Chapter 9

Three-Dimensional Magnetic Resonance Imaging in patients with uni-and bilateral Menière’s disease

Introduction

Since Yamakawa [1] and also Hallpike and Cairns [2] in 1938 discovered hydrops of the endolymphatic system in the temporal bones of patients suffering from Menière’s disease, endolymphatic hydrops has been generally accepted as the basic histopathological substrate of the disease. A functional limitation in the resorptive capacity of the endolymphatic sac is regarded to be a major causative factor in the pathogenesis of Menière’s disease [3], although disturbances in the production of endolymph may also contribute to the development of endolymphatic hydrops [4]. Post-mortem histological investigations revealed a significantly smaller vestibular aqueduct in patients suffering from Menière’s disease [5,6]. Radiological examination of the vestibular aqueduct in Menière’s patients was performed using conventional tomography or computed tomography [7,8]. However, the endolymphatic sac and duct can not be visualized by these imaging techniques. With Magnetic Resonance Imaging (MRI), it has become possible to detect soft tissue lesions of the inner ear. Magnetic Resonance Imaging with gadolineum enhancement has proven to be a very sensitive method to visualize lesions in the cerebellopontine angle and internal auditory canal. Casselman [9] introduced a new imaging technique called Three Dimensional Fourier Transformation Constructive Interference in Steady State (3DFT-CISS) Magnetic Resonance Imaging. This technique provides an excellent visualization and identification of the membranous labyrinth, including the endolymphatic duct and sac in the temporal bone. Using the 3DFT-CISS MRI technique, Albers et al. [10] found a significantly smaller endolymphatic sac and duct in association with a reduced distance between the vertical part of the posterior semicircular canal and the posterior fossa in Menière’s patients, compared to a control group. However, they did not find significant differences between affected and unaffected ears within the Menière group.

In this study 3DFT-CISS MRI was used to quantify the distance between the vertical part of the posterior semicircular canal and the posterior fossa as a measure of the endolymphatic sac and duct in patients with Menière’s disease. Differences in this distance between affected and unaffected ears as well as differences between unilaterally and bilaterally affected patients were studied and compared to a control group. Also possible correlations between the measured distance (between the posterior semicircular canal and the posterior fossa) and the duration and severity of symptoms, age and average hearing loss were investigated.

Patients and methods

Hundred-eleven patients suffering from Menière’s disease were included in the study. The diagnosis of Menière’s disease was defined by the following criteria: cochlear
hearing loss, tinnitus (in the past) and periodic attacks of vertigo (at least two in the past). In order to confirm the diagnosis and to exclude other underlying pathology, the patients were examined according to the Groningen Diagnostic Protocol, including routine ORL-examination and audiological tests (pure-tone and speech audiometry, tympanometry, stapedial reflex measurements, brainstem evoked response audiometry, otoacoustic emission measurements and electrocochleography). Also vestibular tests, perilymphatic pressure measurements, laboratory tests, psychological consultation and Magnetic Resonance Imaging of the temporal bones and cerebellopontine angles were performed. In addition, the duration and severity of the symptoms (hearing loss, tinnitus, vertigo and aural fulness) were scored with a standard questionnaire. Sixty-two ears with normal cochlear and vestibular function were used as control.

Figure 1. 0.7 mm axial 3 DFT-CISS MRI; right ear. The internal meatus (1) with the vestibulocochlear and the facial nerve can be seen, as well as the cochlea (2), the vestibulum (3) and the horizontal semicircular canal (4). The vertical part of the semicircular canal (5) and the posterior fossa (6) are clearly visible.

In this study, all patients were scanned by MRI in a 1.0 or a 1.5 Tesla superconductive active shielded magnet (Expert Magnetom Siemens, Erlangen, Germany, 1.0 T and Vision Magnetom Siemens, Erlangen, Germany, 1.5 T). T1-, T2-, and gadolinium enhanced T1 weighted spin echo imaging were used to exclude retrocochlear pathology and lesions in the cerebellopontine angle. 3DFT-CISS MRI was used to
quantify the distance between the vertical part of the posterior semicircular canal and the posterior fossa (see figures 1 and 2).

Contigious axial 3DFT-CISS MRI slices of 0.7 to 1.0 millimeter (mm) were made by a radiologist according to a strict protocol. Measurements were taken by two professionals, namely a radiologist and an otolaryngologist, using a ruler and the original scan. This was done with a measurement accuracy of about 0.5 mm. This leads to a measurement error in the mean MRI distance of $0.5/\sqrt{n}$, where ‘n’ is the number of ears in the group. In this study the smallest group to be used consisted of 30 ears, leading to an error of 0.22 mm. We therefore state that differences in MRI distance between groups in this study are only reliable when they are over 0.25 mm (regardless of statistical significance).

Figure 2. 0.7 mm axial 3DFT-CISS MRI. detailed image of the right ear at the level of the measured distance between the vertical part of the posterior semicircular canal (1) and the posterior fossa (2).

