Noninvasive evaluation of the effect of endolymphatic sac decompression in Ménière’s disease using magnetic resonance imaging

FANG LIU1, WEINING HUANG1, QINGHUA CHEN2, XIXI MENG3, ZHENCHANG WANG2 & YUXIA HE1

1Department of Otolaryngology, Beijing Hospital, Beijing, 2Department of Radiology, Beijing Tongren Hospital, Capital Medical University, Beijing and and 3Department of Otolaryngology, Beijing Institute of Otolaryngology, Beijing, China

Abstract
Conclusions: This study is the first to demonstrate noninvasive evaluation of the effect of endolymphatic sac decompression (ESD) in Ménière’s disease using magnetic resonance imaging (MRI). Objective: To evaluate the effect of ESD for the treatment of Ménière’s disease by applying noninvasive intratympanic gadolinium (Gd) perfusion through the eustachian tube and three-dimensional fluid-attenuated inversion MRI (3D-FLAIR MRI). Methods: This was a prospective study. 3D-FLAIR MRI was performed with a 3 Tesla unit 24 h after intratympanic administration of Gd through the eustachian tube in five patients with intractable Ménière’s disease before and 3 months after ESD, with a 2-year follow-up on the effect of ESD. Results: Gd was present in the perilymph of the inner ear in all the patients, which clearly displayed the endolymphatic space on 3D-FLAIR MRI with a visible borderline between the perilymph and the endolymph. According to the normal values for the endolymphatic space, four of five patients had a ratio of more than 26% in the cochlea, and three of five patients had a ratio of more than 41% in the vestibule preoperatively. All the patients had a ratio of less than 26% in the cochlea and 41% in the vestibule postoperatively. ESD was effective in reducing the incidence and severity of vertigo attacks with significant improvement in 60% of patients.

Keywords: Gadolinium, 3D-FLAIR MRI

Introduction
Ménière’s disease appears to be a complex inner ear disorder. The underlying increased pressure in the membranous labyrinth, the so-called endolymphatic hydrops, is associated with the classic features of spontaneous, episodic attacks of vertigo; fluctuating, progressive sensorineural hearing loss; tinnitus; and aural fullness. In 1938, Hallpike and Cairns demonstrated the histological findings of ‘hydrops’ in patients with Ménière’s disease. Despite this well-known symptom complex, Ménière’s disease remains a controversial and often difficult disease as regards determination of diagnosis, pathogenesis, and optimal treatment [1,2]. Traditionally, when patients with Ménière’s disease fail to respond to medical management, surgical options are indicated to stabilize the symptoms, which include endolymphatic sac surgery (ESS), three semicircular canals occlusion, transtympanic gentamincin, labyrinthectomy, and vestibular neurectomy. Recently, ESS has become a favorable surgical option because it has a low surgical morbidity and it does not significantly impact on hearing. The main types of ESS involve endolymphatic sac decompression (ESD), endolymphatic mastoid shunt (EMS), and endolymphatic sac excision (ESE), since it was first described by Portmann in 1927. However, ESS remains controversial and its effectiveness for the treatment of Ménière’s disease is debated [3].

Correspondence: Fang Liu, MD, Department of Otolaryngology, Beijing Hospital, No. 1 Dahua Road, Dongdan, Beijing 100730, China. E-mail: liufangpeking@sohu.com and Qinghua Chen, MD, Department of Radiology, Beijing Tongren Hospital, Capital Medical University, No. 1 Dongjiaominxiang, Beijing 100730, China. E-mail: 13661042486@163.com

(Received 7 November 2013; accepted 9 January 2014)
Diagnosis by magnetic resonance imaging (MRI) may play a key role in understanding Ménière’s disease without obtaining temporal bone histopathologic specimens as in autopsy cases. In 2013, Uno et al. reported that the changes in endolymphatic hydrops after sac surgery were examined by Gd-enhanced MRI [4]. However, the actual values for the endolymphatic space were the ranges measured using specimens of temporal bone [5,6]. There was still an absence in the range of normal values for endolymphatic space to allow diagnosis ‘endolymphatic hydrops’ and to accurately estimate the changes in hydrops after sac surgery. As part of a series of related studies, in 2011 and 2012, Liu et al. devised a new method for noninvasive standard evaluation of normal endolymphatic space and endolymphatic hydrops using MRI and first indicated the normal values for the endolymphatic space of the inner ear in healthy volunteers [7,8]. We continued to pursue further studies in clinical subjects for the evaluation of the effect of ESD for the treatment of Ménière’s disease by applying noninvasive intratympanic Gd perfusion through the eustachian tube and three-dimensional fluid-attenuated inversion MRI (3D-FLAIR MRI).

