



Volume-rendered computed tomography images of the surgical field for endolymphatic sac surgery

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Abstract

Purpose Identification of the endolymphatic sac has failed occasionally. Postoperative complications have also rarely been reported. Given a safer and more reliable surgery, preoperative anatomical assessments are valuable, however, the vestibular aqueduct has seldom been seen with multi-planar reconstruction (MPR) computed tomography (CT) images yet. Our study aimed to determine the significance and utility of volume-rendered (VR) CT images of the surgical field for identifying the vestibular aqueduct, compared with MPR CT images.

Subjects and methods 14 patients with Meniere's disease who underwent endolymphatic sac surgery between 2008 and 2011. Location and size of the vestibular aqueduct were assessed using VR and MPR CT images, independently.

Results Accuracy of identifying the location differed significantly between VR and MPR CT images (rate of total correct evaluations: 100% by VR CT images vs 75% by MPR CT images, $p=0.02$). Size was correctly identified in cases with a small endolymphatic sac using VR CT images (rate of total correct evaluations for size of the vestibular aqueduct: 100% by VR CT vs 57% by MPR CT, $p=0.046$). VR CT images also demonstrated clearly the relationship between the endolymphatic sac and high jugular bulb. In two cases, the endolymphatic sac was identified by VR images, not by MPR images.

Conclusion Accurate information about the location and size of vestibular aqueduct can allow sac surgeons to identify a tiny endolymphatic sac more easily and certainly, and also aids surgical trainees to learn sac surgery safely.

Keywords Meniere's disease · Endolymphatic sac · Cone-beam CT · Volume-rendering technique · Three-dimensional image

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Introduction

Endolymphatic sac surgery is well known to be effective and beneficial for patients with Ménière's disease [1–7]; however, identifying the endolymphatic sac in the surgical field is not easy in some cases [8–10]. Ménière's disease is characterized by symptoms of episodic vertigo, fluctuating sensorial hearing loss, tinnitus and aural fullness [11]. The surgery was described by Portmann in 1927 [1], was revived in the 1960s by House [2] and has been extensively used to prevent disabling episodic vertigo resistant to medical treatment [3–7]. The volumes of the endolymphatic sac and vestibular aqueduct are significantly lower in patients with Ménière's disease than in those with endolymphatic hydrops without vertigo [12, 13]. Surgical observations of the endolymphatic sac have clarified that 59% of 101 cases were type III, located far inferior to the posterior semicircular canal and close to the jugular bulb, while 26% were small (< 3 mm in length, < 2 mm in width) [14, 15]. Even

prominent otologic surgeons such as Shambaugh [8] and House [9] described the endolymphatic sac is not identified in 10–14% of patients during surgery. The surgery has been reported to fail to expose the endolymphatic sac in 33% of specimens in the temporal bone collections that underwent the surgery in life [10]. In addition, a high jugular bulb and jugular bulb diverticulum are identified more frequently in these patients [16] and postoperative complications such as facial palsy and posterior semicircular canal dehiscence cannot be ignored [17–19]. Accordingly, better accuracy and safety of this operation are required.

Careful anatomical assessments prior to surgery are indispensable for the accurate, safe and expedient operation. Even using multi-slice CT (MSCT), the rate of non-visualization of the vestibular aqueduct in patients has been reported as 27.8–33.3% under conventional techniques [20, 21]. A recent decrease to 5.6% has been seen with multiplanar reconstruction (MPR) [22, 23]. These reports have indicated that in some cases sac surgeons start to perform surgery without the exact information of location and size of the endolymphatic sac. In addition, knowing the location and size of the endolymphatic sac and its positional relationship to other anatomical structures is considered significant and useful for understanding the difficulty of the operation in each case. Therefore, because volume-rendering (VR) techniques provides realistic images of the surgical field, this study retrospectively investigated imaging accuracy of the size and location of the vestibular aqueduct between MPR and VR CT, and examined the advantages of VR CT images.

