not provide information.

**Conclusion** The unexpected occurrence of gusher during stapes surgery represents a relevant issue for the otologic surgeon. Its management most commonly consists in plugging the oval window and the tympanic cavity. In most of the cases, a stapes prosthesis could be positioned. The results on hearing and vestibular functions are widely variable.

**Keywords** Gusher · Perilymphatic leak · Stapes surgery · Stapes fixation

## Introduction

“Gusher” is considered a dramatic occurrence during the course of stapes surgery, and consists of a sudden and profuse flow of perilymphatic fluid immediately upon opening the vestibule. This flow may completely fill the middle ear and the external auditory canal (EAC) within seconds, and its management may be problematic for otologic surgeons. This rapid egress of cerebrospinal fluid (CSF) may lead to severe hearing loss, tinnitus or vestibular dysfunction.

It is a rare complication (roughly 0.3% according to literature [1]) of surgery for otosclerosis in adult age, and can also be associated with congenital X-linked stapes fixation.

This phenomenon generally occurs as the result of an abnormal communication between the perilymphatic and subarachnoid spaces [2]. In the majority of the cases the abnormal connection is through the internal auditory canal (IAC) or might involve the cochlear aqueduct (CA) [3].

The impossibility of defining a preoperative clinical diagnosis, associated with the absence of pathognomonic signs of the disease, is a critical point in patients with gusher.

Moreover, due to the rarity of its occurrence, no large case series can be gathered by any author, so literature almost completely consists of case reports or small case series.

The aim of present paper would be to perform a systematic literature review on this serious complication of stapes surgery to understand its surgical management and possible outcomes.

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## Methods

PRISMA 2009 guidelines were applied in this systematic literature review.

The following search string was run on PubMed: gusher [All Fields] AND ("stapes"[MeSH Terms] OR "stapes"[All Fields]).

After running the above search string in October 2018, abstracts and titles obtained were screened independently by two of the authors (GM and MSR), who subsequently met and discussed disagreements on citation inclusion.

Inclusion criteria for citations were English, Italian or French language; subject related to stapes surgery; mention of gusher or perilymphatic leak. Exclusion criteria for citations were subject totally unrelated to surgery (e.g. genetic analysis of congenital syndromes, other causes of hearing loss, third-window anomalies).

Then the full texts of the articles identified were screened by the same two authors, who met and discussed disagreements on article inclusion. Inclusion criterion for full-text articles identified was reporting on the occurrence of intra-operative gusher during stapes surgery.

Full-texts lacking information about the management of gusher and/or the hearing outcome after the complicated procedure were excluded.

A further manual check of the references included in the articles was performed, adding eight articles.

Information from each study was extracted using a standardized data extraction form. The general characteristics of each study (source, year of publication, study type, number of patients with gusher, treated disease, type of stapes surgery, management of gusher, hearing outcome, post-operative vestibular symptoms, radiologic abnormalities, intraoperative pathological or unusual findings, relevant patient's history) were summarized in Table 1. No assessment of risk of bias was undertaken in the present study as the authors felt that studies of any quality should be included, so as not to miss any eligible case of gusher. Moreover, since a meta-analysis was not applicable due to the qualitative nature of the results, bias assessment of single studies was considered not to influence the results of our study.

## Results

Running the above search string in PubMed, 70 articles were identified. After initial check, full-text retrieval, and manual crosschecking of the references, 24 articles were eventually included in the study (Fig. 1). Articles included were published between 1961 and 2018. Most of the included articles were case report (12) or case series (11). Two studies were retrospective.

The total number of patients included in the qualitative synthesis was 76. The largest study population consisted of 38 patients.

Regarding the disease, 54 patients (71%) were treated for suspected otosclerosis while 20 (26%) for congenital stapes fixation (either X-linked or with other inheritance pattern).

Surgical procedure on the stapes was stapedotomy in 16 cases (21%), and stapedectomy in 56 cases (74%) (total in 29 cases vs partial in 27). In three reports it was not possible to define the type of stapes surgery.

The management most commonly consisted of covering the oval window and/or filling the tympanic cavity. Absorbable materials (Gelfoam, spongostan, and fibrin glue) and autologous graft materials (fat, vein, fibrofatty tissue, muscle fascia, and perichondrium) were used to perform a multi-layer cover of the perilymphatic leak. In 53 patients (70%), stapes prosthesis was placed and the procedure accomplished, while stapes surgery was abandoned in the remaining 23 patients (30%) (Table 2).

