A comparative evaluation of the Eustachian tube cartilage between healthy and diseased ears using a 3 Tesla MRI

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Abstract

Purpose: The purpose of this study was to prospectively assess the Eustachian tube (ET) cartilage using 3 Tesla (3T) magnetic resonance imaging (MRI) and compare the results between healthy ears and those with a middle ear disease.

Material and methods: The study included 56 ears with a middle ear disease as the patient group and 100 ears without a middle ear disease as the control group. The patients' age ranged from 18 to 65 years. The axial three-dimensional (3D) multiple echo recombined gradient echo (MERGE) sequence and oblique parasagittal planes were obtained. Visualisation of the ET cartilage was assessed on the MR images using a three-point numerical rating score. In the axial plane, the ET lumen's diameter was measured from the mid-portion of the cartilage.

Results: There was no significant difference between the patient group and the control group according to patients' age and gender, and the medial laminal thickness of the ET cartilage. In the patient group, the diameter of the ET cartilage was significantly smaller than in the control group. The ET lumen diameter was significantly lower according to each of the three scoring systems.

Conclusions: 3T MRI provides an evaluation of the ET cartilage and isthmus level, which are small but important anatomical localisations and surgical landmarks. MR imaging has the potential to provide essential information on ET prior to new surgical treatments, such as balloon dilation for middle ear diseases.

Key words: 3T MRI, Eustachian tube, Eustachian tube cartilage.

Introduction

The pharynx and middle ear are connected by the Eustachian tube (ET), which plays an important role in the ventilation, protection, and cleaning of the middle ear [1]. ET dysfunction is associated with a variety of middle ear diseases. The structure of the ET is very complicated, consisting of various tissues, such as cartilage, muscle, and fat. The ET lumen is encircled by the ET cartilage (ETC), tensor, and levator veli palatini muscle. The ETC is an important contributor of ET function. Therefore, the morphology of the ETC can affect ET function [1-3]. Near the pharyngeal orifice, the ETC is a dome-shaped or hook-shaped structure with short lateral and long medial laminae [1,4]. Elasticity of the ETC is similar to that of the auricle or nose cartilage [1]. The ETC is a major surgical landmark; however, transnasal endoscopy does not provide data about the ETC, submucosal, or deep structures [5-7]; thus, magnetic resonance (MR) is used to visualise the ET in detail, including the surrounding muscles and the Ostmann fat pad [4]. The purpose of this study was to prospectively assess the ETC using 3 Tesla (3T) magnetic resonance imaging (MRI) and compare the results between healthy ears and those with a middle ear disease.
Material and methods

The study was conducted in our university hospital between January 2014 and May 2015, and included 56 ears of volunteers with a middle ear disease as the patient group and 100 ears of volunteers without a disease as the control group. The population consisted of adults between the ages of 18 and 65 years. The patient and control groups were randomly selected. The ETC of the patient and control groups were prospectively visualised using 3T MRI. A middle ear disease diagnosis was made based on the temporal computed tomography (CT) and/or MR image findings. Patients with syndromic and craniofacial anomalies were excluded from the study. The study protocol complied with the ethical guidelines of the Declaration of Helsinki, and approval for the study was obtained from the Ethics Committee. Before performing MR procedures, written informed consent was obtained from all volunteers. During MR scanning, no oral or intravenous contrast agent was used. MR imaging was performed using a 3 Tesla system (General Electric Healthcare, Milwaukee, WI) in a supine position with a conventional quadrature head coil (GEM suite, GE Healthcare, USA). An axial 3D multiple echo recombined gradient echo (MERGE) sequence in the oblique parasagittal plane was obtained unilaterally or bilaterally in each patient to visualise the ETC. Before the MERGE sequence, standard temporal MR sequences were acquired for each patient. The axial 3D MERGE sequence parameters are shown in Table 1. The MR images were assessed by a head and neck radiologist with 10 years’ experience using a workstation (GE Medical Systems). The oblique parasagittal images were obtained perpendicularly to the mid-portion of the ETC long axis on the axial images using median price ratio (MPR). Visualisation of the ETC in the oblique parasagittal plane of the MERGE scans was evaluated according to a three-point numerical rating score (Table 2). Heterogeneity of the MR signal intensity of the ETC was noted as degenerative changes and graded (Table 3). The medial laminar thickness of the ETC was measured in the oblique parasagittal planes. In addition, the diameter of the ET lumen was measured unilaterally or bilaterally at the mid-level of the cartilage in the axial plane. Craniofacial anomalies were excluded. After the specimens were grouped by scoring and grading system, 156 ears were assessed in terms of presence/absence of a middle ear disease according to the temporal MRI and/or prior temporal CT results obtained from the picture archiving and communication system. The patient group with a middle ear disease and the control group without a middle ear disease were compared according to the scoring and grading system, and measurements. ETC scoring was based on the system described by Oshima et al. [4] with a slight modification. We excluded Score 0 (impossible to determine the outline) because we did not have any patient with this score.