Subjects and methods

Subjects

The study included 14 ears in 14 patients (5 men, 9 women; mean age, 51.8 ± 11.7 years) with Ménière's disease who underwent an endolymphatic mastoid shunt operation in our hospital between 2008 and 2011. In the operative findings by the senior author (N.Y.), the size of the endolymphatic sac was large in 1 case, moderate in 6 and small in 7, while the location of the endolymphatic sac was type I in 12 cases, type II in 1 and type III in 1. Location and size of the endolymphatic sac were classified into three grades as described by Arenberg et al. [11], and modified by Yazawa et al. [12]. Briefly, in type I, the endolymphatic sac is located along Donaldson's line. In type III, it is located far inferior to the posterior semicircular canal and close to the jugular bulb. Type II is intermediate between types I and III. A large endolymphatic sac is > 6 mm in length and > 4 mm in width, while moderate is between 3 and 6 mm in length and between 2 and 4 mm in width, and small is < 3 mm in length and < 2 mm in width.

The study protocol was approved by the ethics committee of our hospital and informed consent was obtained from all subjects before surgery.

Analytical procedures

Volume data sets on temporal bones were obtained using a high-resolution cone-beam CT (CBCT) scanner (3D-Accu-ito F17[®]; J Morita Manufacturing Co., Kyoto, Japan) yielding images of voxel dimensions $80 \times 80 \times 80 \mu\text{m}^3$. Scanning parameters were: 90 kV; 8 mA; rotation time, 17.5 s; field-of-view, 60 mm in diameter and 60 mm high; and matrix, 750×750 . VR CT images were then reconstructed using inbuilt workstation software (i-view[®]; J Morita Manufacturing Co.). For determining the location and size of the vestibular aqueduct, the VR CT image was rotated to the surgeon's view (Fig. 1b–d, see Video, Supplemental file), which demonstrates the procedure to interpret VR CT images. Soft-tissue images were then signalized and bone images were disappeared by changing the gray-scale value from > 4000 (automatic estimation) to 3000–4400 using the controller of the gray scale in the software, as previously reported [24]. On the view, images of the upper area were removed using a sequential cutting tool in the software. The facial canal, semicircular canals and finally the vestibular aqueduct were then identified. At this point, the gray scale was optimally conditioned for each image as depicting the inside of semicircular canals realistically. MPR CT images were also reconstructed with the same workstation as previously reported [22]. Location and size of the vestibular aqueduct in VR or MPR CT images were independently defined by two observers each (VR CT images: S.M., J.H.; MPR CT images: M.K., D.T.) using the same grading system as the operative findings.

Statistical analysis

Significant level was set at values of $p < 0.05$ using Fisher's exact probability test which were taken as indicating statistical significance.

Results

Figure 2 shows representative images, demonstrating that VR CT images of the surgical field appeared more realistic than MPR CT images.

In terms of location of the vestibular aqueduct, locations identified from VR CT images matched the operative findings. In contrast, from MPR CT images, of the 12 cases with type I endolymphatic sac by operative findings, eight were identified as showing a type I vestibular aqueduct, three as type II and one as invisible (Table 1).

