Conformity between sonotubometry and tympanometry in examining eustachian tube ventilatory function in adults with normal hearing

To cite this article: J Bashiruddin et al 2018 J. Phys.: Conf. Ser. 1073 022023

View the article online for updates and enhancements.
Conformity between sonotubometry and tympanometry in examining eustachian tube ventilatory function in adults with normal hearing

J Bashiruddin1*, R Martiastini A1, W Alviandi1 and J Prihartono2

1Department of Otolaryngology, Faculty of Medicine, Universitas Indonesia, Jakarta, 10430, Indonesia
2Department of Community Medicine, Faculty of Medicine, Universitas Indonesia, Jakarta, 10430, Indonesia
*E-mail: jenny.bashiruddin@yahoo.com

Abstract. Sonotubometry is a noninvasive, easy-to-perform test for examining the ventilatory function of the Eustachian tube, and it can be performed in subjects with intact or perforated tympanic membranes. To examine the ventilatory function of the Eustachian tube, three components, namely acoustic intensity (amplitude), frequency, and the duration of Eustachian tube opening, are assessed as parameters. On the contrary, tympanometry measures the ventilatory function of the Eustachian tube on the basis of changes in middle ear pressure. This study examined the conformity between sonotubometry and tympanometry as tools for evaluating Eustachian tube ventilatory function in adults with normal hearing. In this cross-sectional study of 40 subjects with normal hearing, sonotubometry was performed via 10 s of wet swallowing, and tympanometry was performed following the Toynbee or Valsalva maneuver. The data were analyzed using the kappa test and McNemar’s analysis. Significant differences and weak conformity were noted for the measurements of Eustachian tube ventilatory function between sonotubometry and tympanometry. The results indicated that sonotubometry can be an option for evaluating Eustachian tube ventilatory function.

1. Introduction
The main function of the Eustachian tube (ET) is middle ear ventilation. ET regulates middle ear pressure by balancing air pressure inside the middle ear with atmospheric pressure [1-3]. Disturbance or failure of the ET opening mechanism can result in impaired hearing, tympanic membrane retraction, atelectatic ear, otitis media with effusion (OME), adhesive otitis, and cholesteatoma. Several etiologies of ET dysfunction are including upper respiratory infection, chronic sinusitis, allergic rhinitis, adenoid hypertrophy, cigarette smoke exposure, stomach acid exposure from reflux, congenital disease of the palatum, radiation exposure, and disturbance of the mastoid cell air system [4-7].

Evaluating ET ventilatory function is important for diagnosing ET dysfunction and OME as well as for determining the indication for ventilation tube insertion and clarifying the middle ear surgery plan [1, 8]. Tymprometry has many uses, such as evaluating the middle ear condition, ET ventilatory function, and the acoustic reflex. Tympanometry has 94% sensitivity and 95% specificity in diagnosing middle ear effusion [9, 10]. Meanwhile, sonotubometry has several advantages in the assessment of ET ventilatory function, including its noninvasive nature, simple procedure, the lack of a need for extreme air pressure, its applicability to children and adults, and the ability to be performed in patients with either intact or perforated tympanic membranes. Sonotubometry has potential as a diagnostic tool for conditions associated with ET dysfunctions, such as OME and palatal cleft [9, 11-13].
Using sonotubometry in healthy subject, Virtanen [8] has reported an ET opening rate of 90%, whereas Holmoquist has reported a rate of 66%. Similarly, Okubo has recorded an ET opening rate of 89% in adults and 65% in children, whereas Palva has reported a rate of 80%. Sonotubometry techniques have been improved over the last two decades. As demonstrated by previous studies, sonotubometry has similar utility as other ET ventilatory function tests [9, 11, 12].

In a study conducted by Van der Avoort and colleagues, two sonotubometry examination sessions comprising 10 swallowing movements over 10 s were conducted in 36 healthy adults [11]. Their results illustrated that at least one ET opening occurred in 33 subjects (91.6%) in the two sessions. Using Spearman’s correlation analysis, they observed a high degree of correlation between the first and second examinations (r=0.91), indicating the good reliability of sonotubometry in examining ET ventilatory function in healthy adults [11].

Additionally, Jonathan and colleagues compared tympanometry and sonotubometry in examining ET ventilatory function in 50 adults [14]. In this study, subjects were instructed to perform wet swallowing movements, saliva swallowing, yawning, or a combination of these three movements to provoke ET opening. Their results revealed a significant correlation between the two methods using chi-squared analysis (p<0.001). Based on the findings, they have stated that sonotubometry has potential utility for evaluating ET ventilatory function.