Table 1. Axial 3D MERGE sequence parameters

| Parameters                  | Axial 3D MERGE |
|-----------------------------|----------------|
| TR                          | 73.7           |
| TE                          | 12.3           |
| FOV (field of view)         | 22             |
| Matrix size                 | 256 × 256      |
| Slice thickness             | 0.8            |
| Flip angle                  | 5              |
| Band width                  | 50             |

TR – repetition time, TE – echo time, FOV – field of view

Table 2. Numeric rating score of Eustachian tube cartilage

| Score | Visualisation of Eustachian tube cartilage |
|-------|-------------------------------------------|
| 1     | Vague outline                             |
| 2     | Intermediate definition                   |
| 3     | Sharply defined                           |

Table 3. Degeneration grade

| Grade | Cartilage degeneration                   |
|-------|------------------------------------------|
| 0     | No degeneration                          |
| 1     | Punctuate degeneration                   |
| 2     | Linear degeneration                      |

Figure 1. Example of grade 0 degeneration. Eustachian tube cartilage (arrow) is shown in oblique parasagittal image

Figure 2. Example of grade 1 degeneration. Eustachian tube cartilage (arrow) is shown in oblique parasagittal image

Figure 3. Example of grade 2 degeneration. Eustachian tube cartilage (arrow) is shown in oblique parasagittal image
The degenerative changes of ETC were graded according to the meniscal tear grading system [8], excluding Grade 3 (tear extending freely over the meniscal surface) (Figures 1-3).

Student’s t-test, Mann-Whitney U test, and Pearson’s \( \chi^2 \) test were utilised, and the results were analysed using IBM SPSS Statistics vs. 20.0 (SPSS Inc., Chicago, IL, USA), and a p value of < 0.05 was considered to indicate statistically significant differences.

### Results

The ETCs of 156 ears were first assessed using the axial 3D MERGE sequence, and then the temporal MRI and/or prior temporal CT results were obtained from picture archiving and communication system to determine the presence/absence of a middle ear disease. The population consisted of adults between the ages of 18 and 65 years. There was no significant difference between the patient and control groups according to age and gender (Tables 4 and 5). The mean medial laminal thickness of the ETC was 3.42 ± 0.90 mm in the patient group and 3.67 ± 0.73 mm in the control group, with no significant difference between the two groups. In the axial plane at the mid-level of ETC, the median value of the ET lumen diameter was 0.90 mm in the patient group and 1.20 mm in the control group. The ET lumen diameter was significantly smaller in the patient group than in the control group (Table 6). Among the patients with a middle ear disease, the mean age was 43.72 ± 10.54, 44.44 ± 11.06, and 43.90 ± 11.29 years for Grade 0, Grade 1, and Grade 2, respectively. There was no significant difference between degeneration grade and mean age in the patient and control groups (Table 8).

### Discussion

In this study, we used the axial 3D MERGE sequence on 3T MR to visualise ETC. We believed that visualisation of ETC was very important because of the new techniques of ET surgery, such as balloon dilation [9]. ETC imaging will shed light on new surgical techniques related to ET. Assessment of the function and the anatomy of the ET are the main reason for imaging [10,11]. The ET is one of the main structures of the ET. Having knowledge about the ETC and saving changes about it will guide new techniques.