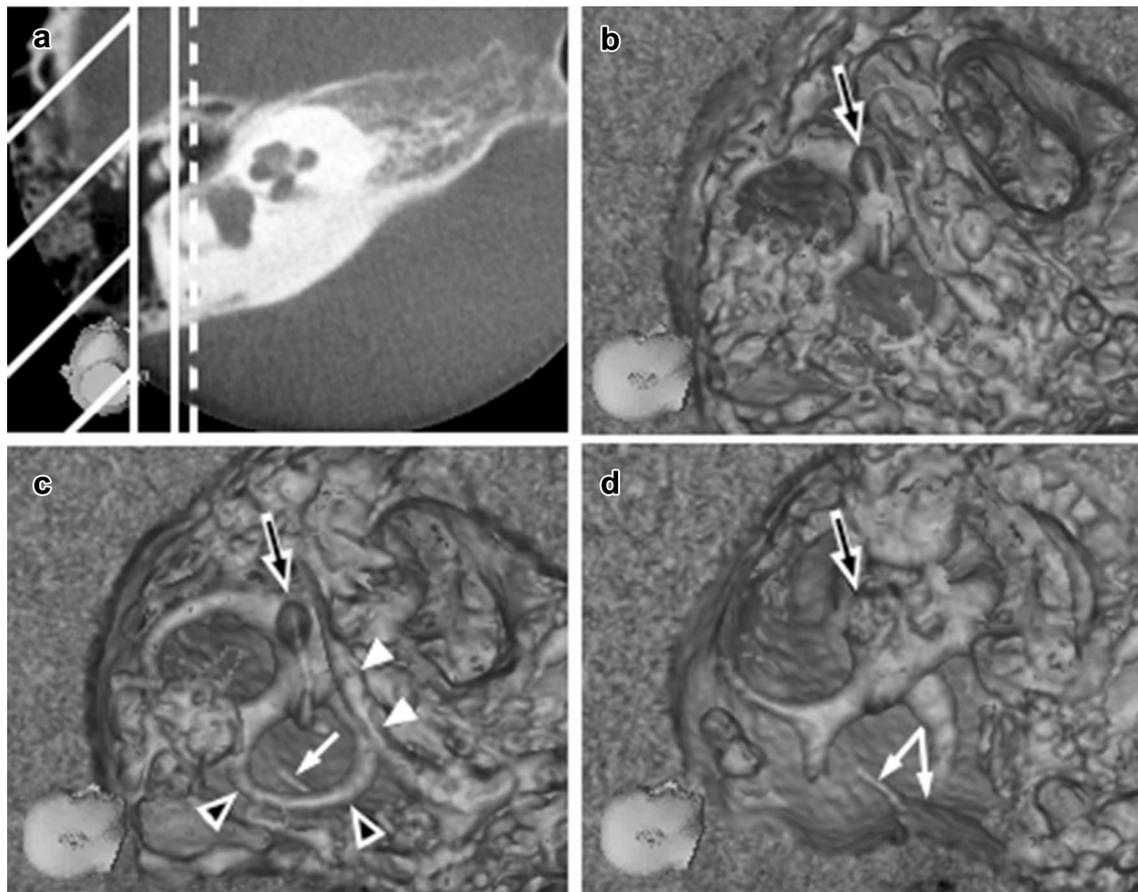


Fig. 1 Reconstruction of VR CT images of surgical field. **a** A VR CT image rotated to the surgeon's view (see mark for the head). **b** Image after the upper area of temporal bone area within oblique lines in **a** was removed using a cutting tool. **c, d** Images after further removal

of the upper areas at the straight and dotted lines shown in **a**. White arrow, vestibular aqueduct; white arrowhead, facial nerve; white and black arrow, lateral semicircular canal; white and black arrowhead, posterior semicircular canal

Of the one case with a type II endolymphatic sac, the vestibular aqueduct was also visualized as type II. Of the one case with a type III endolymphatic sac, the vestibular aqueduct was invisible. As a result, accuracy differed significantly between VR and MPR CT images (rate of total correct evaluations about position of the vestibular aqueduct: 100% by VR CT images vs 75% by MPR CT images, $p = 0.02$).

In terms of size of the vestibular aqueduct, in cases with a large or moderate endolymphatic sac, the depiction by VR CT images was similar to that by MPR CT images. Conversely, in seven cases with a small endolymphatic sac, a small vestibular aqueduct was correctly identified by VR CT images, while MPR CT images identified one as moderate (bigger than actual), four were small and two were invisible (rate of total correct evaluations of size of vestibular aqueduct: 100% by VR CT images vs 57% by MPR CT images, $p = 0.046$).

