

# Differences between endolymphatic duct blockage and endolymphatic sac drainage surgery in the reversal of endolymphatic hydrops in patients with Meniere's disease, preliminary results

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## Research Article

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# Abstract

To explore the differences between endolymphatic duct blockage (EDB) and endolymphatic sac drainage (EDD) surgery in the reversal of endolymphatic hydrops (EH) in patients with intractable Meniere's disease (MD). A total of 19 MD patients receiving EDB (n=10) and EDD (n=9) treatment underwent gadolinium-enhanced inner ear magnetic resonance imaging (MRI) scans prior to, 2 weeks after and at >12 months following surgery. In the EDB group, the second MRI revealed no changes in EH, whereas the third MRI revealed a reversal of vestibular EH in 3 patients and a downgrading of cochlear hydrops in 2 of these 3 patients, who presented with an improvement in their hearing and complete control of vertigo. In the EDD group, the second MRI showed a reversal of EH in 4 patients, and no changes in EH in the remaining 5 patients, whereas the third MRI showed that those 4 patients who presented with a reversal of EH at the second MRI stage remained unchanged, with the exception of one patient who experienced a recurrence of vestibular hydrops. All 4 patients exhibited a complete control of vertigo, although hearing improved in only 1 of them, worsened in 1 and remained unchanged in 2. The present study showed the reversal in EH was likely due to the delayed effect of surgery accompanied by an improvement in hearing in EDB group, whereas the reduction in the endolymph volume presented as an acute reversal of hydrops in EDD group without a cause-effect relationship with hearing function.

## Introduction

Meniere's disease (MD) is characterized by episodic vertigo, fluctuating sensorineural hearing loss and aural symptoms [1]. Although the specific underlying pathophysiological mechanisms of MD remain unknown, the presumed cause of the symptoms experienced in MD is considered to be due to endolymphatic hydrops (EH), which is characterized by an enlargement of the cochlear and vestibular endolymphatic space [2]. EH is considered to be caused by immune, metabolic, infectious, traumatic, or other insults to the inner ear associated with a temporarily dysfunctional endolymphatic sac [3,4]. Consequently, when conventional medical treatments for MD fail, endolymphatic sac surgery, as the first surgical procedure, is usually performed according to the treatment guidelines for MD [5]. The effectiveness of endolymphatic sac drainage (EDD) surgery, which was described by Portmann in 1927, was considered to be achieved through opening the endolymphatic sac, reducing the endolymphatic pressure for MD [6]. More recently, a novel surgical sac technique for the treatment of MD, endolymphatic duct blockage (EDB), was shown to be effective for the control of symptoms of MD, without any noticeable cochlear and vestibular damage [7]. The procedure was also considered to decrease hydrops, most likely due to a reduction in the volume of the endolymph in the inner ear coming from the sac. However, the efficacy of these treatments has not been proved, and the mechanisms underlying their effects remain speculative. With such sac surgery, it is unclear whether the EH in patients with MD can be reduced, and if it should happen, it is not clear when the reduction in EH occurs or how the reduction of EH is associated with the dynamic changes of hearing threshold and vertigo attacks.

To improve our understanding of these matters, in the present study, the dynamics of EH were evaluated using a gadolinium (Gd)-enhanced inner ear magnetic resonance imaging (MRI) technique at three time

points: i) prior to surgery; ii) 2 weeks after surgery; and iii) at the latest follow-up, with a >12-month interval after surgery in patients with intractable MD who underwent EDB or EDD treatment. The aim of the present study was to determine the comparative effectiveness of the two techniques and the different time points in terms of reversing EH in patients with MD.

## Methods

*Patients.* The diagnostic criteria for MD jointly formulated by the Classification Committee of the Bárány Society [5] were closely followed. Twenty-six patients with unilateral definite MD and MRI-based *visualization* of unilateral EH underwent EDB surgery, and 18 patients with unilateral definite MD and MRI-based *visualization* of unilateral EH underwent EDD surgery for treatment of intractable MD at our University Hospital between June 2017 and June 2019. Intractable MD in patients was defined as recurrent vertigo/dizziness for  $\geq 6$  months with a failure of systematic medical treatment and psychological management, including appropriate life guidance (i.e., reduction of stress, prevention of overworking and appropriate exercise), as well as oral therapies involving the administration of osmotic diuretic medicine, ameliorants of inner ear circulation, cyanocobalamin and traditional Chinese medicine.

Definitive vertigo dizziness lasting >20 min was considered as a vertigo attack. The frequency of vertigo spells before surgery was calculated based on the number of vertigo attacks during the 6 months prior to surgery. All the participants were instructed to keep a daily vertigo diary to document the occurrence of MD attacks following surgery. The frequency of vertigo spells following surgery was calculated based on the number of vertigo attacks during the most recent 6 months following surgery. Hearing function was measured using a pure-tone audiometer, and was evaluated based on the four-tone average air-conductive hearing threshold formulated by  $(a+b+c+d)/4$ , where a, b, c and d represent hearing levels at 0.25, 0.5, 1.0 and 2.0 kHz, respectively. The worst hearing level during the 6 months prior to EDB or EDD treatment was used to evaluate the hearing level before surgery, whereas the worst hearing level during the most recent 6 months following surgery was used for evaluation of the hearing level following surgery. Changes in the hearing level were defined as 'worsened' ( $\geq 10$  dB elevation), 'improved' ( $\geq 10$  dB decline), or 'no effective change' (within a range of  $\pm 10$  dB).

The present study was approved by the Medical Ethics Committee of the Second Xiangya Hospital (certificate number: S452). All participants provided their written informed consent in accordance with the Declaration of Helsinki. At the time of diagnosis, EH was assessed by MRI imaging (at the first MRI examination), in addition to routine neurotological testing. Once their informed consent had been obtained, the patients underwent surgery. All patients who were followed-up for Gd-MRI were fully informed about the execution and goals of the study and provided informed consent to participate in this study for evaluating the dynamics of their EH.

In order to compare the dynamic changes of EH between the patients enrolled in the present study in the EDB group and those in the EDD group, a second MRI examination was performed 2 weeks after surgery, and a subsequent third MRI examination was performed at a >12-month interval following surgery. There

were a total of 10 subjects in the EDB group (5 females and 5 males; age range, 37-62 years; mean age, 49.4 years) and 9 subjects in the EDD group (6 females and 3 males; age range, 29-66 years; mean age, 48.1 years) who met the inclusion criteria.

*Gd-MRI administration.* MRI was performed using intratympanic and intravenous application of gadopentetate dimeglumine (IT-Gd +IV-Gd) as previously described [8,9]. For the second and third Gd-MRI, if patients were reluctant to receive intratympanic injections in their healthy ear, the intratympanic administration of contrast agent was used in the ear undergoing surgery alone. Therefore, all the surgical ears received IT-Gd +IV-Gd MRI using essentially the *same imaging technique* in the first, second and third Gd-MRI.

