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REVIEW ARTICLE

Multi-Frequency Tympanometry: Clinical Applications for the Assessment of the Middle Ear Status

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Abstract The aim of the present paper was to review the current knowledge on multi-frequency tympanometry and explore its role as a diagnostic tool in various otologic conditions. Literature review in Medline and other database sources. Prospective controlled, prospective comparative, and prospective cohort studies, animal studies, retrospective studies and systematic reviews. Multi-frequency tympanometry provides more accurate and detailed information about the middle ear dynamics than standard tympanometry. Otosclerosis and rheumatoid arthritis characteristically increase the resonant frequency (RF) of the middle ear. Ossicular chain discontinuity, atelectatic tympanic membrane, and otitis media with effusion typically decrease the RF of the middle ear. Multifrequency tympanometry can also assess the stage of rheumatoid arthritis in the presence of middle ear involvement. The RF can be affected by the mechanical impedance of the cochlea, and multi-frequency tympanometry can be helpful in the diagnostic workup of LVAS. Multi-frequency tympanometry can be a useful tool to predict the diagnosis of various middle ear pathologies preoperatively, due to the ensuing changes in the RF of the mechano-acoustic system of the middle ear, which can be accurately determined when this methodology is applied.

Keywords Multi-frequency · Resonant frequency · Tympanometry · Middle ear · Impedance

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Introduction

Tympanometry is the measurement of the acoustic immittance of the ear as a function of the ear canal pressure. It was introduced by Terkildsen and Thomsen [1] as a method of evaluating the middle ear pressure, and has become a routine component of the audiologic and otologic evaluation process worldwide.

Tympanometry is known to be a sensitive, inexpensive, non-invasive, and simple method for the diagnosis of middle ear disease [2]. Although low frequency probes are most frequently used, the use of higher frequencies is increasingly gaining clinical acceptance, due to its higher sensitivity for diagnosis of ossicular chain diseases [2].

Multi-frequency tympanometry in particular provides information on how components of admittance (i.e., conductance (G), mass reactance and stiffness reactance) change as a function of probe frequency. The frequencies at which these changes occur may differ markedly between normal and pathological cases. One such frequency is the resonant frequency of the middle ear system (RF). Changes in the transmission characteristics of the system can be easily determined from the ensuing changes in the RF [3].

The aim of the present paper is to review the current knowledge on multi-frequency tympanometry and explore its role as a diagnostic tool in various otologic conditions.

Materials and Methods

An extensive search of the literature was performed in Medline and other available database sources, using the keywords "multi-frequency", "tympanometry", "RF", "middle ear", "impedance", "immittance", "admittance", and "susceptance (B)". The keywords "multi-frequency" and "tympanometry" were considered primary and were either combined to each of the other keywords individually, or used in sets of three. In addition, reference lists from the retrieved articles were manually searched. Language restrictions limited the search to English-language articles only.

Results

Twelve prospective controlled studies, four prospective comparative, and seven prospective cohort studies, one retrospective study, three animal studies, and one systematic review met the defined criteria and were included in study selection.

Discussion

Multi-frequency tympanometry is based on the analysis of tympanograms at a wide range of frequencies between 226 and 2,000 Hz. The acoustic immittance is a term that encompasses impedance, admittance, and their components. Impedance (Z, measured in acoustic ohms) in the middle-ear system is defined as the total opposition of this system to the flow of acoustic energy. Admittance (Y, measured in acoustic mmhos) is the opposite of impedance, and is the amount of acoustic energy that flows into the middle-ear system. Admittance has three components: mass susceptance (Bm), stiffness susceptance (Bs), and G. Currently available immittance instruments typically measure admittance.

The RF is described as the frequency at which both stiffness and Bm are equal. Bs is proportional to frequency and Bm is inversely proportional to frequency. The total B near the RF is nearly zero, so the G is the only component contributing to the admittance of the system.

The first experimental data on multi-frequency tympanometry were published in the 1960s [4, 5] whereas Colletti [6] reported changes in the shape of the tympanometric curve as the frequency of the probe tone increased from 200 to 2,000 Hz. Based on the results from a series of 290 patients Colletti subdivided the obtained tympanograms into three groups: low frequency tympanograms were found to be V-shaped, mid-range frequency W shaped and high frequency inverted V-shaped. The W pattern of the tympanometric curve (tympanogram at the RF) was observed at frequencies from 650 to 1,400 Hz (mean 1,000 ± SD 170 Hz) (Fig. 1).