Given the importance of ET ventilatory function, a standard method for examining this function using a physiological mechanism that is noninvasive, applicable to both intact and perforated tympanic membranes, and easy to perform in both adults and children is needed. While tympanometry has been regularly performed for this purpose since 1970, the suitability of sonotubometry for this evaluation has not been clarified to date. Thus, in this study, we examined the conformity between sonotubometry and tympanometry in the measurement of ET ventilatory function in adults with normal hearing.

2. Materials and Methods

The study protocol was approved by the Health Research Ethics Committee, Faculty of Medicine Universitas Indonesia-Cipto Mangunkusumo Hospital. The study subjects were Otorhinolaryngology Department specialist students and Cipto Mangunkusumo Hospital’s otorhinolaryngology clinic employees ranging in age from 19 to 50 years. In total, 40 subjects (30 females and 10 males) with normal hearing who fulfilled the sonotubometry examination criteria were enrolled. The study was performed at the otorhinolaryngology clinic, Cipto Mangunkusumo Hospital, between December 2015 and January 2016. Data were collected using a questionnaire, physical examination, and hearing examination with a pure tone audiometer. The middle ear condition and ET function were also examined using a tympanometer. All subjects underwent nasendoscopy to ensure the absence of infection or obstruction in the nose. Sonotubometry was performed using two 10-s sessions of wet swallowing movements.

The sonotubometry tool used was manually created using guidance from the literature. This tool was validated by Hisyam [13] in 10 healthy subjects using a wet swallowing maneuver for 10 s, and this test was repeated three times in each ear. Sonotubometry instrument settings included 8000 Hz pure sound frequency stimulus and 75 dB intensity. The coefficients of variation for ET opening, amplitude changes, and ET opening duration were 0.10, 0.09, and 0.08, respectively.

The results were documented and processed using SPSS for Windows 20.0. For numeric scale data, the Kolmogorov–Smirnov test was used to assess normality. Data that were normally distributed (p>0.05) were presented as the mean and standard deviation, whereas non-normally distributed data (p<0.05) were presented as the median, mean, minimum, and maximum. Scales with ordinal or nominal data were presented as frequency distributions. McNemar’s test was performed to test the conformity between sonotubometry and tympanometry in evaluating ET ventilatory function. A matching test using kappa statistics was also performed to examine conformity between the tests.

3. Results

ET ventilatory function was examined using a tympanometer via the Toynbee maneuver for 66 ears (82.5%) and the Valsalva maneuver for 65 ears (81.25%) as shown in Table 1. Results were obtained using a sonotubometer for 65 ears and a tympanometer for 55 ears.
Table 1. Subject characteristics

| Characteristic     | Total | Percentage |
|-------------------|-------|------------|
| Sex               |       |            |
| Male              | 10    | 25%        |
| Female            | 30    | 75%        |
| Risk factor       |       |            |
| Without           | 17    | 42.5%      |
| With              | 23    | 57.5%      |
| Δ (P1-P2)         |       |            |
| Normal            | 66    | 82.5%      |
| Abnormal          | 14    | 17.5%      |
| Δ (P1-P3)         |       |            |
| Normal            | 65    | 81.25%     |
| Abnormal          | 15    | 18.75%     |
| ETF tympanometry  |       |            |
| Normal            | 55    | 68.75%     |
| Abnormal          | 25    | 31.25%     |
| ETF Sonotubometry |       |            |
| Normal            | 65    | 81.25%     |
| Abnormal          | 15    | 18.75%     |

Table 2 shows the association between ET ventilatory function scores obtained using tympanometry and sonotubometry in 80 ears. The results revealed low conformity between sonotubometry and tympanometry in examining ET ventilatory function.

Table 2. Measurement of ET ventilatory function using tympanometry and sonotubometry (n=80)

| ETF tympanometry | ETF Sonotubometry | Total |
|------------------|-------------------|-------|
| Normal           | 49                | 6     | 55    |
| Abnormal         | 16                | 9     | 25    |
| Total            | 65                | 15    | 80    |

McNemar’s test, p=0.05; Kappa R=0.282; p=0.008

Table 3 presents the association between ET ventilatory function scores for tympanometry performed using the Toynbee maneuver and sonotubometry. The results revealed no proportional differences or conformity between the tests.