*Image evaluation.* All three-dimensional real inversion recovery (3D-real IR) sequence MRI images after IT-Gd + IV-Gd were evaluated as previously described [8,9] by two experienced head and neck radiologists who were blinded to the diagnosis of all patients. If their evaluations differed, a third head and neck radiologist made the final decision. The corresponding MRI colored image could be achieved by the pseudocolor technique, where the blue color represents the endolymphatic spaces and the green color represents the perilymphatic spaces in the cochlea and vestibule. According to the criteria previously set out by Nakashima et al [10] and Wesseler et al [11], the degree of EH in the cochlea was assessed by visual comparison of the relative areas of the non-enhanced endolymphatic space vs. the contrast-enhanced perilymph space in the axial plane on the mid-mediolar level with regards to a possible dislocation of Reissner's membrane. The degree of cochlear hydrops was categorized as none (normal finding without EH), grade I (mild EH) or grade II (significant EH), as explained below (Fig. 1A). An EH of the vestibule was determined according to the volume-ratio of endolymphatic space to the total vestibule (endolymph to vestibule-volume ratio, or EVVR) using the Syngo.via software package (VB20A; Siemens AG). The categories of EH were graded as follows: None (or grade N), <30% of the vestibular space was filled with endolymph; grade I, 30-50% of the vestibular space was filled with endolymph; and grade II, >50% of the vestibular space was filled with endolymph (Fig. 1B), that was previously described by Nakashima et al [10]. Following Wesseler et al [11], this ratio was not estimated based on one section plane alone, but was measured separately in every plane showing the vestibule; subsequently, the average of those values was calculated to obtain the overall result. The number of planes varied between four and five. Thereby, the interpersonal variability in the assessment of an image was minimized.

Change in the vestibular hydrops was defined as previously described [8, 9]. An EVVR increase of >10 percentage points (%) was defined as an enhancement of vestibular hydrops, whereas an EVVR decrease of >10 points (%) was defined as a reduction of vestibular hydrops. An EVVR change of  $\leq 10$  points (%) was defined as no change in the vestibular hydrops, and an EVVR of <30 points (%) was defined as the complete reversal of vestibular hydrops.

*Surgical techniques.* The surgical procedure used for EDB was similar to that previously described by Saliba [7] and Peng et al [8]. Briefly, a simple mastoidectomy was performed to expose the endolymphatic sac in the area between the sigmoid sinus and the inferior margin of the posterior semicircular canal,

including the rugose portion. A pair of small titanium clips was used to block the dissected endolymphatic duct using the ligating clip applicator. By contrast, the surgical procedure used for EDD was similar to that previously described by Kitahara et al [12]. Briefly, following the complete skeletonization and decompression of the sac, including removal of the bone of the vestibular aqueduct operculum. The extraosseous endolymphatic sac was opened with an L-shaped incision for drainage of excess endolymphatic fluids in sac. Postoperative wound management and postoperative care were similar to those used in other mastoid surgical operations.

Statistical analysis. For the statistical analysis, paired Student's t-tests was used for the analysis of two groups.  $P < 0.05$  was considered to indicate a statistically significant difference. SPSS (version 26.0; IBM Corp.) software was used for the statistical analysis.

**All methods were carried out in accordance with relevant guidelines and regulations.**

## Results

Table 1 shows the preoperative and postoperative clinical profiles of the 19 patients enrolled in the present study, including the age, gender, duration of symptoms, follow-up duration, the number of vertigo spells experienced during the final 6 months before surgery and the most recent 6 months following surgery, and also the dB hearing levels in the corresponding periods and the results of IV-Gd + IT-Gd MRI administration prior to surgery, 2 weeks after surgery, and at the final follow-up >12-months following surgery. The T2-weighted cisternography sequence was used to rule out the presence of vestibular schwannoma or endolymphatic sac tumors. No statistical difference in age, gender, duration of symptoms, follow-up duration, preoperative hearing threshold or number of vertigo attacks was identified between the EDB group and EDD group ( $P > 0.05$ ).

**Table 1** Clinical profiles of all 19 patients, including case nos. 1-10 in the EDB group (n=10) and case nos. 11-19 in the EDD group (n=9)

Case No.	Age/Gender	Duration of symptoms (Mon)	Hearing (dB)		Vertigo Attacks (a/mo)		EVVR			CH			Follow-up (Mon)
			Pre	Post	Pre	Post	First (%)	Second (%)	Third (%)	First	Second	Third	
1	37/M	10	55.0	57.5	4.2	1.8	56.42	58.25	59.55	☒	☒	☒	21
2	39/F	22	37.5	25.0	3.8	0	74.68	76.55	15.45	☒	☒	N	20
3	61/F	14	56.3	66.3	3.8	0.7	46.55	45.60	52.10	☒	☒	☒	19
4	52/F	16	46.3	58.8	3.0	3.3	37.85	39.80	52.30	☒	☒	☒	18
5	46/M	32	55.0	36.3	2.5	0	82.65	84.35	47.45	☒	☒	☒	18
6	48/M	16	56.3	58.8	2.5	0	54.55	58.75	46.25	☒	☒	☒	16
7	62/F	66	55.0	26.3	4.3	0	78.73	82.45	13.89	☒	☒	☒	16
8	48/M	12	43.8	47.5	3.7	1.7	41.30	40.28	45.15	☒	☒	☒	15
9	52/M	42	60.0	56.3	2.5	0	66.82	68.30	64.25	☒	☒	☒	14
10	49/F	12	47.5	51.3	3.3	0	50.65	53.58	47.48	☒	☒	☒	13
11	29/F	45	66.3	61.3	4.2	0.5	78.65	76.45	79.35	☒	☒	☒	26
12	49/M	12	56.3	72.5	3.3	0	72.55	18.25	25.35	☒	N	N	22
13	48/M	36	61.3	67.5	2.8	1.8	66.45	68.33		☒	☒	☒	17

					78.66			
14	66/F	55	68.8 72.5	4.0 0	62.56 12.25 65.30	☒ N	N	17
15	39/F	24	43.8 32.5	2.5 0	52.66 15.30 18.35	☒ N	N	15
16	62/F	18	61.3 58.8	4.3 0	65.60 10.20 18.25	☒ N	N	15
17	47/F	13	40.0 37.5	3.8 0	56.44 54.80 52.46	☒	☒	☒ 15
18	56/M	72	68.8 80.0	3.0 0.8	72.22 74.55 76.36	☒	☒	☒ 14
19	37/F	11	30.0 35.0	1.8 0.5	48.35 51.25 54.64	☒ ☒	☒	13

The red color represents a reduction in the vestibular hydrops, downgrading of cochlear hydrops, or hearing improvement, whereas the blue color represents the enhancement of vestibular hydrops, upgrading of cochlear hydrops, or hearing worsening prior to and following surgery. EVVR, endolymph to vestibule-volume ratio; CH, cochlear hydrops; BT, before treatment; AT, after treatment; F, female; M, male; L, left; R, right; Mon, month; N, no endolymphatic hydrops; I, mild endolymphatic hydrops; II, significant endolymphatic hydrops

Compared with the pre-surgery recordings (first MRI examination), in the EDB group (patient case nos. 1-10), the second MRI examination revealed no changes in either the vestibular or the cochlear hydrops in any of the subjects. By contrast, the results of the third MRI scans showed a reversal of vestibular EH in 3 patients, accompanied by a downgrading of cochlear hydrops in 2 patients, who also showed an improvement in their hearing and complete control of vertigo attacks. One patient showed an enhancement in vestibular EH, accompanied by an upgrading of cochlear hydrops and an increase in the number of vertigo attacks. Six patients showed no changes in EH or hearing, and complete control of vertigo attacks in 3 patients and partial control of vertigo attacks in the remaining 3 patients.