Another model of tympanometric patterns which seems to predict the shape of B and G tympanograms at 678 Hz in normal ears and in various pathologies was proposed by Vanhuyse et al. [7]. This model was later adapted to higher probe tone frequencies also by Margolis and Goycoolea [8]. As the system shifts from stiffness to mass controlled, B and G tympanograms progress through a sequence, referred to as 1B1G, 3B1G, 3B3G, and 5B3G, indicating the number of peaks and troughs in the components (Fig. 2). RF is the most useful parameter measured by multi-frequency tympanometry, with the published data showing a relative consistency in normal adults. The mean RF is around 950 Hz, ranging from 650 to 1,400 Hz [3, 8–20] (Table 1).

Multi-frequency tympanometry can be a useful tool to predict the diagnosis of various middle ear pathologies preoperatively, as changes in mass and/or stiffness of the mechano-acoustic system of the middle ear are found to affect the RF.

Otosclerosis and rheumatoid arthritis represent pathologies that characteristically increase the RF (Table 2). Otosclerosis in particular increases the stiffness of the system due to the fixation of the stapes. It therefore increases RF. In addition, Coletti was the first to show not only that the RF is higher in otoscleotic ears, but also that there is a tendency towards lower values in ears that had a total stapedectomy, compared to the ones where the stapedial tendon was preserved, thus confirming that preservation of the stapedial tendon adds significant stiffness to the system [6, 21]. His results were later confirmed by other authors [6, 13, 16–18]. Higher RF is also found in patients with rheumatoid arthritis (RA) [22, 23]. A correlation between the stage of the disease and the RF has also been described [23].

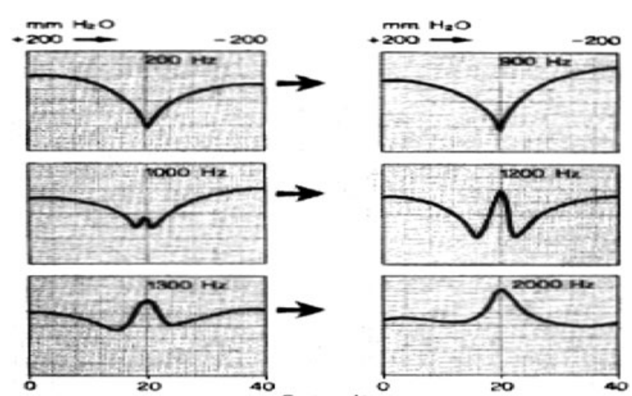

Fig. 1 Multifrequency tympanometric findings in a subject with normal hearing and normal tympanic membrane using ear pressure values from +200 to −200 mm H_2O [3]