Material and methods

Patients

A total of five patients with Ménière’s disease according to the criteria of the 1995 AAO-HNS guidelines [9], referred to the Department of Otolaryngology in Beijing Hospital to undergo ESD, were enrolled in this study. All the patients had failed on medical management including a low-salt diet, diuretics, and vestibular suppressants. The patients’ demographics are shown in Table I. The selection criteria were as follows. (1) All the patients had a diagnosis of unilateral definite Ménière’s disease. (2) Brainstem audiometry was conducted and MRI or CT scans were also used to rule out cerebellopontine angle tumor or other intracranial disease. (3) There was no history of middle ear diseases. (4) A test for perilymphatic fistula was performed. (5) Stage on hearing was 2–3. The exclusion criteria were as follows. (1) Patients were excluded if they had undergone previous surgical treatment for inner ear diseases, had any systemic disease requiring steroid therapy, had used diuretics or vasodilators within 2 weeks before entering the study, or had active bilateral disease or had undergone any previous destructive procedure (e.g. injections with gentamicin). (2) Allergic conditions, a history of allergy to Gd, and pregnancy also prohibited participation.

Intratympanic Gd perfusion through eustachian tube and MRI

Standard intratympanic Gd perfusion through the eustachian tube and MRI were performed as reported previously [7,8].

ESD

A simple mastoidectomy was performed under general anesthesia. The facial nerve, posterior semicircular canal, and sigmoid sinus were identified. The sigmoid sinus, the posterior fossa dura, and the endolymphatic duct around the posterior semicircular canal were skeletonized. The endolymphatic sac was identified around Donaldson’s line and the extension line from the endolymphatic duct. The sac itself and surrounding dura were then decompressed from the region of the otic capsule bone superiorly to approximately 5 mm inferior to the sac. The surgeon (F.L.) preferred ESD for all the patients with Ménière’s disease.

3D-FLAIR MRI was performed with a 3 Tesla MRI unit at 24 h after intratympanic administration of Gd through the eustachian tube. The procedure was carried out before ESD and 3 months after ESD. The endolymphatic space was evaluated using

Table I. Patient demographics, follow-up, PTA, and vertigo class.

<table>
<thead>
<tr>
<th>Patient no.</th>
<th>Age (years)</th>
<th>Sex</th>
<th>Ear affected</th>
<th>Follow-up (months)</th>
<th>Stage</th>
<th>6 months preop</th>
<th>18–24 months postop</th>
<th>Vertigo control class</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>45</td>
<td>M</td>
<td>L</td>
<td>62</td>
<td>3</td>
<td>52</td>
<td>47</td>
<td>C</td>
</tr>
<tr>
<td>2</td>
<td>54</td>
<td>F</td>
<td>L</td>
<td>58</td>
<td>3</td>
<td>65</td>
<td>64</td>
<td>B</td>
</tr>
<tr>
<td>3</td>
<td>52</td>
<td>F</td>
<td>L</td>
<td>29</td>
<td>2</td>
<td>40</td>
<td>33</td>
<td>A</td>
</tr>
<tr>
<td>4</td>
<td>47</td>
<td>M</td>
<td>R</td>
<td>24</td>
<td>3</td>
<td>47</td>
<td>50</td>
<td>C</td>
</tr>
<tr>
<td>5</td>
<td>53</td>
<td>F</td>
<td>R</td>
<td>25</td>
<td>3</td>
<td>52</td>
<td>45</td>
<td>A</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>50.2 ± 4.0</td>
<td></td>
<td>39.6 ± 18.8</td>
<td></td>
<td>51.2 ± 9.1</td>
<td>47.8 ± 11.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Db, decibel; HL, hearing level; PTA, pure-tone average thresholds; SD, standard deviation.
3D-FLAIR MRI, as described previously [7,8]. In the basal turn of the cochlea, the sectional area of the endolympathic space and the fluid space (sum of the endolympathic and perilymphatic space) was measured and the ratio of the area of the endolympathic space to that of the fluid space was evaluated on images parallel to the modiolus cochlea. In the vestibule, the sectional area of the endolympathic space (sum of the utricle and saccule) and the fluid space (sum of the endolympathic and perilymphatic spaces) were measured and the ratio of the area of the endolympathic space to that of the fluid space was evaluated on images parallel to the longitudinal axis of the vestibule.

The severity of Ménière’s disease was evaluated by AAO-HNS criteria for hearing loss and vertigo [9]. The worst pure-tone average (PTA) at 500 Hz, 1 kHz, 2 kHz, and 3 kHz in the 6-month period before ESD and the period 18–24 months after ESD was compared. A change of 10 dB HL or more in PTA was considered clinically significant. Likewise, the average number of episodes of vertigo 6 months preoperatively and 24 months postoperatively was reported.