Table 3. Measurement of ET ventilatory function using tympanometry and sonotubometry performed after the Toynbee maneuver (n=80)

| Toynbee Maneuver | Sonotubometry | Total |
|------------------|---------------|-------|
| Normal           | 56            | 10    | 66    |
| Abnormal         | 9             | 5     | 14    |
| Total            | 65            | 15    | 80    |

McNemar’s test, p = 1.00; Kappa R = 0.2; p = 0.07

Table 4 shows the association between ET ventilatory function examined using a tympanometer after the Valsalva maneuver and sonotubometry. The data revealed no proportional differences between the tests. Kappa statistics (conformity) additionally produced an R of 0.097 (p=0.383), further demonstrating the absence of concordance between the results for the two tests.
Table 4. Measurement of ET ventilatory function using tympanometry and sonotubometry performed after the Valsalva maneuver (n=80)

| Valsalva Maneuver | Sonotubometry | Total |
|-------------------|---------------|-------|
|                   | Normal | Abnormal |       |
| Normal            | 54     | 11       | 65    |
| Abnormal          | 11     | 4        | 15    |
| Total             | 65     | 15       | 80    |

McNemar’s test, p=1.00; Kappa R=0.097; p=0.383

4. Discussion
The current study obtained different results from those obtained in an analysis conducted by Jonathan and colleagues [14], who also compared tympanometry and sonotubometry for evaluating ET ventilatory function in healthy subjects. Of note, Jonathan and colleagues have reported a strong correlation between tympanometry and sonotubometry tests in this assessment. Although the subjects in both studies showed a mean age of 29 years, a number of methodological differences exist between the two studies. Specifically, the two studies used different tympanometry and sonotubometry instrument settings in addition to different techniques, which could explain the contradictory findings.

Virtanen and Martilla, as quoted by Van Neste Kenny [15], have reported that some subjects exhibited normal ET ventilatory function despite extremely negative middle ear pressure. Moreover, Bluestone [3] has noted healthy ears could fail to balance negative middle ear pressure in adults with intact tympanic membranes and no otology disorder. Van der Avoort and colleagues [11] have observed normal ET ventilatory function in subjects with abnormal middle ear pressure, while Iwano and colleagues [16] have observed differences between the sonotubometry records and equalization results. These different findings might be attributable to differences in the ET opening duration or middle ear health. In particular, a longer ET opening duration is associated with better sonotubometry and tympanometry scores than a shorter duration. Previous results have indicated that a shorter ET opening duration was not sufficient to allow imbalances between middle ear and atmospheric pressures to be normalized [3, 15, 16].

Reportedly, the Toynbee maneuver can sometimes lead to false-negative results in the assessments of ET ventilatory function using a tympanometer. Thomsen, as quoted by Bluestone [17], has stated that the Toynbee maneuver can lead to changes in ET function scores, but these changes do not always indicate poor ventilatory function. Low ET lumen resistance results in negative middle ear pressure, but pressure can normalize after the Toynbee maneuver, which may often be interpreted as a negative Toynbee maneuver result. Conversely, positive pressure after the Toynbee maneuver could be caused by the formation of biphasic pressure after the maneuver, which may also be interpreted as a false-negative result. Meanwhile, an abnormal tympanometry score based on a negative Valsalva test could be caused by the absence of positive pressure in the nasopharyngeal region because of subjects’ failure to correctly perform the maneuver. However, this possibility was minimized in our study due to the inclusion of otorhinolaryngology specialist program students, who were considered to have sufficient knowledge of performing the maneuver [17].

A lack of change of middle ear pressure after the Toynbee maneuver is not an indicator of abnormal ET function. In some subjects with intact tympanic membranes but low ET lumen barrier function, air more easily moves from the middle ear to the nasopharyngeal region. In such cases, although negative pressure is observed following the Toynbee maneuver, it rapidly returns to normal or becomes positive. Bluestone [17] has reported that ET ventilatory function could remain normal even when negative pressure was observed during middle ear testing. This occurs because when negative pressure gradually develops, the ET lumen becomes stiffer, but it retains the ability to actively open. Swart, as quoted by Bluestone [17], has stated that the Valsalva maneuver that showed change to positive pressure indicated ET lumen is patent, or can open by that maneuver but less information on how real ET ventilation functional is.

Negative pressure in the middle ear can gradually change in the early stages of ET dysfunction, leading to the measurements of normal pressure in tympanometry. For example, negative pressure can gradually develop as a primary consequence in the early stage of upper respiratory tract infection or
secondarily due to stomach acid reflux that reaches the nasopharyngeal region and enters the middle ear through an opened ET lumen. Middle ear mucosal inflammation due to reflux subsequently causes ET dysfunction by obstructing the ET osseous lumen. Doyle, as quoted by Bluestone, has stated that abnormal middle ear pressure could arise if there was an approximately 54-mmHg difference in the middle ear pressure and middle ear mucosal microcirculation [3,5,18].

The ET tympanometry score is considered normal if the Valsalva and Toynbee maneuvers show positive scores. Elner and colleagues, as quoted by Bluestone [17], have stated that positive results in the Valsalva test are not reliable as an indicator of ET ventilatory function. Positive results after the Valsalva maneuver could be false positives because the middle ear pressure can become positive after the maneuver if the ET lumen is patent and has low resistance, thus permitting it to easily open in response to positive pressure.