Discussion

Our study demonstrated realistic images of the surgical field during endolymphatic surgery including the vestibular aqueduct. Making bone apparent invisible in the images is considered to represent greater depth within the structure, therefore the images were thought to display the periosteum of the vestibular aqueduct, which is closely related to the osseous endolymphatic sac and part of the endolymphatic duct [25]. Location of the vestibular aqueduct in all cases, and size of the vestibular aqueduct in all cases with a small endolymphatic sac were identified correctly by VR CT images.

Preoperative assessments about a narrowed or invisible vestibular aqueduct in patients with Ménière's disease have remained problematic since the first report in 1968 [26]. Differences in the proportion of locations and sizes

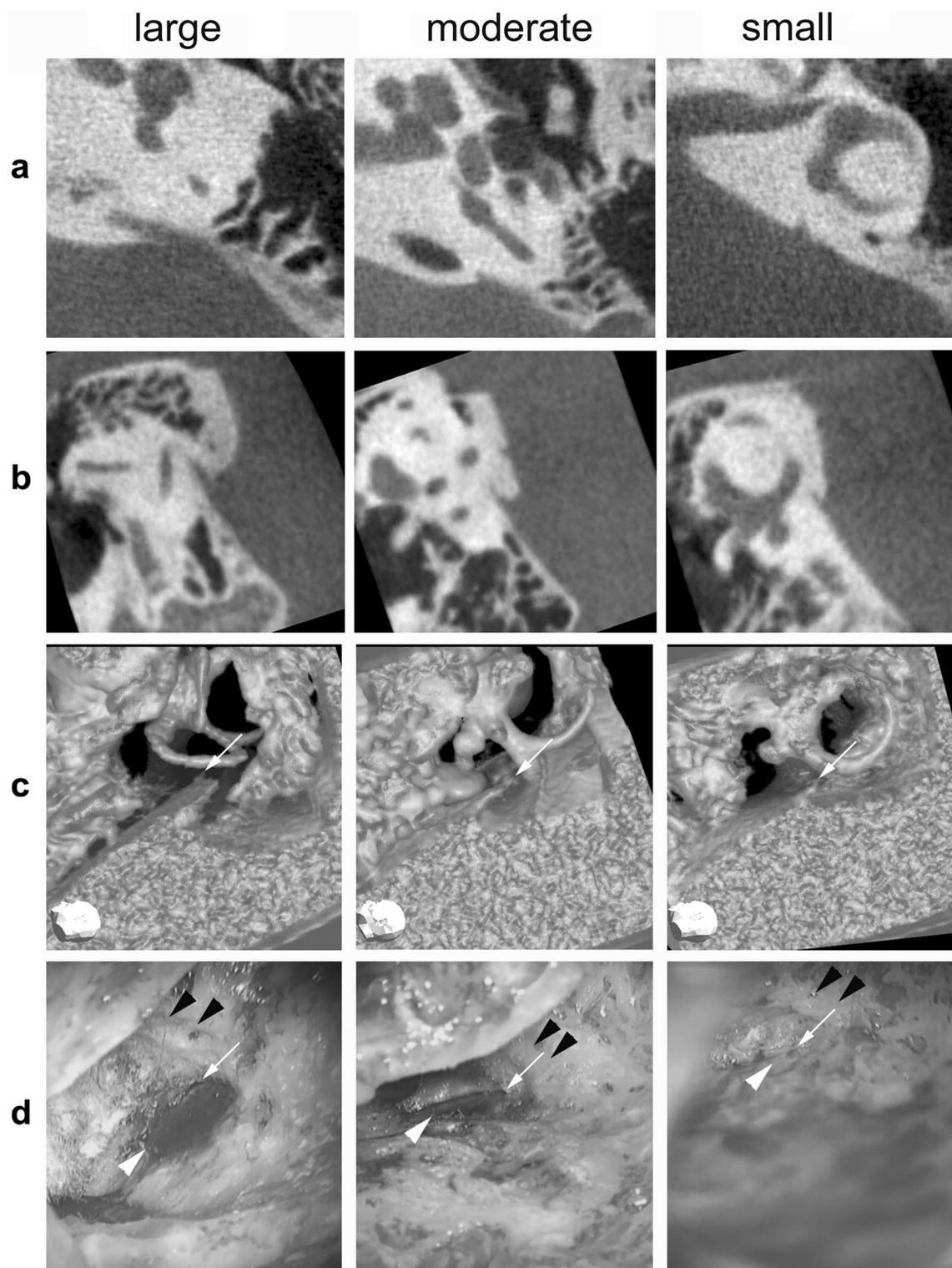


Fig. 2 MPR and VR CT images, and operative findings. **a** Axial MPR images. **b** Sagittal MPR images. **c** Surgeon's view of VR images. **d** Operative findings. A case with a large, type I endolymphatic sac is displayed on the left, a case with a moderate type II endolymphatic

sac in the middle, and a case with a small, type I endolymphatic sac on the right. White arrow, vestibular aqueduct; white arrowhead, posterior edge of endolymphatic sac; black arrowhead, posterior semicircular canal

Table 1 Comparisons of location and size between operative findings of the endolymphatic sac and CT images of the vestibular aqueduct

| Location | MPR | | | | VR | | |
|----------|-----|----|-----|-----------|----|----|-----|
| | I | II | III | Invisible | I | II | III |
| Op | | | | | | | |
| I | 8 | 3 | | 1 | 12 | | |
| II | | 1 | | | | 1 | |
| III | | | | 1 | | | 1 |
| Size | MPR | | | | VR | | |
| | L | M | S | Invisible | L | M | S |
| Op | | | | | | | |
| L | 1 | | | | 1 | | |
| M | 3 | 3 | | | 2 | 4 | |
| S | | 1 | 4 | 2 | | | 7 |

Location: type I, II, and III, and size: L; large, M; moderate, S; small, were defined by previous reports [11, 12]
op indicates operative findings of the endolymphatic sac, *MPR* multi-planar reconstruction, *VR* volume rendering