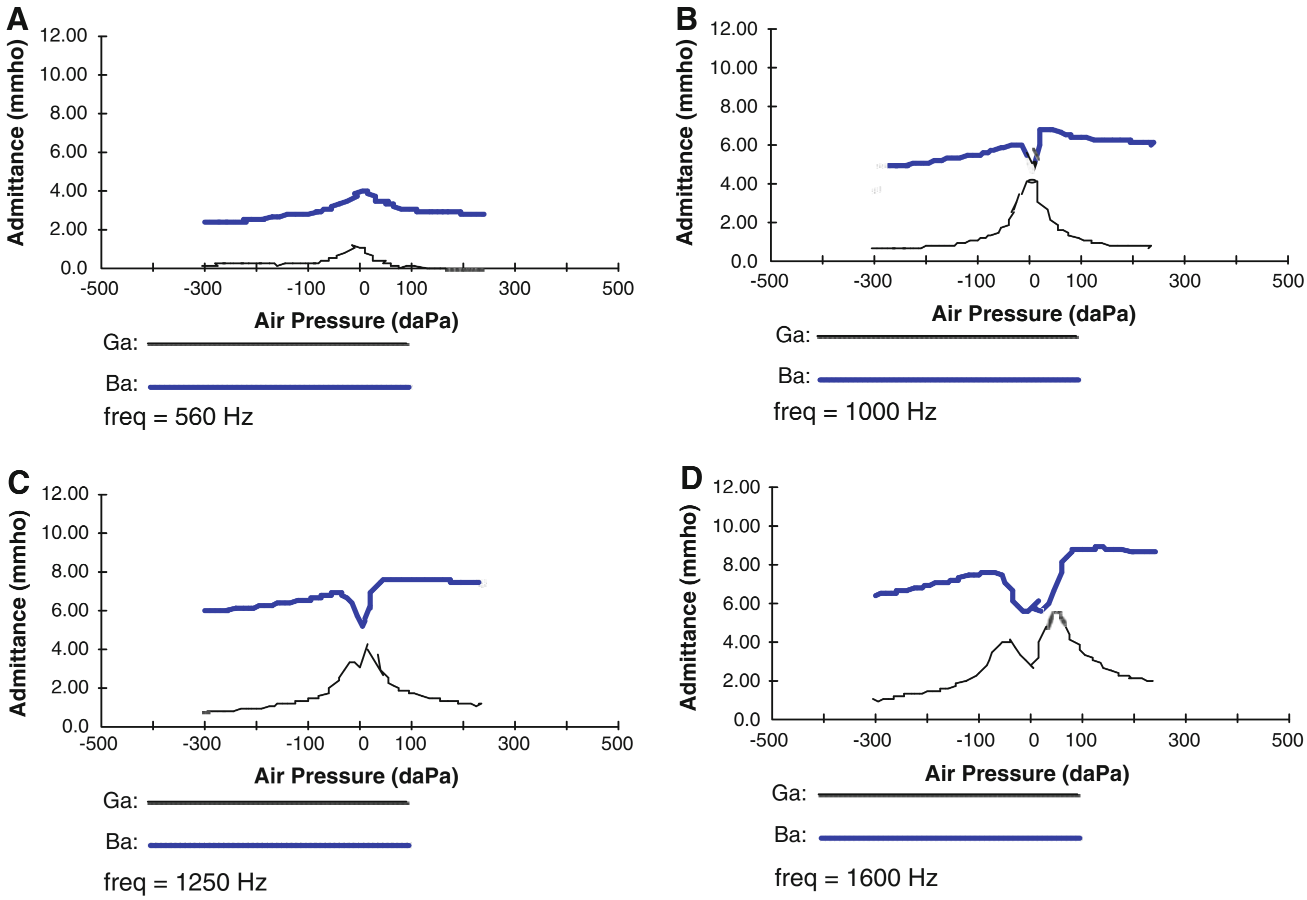

Fig. 2 The Vanhuyse model showing the four patterns of susceptance (B_a) and conductance (G_a) tympanograms, 1B1G **a**; 3B1G **b**; 3B3G **c**; and 5B3G **d** [4]

Table 1 Normative data in multifrequency tympanometry

Study	Number of ears	Instrument	Mean RF (Hz)	SD (Hz)	90% range
Margolis and Goycoolea 1993 [8]	56	Virtual 310	1,135	306	800–2,000
Shanks et al. 1993 [9]	26	Virtual 310	817	–	565–1,130
Hanks and Rose 1993 [10]	90	GSI 33 v 2	1,003	216	650–1,300
Valvik et al. 1994 [11]	100	GSI 33 v 2	1,049	261	650–1,150
Holte 1996 [2]	144	Virtual310	905	184	630–1,250
Hanks and Mortensen 1997 [12]	106	GSI 33 v 2	908	188	650–1,300
Shahnaz and Polka 1997 [13]	68	Virtual 310	894	116	630–1,120
Wada et al. 1998 [14]	275	Original	1,170	270	–
Wiley et al. 1999 [15]	467	Virtual 310	826	146	–
Miani et al. 2000 [16]	48	Virtual 310	1,085	244	–
Nakashima et al., 2000 [17]	35	GSI 33 v 2	946	191	–
Franco-Vidal 2005 [19]	48	GSI 33 v 2	926	238	–
Shahnaz and Davies 2006 [20]	303	Virtual 310	Caucasian:818	154	560–1,120
			Chinese:890	163	630–1,250
Ogut et al. 2008 [18]	100	GSI 33 v 2	934.6	142.70	–

