Tubal compliance — changes with age and in tubal malfunction

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Abstract

Objective: It is known that eustachian tubal compliance has influence on the tubal function. We applied the direct measurement method to ascertain whether or not aging and tubal diseases are related to the compliance of the cartilaginous part of the eustachian tube. Methods: We developed a method for directly measuring tubal compliance by inserting a balloon catheter, which is inflated with water, into the eustachian tube and comparing the change in balloon pressure with the balloon volume. This method is advantageous in that one can directly measure tubal compliance in the cartilaginous part of the eustachian tube. Using this method we examined tubal compliance in 16 normal young volunteer ears, 21 normal elderly volunteer ears, 11 elderly ears with patulous tube and 12 elderly ears with stenotic tube including otitis media with effusion. Results: In adults the tubal compliance increases in value with age. Tubal compliance of the elderly patulous tube was significantly higher than that of the normal elderly one, on the other hand the compliance of the elderly stenotic tube was significantly lower than that of the normal one. Conclusion: Tubal compliance was considered to be changed with aging and influence of the patulous and stenotic tubes. © 2001 Elsevier Science Ireland Ltd. All rights reserved.

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1. Introduction

Dysfunction of the eustachian tube is regarded as a cause of middle ear diseases. It is especially important that the otitis media with effusion (OME) is a cause of functional obstruction of the eustachian tube (ET) [1–4]. Blueston et al. [5] speculated that an increase of ET compliance contributes to its functional obstruction. As OME in children is thought to be due to high compliance and that their tubal lumens collapse as a result of negative middle ear pressure, and are unable to equilibrate negative middle ear pressure in spite of normal passive opening ability. He referred to this state of the ET as a compliant tube, which constitutes an important cause of OME in children.

In analyzing ET compliance, Takahashi et al. [6] measured the decrease in resistance (pressure/air flow) by increasing the air flow rate through the ET. They reported that tubal compliance in children with OME was greater than that in adults with OME. With the tubal resistance test, the influence of mucosal swelling in the middle ear cavity and pathologic change in the bony part of the ET cannot be excluded although compliance of the cartilaginous part of the ET is known to have a role in the pathogenesis of tubal diseases. We thus reported before [7] that we developed a method for directly measuring tubal compliance by inserting a balloon catheter, which is inflated with water, into the ET and comparing the change in balloon pressure with the balloon volume, and measured tubal compliance in adults with disease free-ears. In the present study we applied the direct measurement method to ascertain whether or not aging and tubal diseases are related to the cartilaginous part of ET.

2. Materials and methods

The subjects were 16 normal young volunteer ears ranging in age from 20 to 39 years old, 21 normal
Normal ears and patulous and stenotic tubes were diagnosed with tubo-tympano-aerodynamic-graphy (TTAG) [8] and sonotubometry [9,10]. Patulous tubes demonstrated a complete patulous pattern using this method. Figs. 1 and 2 show the typical wave patterns of patulous tube in TTAG and sonotubometry. The change of external auditory pressure synchronizes with the change of nasopharyngeal pressure in TTAG. In sonotubometry the external auditory pressure shoots up while the ET is opening with normal swallow. The duration of tubal opening is less than 400 ms. As compared with the duration of tubal opening under normal conditions it extends remarkably in the patulous tube. It is not seen that the external auditory pressure and sound pressure ascend in TTAG and sonotubometry in the stenotic tube. Furthermore, after myringotomy, the inflation–deflation test was performed on the cases with OME and they presented obstructive patterns.

Fig. 3 illustrates the measuring system. The balloon, made of rubber, is 0.02 mm thick and 7 mm in diameter. We use a double lumen catheter with a low compliance and connect one end of this catheter to an infusion pump (Nipro SP-60) as well as to a pressure transducer (Nihon Kohden TP-400), with the apparatus having an air valve at the other end. Before examining tubal compliance the system is completely filled with water. Air bubbles are removed by opening the air valve since bubbles in the system will affect the pressure change when water is injected into the measuring system. The balloon is inserted into the ET using an endoscope and a guide catheter with the tip being placed 1 cm deep from the pharyngeal orifice. It is then inflated with water using the infusion pump. The rate of water flow is 20 ml/h, and measurements are taken in the recumbent position.