Packing of the EAC was reported in 51 patients (67%); among the cases where the packing technique was specified, it was found that absorbable material only (such as Gelfoam) was used in a minority of cases, while a dressing or gauze (usually cotton-made) was most commonly preferred to fill the EAC and applied some compression.

In an attempt to reduce CSF flow, bed rest with head elevation (in 45 patients, 59%) and lumbar drain (in 5 patients, 7%) were additional measures adopted by some authors. Lumbar drain was positioned immediately after gusher in three patients (who maintained it for 3 days) and after evidence of persistent CSF leak in two patients.

Persistence of CSF leak (otorrhea and/or rhinorrhea) occurred in 16 patients (21%): 10 of them were treated conservatively and stopped after few hours to several days. One patient underwent revision surgery after 9-month long otorrhea and chronic infection, despite no fistula being seen intraoperatively. In five, patients management of CSF leak was not explained.

One patient only experienced recurrence of CSF leak (complete closure of the leak and discharge, then readmission for profuse otorrhorrhea, with evidence of flow from oval and round window) and was operated on 3 weeks after readmission with plugging of the oval window, packing of the EAC with sterile cotton, and spinal tap. Conservative treatment was done for persistent post-revision surgery CSF leak. Only Krouchi et al. quote pneumococcal vaccination as further precaution after gusher in a 30-year-old patient.

Regarding post-operative hearing outcome, no information was available in 44 patients (58%).

The results showed that gusher was related to complete/profound loss of hearing in 8 cases (8/32, 25%), while to a worsening of hearing function in 10 cases (10/32, 31%). Among these, five experienced also tinnitus after gusher. Six

**Table 1** Summary of included studies

Study No	Source	Study type	Number of patients with gusher	Pt number	Treated disease <sup>a</sup>	Type of stapes surgery <sup>b</sup>	Management of gusher	Hearing outcome	Post-operative vestibular symptoms	Radiologic abnormalities	Intraoperative pathological or unusual findings
1	Varadarajan et al. [20]	Case series	2	1	C+E	A	Positioning of fascia, stapes prosthesis and gelatin sponge over the stapedotomy	Improvement	Not reported	Bony defect between IAC and the basal turn of the cochlea visible with coronal and oblique image reformation	Diffuse annular bony overgrowth and a centrally thin footplate (fixation of malleus and incus to the epitympanum)
2	Quesada et al. [4]	Retrospective observational multicenter study	38	38	A	13 B 25 C	Positioning of fibrofatty tissue, TORP and gelatin sponge on the oval window	Invariate	Not reported	Bony defect between IAC and the basal turn of the cochlea visible only on oblique image reformation	N/A
3	Krouchi et al. [21]	Case series	2	1	A	A	Intratympanic placement of Gelfoam, packing of EAC, antibiotic, post-operative elevation of the head at 45°. If massive flow of CSF: no prosthesis insertion, positioning of autologous graft (perichondrium or muscular fascia) on the oval window and intratympanic Gelfoam	Patients with post-operative CSF leak had significantly greater hearing loss; worst hearing outcomes and the highest incidence of complications seen in the 6 patients who had not received a prosthesis	No vestibular symptoms	Dysplasia of LSC and dilation of the facial nerve	Very spindly stapes muscle and incus discontinuity
4	Nguyen et al. [22]	Case report	1	1	A	B	Positioning of venous graft over oval window, 0.6 mm fluoroplastic piston secured with fibrin tissue adhesive; lumbar drain for 3 days	Worsening	Recurrent episodes of dizziness	Bulbous and wider IAC than contralateral	Negative
							After failure of a venous graft, positioning of temporalis fascia, 0.6 mm fluoroplastic piston secured with fibrin tissue adhesive; lumbar drain for 3 days	Worsening	Persistent vertigo after first surgery, recovered after dehiscence repair	Anterior semicircular canal dehiscence with meningocele of the tegmen tympani	Negative

Table 1 (continued)