In the EDD group (patient case nos. 11-19), the second MRI examination revealed the reversal of both vestibular and cochlear hydrops in 4 patients, but no changes in EH in the remaining 5 patients. The third MRI examinations revealed that the reversal of EH in the 4 patients that were identified in the second MRI scans remained unchanged, except for one patient, for whom a recurrence of vestibular hydrops was detected. In all these 4 patients who showed a reversal of EH, the vertigo attacks were completely controlled, whereas hearing improved only in one of them, worsened in another patient, and was stabilized in the other two. One patient showed an enhancement of vestibular EH, accompanied by no

changes in hearing and a reduction in vertigo attacks. The other 4 patients showed no changes in EH, with one patient exhibiting a worsening of their hearing, although hearing was unchanged in the remaining three, and complete control of vertigo attacks was recorded for one patient, whereas vertigo attacks were only partially controlled in the other three.

3 shows the dynamic changes of EH in patient no. 7 in the EDB group. The second MRI examination revealed that the EVVR increased to 82.45% from 78.73% in the first MRI examination, suggesting that there was a tendency for EH to *temporarily* increase 2 weeks after surgery, whereas the results of the third MRI showed complete reversal of vestibular hydrops, with a decrease of the EVVR from 78.73% in the first MRI scan to 13.89% 16 months following surgery, and a concomitant downgrading of cochlear hydrops from grade II to grade I.

Fig. 4 and 5 shows the dynamic changes of EH in patient no. 14 in the EDD group. The second MRI examination showed complete reversal of vestibular and cochlear EH, with a decreased EVVR from 62.56% (first MRI scan) to 12.25%, and a downgrading of the cochlear hydrops from grade I (first MRI scan) to grade N, whereas the results of the third MRI showed that the reversal of cochlear hydrops remained unchanged, although a recurrence of vestibular hydrops was found.

## Discussion

In the present study, it was first reported the differences between EDB and EDD in the reversal of endolymphatic hydrops in MD. Inner-ear Gd-enhanced MRI revealed that both the EDB and EDD procedures could reduce EH in certain patients with MD. The reversal of EH was detected 2 weeks following surgery in the EDD group; by contrast, no reduction in EH was observed 2 weeks after surgery for the patients in the EDB group, although the reversal of EH was identified several months after surgery in this group.

In vivo visualization of hydrops with Gd-MRI is no longer limited to only showing evidence of the hydrops for the diagnosis of MD. Changes in EH may be used to objectively evaluate and differentiate the effects of various treatments for patients with MD [13-16]. In the present study, a reduction in EH was found in 3 of 10 patients with EDB, and 4 of 9 patients with EDD, suggesting that both the EDB and EDD procedures had the potential to reduce EH in certain patients with MD. However, 5 of 10 patients in the EDB group, and 4 of 9 patients in the EDD group did not exhibit any change in their EH, indicating that sac surgery does not always result in an improvement of EH in MD. An enhancement of EH was identified with 1 patient who underwent EDB, and 1 patient who underwent EDD, and this may have been due to the natural course of MD with the progression of EH [17, 18].

Physiologically, EDB represents a completely different approach to EDD in terms of the surgery that has been taking place over a large number of years with the aim of improving endolymphatic drainage. However, the mechanistic and pathophysiological basis underlying endolymphatic sac surgery remains poorly understood. An immunohistochemical and ultrastructural investigation of the human endolymphatic sac in MD revealed both the secretion of glycoproteins and the possible existence of

hypersecretions of endolymph in the sac [19-21], and an increased expression of aquaporin-2 in the endolymphatic sac epithelium of patients with MD was proposed to be involved in the pathophysiology of EH [22], which may support the hypothesis that an increased secretion outweighs a decreased absorption, resulting in increased pressure in the inner ear [7]. Therefore, by blocking the endolymphatic duct, EH may be decreased due to a reduction in the volume of endolymph in the inner ear arising from the sac, this hypothesis provides the rationale potentially explaining how EDB may work in the treatment of MD. By contrast, EDD is based on the hypothesis that deficient absorption in the endolymphatic sac is one of the causes of EH, regardless of all other uncertainties surrounding the treatment of MD [23, 24]. Endolymphatic sac drainage is still *universally* considered by surgeons to be an excellent option for vertigo control and hearing preservation [25]; moreover, a decrease in the volume of EH following sac drainage surgery has recently been confirmed with Gd-MRI [26-28]. However, the reversal of EH achieved in certain patients with MD via the two opposing surgical approaches on the endolymphatic sac, as investigated in the present study, has demonstrated the *inhomogeneity* and complexity of the mechanisms underpinning the development of EH. The exact role of the endolymphatic sac in MD remains unknown.

Interestingly, in the EDB group, the EH remained unchanged 2 weeks after surgery, and the reversal of EH could only be detected in some of the patients at >12 months following surgery, suggesting the reduction in the volume of endolymph was likely due to a delayed effect associated with the EDB surgery that *progressed over time*. By contrast, in the EDD group, the reduction in EH could be detected 2 weeks following surgery, suggesting that EDD resulted in the reversal of EH very soon after surgery, which was likely due to the mechanical effect of the opened endolymph sac with an acute reversal of EH. Since no further patients showed any reduction in the endolymph space at >12 months following surgery—indeed, a recurrence of vestibular hydrops in one patient was detected in comparison with the results of Gd-MRI 2 weeks following surgery—a delayed effect on EH for EDD was not found. Although a precise understanding of the physiological mechanisms underlying MD-related vertigo has yet to be elucidated, vertiginous attack is considered to result from acute development or exacerbation of EH [29], suggesting that the reduced volume of EH was likely to have been associated with a reduction of spells. This hypothesis seems likely to explain how a complete control of vertigo was achieved in the patients in both the EDB and EDD groups who exhibited a reversal of EH in the present study. In addition, a major body of evidence already exists in support of a direct link between hydrops and disordered auditory physiology, suggesting that low-tone sensorineural hearing loss in MD is caused by the mechanical impact of high endolymphatic pressure [2]; therefore, a reduction in the volume of the endolymph is expected to result in an improvement in hearing. In the present study, all 3 patients in the EDB group for whom reversal of EH was confirmed were found to have improved hearing, revealing a cause-effect relationship between EH and hearing function. However, with the 4 patients in the EDD group for whom reversal of EH was confirmed, hearing improved in only one patient, worsened in one, and was stabilized in the other two, suggesting no correlation between the changes in hearing function and the volume of EH after sac drainage surgery, a finding that was consistent with previous reports [26-28]. In the former case (EDB), the reversal of EH was found to be a delayed effect associated with the surgery that progressed over time,

*which* was likely to be linked with *physiological recovery* in the homeostasis of the endolymph. In the latter case (EDD), the reduction in EH was presented as an acute reversal of EH, which was likely to be due to the mechanical effect of drainage of endolymph from an incised sac, suggesting that a different process was operative in terms of the decrease of endolymph volume and *consequences of hearing function* compared with the former technique.