The protocol of the study was approved by the Ethics Review Committee of Beijing Hospital. All the patients gave their informed consent to participation in this study, in accordance with the suggestion of the Ethics Review Committee.

Data analysis

All data were extracted from the subject charts and then displayed in tabular form. Statistical analysis was performed using the SPSS 17.0/PC program. Descriptive statistics were applied using mean ± SD.

Results

First, on MRI scans taken 24 h after the intratympanic Gd injection through the eustachian tube in all the patients before and 3 months after ESD, Gd was observed in the cochlea, the vestibule, and/or parts of the semicircular canals. When the Gd entered the perilymph of the cochlea and the vestibule, the endolympathic space without Gd could be seen clearly. An example from a patient is shown in Figure 1. The endolympathic space was evaluated using 3D-FLAIR MRI in all the patients (Table II). As reported earlier, the normal value for the endolympathic space in the cochlea ranged between 8% and 26%, and that in the vestibule between 20% and 41% in healthy volunteers aged between 45 and 55 years [8]. According to the normal value for endolympathic space, four of five patients had a ratio of more than 26% in the cochlea, and three of five patients had a ratio of more than 41% in the vestibule before ESD. All the patients had a ratio of more than the normal value in the cochlea and/or the vestibule. However, all the patients had a ratio of less than 26% in the cochlea and 41% in the vestibule 3 months after ESD.

Second, among the five patients, vertigo control at 18–24 months was class A (two patients), class B (one patient), and class C (two patients) (Table I). For the purpose of this study, those patients who experienced class A or B results were considered to have a successful outcome. Accordingly, the success rate was 60%.

Third, of five patients, the average PTA before and 2 years after ESD was 51.2 dB HL and 47.8 dB HL, respectively (Table I). According to AAO-HNS criteria, there was no significant change in PTA preoperatively and postoperatively [9].

Finally, no adverse effects of the intratympanic injection of Gd were observed. There were no serious complications (such as cerebrospinal fluid leaks, facial nerve palsy, meningitis, or wound infections) in any of the patients.

Discussion

ESS is widely performed to control vertigo spells and preserve inner ear functions in patients with intratable Ménière’s disease, although there has been some debate about the optional treatments (shunt, excision, and decompression) [10–12].

The previous theory for EMS proposed that endolymph was passively drained into the mastoid from the sac, which decompressed the hydropic inner ear. However, this seems irrational because of the rapid overgrowth of the shunt by mucosa within days of surgery. A histologic study of explanted Arenberg shunt found that acellular debris filled the vestibule around the valve in all cases and showed ingrowth of fibrous tissue to the sponge [13]. Moreover, Silastic applied to the shunt was also coated in a fibrous scar, which limited the drainage potential of the biocompatible material [10]. In 1994, Gibson proposed that an abnormal build-up of fluid in the inner ear triggers a response in the endolympathic sac to secrete osmotically active glycoproteins, creating a rapid drainage of endolymph from the inner ear toward the sac, which causes the attacks of vertigo [14]. Based on the theory, destruction of function of the sac or occlusion of the duct may be the reason for improvement in vertigo control. Therefore, elimination of the secretion of glycoproteins into the sac may control rapid fluid changes, which would decrease vertigo. In 1996, Welling et al. reported that EMS and ESE appear equally effective in the treatment of Ménière’s disease.

According to the results, it was presumed that the removal of the sac would still allow hydrops...
formation, but there would not be rapid endolymphatic shifts to disturb the neuroepithelium, thereby preventing the episodic vertigo [10]. However, several observations of the development of low-frequency air-bone gaps, minimal deterioration of long-term hearing levels, after EMS and ESE, also suggest that inner ear micromechanics have been altered by the surgeries, perhaps by creation of a third window phenomenon [14,15].

In 2007, Brinson et al. reported that EMS and ESD are equally effective in reducing the attacks of vertigo, with significant improvement in 67% and 66% of patients, respectively. Moreover, the risk of postoperative profound hearing loss is higher when the endolymphatic sac is incised [12]. Although ESD is an effective and safe procedure for patients with intractable Ménière’s disease, the rationale for the use of ESD remains controversial.