Meanwhile, findings of abnormal ET ventilatory function based on sonotubometry can be interpreted as false negatives. Van der Avoort, as quoted by Van Neste Kenny [15], has noted that a high frequency of pure sound stimulation after passing through the ET and middle ear could be reflected back to the tympanic membrane by a microphone close to the ear canal. The combination of reflection and coming waves from the middle ear form a standing wave pattern that does not produce sound, resulting in a false-negative interpretation of the record. Studies have reported that standing wave patterns with wavelengths of 5500–7500 Hz could decrease the false-negative interpretation caused by standing wave pattern formation [9, 11, 15].

All participants who exhibited abnormal ET function using either test presented with risk factors for allergic rhinitis. Because of the high variability of both sonotubometry and tympanometry in assessing ET ventilatory function, no standards have been established regarding abnormal results. Therefore, the subjects were determined to have abnormal ET ventilatory function on the basis of cutoff values selected for this research even though some participants did not exhibit symptoms or dysfunction on hearing tests or nasendoscopy.

5. Conclusion
Sonotubometry with 8000-Hz pure sound frequency stimulus and 75-dB sound intensity can be used as an alternative to tympanometry for assessing ET ventilatory function.

References
[1] Van der Avoort S J C 2005 Sonotubometry: Measurement of Eustachian tube function (Nijmegen: University Nijmegen)
[2] Bluestones C D 2005 Anatomy Eustachian tube Eustachian tube: structure, function, role in otitis media ed MB Bluestones (New York: BC Decker) p 25–56
[3] Bluestones C D 2005 Physiology of Eustachian tube Eustachian tube: structure, function and role in otitis media ed MB Bluestones (New York: BC Decker) p 51–65
[4] Siebert J W and Danner C J 2006 Eusthian tube function and the middle ear Otolaryngol. Clin. N. Am. 39 1221–35.
[5] Bluestones C D 2005 Pathophysiology of Eustachian tube Eustachian tube: structure, function and role in otitis media ed MB Bluestones (New York: BC Decker) p 67–91
[6] Bunne M, Falk B, Magnuson B and Hellstrom S 2000 Variability Of Eustachian tube function: Comparison of ears with retraction disease and normal middle ears Laryngoscope. 110 1389–95
[7] Schroder S, Lehmann M, Sauzet O, Ebmeyer J and Sudhoff H 2014 A Novel diagnostic tool for chronic obstructive Eustachian tube disfunction-The Eustachian tube score Laryngoscope. 125 1–6
[8] Virtanen H 1977 Acoustical measurement of auditory tubal opening (Helsinki: University of Helsinki)
[9] Van der Avoort S J C, Heerbeek N, Zielhuis G A and Cremer C W. Sonotubometry: Eustachian tube ventilaroty function test: A state-of-the-art review Otol. Neurotol. 26 538–43
[10] Smith M E and Tysome J R 2014 Test of Eustachian tube : A Review (Cambridge: Cambridge University)
[11] Van der Avoort S J C, Van Heerbeek N, Zielhuis G A and Cremers C W 2006 Validation of sonotubometry in health adults. *J. Laryngol. Otol.* 120 853–6

[12] Borangiu A, Popescu A, PurcareaV L and Davilla C 2014 Sonotubometry, a useful tool for the evaluation of the Eustachian tube ventilatory function. *J. Med. Life.* 7 604–10.

[13] Hisyam A and Widiarni D W A 2014 Perbandingan fungsi ventilasi tuba Eustachius pada subjek celah palatu dengan subjek sehat menggunakan sonotubometri (Jakarta: University of Indonesia)

[14] Jonathan D A, Chalmers P and Wong K 1986 Comparison of sonotubometry with tympanometry to assess Eustachian tube function in adult. *Br. J. Audiol.* 20 231–5

[15] Van Neste Kenny S P 2007 Clinical application of the interacoustics reflwin system wideband energy machine in the assessment of the Eustachian tube (Vancouver: The University of British Columbia)

[16] Iwano T, Ushiro Koichi, Yukawa N, Doi T, Kinoshita T, Hamada E, and Kumazawa T 1993 Active opening function of the human Eustachian tube: comparison between sonotubometry and pressure equilibration test. *Acta Otolaryngol.* 500 62–5

[17] Bluestone C D 2005 Diagnosis and tests of function of Eustachian tube *Eustachian tube: structure, function, and role in otitis media* ed MB Bluestone (New York: BC Decker)

[18] Bluestones C D 2005 Pathogenesis of Eustachian tube *Eustachian tube: structure, function and role in otitis media* ed MB Bluestones (New York: BC Daker) p 93–105.