A COMPARISON OF TYMPANOMETRY BY USING PROBE TONE FREQUENCY 226 AND 660 Hz IN NORMAL FULL TERM NEONATES

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Tympanometry is the dynamic measurement of acoustic immittance in the external ear canal as a function of changes in air pressure in the ear canal. The use of 226 Hz tympanometry in neonates and infants has been controversial due to the large number of false negative responses for middle ear pathology. A review of literature highlights several anatomical differences between this population and that of the adult, which is not recognized during interpretation of their tympanograms. The purposes of this study were to compare the tympanometric patterns and parameters of tympanogram in neonates by using probe tone frequencies of 226 and 660 Hz.

The instrumentation in this study was a Virtual model 310. The parameters for this study were as follows; an ascending direction type for pressure direction setting, 125 daPa/second for rate pressure change, and 85 dBSPL for the intensity signal. Eighty normal full term neonates served as the subjects for this study. Their ages ranged from 2-7 days.

The results of this study showed that the tympanogram shapes were both single peaked and notched tympanogram. In polar notation, the recordings by using 226 Hz, showed a single peaked tympanogram (1Y) 43.8%, and a notched tympanogram (3Y) 56.2%. In rectangular notation, the recording showed a single peaked tympanogram (1B1G) 26.3% and a notched tympanogram (3B1G, 3B3G) 35.6%,38.1%.In a part of probe tone frequency 660 Hz, the recording in polar notation showed single peaked (1Y) 66.3% and a notched tympanogram (3Y) 33.7%. In rectangular notation, the recording showed single peak (1B1G) 59.4% and notched tympanogram 3B1G, 3B3G) 18.1%, 22.5%, respectively. The mean amplitude and tympanometric peak pressure (TPP) of Y tympanogram at probe tone frequency of 226 Hz ($\bar{X}$=0.72mmhos, $\bar{X}$=77.76 daPa, respectively) was significantly different (p=0.000. p=0.000, respectively). The mean amplitude and tympanometric peak pressure (TPP) of Y tympanogram at probe tone frequency 660 Hz ($\bar{X}$=0.42 mmho, 140.09 daPa) was significantly different (p=0.000, and p=0.000). The mean amplitude of Y, tympanogram in males and female at probe tone frequency 226 Hz ($\bar{X}$=0.70, 0.74 mmho), and the mean amplitude of Y, B, G tympanogram at probe tone frequency 660 Hz in male ($\bar{X}$=0.42, 0.39 and 0.76 mmho), in female ($\bar{X}$=0.42, 0.41 and 0.75 mmho) were no significantly different (p=1.000, 0.467 and 0.840, respectively). The mean TPP of Y, B, G tympanogram in males ($\bar{X}$= 143.78, 138.13, 61.25 daPa), in females ($\bar{X}$= 136.40, 143.69, and 42.25, respectively), was no significantly different.

The finding of this study suggest tympanometry can be use to assess the status of the middle ear in neonates.

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Tympanometry คือการตรวจเพื่อประเมินการทำงานของหูชั้นกลางโดยการวัดค่าแรงต้านของระบบต่อการไหลของพลังงานเสียง สัมพันธ์กับการเปลี่ยนแปลงความดันอากาศในช่องหูชั้นนอก การทดสอบ tympanometry ที่ความถี่ 226 Hz ในเด็กทารกแรกเกิดและเด็กเล็กยังเป็นที่ถกเถียงกันอยู่ เนื่องจากยังมีผลตอบรับที่ตรงกันข้ามกับอาการผิดปกติที่เกิดขึ้นอยู่จำนวนมากในการวินิจฉัยแยกโรคของหูชั้นกลาง ทั้งนี้เนื่องจากความแตกต่างทางด้านกายวิภาคของเด็กทารกที่แตกต่างจากผู้ใหญ่ วัตถุประสงค์ในการศึกษาวิจัยครั้งนี้ เพื่อศึกษาเปรียบเทียบ รูปร่างและส่วนประกอบต่างๆ ของ tympanogram โดยใช้ความถี่ 226 และ 660 Hz

เครื่องมือที่ใช้ศึกษาวิจัย คือ Virtual model 310 มีการเปลี่ยนแปลงความดันชนิด ascending direction 125 daPa/second และใช้ความดัง 85 dBSPL. ในเด็กทารกแรกเกิดจำนวน 80 คน อายุเฉลี่ย 2 ถึง 7 วัน

ผลการศึกษาในครั้งนี้พบว่า รูปร่างของ tympanogram เป็นทั้งแบบ single peaked และ notched tympanogram ในการบันทึกแบบ polar notation ที่ความถี่ 226 Hz แสดง single peaked (1Y) 43.8% และพบ notched tympanogram (3Y) 56.2% ถ้าบันทึกแบบ rectangular rotation แสดง single peaked tympanogram (1B1G) 26.3% และ notched tympanogram (3B1G,3B3G) 35.6 %, 38.1% ตามลำดับ ส่วนผลการทดสอบโดยใช้ความถี่ 660 Hz พบว่าแบบ polar notation แสดง single peaked (1Y) 66.3 % และ notched tympanogram (3Y) 33.7 % แบบ rectangular notation แสดง single peaked (1B1G) 59.4 % และ notched tympanogram (3B1G, 3B3G) 18.1%, 22.5% ตามลำดับ ค่าเฉลี่ยของ amplitude และ tympanometric peak pressure (TPP) ของ Y tympanogram โดยใช้ความถี่ 226 Hz มีค่าเท่ากับ 0.72 mmhos และ 77.76 daPa ตามลำดับ ซึ่งน้อยกว่าค่าเฉลี่ยของ amplitude และ TPP ของ Y tympanogram เมื่อใช้ probe tone frequency 660 Hz ($p=1.000$, 0.467 และ 0.840 ตามลำดับ) นอกจากนี้ ค่าเฉลี่ย TPP ของ Y, B, G ในเพศชาย ($\bar{X}=143.78$, 138.13 และ 61.25 ตามลำดับ) เมื่อเปรียบเทียบกับเพศหญิง พบว่าไม่แตกต่างกันอย่างมีนัยสำคัญทางสถิติกับเพศหญิง ($\bar{X}=136.40$, 143.69 และ 42.25 ตามลำดับ)