Some studies suggested that a functioning endolymphatic sac may have both resorptive and secretive properties, and has the ability to rapidly respond to a pressure change. The highly osmolar proteins secreted by the endolymphatic sac appear to occur with rapid changes in the endolymphatic pressure but not endolymphatic duct obstruction, which may create an osmotic gradient to attract fluid into the endolymphatic sac and duct from the surrounding tissues and also cause a fluid shift from the cochlea and the vestibule. Some factors that may damage the sac, such as infection, immunologic reaction, or trauma, can upset the homeostatic function of the sac by disruption of the secretion or function of such proteins, resulting in endolymphatic hydrops [16–18]. Two main theories were proposed as to the cause of vertigo attacks in endolymphatic hydrops. The first, reported by Schuknecht, is the rupture of
Reissner’s membranes due to overdistension of the endolymphatic compartment, which leads to a mixing of the endolymph and perilymph then causes acute vertigo attack [19]. Another theory proposed by Shea is that the distension of the membranous labyrinth in the hydrops of inner ear causes neural discharge, which resolves as the membrane distension subsides [20].

To the best of our knowledge, the results of this study are the first to show the effect of ESD on the endolymphatic space in Ménière’s disease by applying noninvasive intratympanic Gd perfusion through the eustachian tube and 3D-FLAIR MRI. According to the normal values for the endolymphatic space, four of five patients had a ratio of more than 26% in the cochlea, and three of five patients had a ratio of more than 41% in the vestibule before ESD. All the patients had a ratio of more than the normal value in the cochlea and/or the vestibule. However, all the patients had a ratio of less than 26% in the cochlea and 41% in the vestibule 3 months after ESD. The success rate of vertigo control was 60%. The data from the study indicate that ESD can influence the endolymph in the inner ear. ESD may impact on the endolymphatic pressure in the inner ear, changes in which make a functioning sac secrete the highly osmolar proteins, which may cause a fluid shift from the cochlea and the vestibule, and improve the resorption of endolymphatic hydrops, controlling attacks of vertigo. Therefore, ESD may play a role in controlling endolymphatic hydrops in the inner ear with a functioning sac, and may stabilize the symptoms in Ménière’s disease.

There was no significant change in PTA between the values before ESD and 2 years after ESD. No adverse effects of the intratympanic injection of Gd were observed, moreover, there were no serious complications (such as cerebrospinal fluid leaks, facial nerve palsy, meningitis, or wound infections) in any of the patients [10–12].

### Conclusion

Noninvasive evaluation of the effect of ESD in Ménière’s disease using MRI was carried out for the first time. This is a stable and repeatable method to provide a preliminary basis to clinically determine the efficacy of ESD for endolymphatic hydrops in Ménière’s disease.

### Declaration of interest:
The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

---

**Table II.** Ratios of endolymphatic spaces before and 3 months after endolymphatic sac decompression (ESD).

| Patient no. | Age (years) | Sex | Cochlea | Vestibule | Utricle and saccule | Preop | Postop | Preop | Postop | Preop | Postop | Preop | Postop | Preop | Postop | Preop | Postop |
|-------------|-------------|-----|---------|-----------|---------------------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|             |             |     |         |           |                     | 0.27 | 0.23  | 0.18  | 0.21  | 0.33  | 0.24  | 0.35  | 0.16  | 0.24  | 0.21  | 0.16  |
| 1           | 45          | M   | 4.00    | 3.53      | 1.08               | 0.11 | 0.11  | 0.03  | 0.03  | 0.03  | 0.03  | 0.03  | 0.03  | 0.03  | 0.03  | 0.03  |
| 2           | 54          | F   | 3.53    | 3.42      | 1.07               | 0.30 | 0.30  | 0.30  | 0.30  | 0.30  | 0.30  | 0.30  | 0.30  | 0.30  | 0.30  | 0.30  |
| 3           | 52          | F   | 4.00    | 3.42      | 1.64               | 0.81 | 0.81  | 0.81  | 0.81  | 0.81  | 0.81  | 0.81  | 0.81  | 0.81  | 0.81  | 0.81  |
| 4           | 47          | M   | 4.00    | 3.42      | 1.10               | 0.48 | 0.48  | 0.48  | 0.48  | 0.48  | 0.48  | 0.48  | 0.48  | 0.48  | 0.48  | 0.48  |
| 5           | 53          | F   | 3.42    | 3.13      | 1.01               | 0.18 | 0.18  | 0.18  | 0.18  | 0.18  | 0.18  | 0.18  | 0.18  | 0.18  | 0.18  | 0.18  |

Mean ± SD, 50.4 ± 4.0 4.08 ± 2.28 1.18 ± 0.26 0.37 ± 0.11 4.08 ± 2.28 1.18 ± 0.26 0.37 ± 0.11 4.08 ± 2.28 1.18 ± 0.26 0.37 ± 0.11.
References