In contrast, ossicular chain discontinuity, atelectatic tympanic membrane, and otitis media with effusion typically decrease the RF [14, 24–26]. Wada et al. [14] reported that a discontinuity in the ossicular chain (surgically confirmed in 84% of their cases) results in lower RF values, by decreasing the stiffness in the middle ear (Table 3). A

Table 2 Middle ear conditions increasing the RF

Pathology	Study	Number of ears	Instrument	Mean RF value	SD
Otosclerosis	Coletti 1977 [6]	56	Original	1,300	–
	Colletti et al. 1993 [21]	138	Virtual 310	1400	–
	Shahnaz and Polka 1997 [13]	14	Virtual 310	920	308
	Miani et al. 2000 [16]	70	Virtual 310	1,264	320
	Nakashima et al. 2000 [17]	50	GSI 33 v 2	1,306	265
	Ogut et al. 2008 [18]	25	GSI 33 v 2	1,190	241.95
Ossicular chain fixation	Wada et al. 1998 [14]	12	Original	1,400	330
Juvenile rheumatoid arthritis	Giannini and Marciano 1997 [22]	60	GSI 33 v2	1,155	295
Rheumatoid arthritis	Frade et al. 1998 [23]	53[a,b]	GSI 33 v2	1,114[a]	189
				895[b]	186

RF resonant frequency, *SD* standard deviation

[a] 25/53 active phase

[b] 28/53 inactive phase

Table 3 Middle ear conditions decreasing the RF

Pathology	Study	Number of ears	Instrument	Mean RF value	SD
Otitis media with effusion	Ferekidis et al. 1999 [24]	76	GSI 33 v 2	499	145
	Lai et al. 2008 [25]	85	GSI 33 v 2	400	124
Ossicular chain discontinuity	Wada et al. 1998 [14]	26	Original	830	250
Atelectatic tympanic membrane	Wada et al. 1998 [14]	1	Original	800	–
Enlarged vestibular aqueduct	Nakashima et al. 2000 [17]	23	GSI 33 v 2	778	215
	Sato et al. 2002 [28]	24	GSI 33 v 2	777	230

RF resonant frequency, *SD* standard deviation

similar mechanism was also proposed in atelectatic tympanic membranes [14]. In addition, Ferekidis et al. [24] reported that the reduced RF in ears with otitis media with effusion seems to persist even after the standard 226-Hz tympanogram has returned to normal.

The diagnostic use of multi-frequency tympanometry can also be expanded in inner ear disease. Indeed, Darousset et al. [27] reported that the RF seems to be determined not only by the mass and stiffness of the middle ear system, but also by the mechanical impedance of the cochlea. Patients with large vestibular aqueduct syndrome (LVAS) have lower RF values, because as the endolymphatic space increases the impedance of the cochlear compartments decreases [28]. The proposed mechanisms include the effect of the increased amount of endolymph on the mechanical impedance at the stapes footplate, or a "third window" effect which can reduce the RF of the entire system [28].

Keypoints

- Multi-frequency tympanometry provides more accurate and detailed information about the middle ear dynamics than standard tympanometry.
- Otosclerosis and rheumatoid arthritis characteristically increase the RF of the middle ear.
- Ossicular chain discontinuity, atelectatic tympanic membrane, and otitis media with effusion typically decrease the RF of the middle ear.
- Multi-frequency tympanometry can also assess the stage of rheumatoid arthritis in the presence of middle ear involvement.
- The RF can be affected by the mechanical impedance of the cochlea, and multi-frequency tympanometry can be helpful in the diagnostic workup of LVAS.

Conflicts of interest None.