Study No	Source	Study type	Number of patients with gusher	Pt number	Treated disease <sup>a</sup>	Type of stapes surgery <sup>b</sup>	Management of gusher	Hearing outcome	Post-operative vestibular symptoms	Radiologic abnormalities	Intraoperative pathological or unusual findings
5	Rebol [23]	Case report	1	1	A	A	Prosthesis was positioned and the leak was reduced; packing of the oval window with gelfoam and fibrin glue. Bed rest with head elevated for 5 days	Improvement	Not reported	Defect in the fundus of IAC	Posterior crus of the stapes poorly developed, footplate very thick and stapes head tilted towards the promontory
6	Cassano et al. [19]	Case report	1	1	A	B	Oval window sealed with fat from the earlobe, eardrum filled with spongostan; endomeatal strip then replaced on the osseous canal, adding spongostan and cotton flock. Half-standing position of the patient. Persistent leakage for few hours post-op, treated conservatively	Worsening	Not reported	Bilateral osseous fistula between the bottom of IAC and labyrinth	Negative
7	Couvreur P et al. [24]	Case series	4	1	A	A	Positioning of vein and fat graft, stabilized by the posterior crus	Complete HL	Vertigo for few days	N/A	Negative
				1	A	B	Positioning of vein graft and prosthesis, with glue	Worsening, tinnitus	No vestibular symptoms	N/A	Negative
				1	A	A	Positioning of vein graft and prosthesis, with glue; lumbar drain	Complete HL	No vestibular symptoms	N/A	Negative
				1	A	C	Positioning of vein and muscle graft and glue	Improvement	No vestibular symptoms	Negative	Negative
8	Papadaki et al. [18]	Case report	1	1	A	A	Absorbent gelatin sponge over the fenestra, filling the middle ear and EAC. CSF rhinorrhea in the next days treated successfully with continuous spinal drainage	N/A	Not reported	Bulbous dilatation of the lateral portion of IAC, incomplete separation of cochlea from IAC and widening of first part of facial nerve	Negative
9	Shirazi et al. [25]	Case report	1	1	B	B	Surgical procedure abandoned, no other information	N/A	Not reported	LVAS	Negative

**Table 1** (continued)

Study No	Source	Study type	Number of patients with gusher	Pt number	Treated disease <sup>a</sup>	Type of stapes surgery <sup>b</sup>	Management of gusher	Hearing outcome	Post-operative vestibular symptoms	Radiologic abnormalities	Intraoperative pathological or unusual findings
10	Talbot et al. [26]	Case report	3	1	B	D	Double tissue grafting procedure	Complete HL	Not reported	IAC dilated laterally; hypoplasia of bone at cochlea base; absence of cochlear bony modiolus; enlarged labyrinthine facial nerve canal; medial origin of vestibular aqueduct; dilated vestibular aqueduct	Negative
11	Carlson et al. [27]	Case report	1	1	B	B	Tissue grafting procedure	Invariate	Not reported	Same as patient above	Negative
12	Flood et al. [28]	Case report	1	1	B	A	Perichondrium graft and Gelfoam	Invariate	Not reported	Same as patient above	Negative
13	Cremers et al. [29]	Case series	3	1	B	N/A	A de la Cruz piston was placed, following the gusher	Profound HL	Not reported	Angulation and widening of IAC	Adhesions between incus, eardrum and promontory
				1	B	B	Application of a tragal perichondrial graft to the oval window and insertion of the prosthesis; CSF otorrhea after 1 h head elevation, antibiotic, lumbar puncture, then spinal drain no leak but neurological signs pneumocephalus, so spinal drain stopped. Leak recommenced but treated only with head elevation	Complete HL	Not reported	Bulbous IAC with symmetric narrowing of the porus and wide dilation of the fundus	Multiple malformations of middle ear (incus fixed to the scutum, absent stapedial tendon)
				1	B	N/A	Replacement of TM, packing the EAC with a dressing	Worsening, tinnitus	Persistent vertigo (unfit to work)	Negative	Negative
				1	B	N/A	Replacement of TM, packing the EAC with a dressing	Worsening	No vestibular symptoms	Negative	Negative
				1	A	N/A	Antitrendelenburg, insertion of prosthesis	Worsening	No vestibular symptoms	Dilation of semicircular canals and of lateral part of the IAC	Negative

Table 1 (continued)