In our study, the oblique parasagittal images were obtained perpendicularly to the mid-portion of the ETC long axis from the axial images using MPR. These images were acquired from the mid-portion to be closer to the isthmus level. Oshima et al. visualised the ETC from the

### Table 4. Mean age in patient and control groups

|        | Patient group | Control group | Statistical analysis |
|--------|---------------|---------------|----------------------|
| Age    | 44.21 ± 9.36  | 44.08 ± 10.96 | t = 0.08, p = 0.93   |

### Table 5. Gender distribution in patient and control groups

| Gender  | Patient group | Control group | Total | Statistical analysis |
|---------|---------------|---------------|-------|----------------------|
| Female  | 30 (34.9%)    | 56 (65.1%)    | 86 (100%) | \( \chi^2 = 0.08 \)  |
| Male    | 26 (37.1%)    | 44 (62.9%)    | 70 (100%) | p = 0.77              |
| Total   | 56 (35.9%)    | 100 (64.1%)   | 156 (100%) |                      |

### Table 6. Mean values of Eustachian tube cartilage medial laminal thickness and median values of Eustachian tube lumen diameter in patient and control groups

|        | Patient group | Control group | Statistical analysis |
|--------|---------------|---------------|----------------------|
| Thickness | 3.42 ± 0.90  | 3.67 ± 0.73  | t = 1.73, p = 0.08   |
| Lumen diameter | 0.90 (0.40-2.60) | 1.20 (0.70-3.10) | Z = 8.10, p = 0.000  |

### Table 7. Comparison of Eustachian tube cartilage score and median value of Eustachian tube lumen diameter in patient and control groups

| Score | Median value of lumen diameter in patient group (min-max) | Median value of lumen diameter in control group (min-max) | Statistical analysis |
|-------|-----------------------------------------------------------|-----------------------------------------------------------|----------------------|
| 1     | 0.85 (0.50-1.20)                                         | 1.15 (0.90-2.30)                                         | Z = 3.12, p = 0.002  |
| 2     | 0.90 (0.40-1.20)                                         | 1.25 (0.90-2.10)                                         | Z = 5.61, p = 0.000  |
| 3     | 0.80 (0.60-2.60)                                         | 1.20 (0.70-3.10)                                         | Z = 3.49, p = 0.000  |

### Table 8. Comparison of Eustachian tube cartilage degeneration and mean age in patient and control groups

| Degeneration grade | Mean age in patient group | Mean age in control group | Statistical analysis |
|-------------------|---------------------------|---------------------------|----------------------|
| 0                 | 42.00 ± 6.92              | 43.72 ± 10.54             | t = 0.36, p = 0.73   |
| 1                 | 43.27 ± 11.67             | 44.44 ± 11.06             | t = 0.35, p = 0.72   |
| 2                 | 44.88 ± 8.33              | 43.90 ± 11.29             | t = 0.44, p = 0.66   |
important because it will guide future studies. Miura et al. is most effective at the level of the ET valve or isthmus. Side effects have been observed [25,26]. Balloon dilation has also been reported to be effective in visualising the meniscus, ligaments, and tendons, as well as cartilage [15]. Oshima et al. visualised ETC with proton and STIR sequences in 1.5T MR [4]. In our study, we used volumetric images in contrast to Oshima et al. [4], and because our aim was only to clearly visualise ET, we chose to use the MERGE sequence. We excluded Score 0 (impossible to determine the outline) from the evaluation because there was no patient with this score. We detected no significant difference between the patient and control groups according to age and gender. In the literature, there are studies investigating the ET length and angle [16-18], ETC amount according to age groups [16], cartilage cell density in relation to age [19], and cartilage elastin amount and volume [20-22]. Most similar to our work related to the measurement of the ET medial laminal thickness is the study undertaken by Amoodi et al. [23]. In their retrospective study, the authors evaluated 25 patients without ET dysfunction, and in addition to the ETC medial laminal thickness, they also measured the ETC medial laminal length, the thickness of the Ostmann fat pad, and the thickness of the tensor veli palatini muscle [23]. The results revealed that the medial laminal thickness did not change with age. In our study, the ET medial laminal thickness and its relationship with middle ear diseases was evaluated; however, no significant difference was found between the patient and control groups in terms of the ET cartilage medial laminal thickness. This result might be related to the age range of the two groups being 18 to 65 years. In the current study, the median value of the ET lumen diameter was calculated in the axial plane at the mid-level of ETC. The ET lumen diameter was significantly smaller in the patient group than in the control group. To the best of our knowledge, the narrowest and most functional part of the tubal lumen is the isthmus. Narrowing of the isthmus is one of the causes of otitis media [24]. It is considered that the ET surgical procedures that are currently performed on ETC will move to the isthmus level in the future as the main part showing ET patency [4]. In recent years, balloon dilation of cartilaginous ET has been shown to have potential clinical benefits in cadaveric studies, especially in cases with chronic otitis media disease, in which no significant side effects have been observed [25,26]. Balloon dilation is most effective at the level of the ET valve or isthmus. One of the reasons for this is that the isthmus cartilage is more rigid [25,27]. Evaluation of the isthmus level is very important because it will guide future studies. Miura et al. evaluated the ET lumen, measuring the volume of the narrowest part [22]. In our study, we measured the ET lumen diameter at the isthmus level, and, as expected, we found it to be significantly smaller in patients with a middle ear disease than in those with healthy ears. However, one of the limitations of the current study was that the area measured was very narrow. In this study, the lumen diameter was also evaluated according to the ETC score. The ET lumen diameter was significantly smaller in the patient group than in the control group for each subgroup of ETC score. While assessing the ETC morphology, we detected heterogeneity in intensity, which we attributed to degenerative changes. However, the lack of a pathological diagnosis for the findings accepted as degeneration can be considered as another limitation of the study. We also graded these degenerative changes. Oshima et al. [4] also detected heterogeneity, but they did not further evaluate it. In contrast, Takasaki et al. associated these structures with partial calcification or fragmentation. Calcification is a common change in the ETC that can affect ET function [28]. In the current study, no significant difference was found between degeneration grade and mean age in the patient and control groups. These degenerative changes might be associated with environmental and genetic factors.