References

1. Terkildsen K, Thomsen K (1959) The influence of pressure variations on the impedance of the human ear drum. J Laryngol Otol 73:409–418
2. Holte L (1996) Aging effects in multifrequency tympanometry. Ear Hear 17:12–18
3. Lilly DJ (1984) Multiple frequency, multiple component tympanometry: new approaches to an old diagnostic problem. Ear Hear 5(5):300–308
4. Zwislocki JJ (1962) Analysis of the middle-ear function. Part I: input impedance. J Acoust Soc Am 34:1514–1523
5. Moller AR (1963) Transfer function of the middle ear. J Acoust Soc Am 35:1526–1534
6. Coletti V (1977) Multifrequency tympanometry. Audiology 16:278–287

7. Vanhuyse VJ, Creten WL, Van Camp KJ (1975) On the W-notching of tympanograms. Scand Audiol 4:45–50
8. Margolis R, Goycoolea HG (1993) Multifrequency tympanometry in normal adults. Ear Hear 14(6):408–413
9. Shanks JE, Wilson RH, Cambron NK (1993) Multiple frequency tympanometry: effects of ear canal volume compensation on static acoustic admittance and estimates of middle ear resonance. J Speech Hear Res 36:178–185
10. Hanks WD, Rose KJ (1993) Middle ear resonances and acoustic immittance measures in children. J Speech Hear Res 36:218–222
11. Valvik B, Johnsen M, Laukli E (1994) Multifrequency tympanometry. Audiology 33:245–253
12. Hanks WD, Mortenson BA (1997) Multifrequency tympanometry: effects of ear canal volume compensation on middle ear resonance. J Am Acad Audiol 8:53–58
13. Shahnaz N, Polka L (1997) Standard and multifrequency tympanometry in normal and otosclerotic ears. Ear Hear 18:268–280
14. Wada H, Koike T, Kobayashi T (1998) Clinical applicability of the sweep frequency measuring apparatus for diagnosis of middle ear diseases. Ear Hear 19(3):240–249
15. Wiley TL, Cruickshanks KJ, Nondahl DM, Tweed TS (1999) Aging and middle ear resonance. J Am Acad Audiol 10:173–179
16. Miani C, Bergamin AM, Barotti A, Isola M (2000) Multifrequency multicomponent tympanometry in normal and otosclerotic ears. Scand Audiol 29(4):225–237
17. Nakashima T, Ueda H, Furuhashi A, Sato E, Asahi K, Naganawa S, Beppu R (2000) Air–bone Gap and resonant frequency in large vestibular aqueduct syndrome. Am J Otol 21:671–674
18. Ogut F, Serbetcioglu B, Kirazli T, Kirkim G, Gode S (2008) Results of multiple-frequency tympanometry measures in normal and otosclerotic middle ears. Int J Audiol 47:615–620
19. Franco-Vidal V, Legarlantezec C, Blanchet H, Convert C, Torti F, Darrouzet V (2005) Multifrequency admittancemetry in Meniere's Disease: a preliminary study for a new diagnostic test. Otol Neurotol 26(4):723–727
20. Shahnaz N, Davies D (2006) Standard and multifrequency tympanometric norms for Caucasian and Chinese young adults. Ear Hear 27(1):75–90
21. Colletti V, Fiorino FG, Sittoni V, Policante Z (1993) Mechanics of the middle ear in otosclerosis and stapedoplasty. Acta Otolaryngol 113(5):637–641
22. Giannini P, Marciano E (1997) Middle ear involvement in children with chronic rheumatoid arthritis. Eur Arch Otolaryngol 254(S1):S30–S33
23. Frade C, Martin C (1998) Diagnostic value of the multifrequency tympanometry in active rheumatoid arthritis. Auris Nasus Larynx 25:131–136
24. Ferekidis E, Vlachou S, Douniadakis D, Apostolopoulos N, Adamopoulos G (1999) Multiple-frequency tympanometry in children with acute otitis media. Otolaryngol Head Neck Surg 121:797–801
25. Lai D, Li W, Xian J, Liu S (2008) MFT in adults with otitis media with effusion. Eur Arch Otorhinolaryngol 265:1021–1025
26. Margolis RH, Hunter LL, Giebink SG (1994) Tympanometric evaluation of middle ear function in children with otitis media. Ann Otol Rhinol Laryngol 103:34–38
27. Darrouzet V, Dulon D, Franco-Vidal V (2007) Multifrequency immittancemetry in experimentally induced stapes, round window and cochlear lesions. Audiol Neurotol 12:85–100
28. Sato E, Nakashima T, Lilly D et al (2002) Tympanometric findings in patients with enlarged vestibular aqueducts. Laryngoscope 112:1642–1646