In addition, *high-quality imaging* in vivo visualization of hydrops with Gd-MRI is very important, especially for evaluating the dynamic changes of EH. Although promising results have been reported using IV-Gd, which has the advantage of not being an off-label use of Gd [30-33]. Yet, they were too time-consuming to use for routine diagnostic procedures, moreover, it was difficult to obtain serial MRI scans by this heavily T2-weighted 3D FLAIR sequence for evaluating the dynamic changes of EH of “after treatment” and “before treatment” groups. In the present study, the use of IT-Gd + IV-Gd MRI not only improved the effectiveness of imaging and evaluation techniques for EH [34], but also prevented the failure of IT-Gd imaging for ~10% of cases [36], which would have been caused by an insufficient Gd concentration with anatomic barriers to the round window, such as adhesions, bone dust blockage or thickened round window, when the IT-Gd method alone was used [35]. As presented in Figs. 2-5, the MRI technique used in the present study had an equal or superior resolution to other techniques reported in previous literature[14, 15, 26-28]. The comparison of serial MRI scans, which were obtained from multiple section planes in the same ear between the before and after treatment, could clearly identify the dynamic changes of EH, showing an objective marker for assessing the effects of treatment in MD.

There were some limitations associated with the present study; first, there was a lack of pathological evidence in the endolymphatic sac to explain why the reversal of EH could be achieved via two opposing surgical approaches on the sac. Further investigations are necessary to determine whether there were different pathological changes in the endolymphatic sac, comparing between the patients who presented with a reversal of EH and were treated with EDB or EDD, respectively. Second, the degree of EH in the cochlea was assessed by visual comparison of the relative areas of endolymphatic space versus the perilymph space, categorizing each ear as normal, grade I hydrops or grade II hydrops, which may be insensitive to subtle changes among scans.

## **Conclusion**

The present study has indicated that both the EDB and EDD surgical procedures have the potential to reduce EH in certain patients with MD. In patients treated with EDB surgery, the reversal of EH was likely to have been due to the delayed effect of surgery accompanying hearing improvement, whereas in patients treated with EDD surgery, the reduction of the endolymph volume presented as an acute reversal of EH, which was likely due to the mechanical effect of drainage of the sac that showed no cause-effect association with hearing function.

## **Declarations**

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## Compliance with ethical standards

Conflict of interest

No conflicts of interest to be declared.

Ethical approval

The present study was approved by the Medical Ethics Committee of the Second Xiangya Hospital (certificate number: S452).

Informed consent

Informed consent of all participants was obtained prior to interview.

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## Figures

EH-grade	Explanation cochlea	Example cochlea		Explanation veatibule	Example veatibule	
grade 0 (normal finding)	cEH grade 0: no dislocation of the Reissner's membrane			vEH grade 0: EVVR < 30%		
grade I (mild EH)	cEH grade I: dislocation of the Reissner's membrane but not reaching over the scala vestibuli			vEH grade I: EVVR 30-50%		
grade II (significant EH)	cEH grade II: endolymphatic space reaches over the scala vestibuli			vEH grade II: EVVR > 50%		

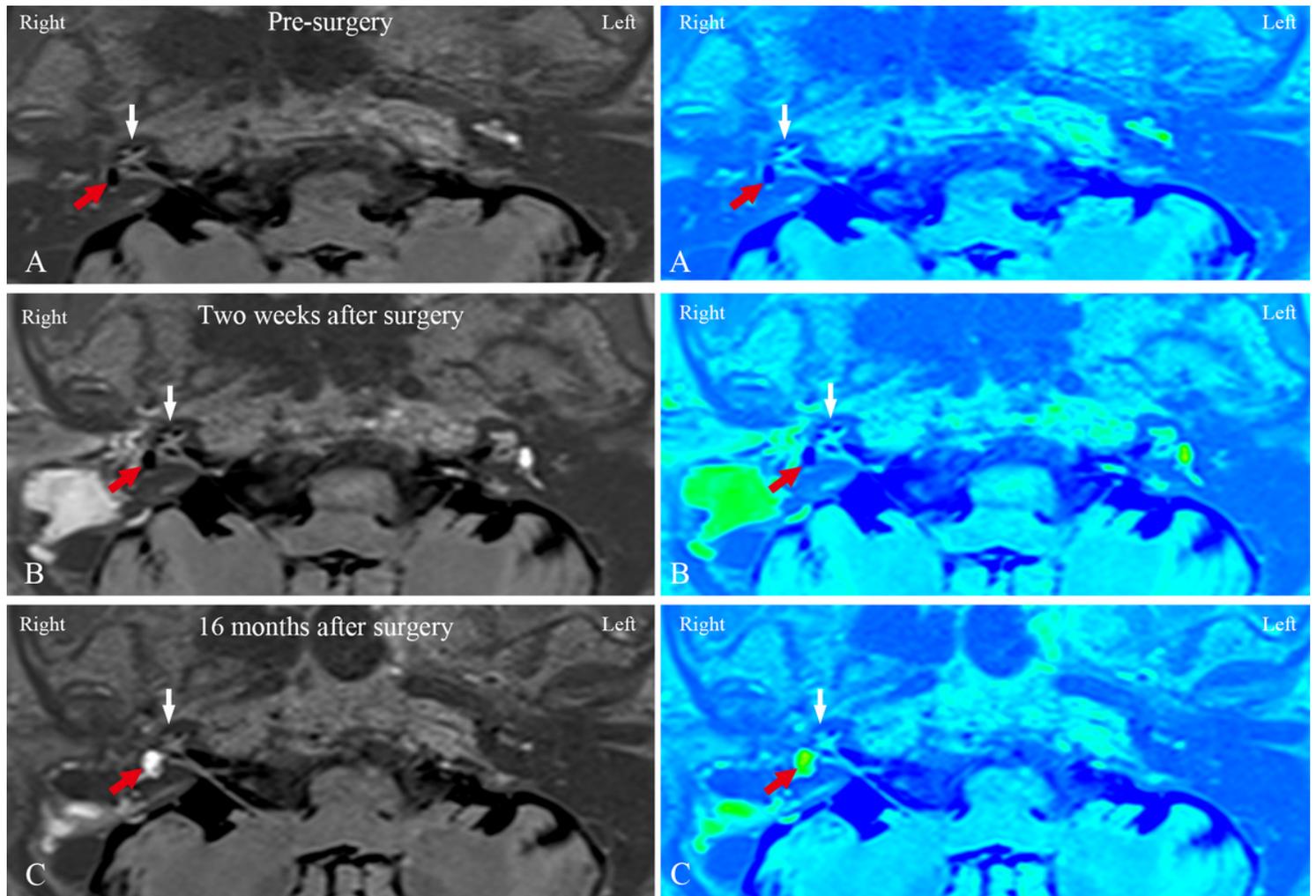
**Figure 1**

Criteria for grading of the cochlear and vestibular hydrops in three-dimensional fluid-attenuated inversion recovery MRI axial scans in the left column, and the corresponding MRI colored image in the right column

