Title
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Measurement of Angle and Length of the Eustachian Tube on the CT Using Multiplanar Reconstruction Technique.

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ABSTRACT

Objective: To obtain clues on the anatomical features of the eustachian tube (ET) related to the susceptibility to otitis media with effusion (OME) in children.

Methods: The angle and length of the ET in children with (54 ears, OME children) and without OME (50 ears, normal children), as well as those of normal adults were measured on the CT using the multiplanar reconstruction technique.

Results: The angles of ET in OME children group, normal children group, and normal adult group were $20.4 \pm 3.5$ degree ($^\circ$) and $21.2 \pm 4.8^\circ$, $19.9 \pm 3.4^\circ$ and $20.0 \pm 3.6^\circ$, and $27.3 \pm 2.7^\circ$ and $27.3 \pm 2.8^\circ$ in the right and left sides, respectively. There was no significant difference between the right and left sides in any group ($p=0.541$, $p=0.952$, $p=0.978$). The lengths of the ET in the OME children group, normal children group, and normal adult group were $37.2 \pm 3.0$ mm (mean $\pm$ standard deviation) and $37.6 \pm 3.2$ mm, $37.5 \pm 3.3$ mm and $38.0 \pm 3.2$ mm, and $42.5 \pm 2.8$ mm and $42.9 \pm 2.9$ mm in the right and the left side, respectively. There was no significant difference between in the right and left sides in any groups ($p=0.670$, $p=0.597$, and $p=0.545$). Both the angles and lengths were significantly greater in the normal adult group than in either the OME children group or normal children group (one-way ANOVA and Fisher's
PLSD tests, p<0.05), but there was no significant difference either in the angle or length of the ET between the OME group and normal children group (p>0.05). In the OME and normal children groups, the angle was observed to constantly increase with age, and the values were found to be within the range of the adult size in all the cases older than 2737 days and 2818 days in the OME children group and in normal children group, respectively. In addition to the angle, the lengths were observed to constantly increase with age, but the increase appeared to be greater in younger age until around 1000 to 1500 days (3 to 4 year old) than in the older age, and the values were found to be within the range of the adult size in all the cases older than 2470 days and 2818 days in OME children group and in normal children group, respectively.

**Conclusion:** The angle and length of ET are more horizontal and shorter in infants than in adults. However, there is no statistical difference between the angle and length of ET in infants with and without OME. These results suggest that short and horizontal ET may be one of the predisposing factors related to the high susceptibility of OME in infants and children rather than etiological factors.
INTRODUCTION

It is known that the eustachian tube (ET) plays an important role in maintaining middle ear physiology and functions (1), and that the ET of an infant is short and located horizontally compared with that of an adult (2, 3). These anatomical features are speculated to be related to high susceptibility to otitis media with effusion (OME) in infants and children. However, cases with OME have not been studied in such reports describing the anatomical difference of the ET between infants and adults mentioned above. Furthermore, there are only a few reports precisely measuring the angle and length of the ET against Reid’s standard plane in patients with OME.

Recent remarkable advances in the imaging technique of computed tomography (CT) are realizing clearer and clearer imaging of the anatomical features of the ET on CT. The multiplanar reconstruction (MPR) technique is one of the new imaging techniques for CT, with which any arbitrarily reconstructed image desired can be obtained by changing the angle of the plane by 0.5 degrees and by changing the place of the plane by 1 millimeter. We previously reported the anatomical features of the ET in patients with patulous ET using this technique (4). The aim of this study is to clarify the precise anatomical features of the ET of infants and children with and without OME on CT using this MPR technique.

MATERIAL AND METHODS

All the participants examined in this study were Japanese. The OME children group comprised 54 ears of 27 patients (15 males and 12 females; age range
from 301 days to 3253 days; mean age 1778 days). Their OME was diagnosed by pure-tone hearing test and/or tympanometry, and all of them were treated by tympanostomy tube at least once. The control group (normal children group) comprised 50 ears of 25 patients (9 males and 16 females; age range from 281 days to 2975 days; mean age 1451 days) without middle ear problems. All of them had sensorineural hearing loss without inner or middle ear anomaly. There was no significant difference in the age distribution between these two groups (p=0.8656). The adult control group (normal adult group) comprised 90 ears of 45 patients (24 males and 21 females; age range from 18 years to 82 years) without any ear problems. All patients were informed of the purpose of the study, and their informed consents to participate in this study were obtained before CT examination.

The CT system used was a GE Hispeed Advantage (GE Medical Systems) and imaging parameters were as follows: 1 mm slice thickness; 1:1 pitch; 0.5 mm reformat; field of view 9.6 cm; window width 4000; window level 400. A total of 80-100 axial CT data of all patients covering the entire part of the ET including surrounding tissues were saved on each compact disk recorder. Using a software (Virtual Place Liberty, Office Azemoto Ltd., Japan) on a personal computer, we reconstructed 1-mm-thick gapless three-dimensional CT images from the CT data (Figure 1).

In the present study, we defined each anatomical site of the ET as follows (4): 1. The pharyngeal orifice of the ET lumen: the point nearest the pharynx where a loop-shaped ET lumen appears. 2. The tympanic orifice: the nearest point in the ET before the external auditory canal appears on the cross-sectional image. Length of the ET was defined as the distance from the pharyngeal orifice to the tympanic
orifice. Angle of the ET was defined as the angle of the straight line representing the length of ET against Reid’s standard plane (Figure 1).

To compare the angle and length of the ET between the right and left sides in each group, we statistically evaluated the data with Student’s t-test, and to compare the angle and length of the ET between the three groups, we used one-way ANOVA and Fisher's PLSD tests ($p < 0.05$).