Study No	Source	Study type	Number of patients with gusher	Pt number	Treated disease <sup>a</sup>	Type of stapes surgery <sup>b</sup>	Management of gusher	Hearing outcome	Post-operative vestibular symptoms	Radiologic abnormalities	Intraoperative pathological or unusual findings
14	Daniilidis et al. [30]	Case series	2	1	A	B	Temporal fascia graft + gel-foam, packing of EAC with cotton wool	Complete HL	Transient vertigo (for few days)	N/A	Negative
				1	A	B	High suction, Teflon-piston placed over temporalis fascia graft + gelfoam in middle ear, packing of EAC with cotton wool	Invariate	Transient vertigo (for few days)	N/A	Anomalies of the cochlea and semicircular canals
15	Glasscock [3]	Case series	1	1	B	A	Packing of the ear with absorbable gelatin sponge. Two years later he was subjected to another stapes surgery (at the same ear) with gusher -> gelatine sponge, mastoidectomy and a piece of temporalis muscle was removed and packed into the IAC, gelfoam, stapedectomy with vein graft and teflon piston	Invariate	No vestibular symptoms	Abnormally dilated IAC in lateral extent and abnormally large vestibule	No annular ligament
16	Nance et al. [16]	Case report	1	1	B	B	Surgery was abandoned and ear packed with gel foam	Invariate	Not reported	N/A	No annular ligament
17	Olson et al. [15]	Case series	2	1	B	B	A wire-gelfoam prosthesis was placed to close oval window; cerebrospinal fluid otorrhea for 5 days	Worsening, tinnitus	Vertigo and nystagmus	N/A	Negative
				1	B	A	A wire-gelfoam prosthesis was placed to close oval window; cerebrospinal fluid otorrhea for 2 days	Complete HL, tinnitus	No vestibular symptoms	N/A	Negative
18	Wolferman [31]	Case report	1	1	A	A	A pellet of gelfoam was pressed into the oval window and EAC was packed with gelfoam and steril cotton, a mastoid dressing was applied for 72 h + Penicillin and bed rest. The otorrhea continued for 3 weeks. On 22nd post-operative day the patient was reoperated and two fat grafts were taken from lobule and inserted into the oval and round window + gel-foam + spinal tap	Improvement	No vestibular symptoms	N/A	Partially uncapped facial canal

**Table 1** (continued)

Study No	Source	Study type	Number of patients with gusher	Pt number	Treated disease <sup>a</sup>	Type of stapes surgery <sup>b</sup>	Management of gusher	Hearing outcome	Post-operative vestibular symptoms	Radiologic abnormalities	Intraoperative pathological or unusual findings
19	Farrior JB et al. [5]	Case series	4	1	B	C	Wire fat prosthesis	Worsening	Not reported	N/A	Deeply placed footplate with overhanging anterior lip of the oval window surrounding the anterior crus of the stapes
				1	B	A	Wire fat prosthesis	Improvement	Not reported	Dilatation of semicircular canal (not specified which)	Deeply placed footplate with overhanging anterior lip of the oval window surrounding the anterior crus of the stapes
				1	B	B	Wire fat prosthesis with a large fat graft	N/A	Not reported	N/A	Deeply placed footplate with overhanging anterior lip of the oval window surrounding the anterior crus of the stapes
20	McFadden et al. [32]	Case series	2	1	B+E	A	Fluoroplastic–platinum piston over a fascia graft and graft was secured with gelatin sponge	Invariate	Not reported	Negative	Negative
				1	B	A	Middle ear was packed with gelatin sponge. The stapes prosthesis was not successfully placed; lumbar drain was placed for 3 days	Invariate	Not reported	Dilated IAC fundus with a deficient modiolar base	Negative
21	Jensen et al. [33]	Case series	1	1	B	A	Head elevation; attempt to deal the hole with gelfoam and Surgicel without success; replacement of TM and packing with gelfoam; packing of the meatus with gauze. Recurrent oozing and infection 2 days after. Revision surgery after 9 months without evidence of perilymph fistula	Worsening	Not reported	Lumen of labyrinth irregularly dilated, IAC widened, abnormal course of its lateral end with a downwards turn towards the basal coil of the cochlea; enlarged irregular cochlea	Congenital stapes fixation, with a chalky area of 0.3 mm along the whole periphery, no annular ligament