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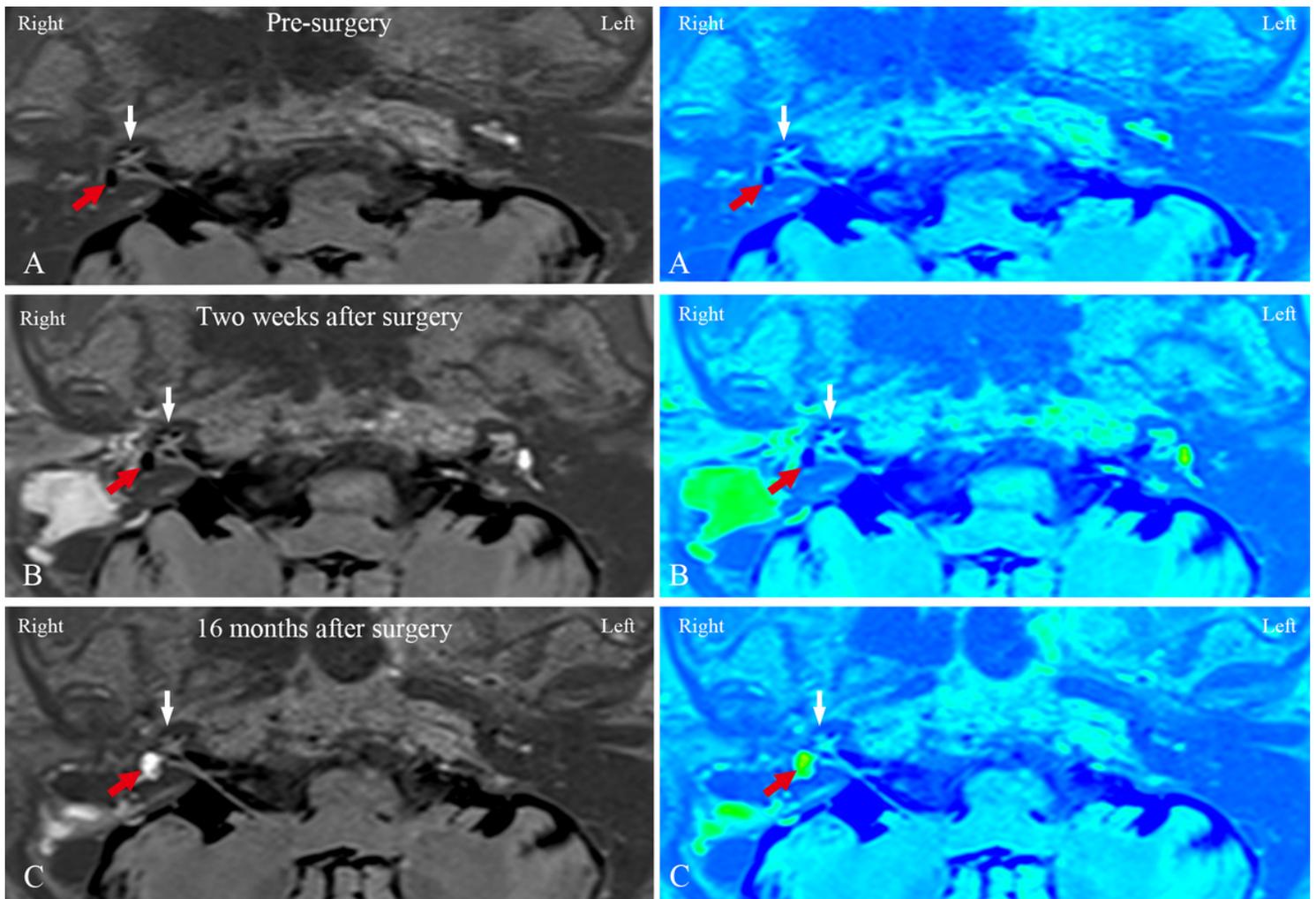
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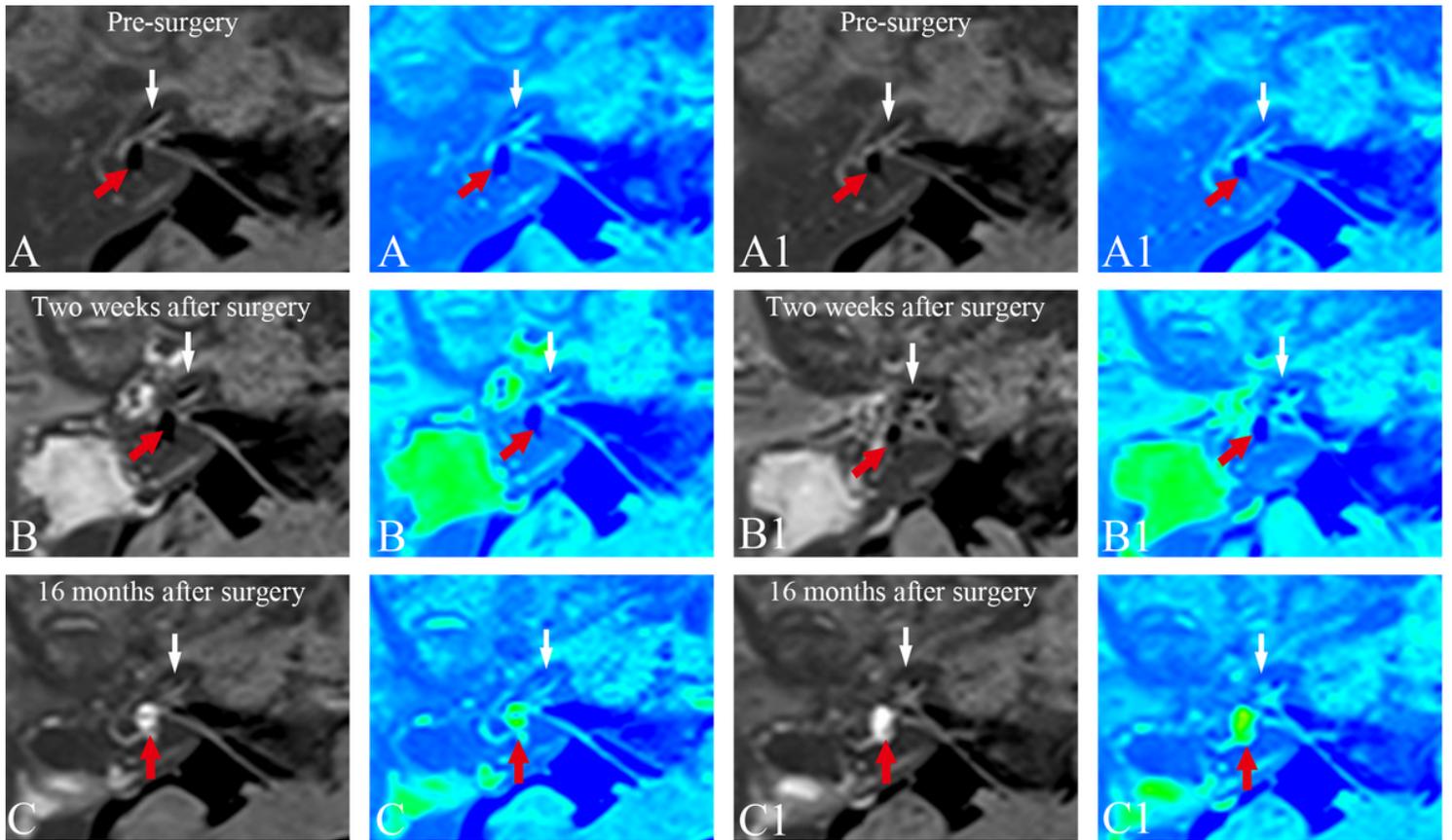
## Figure 2