Results

Of the initially included Menière population (111 patients), 90 patients underwent a 3DFT-CISS MRI scan.

Twenty-one patients (13 unilaterally affected, 8 bilaterally affected) did not undergo an MRI scan because of claustrophobia, or contra-indications for MRI such as a pacemaker, osteosynthesis materials or back problems. To allow a better comparison of data, only patients who underwent MRI scanning of both ears were analyzed. For this
reason another 4 patients were excluded for further analysis. Finally, 86 patients were analyzed in this MRI study. Fifty-six patients suffered from unilateral and 30 patients from bilateral Menière’s disease (116 affected and 56 unaffected ears).

**Menière’s disease versus non-Menière’s disease**

A comparison was made between all ears of Menière patients and the control group. The 62 control ears had a mean MRI distance of 3.8 (±1.7) mm. This distance was significantly larger (p<0.001) than the mean distance of 2.8 (±1.6) mm, found in the 172 ears of the Menière patients. The difference of 1.0 mm was tested for significance with a Wilcoxon Signed Rank-test because the distributions were not normal. If the group of Menière patients was splitted into bilaterally affected and unilaterally affected patients, the differences between each of these separate groups and the control ears remained significant (p=0.03 and p<0.001, respectively). (see table 1 for a complete overview).

**Table 1.** Mean distances between the vertical part of the posterior semicircular canal and the posterior fossa (mm) in affected and unaffected ears of patients with uni- and bilateral Menière’s disease, and non-Menière patients

<table>
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<tr>
<th></th>
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<th>mean MRI distance (mm)</th>
<th>std. deviation (mm)</th>
<th>S.E. mean (mm)</th>
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<td>1.7</td>
<td>0.2</td>
</tr>
<tr>
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<td>1.5</td>
<td>0.3</td>
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<tr>
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<td>3.4</td>
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</table>

Unilateral versus bilateral disease

In order to investigate possible differences between unilaterally and bilaterally affected ears, we compared all 60 bilaterally affected ears to all 112 ears of unilaterally affected patients. The mean distance in the ears of unilaterally affected patients was 2.7 (±1.7) mm and the mean distance in the bilaterally affected patients was 3.2 (±1.3) mm. The difference in distance of 0.5 mm is about 17% of the measured distance and was significant (p=0.004, Wilcoxon Signed Rank-test).
Unilateral disease
Within the group of unilaterally affected Menière patients, affected ears can be compared to unaffected ears. Although the distributions of MRI-distances in affected and unaffected ears in this group of patients are not normal, the distributions of differences between affected and unaffected ears are (approximately) normal, allowing the use of a Paired-Samples T-test. The mean MRI distance found in the unilaterally affected patients was 2.7 (±1.7) mm in unaffected ears, and 2.6 (±1.7) mm in affected ears (table 1). The difference of 0.09 mm was statistically not significant (p=0.44).

Bilateral disease
Next, the MRI distances in ears of bilaterally affected patients were studied. Based on the average hearing loss (averaged over all 6 frequencies of the pure-tone audiogram), the least affected ear of each patient was compared to the most affected ear. The mean distance in the group of least affected ears was 3.3 (±1.4) mm, and the distance in the group of most affected ears was 3.1 (±1.2) mm (table 1). The difference between the least and the most affected ears (0.22 mm) was not statistically significant (Paired-Samples T-Test, p=0.19).

MRI distance, duration of Menière’s disease and age
A possible relationship between the distance of the vertical part of the posterior semicircular canal to the posterior fossa and the duration of the disease was studied.

![Figure 3. Difference in duration between the first and the last affected ear of each bilateral Menière patient (n=30).](image-url)
Figure 4. Scatterplot: MRI distance (mm) versus duration (years) in the affected ears of unilateral Menière patients (n=56).

The same relation was studied for the ears of bilaterally affected patients (figure 5). Only a very poor correlation (-0.044) was found, which was not statistically significant (Two-Tailed Pearson Chi-Square Test, p=0.74). These data indicate that, like in unilaterally affected ears, no relation was found between the MRI distance and the duration of the disease in the bilaterally affected ears.

Figure 5. Scatterplot: MRI distance (mm) versus duration (years) in the ears of bilateral Menière patients (n=60).
We investigated whether the MRI distance is linked to either the age at the moment of measurement or the age at the first appearance of the symptoms. A correlation study showed no significant relation, in both unilaterally affected ears ($r=-0.09$, $p=0.51$ and $r=-0.07$, $p=0.61$, respectively) and bilaterally affected ears ($r=0.04$, $p=0.76$ and $r=0.07$, $p=0.61$, respectively).