The structure of ET is very complicated, consisting of various tissues, including cartilage, muscle, and fat. The ETC is an important contributor of ET function. Therefore, the morphology of ETC can affect ET function and patency. 3T MRI allows evaluation of ETC and the isthmus level, which are small but important anatomical localisations and surgical landmarks. MR imaging has the potential of providing essential information on ET prior to new surgical treatment of middle ear diseases. As the number of studies on ET cartilage increases, the morphological and functional relationship will be further elucidated. The changes in cartilage resulting in heterogeneity, which we interpreted as the presence of degeneration, should be confirmed by future studies.

**Conclusions**

In this study, we measured the ET lumen diameter at the isthmus level, and, as expected, we found it to be significantly smaller in patients with a middle ear disease than in those with healthy ears. While assessing the ETC, we detected heterogeneity in intensity, which we attributed to degenerative changes.

3T MRI allows evaluation of ETC and the isthmus level, which are small but important anatomical localisations.

**Conflict of interest**

The authors report no conflict of interest.
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References

1. Bluestone CD. Eustachian tube: structure, function, role in otitis media. BC Decker Inc, London 2005.
2. Sando I, Takahashi H, Matsune S, et al. Localization of function in the Eustachian tube: a hypothesis. Annual Otol Rhinol Laryngol 1994; 103: 311-314.
3. Takahashi K, Thompson SW, Sando I. Ossification of Eustachian tube cartilage and Ostromann’s fatty tissue in chronic renal failure. Otolaryngol Head Neck Surgery 2000; 122: 567-571.
4. Oshima T, Kikuchi T, Hori Y, et al. Magnetic resonance imaging of the Eustachian tube cartilage. Acta Otolaryngol 2008; 128: 510-514.
5. Poe DS, Pyykko I, Valtonen H, et al. Analysis of Eustachian tube function by video endoscopy. Am J Otol 2002; 21: 602-607.
6. Poe DS, Abu-Halawa A, Abdel-Razek O. Analysis of the dysfunctional Eustachian tube by video endoscopy. Otol Neurotol 2001; 22: 590-595.
7. Mathew GA, Kuruvilla G, Job A. Dynamic slow motion video endoscopy in Eustachian tube assessment. Am J Otolaryngol 2007; 28: 91-97.
8. Harner CD, Fu FH, Vince KG, et al. Knee Surgery, vol 1. Williams & Wilkins, Philadelphia 1994; p. 325-352.
9. Miller BJ, Elhassan HA. Balloon dilatation of the Eustachian tube: an evidence-based review of case series for those considering its use. Clin Otolaryngol 2013; 38: 525-532.
10. Smith ME, Scoffings DJ, Tykome JR. Imaging of the Eustachian tube and its function: a systematic review. Neuroradiology 2016; 58: 543-556.
11. Smith ME, Tyksome JR. Tests of Eustachian tube function: a review. Clin Otolaryngol 2015; 40: 300-311.
12. Recht MP, Kramer J, Marcelis S, et al. Abnormalities of articular cartilage in the knee: Analysis of available MR techniques. Radiology 1993; 187: 473-478.