MRI axial scans (left column), and the corresponding MRI colored images (right column) of patient no. 7 (Table 1) in the EDB group with right MD (A) prior to surgery, (B) 2 weeks after surgery, and (C) 16 months after surgery are shown. (A) 3D real IR MRI revealed a significant EH both in the cochlea (white arrow) and vestibule (red arrow) in the right ear, and no pathological findings were identified in the left ear. (B) Compared with the imaging in the same slice level in the first MRI examination (A), the second MRI examination showed that the EH tended to temporarily increase both in the cochlea (white arrow) and the vestibule (red arrow). (C) The third MRI examination showed complete reversal of vestibular hydrops (red arrow) and downgrading of cochlear hydrops (white arrow) from grade II to grade I. EDB, endolymphatic duct blockage; EH, endolymphatic hydrops; MD, Meniere's disease; 3D real IR MRI, three dimensional real inversion recovery, MRI, magnetic resonance imaging



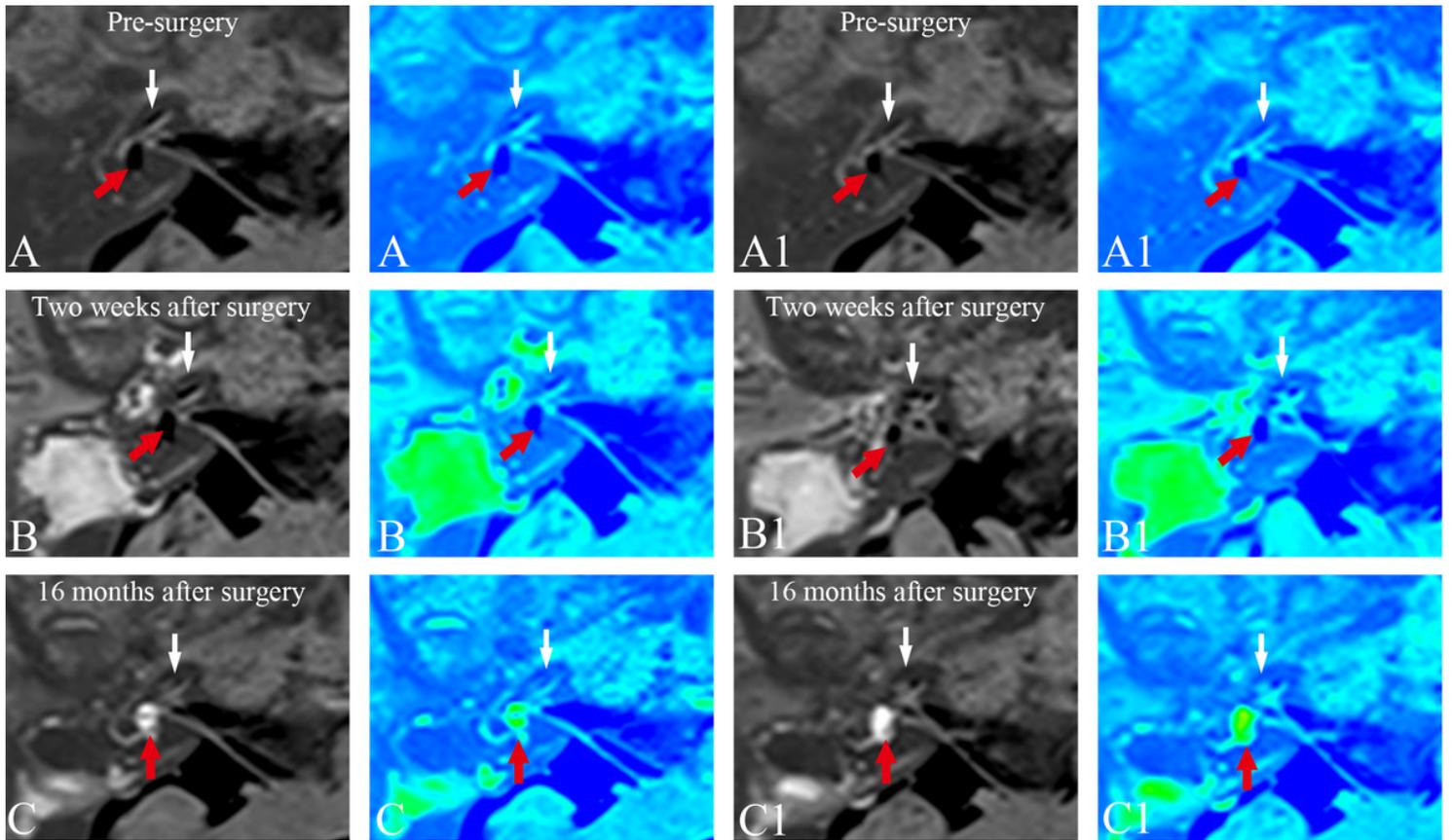
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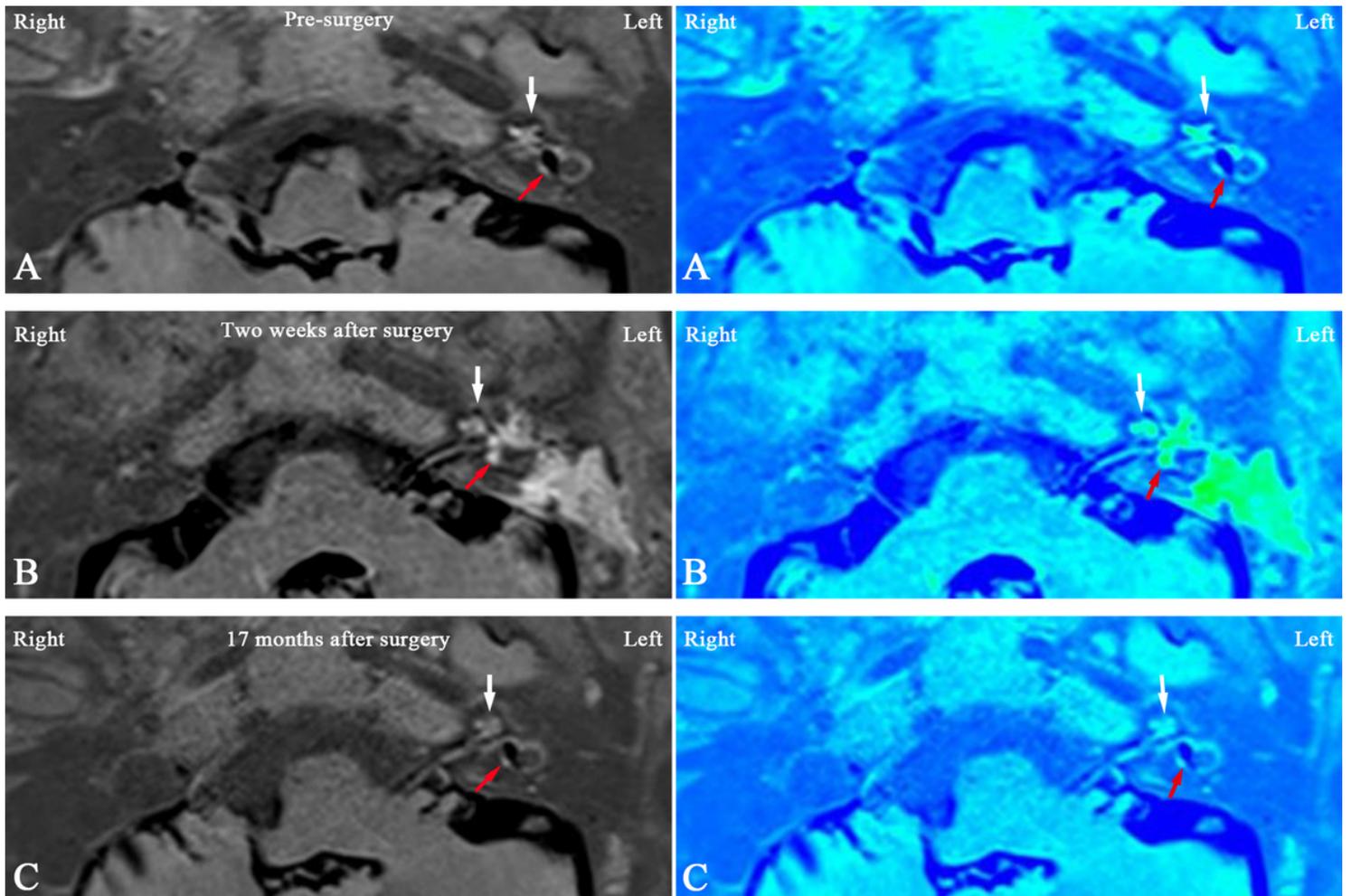
**Figure 3**