MRI distance in relation to severity of Menière’s disease
The MRI distance was divided into 4 different classes (0-1.5 mm, 1.5-2.6 mm, 2.6-3.8 mm and >3.8 mm), based on the interquartile distances of the data. The severity of hearing loss was divided into 4 classes (unchanged, improved, worsened and fluctuating), based on the last three months. The severity of tinnitus and aural pressure were also divided into 4 classes (none, mild, moderate and severe), also over the last three months. Vertigo symptoms were separated into 2 classes (absent or instability, and attacks lasting more than 5 minutes) based on the last three months. Crosstabulation and a Pearson Chi-Square Test showed no relationship between the MRI distance and severity of hearing loss ($p=0.35$), tinnitus ($p=0.45$), vertigo ($p=0.32$) or aural pressure ($p=0.32$).

Discussion
With 3DFT-CISS MRI it was possible to clearly visualize and identify the membraneous labyrinth, including the endolymphatic sac and duct by using the same technique as Casselman in 1993 [9]. It has been shown that the distance between the vertical part of the posterior semicircular canal and the posterior fossa is representative for the size of the endolymphatic sac [10]. Measurements using a ruler and the original scan were more accurate than those using the cursor of the MRI computer. The measurement inaccuracy using a ruler was at most 0.5 mm, leading to a measurement error in the mean distance of at most 0.22 mm. So, regardless of statistical significance, differences in MRI distance between groups in this study were only considered reliable when they were over 0.25 mm.

In this study the MRI distance between the vertical part of the posterior semicircular canal and the posterior fossa was significantly smaller in the ears of Menière patients than in ears of a control group, not suffering from Menière’s disease. This finding corroborates the results of Albers et al. [10] and supports the hypothesis that a smaller MRI distance is a predisposing factor for endolymphatic hydrops. Albers et al. did not find any significant differences in distance between affected (1.9 mm) and unaffected ears (2.3 mm) within their Menière group, but they did not separate the uni- from the bilaterally affected patients. Grouping the ears in our study...
also does not lead to statistically significant differences (p=0.20). However, the differences between uni- and bilaterally affected patients found in our study leads us to the conclusion that separating these two groups is advisable. In bilaterally affected patients the measured MRI distance was significantly larger than in unilaterally affected patients. The difference of 0.5 mm was large enough to be clinically relevant (17%) and reliable with respect to the measurement error. Within the uni- or bilaterally affected groups, no differences were found between affected and unaffected ears, or between most and least affected ears. Differences between uni- and bilateral Menière’s disease have been studied in the past. Kodama et Kitahara [11,12] described the clinical characteristics of Menière’s disease with bilateral fluctuating hearing loss. However, this imaging study using 3DFT-CISS MRI techniques for the first time revealed anatomical differences between uni- and bilateral disease.

The bilaterally affected group was further investigated to exclude a possible difference in duration of disease between the first and the last affected ear of each patient (figure 3). The assumption that bilaterally affected patients used to be unilaterally affected, and that the disease subsequently ‘crossed over’ to the unaffected ear is contradicted by the observation that for most patients the difference in duration is less than one year. This observation, in combination with the fact that there is a significant difference in distance between unilaterally and bilaterally affected patients, strongly suggests that uni- and bilateral affection are two different entities.

Recently, a two-phase model of the mechanism operational in Menière’s disease has been suggested [4]. This model indicates two processes underlying the symptoms: a reduced resorptive capacity of the endolymphatic sac in combination with a periodic overproduction of endolymph by activation of Na/K ATP-ase in the stria vascularis under influence of stress-hormones. The results of this study support the hypothesis that the size of the endolymphatic sac is not the only factor in the pathogenesis of Menière’s disease. In the unilaterally affected patients the limited resorption, linked to reduced dimensions of the endolymphatic space, may play the major role in development of endolymphatic hydrops, whereas in the bilaterally affected patients the overproduction of endolymph is the dominant causative factor.

No relation was found between the MRI distance and the duration of the disease in the unilateral affected ears. Similar to unilaterally affected ears, there was no relation between the MRI distance and the duration of the disease in the bilaterally affected ears. It could be expected that no relationship between MRI distance and duration would be found, because MRI distance probably does not correlate with the actual pathophysiological state of the endolymphatic system. It is, however, conceivable that MRI distance varies (slightly) with age. This could mean that MRI distance is linked to either the age at the moment of measurement or the age at the first appearance of the symptoms. However, a correlation study showed no significant relation, in both unilaterally affected ears and bilaterally affected ears. The fact that the MRI distance
does not have any relation with duration of the disease or age, indicates that the MRI distance is a congenital feature that remains constant through life.

Conclusions

The difference in distance between the vertical part of the posterior semicircular canal and the posterior fossa, measured with 3DFT-CISS MRI, was significantly smaller in the ears of patients with Menière’s disease compared to the control group. The difference in MRI distance between uni- and bilaterally affected patients strongly suggests that uni- and bilateral affection are two different entities. The size of the endolymphatic sac seems to be not the only factor in the pathogenesis of Menière’s disease. The fact that the MRI distance does not have any relationship to duration of the disease and age indicates that this distance is a congenital feature.

References