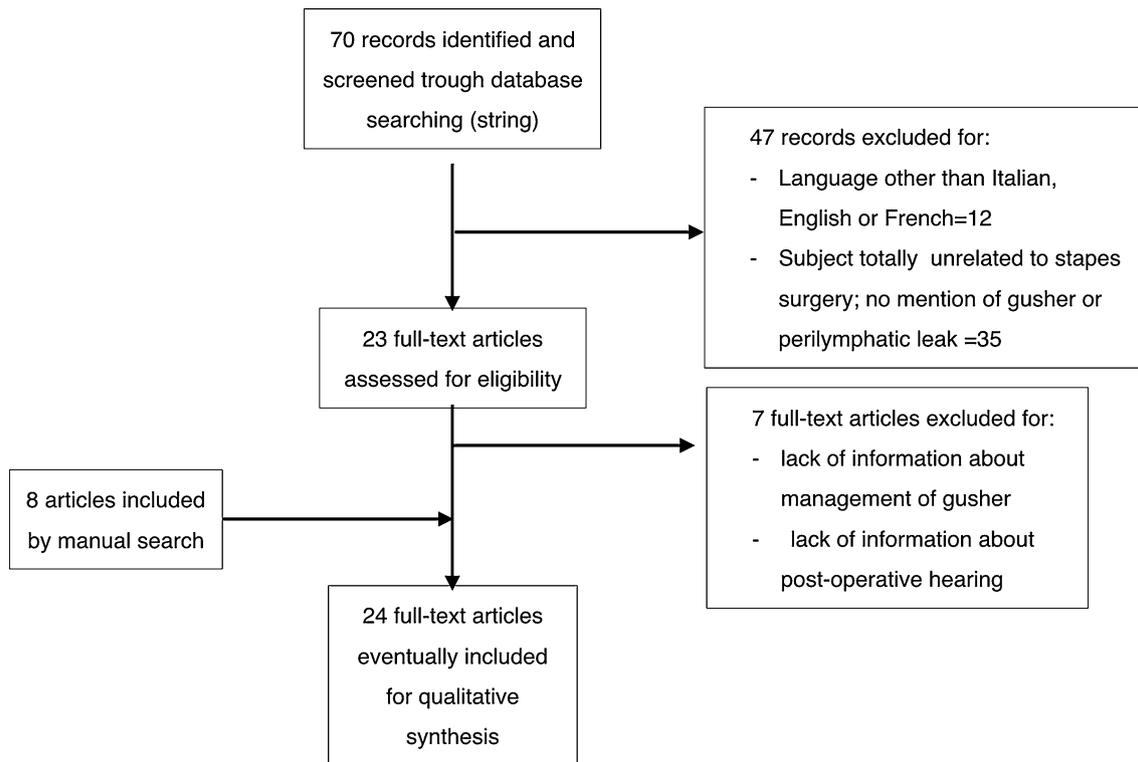
Table 1 (continued)

Study No	Source	Study type	Number of patients with gusher	Pt number	Treated disease <sup>a</sup>	Type of stapes surgery <sup>b</sup>	Management of gusher	Hearing outcome	Post-operative vestibular symptoms	Radiologic abnormalities	Intraoperative pathological or unusual findings
22	Hipskind et al. [34]	Case series	1	1	D	B	Gelfoam (without success), tapered fat pad from ear lobule in the oval window, gelfoam in eustachian tube, further fat in the middle ear; packing of the external ear canal	N/A	Not reported	Congenital anomalies involving the right cochlear, vestibule and semicircular canals; ossicular chain defect; possible communication between the middle ear and cranial cavity via the IAC, vestibule and oval window through a defective footplate	Unusual stubby configuration of the stapes
23	Ward [35]	Case report	1	1	A	B	Absorbable gelatin sponge was packed over the fractured footplate, and polyethylene strut was inserted between the gelatin sponge and the incus. A mastoid dressing was applied with gentile presure for 7 days	Improvement	Minimal post-operative vertigo	N/A	Thinned footplate (fracture)
24	Pech et al. [36]	Case report	1	1	A	B	Total platinectomy, Schuknecht piston positioning, connective tissue and temporalis fascia, gelfoam in the tympanic cavity, packing of the EAC; persistent otorrhea for 4 days post op	Invariate	Not reported	Bilateral enlargement of the CA	

No number, Pt patient, IAC internal auditory canal, TORP total ossicular replacement prosthesis, N/A data not available from the text, EAC external auditory canal, CSF cerebrospinal fluid, LSC lateral semicircular canal, HL hearing loss, LVAS large vestibular aqueduct syndrome, TM tympanic membrane CA cochlear aqueduct

<sup>a</sup>A otosclerosis, B congenital stapes fixation, C chronic ear disease, D other, E previous surgery

<sup>b</sup>A stapedotomy, B (total) stapedectomy, C partial stapedectomy, D other



**Fig. 1** Articles selection

patients (6/32, 19%) were reported to have an improvement in their hearing tests; on the other hand in 9 cases (9/32, 28%) the hearing function was unchanged with respect to pre-operative hearing levels.

Post-operative vestibular symptoms were reported in seven patients of the cohort, and were mainly mild and transient. The absence of vestibular symptoms was underlined in nine patients, while in most of the cases the authors did not provide information (79%). In the paper from Nguyen et al., the patient presented persistent vertigo after first surgery, which lead to the identification of an anterior semicircular canal dehiscence with meningocele of the tegmen tympani. As a consequence, the vertigo disappeared after dehiscence repair in this patient.