13. Disler DG, McCauley TR, Wirth CR, et al. Detection of knee hyaline cartilage defects using fat-suppressed three-dimensional spoiled gradient-echo MR imaging: Comparison with standard MR imaging and correlation with arthroscopy. AJR Am J Roentgenol 1995; 165: 377-382.
14. Disler DG, Peters TL, Muscoreil SJ, et al. Fat-suppressed spoiled GRASS imaging of knee hyaline cartilage: Technique optimization and comparison with conventional MR imaging. AJR Am J Roentgenol 1994; 163: 887-892.
15. Trattnig S, Mlynárik V, Huber M, et al. Magnetic resonance imaging of articular cartilage and evaluation of cartilage disease. Invest Radiol 2000; 35: 595-601.
16. Sadler-Kimes D, Siegel MI, Todhunter JS. Age-related morphologic differences in the components of the Eustachian tube/middle-ear system. Ann Otol Rhinol Laryngol 1989; 98: 854-858.
17. Seibert JW, Danner CJ. Eustachian tube function and the middle ear. Otolaryngol Clin North Am 2006; 39: 1221-1235.
18. Dinc AE, Damar M, Uğur MB, et al. Do the angle and length of the Eustachian tube influence the development of chronic otitis media? Laryngoscope 2015;125: 2187-2192.
19. Yamaguchi N, Sando I, Hashida Y, et al. Histologic study of Eustachian tube cartilage with and without congenital anomalies: a preliminary study. Ann Otol Rhinol Laryngol 1990; 99: 984-987.
20. Matsune S, Sando I, Takahashi H. Comparative study of elastic at the hinge portion of Eustachian tube cartilage in normal and cleft palate individuals. In: Lim DJ, Bluestone CD, Klein JO (eds.). Recent advances in otitis media: proceedings of the Fifth International Symposium. BC Decker, Burlington 1993; 4-6.
21. Aoki H, Sando I, Takahashi H. Anatomic relationships between Ostromann’s fatty tissue and Eustachian tube. Ann Otol Rhinol Laryngol 1994; 103: 211-214.
22. Mura M, Sando I, Hirsch BE, et al. Anomaly of the Eustachian tube and its associated structures in patients with multiple congenital malformation: a histopathological and morphometric study. Int J Pediatr Otorhinolaryngol 2002; 64: 207-216.
23. Amooli H, Bance M, Thehmbao A. Magnetic resonance imaging illustrating change in the ostromann fat pad with age. J Otolaryngol Head Neck Surg 2010; 39: 440-441.
24. Grimmer JF, Poe DS. Update on Eustachian tube dysfunction and the patulous Eustachian tube. Curr Opin Otolaryngol Head Neck Surg 2005; 13: 277-282.
25. Poe DS, Hanna BM. Balloon dilation of the cartilaginous portion of the Eustachian tube: initial safety and feasibility analysis in a cadaver model. Am J Otolaryngol 2011; 32: 113-123.
26. Schloegel L, Gottschall JA. Balloon dilation of the Eustachian tube: safety and utility. Otolaryngol Head Neck Surg 2009; 141: 134.
27. Poe DS, Silvola J, Pyykko I. Balloon dilation of the cartilaginous Eustachian tube. Otolaryngol Head Neck Surg 2011; 144: 563-569.
28. Leeon TS, Leeson CR. Histology. WB Saunders, Philadelphia 1981; 37-164.