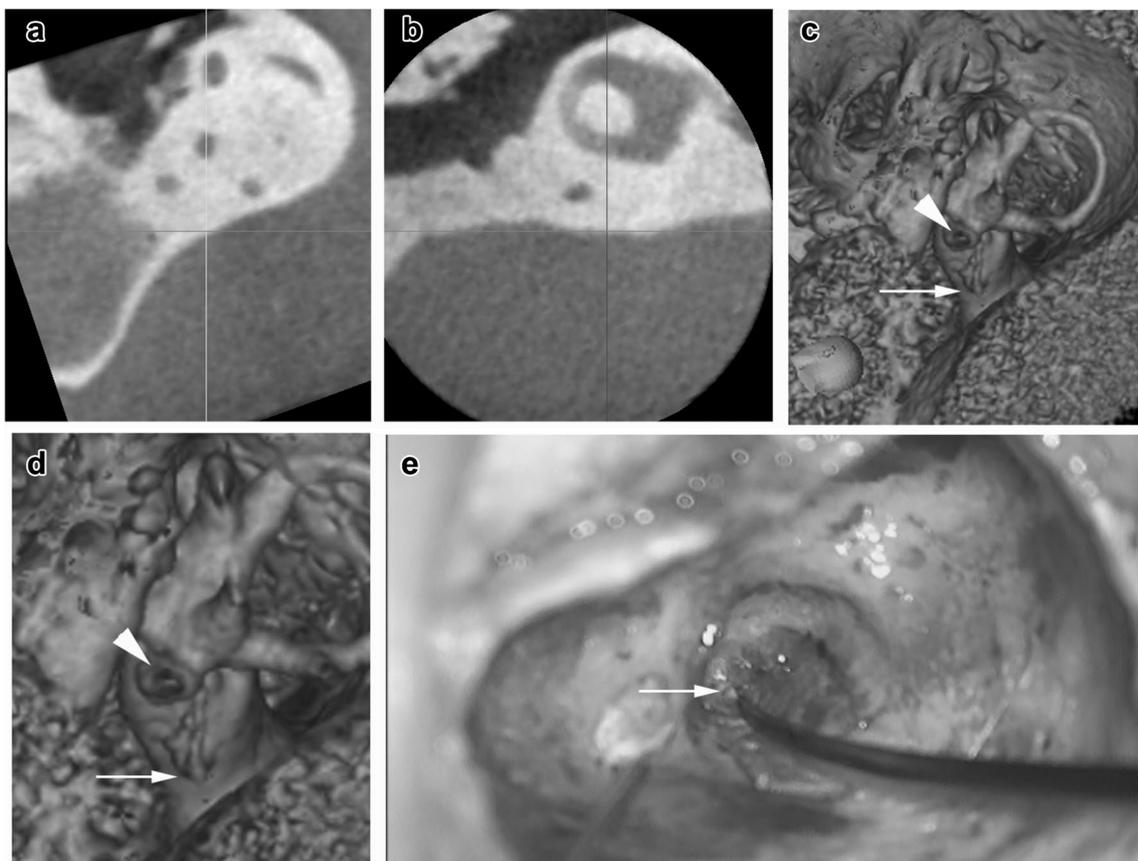


Fig. 3 CT images and operative findings of a primary non-visualization case. VR CT images demonstrate location and size of the vestibular aqueduct even in a case not identifiable on MPR CT images.

a, b Sagittal and coronal CT images, respectively; **c, d** low- and high-magnification VR CT images. Arrow: vestibular aqueduct; arrowhead: lateral semicircular canal

of the vestibular aqueduct between patients and normal populations have been investigated [22, 27, 28]. A type III and/or small vestibular aqueduct reportedly correlates

with poor pneumatization [20, 29], and short distance between the posterior petrous surface and posterior semicircular canal [30]. The rate of non-visualization of the

endolymphatic sac has been reported as 23.3–65% [27] in the era using conventional CT. Even using MSCT, the rate of non-visualization has been reported as 27.8–33.3% with the traditional technique [20, 21], and 5.6% with the MPR technique [22, 23]. Only one report from 1977 appears to have described the relationship between assessments prior to surgery and surgical findings, and that used plastic models [11]. Accordingly, accurate images depicting the size and location of the vestibular aqueduct have remained unavailable.

The VR technique was developed for pre- and post-operative assessments of tympanoplasty to allow ready identification of the tiny middle ear structures, compared with two-dimensional CT images [31–33]. A high-resolution CBCT technology has been introduced in otologic practices to allow accurate imaging of tiny bony structures in the temporal bone under low radiation exposure [34, 35]. This displays more detailed postoperative findings, combined with the VR technique [36].

Our study demonstrated that VR CT images are valuable to understanding the location and size of the vestibular aqueduct, including relative anatomical landmarks readily as preoperative assessments of endolymphatic sac surgery. In a panel discussion about endolymphatic sac surgery by nine sac surgeons in 1987, Gardner [37] mentioned that the position of

the endolymphatic sac is more important to identify during the operation than the size. This study displayed the fidelity of VR CT images for showing both location and size of the vestibular aqueduct. In two cases in which the vestibular aqueduct was not identified by MPR CT images, VR CT images depicted the structure obviously, suggesting that VR images are able to decrease invisible cases (Fig. 3). Since 1 of the 2 cases was type I and the other type III in the location of the vestibular aqueduct, we thought that the variation of the invisible vestibular aqueduct potentially made surgery difficult. Moreover, the relationship between the vestibular aqueduct and high jugular bulb referred to by Hughes [37] as a troublesome anatomical finding during surgery in the panel, was also confirmed as accurate (Fig. 4). We think that VR CT images of the surgical field can contribute more to the operation than MPR images, especially for identifying a small endolymphatic sac during surgery.