In eight patients a relevant personal history was found. One case of gusher occurred in a patient with MEN syndrome, one in a patient with Klippel Feil syndrome. Familiarity for hearing loss (HL) was found in three cases. Other comorbidities (such as epilepsy, ADHD, mental retardation...) were found among some of the patients included.

Twenty-one patients (27%) were diagnosed with congenital anatomical anomalies on post-operative radiologic scans or on re-evaluation of preoperative ones. The majority (16/21, 76%) affected the IAC, its cochlear end and/or the cochlea itself. In five (5/21, 24%) patients a large vestibular aqueduct was found, while a large CA was found in the case

by Pech et al. Abnormal features of the semicircular canals were also reported, such as anterior semicircular canal dehiscence or dilation or dysplasia of one or more semicircular canals. In five (5/21, 24%) patients a widening of the first segment of the facial nerve was shown. In 52 (77%), data on radiologic tests were not available; these papers are mainly before 1980, while only 3 were published after 2003.

Only in four patients (5%) no anatomic anomaly was found on radiologic evaluation after gusher.

Occasionally (19%), gusher was associated to intraoperative unusual appearance of the stapes, the stapedia tendon, or other intratympanic structures.

## Discussion

Perilymphatic fluid leak coincident with fenestrating or removing the footplate of the stapes is an uncommon occurrence that surgeons can encounter during stapes surgery. If it consists of a rapid and profuse perilymphatic leak that immediately completely fills the middle ear and wells up in the external canal during stapes surgery it is usually defined as stapes gusher. When the flow is slower and less profuse, it is referred to as oozing leak [2, 4], despite this classification is not clearly stated in several papers on this topic.

**Table 2** Data on intraoperative and post-operative management of gusher

Study No	Source	No of patients with gusher	Pt number	Packing of the oval window		Packing of the EAC (material)	Lumbar drain (number of days maintained)	Bed rest/head elevation (number of days maintained)	Persistence of perilymphatic leak (duration), management
				Autologous graft	Absorbable material				
1	Varadarajan et al. [20]	2	1	X	X	No	No	No	No
2	Quesada et al. [4]	38	1 32 6 cases with massive flow of CSF	X	X	No	No	No	No
3	Krouchi et al. [21]	2	1	X	X	No	Yes (3)	No	No
4	Nguyen et al. [22]	1	1	X	X	No	Yes (3)	No	No
5	Rebol [23]	1	1	X	X	No	No	No	No
6	Cassano et al. [19]	1	1	X	X	No	No	Yes (5)	No
7	Couvreux et al. [24]	4	1	X	X	Gelfoam and cotton	No	Yes (not specified)	Yes (few hours), conservative treatment
8	Papadaki et al. [18]	1	1	X	X	No	No	No	No
9	Shirazi et al. [25]	1	1	X	X	No	No	No	No
10	Talbot et al. [26]	3	1	X	X	No	No	Yes (not specified)	No
11	Carlson et al. [27]	1	1	X	X	No	No	No	No
12	Flood et al. [28]	1	1	X	X	Gelatin Sponge	Yes, after evidence of persistent leak	No	Yes (not specified), lumbar drain
13	Cremers et al. [29]	3	1			Dressing	No	Yes, after evidence of persistent leak	Yes (not specified), head elevation and lumbar drain
			1			Dressing	No	No	Yes (several days), conservative treatment
			1			Dressing	No	No	Yes (several days), conservative treatment
			1			No	No	Yes (not specified)	No

**Table 2** (continued)

Study No	Source	No of patients with gusher	Pt number	Packing of the oval window		Packing of the EAC (material)	Lumbar drain (number of days maintained)	Bed rest/head elevation (number of days maintained)	Persistence of perilymphatic leak (duration), management
				Autologous graft	Absorbable material				
14	Damiliadis et al. [30]	2	1	X	X	Cotton dressing	No	No	No
			1	X	X	Cotton dressing	No	No	No
15	Glasscock [3]	1	1	X	X	Gelfoam	No	No	Yes (3 days)
16	Nance et al. [16]	1	1	X	X	Gelfoam	No	No	Yes (2 days), conservative treatment
17	Olson et al. [15]	2	1	X	X	No	No	No	Yes (not specified), conservative treatment
			1	X	X	No	No	No	
18	Wolferman [31]	1	1	X	X	Cotton	No	Yes (not specified)	Recurrence (See text)
19	Farrion et al. [5]	4	1	X	X	No	No	No	No
			1	X	X	No	No	No	No
			1	X	X	No	No	No	No
			1	X	X	No	No	No	No
20	McFadden et al. [32]	2	1	X	X	No	No	No	No
21	Jensen et al. [33]	1	1	X	X	No	Yes (3)	No	No
			1	X	X	Gauze	No	Yes (not specified)	Yes (several months), revision surgery without evidence of fistula
22	Hipskind MM et al. [34]	1	1	X	X	Cotton	No	No	No
23	Ward [35]	1	1	X	X	Gauze	No	No	Yes (days), conservative treatment
24	Pech et al. [36]	1	1	X	X	Yes (not specified)	No	No	Yes (4 days), conservative treatment