Serial MRI axial scans (left column) and the corresponding MRI colored images (right column) revealed a significant EH both in the cochlea (white arrow) and vestibule (red arrow) prior to surgery (A1 and A2), a tendency for EH to temporarily increase both in the cochlea (white arrow) and the vestibule (red arrow) 2 weeks after surgery (B1 and B2) and a complete reversal of vestibular hydrops (red arrow) and downgrading of cochlear hydrops (white arrow) from grade II to grade I 16 months after surgery (C1 and C2) in the same patient in Fig. 2. EH, endolymphatic hydrops; MRI, magnetic resonance imaging



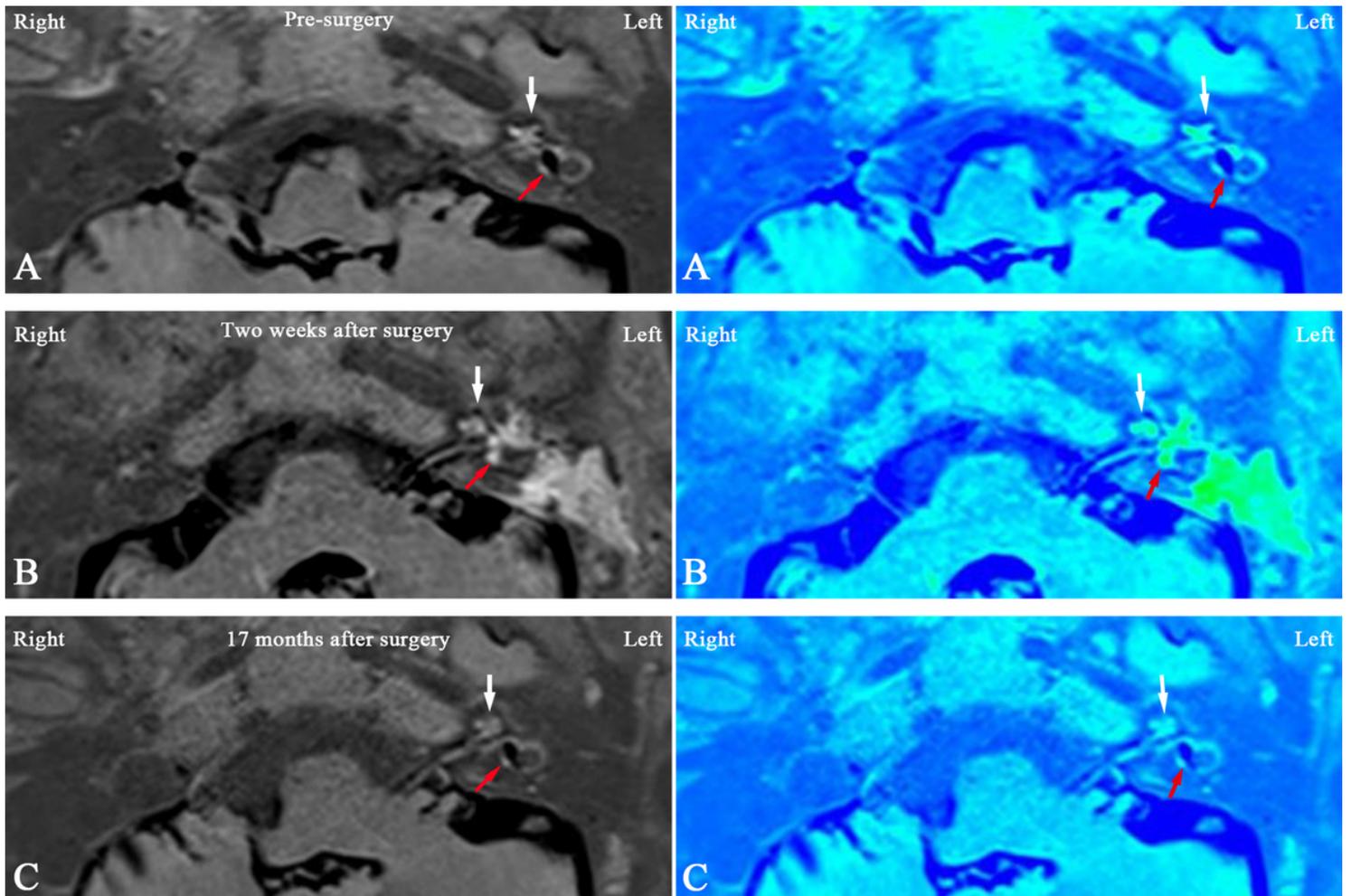
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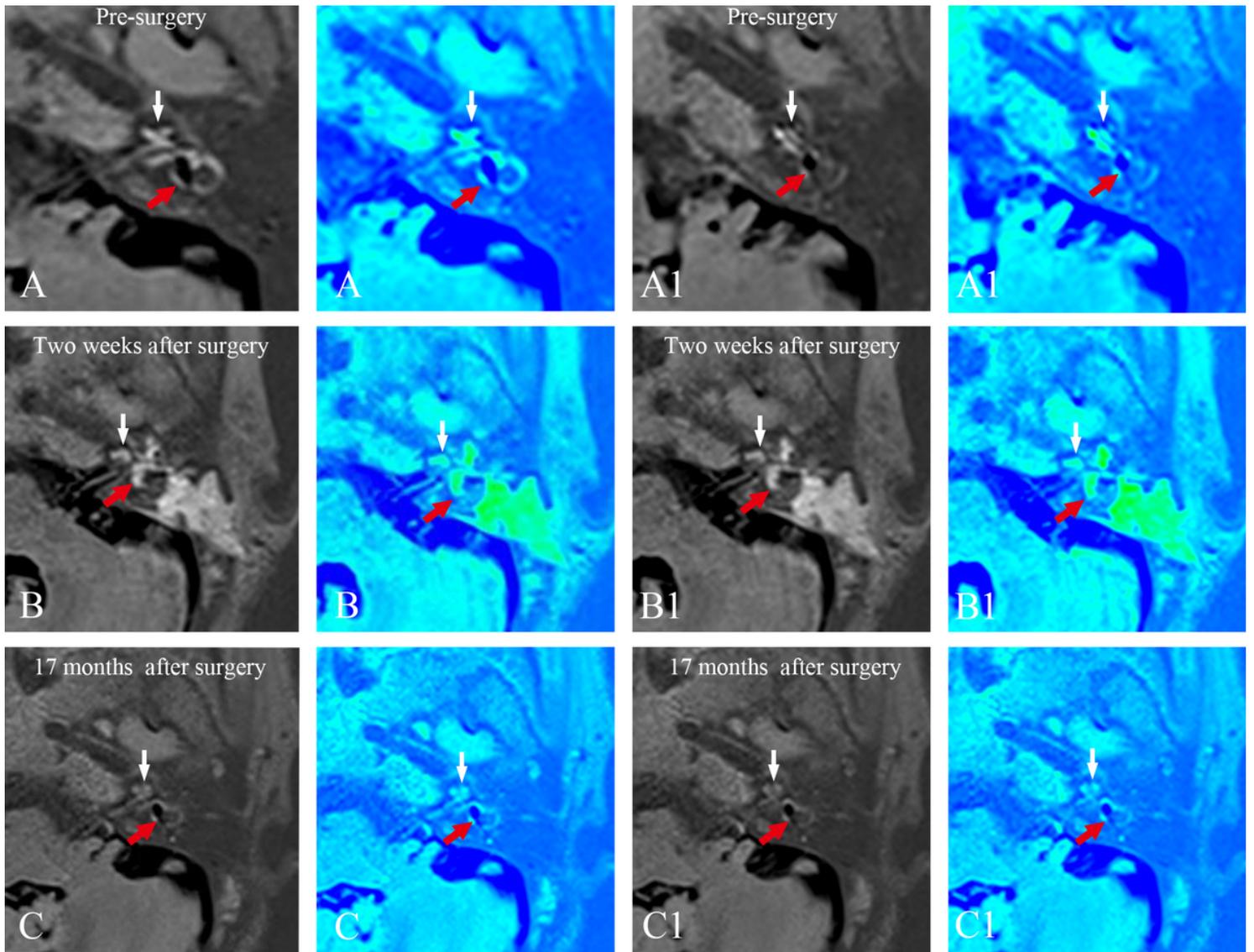
**Figure 4**