RESULTS

The mean values and standard deviations (SD) of the angles and lengths of the ET on the right and left sides of the three groups are described in the Table, indicating no significant difference between the right and left sides in any of the groups. Both the angles and lengths were significantly greater in normal adult group than in either OME children group or normal children group (one-way ANOVA and Fisher's PLSD tests, $p<0.01$), but there was no significant difference either in the angle or length of the ET between OME group and normal children group ($p>0.01$).

Figure 2 shows the distribution of the angle of the ET as a function of age in OME and normal children groups. In both groups, the angle was observed to constantly increase with age, and the values were found to be within the range of the adult size (mean value±2SD) in all the cases older than 2737 days and 2818 days (7 years old) in OME children group and in normal children group, respectively. In Figure 3, the distribution of the length of the ET of OME and normal children groups is shown as a function of the age. In addition to the angle, the lengths were observed to constantly increase with the age, but the increase appeared to be greater in younger age
until around 1000 to 1500 days (3 to 4 years old) than in the older age, and the values were found to be within the range of the adult size in all the cases older than 2470 days (6 years old) and 2818 days (7 years old) in OME children group and in normal children group, respectively.

DISCUSSION

The present study was the first report measuring the angle the ET using CT images. The value of the angle of the ET in the present study was quite different from that in Proctor’s report (2), in which the angle of the ET to the horizontal plane is 45 degrees in adults, and 10 degrees in infants. Since there has been no anatomical report about the angle of the ET in Japanese infants and children to date, a race difference might be related to this discrepancy. However, since Proctor’s measurements were probably done by the gross anatomical method, the results may lack accuracy. Also in his report, it is not stated whether the angle of ET was measured against the “Reid’s standard plane” or not. We think that it is extremely difficult to accurately measure the angle of the ET against the Reid’s standard plane by the gross anatomical technique. We believe that the values of the angle and length of the ET in the present study are more accurate, because we can precisely measure the angle and the length of the organs on the CT using the MPR technique (4, 5).

As the angle of the ET in OME cases was not stated in previous reports (2, 3), the relation between the angle and the incidence of OME is unclear. In the present study, we demonstrated that the angle and length of the ET were more horizontal and shorter in children than in adults, and there was no significant difference between
the angle and length of the ET in children with OME and those without OME. 
Furthermore, the values of the angle and length of ET in 6 or 7 year-olds or older are 
similar to those in adults, regardless of the presence or absence of OME. These results  
suggest that a short and horizontal ET is not a major etiological factor but one of the  
predisposing factors of OME in infants and children. It is also interesting that the  
length of the ET was found to develop in early childhood, when OME is generally  
prevalent. This may be related to the high susceptibility of OME in early infancy (6).  

O'Donoghue et al. reported that the development of the petrous and  
squamous portion of the temporal bone was at its greatest in the first two years of life  
(7). In the present study, we revealed that the values of the angle and length of ET  
were the same value as an adult at 7 years old. This means that the ET may become  
morphologically closer to that of an adult around 7 years old. Further investigation  
using an adequate amount of cases is necessary to discuses the development of the ET.  

In the present study, we did not measure the length of the ET along the  
course, but as the straight distance from the pharyngeal orifice to the tympanic orifice.  
Although Ishijima et al. (8) reported that the ET curves in adults, Yoshida et al. (4)  
reported that the whole air space in the ET with an adult patient with severe patulous ET  
was depicted as almost a straight line in a plane on the CT. Therefore, it does not  
appear to cause a serious problem to substitute the straight distance from the tympanic  
orifice to the pharyngeal orifice for length of the ET.  

CONCLUSION  
The anatomical features of the ET related to the susceptibility to OME  
in children were measured on the CT using the multiplanar reconstruction technique.
The angle and length of ET are more horizontal and shorter in infants than in adults.

There is no statistical difference between the angle and length of ET in infants with and without OME. These results suggest that short and horizontal ET may be one of the predisposing factors related to the high susceptibility of OME in infants and children rather than etiological factors.

REFERENCE


LEGEND

Figure 1. Reconstructed CT images of the left-side eustachian tube (ET) and its surrounding tissues in a 4-year-old child without otitis media with effusion are demonstrated. “Plane A” is perpendicular to Reid’s standard plane, including the left pharyngeal orifice of ET (a) and tympanic (b) orifices of ET. “Point c” is the reference point on the reflected ET line in the plane parallel to Reid’s standard plane at the level of the left tympanic orifice of ET (b). “☆” and “*” indicate the length and angle of the ET in this case, respectively. “Plane B” is perpendicular to Reid’s standard plane and “plane A”, including the left pharyngeal orifice of ET (a). “Plane C” is horizontal plane at the level of the left tympanic orifice of ET (b) parallel to Reid’s standard plane, and perpendicular to “plane A” and “plane B”, including “Point c”. “Plane D” shows a three-dimensional volume rendering image of the patient.


Figure 2. The results of the angle of the eustachian tube (ET) as a function of age in the OME children group (A) and in normal children group (B) are shown. The area enclosed by the dotted line demonstrates normal range of adults calculated from the mean and 2SD of the normal adult group.

Figure 3. The results of the length of the eustachian tube (ET) as a function of age in OME children group (A) and in normal children group (B) are shown. The area enclosed by the dotted line demonstrates the normal range of adults calculated from the mean and 2SD of the normal adult group.
Figure 2-A

Age (days) vs. Angle of ET (degree) showing the normal adult range.
Figure 2-B

Angle of ET (degree) vs. Age (days)

Normal Adult Range

Legend:
- Normal Adult Range

Data Points

0 500 1000 1500 2000 2500 3000 3500

0 5 10 15 20 25 30 35

Figure 2-B
Figure 3-A
Figure 3-B