No number, Pt patient, EAC external auditory canal, CSF cerebrospinal fluid

The incidence of stapes gusher has been reported ranging from 1 in 500 to 1 in 3300 stapes operations [5, 6]. A survey by the American Otological Society published in 1993 found that 46% of surgeons had dealt with one or two gushers in their practice, 41% with more than two, and only 13% had never encountered a gusher [7].

When gusher occurs, only the first millilitres are true perilymph fluid, the remaining flow consists of CSF [2].

Indeed, the etiology of stapes gusher can be traced back to a congenital malformation with an abnormal connection between the subarachnoid and perilymphatic spaces.

Physiological communication between the subarachnoid and the perilymphatic space is established through the CA and the perineural sheets of nerves located in the IAC. A widened CA or a defect of the fundus of IAC has shown to be related to the occurrence of stapes gusher or CSF oto(rhino)rrea associated with recurrent meningitis by some authors [7].

Of all the case reports on gusher, the most convincing on the hypothesis of a persistently patent CA as the source of profuse flow is that by Farris and Endicott. They described two patients in whom profuse flow was seen upon the opening of a congenitally fixed stapes, and ablation of the CA was required to control the leak [5]. Other authors supported this hypothesis [8, 9], while in others reports the leakage was directly visualized from the medial wall of the vestibule and packing off the IAC stopped the leak [3, 10–12].

Glasscock described a case of profuse gusher that continued to flow slowly through the tympanic cavity packing. He thus performed a simple mastoidectomy and attempted to locate the CA, which was not found and at the same time, the IAC was packed with a piece of temporalis muscle. The removal of the pack from the IAC determined the restart of the leak, and this mechanism suggested the possible abnormal communication with the IAC as its etiology [3].

Schuknecht et al. proposed that the cause of oozer may be in a widely patent CA, but that gushers are due to fundus defects of the IAC [2]. Similarly, Jackler and Hwang, measuring the CA in 100 ears on high-resolution CTs, found that radiographic enlargement of the CA must be exceedingly rare or perhaps even a non-existent malformation, thus its role would not be relevant for stapes gushers or transotic CSF leaks. On the other hand, they suggested that a defect of the fundus of the IAC is more likely to produce a perilymph gusher [13].

Glasscock was the first to report the radiographic abnormalities in patients affected with this disorder, describing an abnormal dilatation of the lateral extent of the IAC and a dilated vestibule [3]; Cremers et al., in addition of these findings, also noted in these patients dilatation of the Fallopian canal, small cochleas, and reduced diameter of the semicircular canals [14].

With the introduction in the clinical practice of high-resolution computed tomography (CT), several authors have identified other signs suggestive of a possible intraoperative gusher.

Despite the high number of patients without information on radiologic characteristics in the present review, it was shown that in the majority a radiological abnormality was detected, both in the otosclerosis group and in the congenital stapes fixation one. Moreover, it should be noticed that one radiologic test reported as negative was a polytomography performed in 1983, suggesting that any anatomical malformations could be overlooked due to low-quality images.

Supporting the idea that an abnormal IAC plays a role in gusher, 16 patients from present review presented an anomaly of the IAC, its cochlear end and/or the cochlea itself. However, the evidence of other anatomical anomalies of other inner ear and skull base structures in gusher patients as reported in Table 1, suggests their possible role in this complication. These results highlight the importance of pre-operative accurate imaging in candidates to stapes surgery. Considering the incidence of otosclerosis and congenital stapes fixation, as well as the rarity of gusher as a surgical complication, it is not meant that radiology is always mandatory before stapes surgery; however, if it is performed, special attention must be paid to the stapes, the cochlea, the vestibule and the IAC.