Three dimensional real inversion recovery MRI axial scans (left column) and the corresponding MR colored image (right column) of patient no. 14 in the EDD group (Table 1) with left MD (A) prior to surgery, (B) 2 weeks after surgery, and (C) 17 months after surgery. (A) The first MRI examination, exhibiting a mild cochlear EH (white arrow) and a significant vestibular EH (red arrow) in the left ear. (B) The second MRI examination showed complete reversal of vestibular (red arrow) and cochlear EH (white arrow), in comparison with the first MRI examination in the same slice level. (C) The third MRI examination, revealing that the reversal of cochlear hydrops remained unchanged (white arrow), and there was a recurrence of vestibular hydrops (red arrow) in comparison with the first and second MRI examinations in the same slice level. EDD, endolymphatic sac drainage; EH, endolymphatic hydrops; MD, Meniere's disease; MRI, magnetic resonance imaging



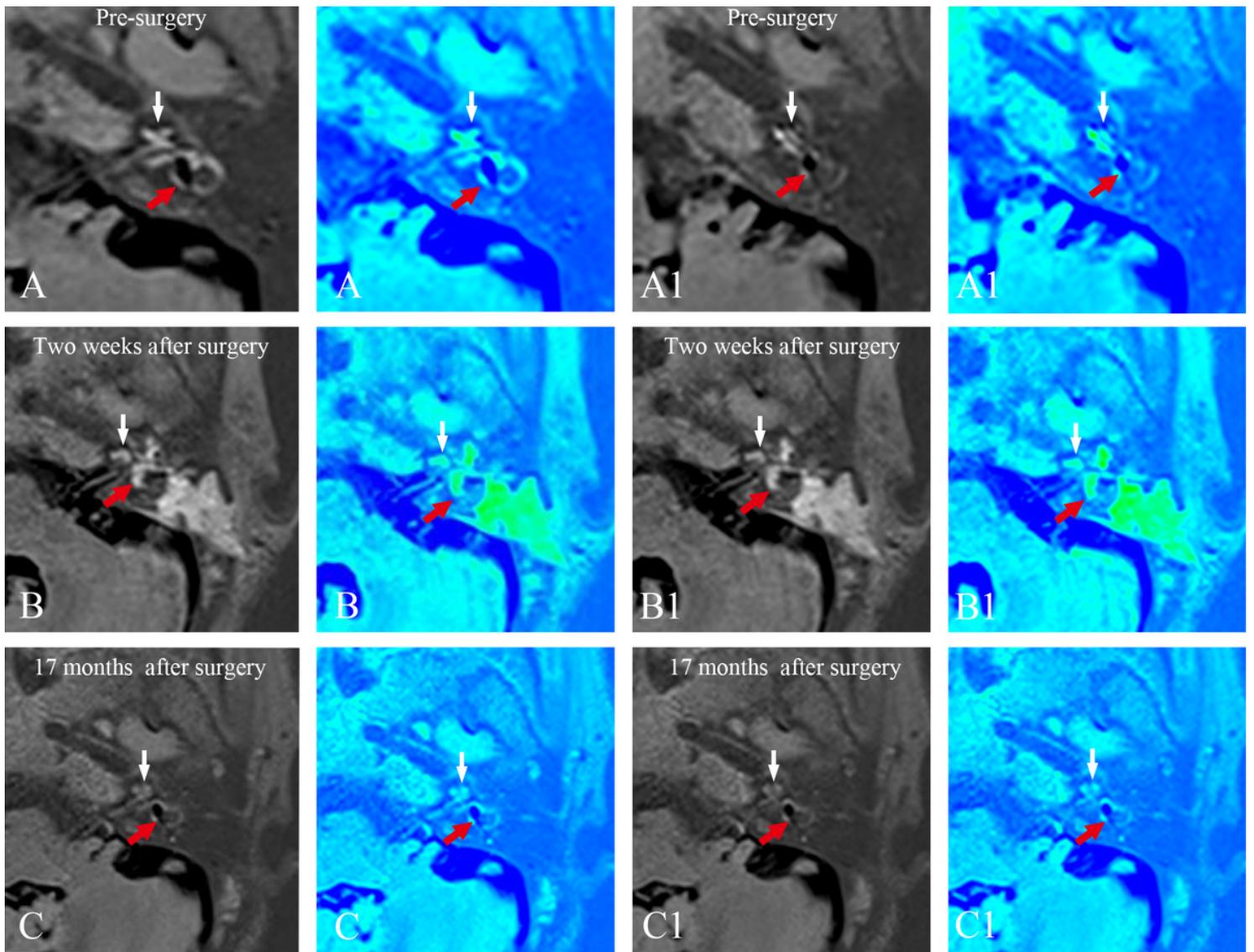
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**Figure 5**

Serial MRI axial scans (left column) and the corresponding MRI colored images (right column) revealed a mild cochlear EH (white arrow) and a significant vestibular EH (red arrow) prior to surgery (A1 and A2), a complete reversal of vestibular (red arrow) and cochlear EH (white arrow) 2 weeks after surgery (B1 and B2), and the reversal of cochlear hydrops unchanged (white arrow) and a recurrence of vestibular hydrops (red arrow) 17 months after surgery (C1 and C2) in the same patient in Fig. 4. EH, endolymphatic hydrops; MRI, magnetic resonance imaging



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