This study had some limitations that merit consideration. First, because the 14 ears of the study represents a small number, cases with non-visualization may still be encountered in the future. However, VR CT images showed realistic images of the surgical field in some cases where the vestibular aqueduct was not identified by MPR CT images. Second, a CBCT scanner, not MSCT, was used in this study. Because the resolutions of the two systems differ, this study may have shown

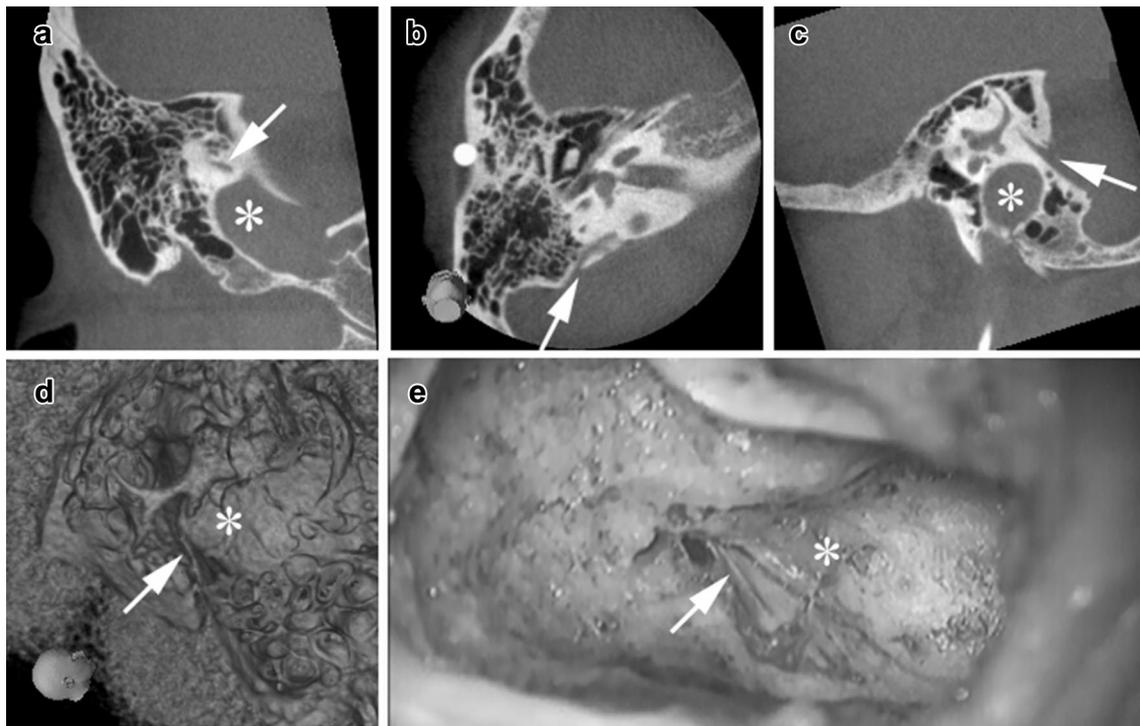


Fig. 4 CT images and operative findings of a case with high jugular bulb. VR CT images accurately demonstrate the relationship between the vestibular aqueduct and the high jugular bulb in the surgeon's

view, which was similar to operative findings. **a–c** Coronal (**a**), axial (**b**) and sagittal (**c**) MPR CT images. **d** VR CT image; **e** operative findings. Arrow: vestibular aqueduct; asterisk: high jugular bulb

more detailed images (standard scanning thickness of MSCT: 0.25–0.6 mm vs voxel sizes of the CBCT: $0.08 \times 0.08 \times 0.08$ mm³). However, because we confirmed that MSCT shows VR CT images of the facial canal, semicircular canals and part of vestibular aqueduct, we consider that the VR technique can be significant and useful for MSCT users.

Conclusion

VR CT images gave more accurate information about the location and size of the vestibular aqueduct, subsequently reducing stress in sac surgeons regarding finding a tiny endolymphatic sac that may be barely identifiable during endolymphatic sac surgery, and to enhance the reliability of surgery. Additionally, we believe that the VR CT images of the vestibular aqueduct including the related anatomical landmarks are useful for surgical trainees to learn the sac surgery safely.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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