Regarding intraoperative findings, Causse and associates described two clues that may tip the surgeon off the possibility of a gusher before the footplate is opened: an avascular congenital middle ear and an abnormally anterior insertion of the posterior crus to the footplate [6].

Interestingly, in the cohort of present review a wide range of stapes anomalies, different from the experience of Causse, was found. For example, in three patients the anterior lip of the oval window was overhanging the anterior crus of the stapes. This should raise awareness in the surgeon that such intraoperative findings could be related to an increased risk of gusher.

Twenty cases included in present review occurred in patients affected by congenital stapes fixation.

According to Shambaugh and House, the criteria for diagnosis of this condition are a history of deafness from birth and a not-progressive conductive type of HL. This syndrome may show an associated sensorineural component of HL, especially in the higher frequencies [15].

Nance et al. in 1971 were the first to describe the X-linked inheritance of congenital mixed deafness, even though Olson and Lehmann, in 1968, had already reported on two maternal half brothers with early childhood mixed deafness who had gusher [15, 16]. Females carriers were usually normal or had a bilateral mixed or purely sensorineural loss [17].

Papadaki et al. presented the first report of two female members with progressive mixed deafness with stapes

gusher of a family with healthy male members. They have hypothesized an autosomal recessive version of that entity as a possible explanation [18].

Since this syndrome is significantly associated to gusher during stapes surgery, it is advisable to do an accurate pre-operative diagnosis and distinguish it from otosclerosis.

Regarding the management, there are no precise indications on the surgical procedure to be adopted in literature, and only few authors have focused on the description of this aspect.

Despite the paucity of information about features of gusher and its specific control by some authors, it is interesting to notice that in most cases the leak was controlled and procedure accomplished, with the positioning of stapes prosthesis in 53 patients (69%).

One of the reason why the prosthesis was not placed and the procedure abandoned in 23 patients could be found in the high flow of perilymphatic leak as well as the persistence of the leakage after packing the oval window, as specified by some authors [4, 16, 18, 19].

In particular, Quesada et al. suggested to discontinue the surgery in case of heavy gusher and repair the oval window with an autologous graft; they specify, on the other hand, that oozing leaks can often be controlled by an insertion of the prosthesis and sealing with connective tissue. Furthermore, patients who had not received prosthesis had a higher incidence of severe vertigo and post-operative CSF leak; in these patients a second-look surgery can help to stop the leak placing prosthesis or adding a graft [4]. The same conclusion is reported by Cassano et al., who specify that second-look surgery depends on the amount of perilymphatic flow and the behaviour of auditive function over time, because a sensorineural hearing loss is a contraindication for surgical revision [19].

Reviewing the full texts, it emerged that there was nor a clear definition of gusher or of its severity from most of the authors. This may influence the interpretation of the management results, since different flows of perilymphatic fluid are considered together.

Despite it seems that gusher is easily manageable, 16 patients experienced a persistence of CSF leak after surgery. Of these, however, only one had to undergo revision surgery: this case was peculiar because it was a congenital form of stapes fixation with the absence of the annular ligament and the CT showed several abnormalities (irregularly dilated lumen of the labyrinth, widened IAC, abnormal course of its lateral end with a downwards turn towards the basal coil of the cochlea; enlarged irregular cochlea).

One case only had recurrence of gusher: a double perilymph leak was noticed (from oval window and round window). This patient had a history of head trauma, but no radiological assessment was made, thus preventing present authors to find significant factors for gusher and for its

recurrence. In the remaining cases, there was insufficient data to identify technical or radiological risk factors predictive for persistent perilymphatic leak.

It is remarkable that most of the papers included lacked of information about the hearing outcome of these patients. It emerged that in most of them the post-operative hearing function was worse (31%) than pre-operatively or unchanged (28%); only 25% of patients experienced profound HL or complete deafness after gusher.

Information is also lacking about post-operative vestibular symptoms. The seven patients who complained about them just reported mild and transient vertigo, suggesting a prompt post-operative vestibular rebalancing. It is interesting that patients who complained of severe vertigo, had significantly greater hearing loss, as reported by Quesada [4].

## Conclusion

The unexpected occurrence of gusher during stapes surgery represents a relevant issue for the otologic surgeon. Because of its rarity, prospective studies on gusher are not achievable. The management of gusher most commonly consists in plugging the oval window and the tympanic cavity with absorbable or autologous graft materials. In most of the cases, stapes prosthesis could be positioned and the surgery accomplished. However, in terms of hearing outcomes, as well as post-operative vestibular symptoms, the results are widely variable.

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## Compliance with ethical standards

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