Fig. 4 is a representative case of tubal compliance measurement. Point 0 indicates the start of water inflation into the balloon and periods 0 and A represent the time it took for the balloon to tightly adhere to the ET lumen. Pressure change and volume of inflated water were measured just after the balloon tightly adhered to
Tubal compliance = \( \frac{\Delta V}{\Delta P} = \frac{F \times a}{b} \) (ml/cm H₂O)

where \( b \) is the pressure change in cm H₂O.

Increased volume of the balloon, \( \Delta V \), was calculated as:

\[ \Delta V (\text{ml}) = \frac{F (\text{ml/h})}{60 \times 60} \times a (\text{s}) \]

where \( F \) (20 ml/h) is the flow of the pump in ml/h, and \( a \) (5 s) is the rise of inflation in s. Tubal compliance was the ratio of \( \Delta V \) and \( \Delta P \), where \( \Delta P \) represents the pressure change in the balloon.

3. Results

3.1. Tubal compliance in normal young adults and elderly

Fig. 5 presents the results of 16 normal adult tubal compliances. The mean value of the tubal compliance of young adults, ranging in age from 20 to 39 years old, was \( 8.23 \times 10^{-4} \) ml/cm H₂O, whereas that of the elderly, ranging in age from 60 to 79 years old, was \( 12.36 \times 10^{-4} \) ml/cm H₂O. The differences between the tubal compliance of young and elderly adults are statistically significant (\( P < 0.05; \ t\)-test).

3.2. Tubal compliance in elderly with patulous tube and stenotic tube

We examined the influence of tubal disease in elderly patients with a patulous tube and a stenotic tube. Fig. 6 compares the results of the compliance of 21 normals, 11 patulous tubes and 12 stenotic tubes in the elderly. The mean values of the tubal compliance were \( 12.36 \times 10^{-4} \), \( 16.36 \times 10^{-4} \) and \( 8.17 \times 10^{-4} \) ml/cm H₂O, respectively, the difference being close to significance (\( P < 0.05; \ t\)-test).

4. Discussion

ET compliance consists of the various tissues of cartilage, mucosa, muscles and connective tissues surrounding the ET. Tomoda et al. [11], reporting on the aging change of tubal muscles and submucosal connective tissues, noted that the diameter of the tensor and levator muscles decreased with advancing age. In submucosal connective tissues large elastic fibers and collagenous fibers increased in number and fine elastic fibers decreased with aging in adults [12]. They considered that the aging change of muscles and connective tissues affected tubal function.

As is well known cartilage is classified into hyaline, elastic and fibro cartilage, with eustachian tubal carti-
lage being an elastic cartilage. It is conceivable that the elasticity of elastic cartilage influences the tubal compliance. As the densities of cartilage cells in an infant's ET are higher than those in adults, ET compliance in infants is higher and the elasticity is lower than adults. What is more, the cell density in cleft palate cases is higher than in normal cases of similar age. From the above fact Yamaguchi et al. [13] indicated that the ET cartilage is immature in infants, which may result in its being hypercompliant or 'flopplpy', and that OME is frequent in infants and patients with cleft palate. An previous reports we determined that the aging change of tissues that constitute the ET is directly responsible for the aging change of the tubal compliance, and that tubal compliance affects tubal diseases and middle ear diseases. For our examination of the aging change of tubal compliance and the cause–effect relationship between tubal compliance and tubal disease, we measured their compliance using the direct measuring method [7]. Since our examination revealed that tubal compliance increases in value with age in adults with a disease-free ear, we believe that the aging change of tubal tissue influences tubal compliance. Patulous tube patients are generally known to be more frequently seen in the elderly than in young adults. Moreover, the tubal compliance of the elderly patulous tube was significantly higher than that of the normal elderly tube in this study. These results have lead us to confirm that the increase in tubal compliance caused by aging constitutes one pathogenesis of the patulous tube.

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References