ผลการศึกษาครั้งนี้จึงมีประโยชน์สำหรับการประเมินความผิดปกติในหูชั้นกลางโดยใช้ tympanometry ในเด็กทารกแรกเกิด

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CHAPTER I

INTRODUCTION

Statement of the problem

Otitis media with effusion (OME) is the most common cause of acquired conductive hearing loss in children (1,2). The true incidence is unknown, but up to 60% of children in their first year may have middle ear effusions that are clinically asymptomatic (3). The onset of otitis media in infancy carries a high risk of subsequent recurrent otitis media and prolonged middle ear effusion or OME (4,5). Infant with OME beginning in the first 6 months of life may be vulnerable to impairment of verbal abilities at age 3 years (6). OME is evidenced by presence of fluid in middle ear space, which compromises the traditional sound pathway to the cochlea and creates some degree of conductive hearing loss. In addition, OME with associated hearing loss may result in significant auditory, linguistic, educational, and psychosocial complications for affected children if the disease is recurrent or of long duration especially in the first year of life (1, 4, 5).

OME can be diagnosed definitely only when the presence of fluid in the middle ear has been confirmed. In the best-designed clinical research studied of diagnostic methods for OME, tympanometry was implemented and followed immediately to document of effusion in infant (5).

Tympanometry is a dynamic measurement of acoustic immittance in the external ear canal as a function of changes in air pressure in the ear canal, which being composed of a battery test useful for detection of a wide variety of middle ear abnormalities. These measurements are recorded on a graph known as a tympanogram, which represents a compliance-air pressure function (7,8,9). The first description of the clinical application of this technique was initiated by Metz as recently as 1946 (10). It was only since the late 1960s that its use with infants and children were investigated and validated by several researchers (10,11,12,13,14,15). In conventional tympanometry, probe tone frequency has now been standardized at 226 Hz. according to the International Electro- technical Commission (IEC 1027, 1991) (16). The use of 226 Hz tympanometry in neonates and infants younger than 6 months has been controversial due to the large number of false negative responses for middle ear pathology. The study of tympanometric results indicated that 91 infants with acute and chronic otitis media between 4 weeks and 5 months showed normal tympanograms, and normal otoscopic findings which correlated highly in 92% of the evaluation. Flat tympanograms and abnormal otoscopy finds were correlated 93% of the time (15).

Moreover, there was no significant difference in the false negative identification of middle ear effusion above and below 7 months of age (17,18). Detection of OME in infants was problematic because at the 226 Hz tympanograms normal or notched tympanograms would be found in cases of confirmed effusion (18,19,21). The reasons for the high false negative rate in this population are unclear. Although it has been speculated that the anatomical difference between the infant and adult middle ear transmission system may be a contributory factor (19,20,21). Anatomical evidence suggests that neonatal ear matured from a positive (mass dominated) to a negative (stiffness-dominated) reactance (15). These developmental changes result in the mass-governed middle ear transmission system gradually changed to the more adult-like stiffness-dominated system (18, 22, 23). This suggests that the middle ear resonance of the infant should initially be of a lower frequency gradually rising as the infant matures (18).

The differential frequency response of the mass and stiffness components requires the use of high frequency probe-tone to evaluate the former more sensitively, and low frequencies for the latter stiffness components. The poor sensitivity of 226 Hz tympanometry to middle ear disease in this principle was well demonstrated by Weatherby and Bennet's (14). Their data showed that neonatal acoustic reflexes were immeasurable using 226 Hz probe tones. However, when employing high-frequency probe tone, acoustic reflexes were obtained at levels comparable to those in adults (24). Some evidences demonstrated good agreement between high frequency probe tone tympanometry (around 660 Hz) and middle ear effusion in young infants (21,23).

In addition, high frequency tympanometry may be more sensitive to middle ear disease in the newborn population. In particular, below 4 months of age, the high frequency probe tone must be used because of the different resonance characteristics of the middle ear (24). Any effects of ear canal wall movement are also minimized by using higher probe tone frequencies (25). The study of tympanometry and acoustic reflex thresholds were performed with high frequency probe tone (660 Hz). These findings were compared with independent otoscopic diagnoses in 67 ears with OME and 69 ears that were effusion free. There was excellent agreement among otoscopy, peak tympanogram susceptance, and ipsilateral acoustic reflex thresholds (agreement 91% to 93%). They concluded that susceptance tympanograms and ipsilateral acoustic reflex thresholds were valid diagnostic methods for OME in infants younger than 5 months of age (26). There was a study comparing 220 Hz and 660 Hz tympanograms discrimination between ears with and without OME (21). A mean susceptance of 0.16

mmho with a 660 Hz probe tone was found to produce very good discrimination between otoscopically normal ears and OME in older infants and children (21).

Another method may be used for confirming or excluding the presence of the OME. Thus, analysis of the Y, B and G tympanograms can be explained by several maturation changes in neonates and infants (27, 28). Various shapes of tympanogram indicate the relative contribution of mass and stiffness to the admittance tympanogram and being used in separating normal from pathological middle ear.

The importance of early identification of middle ear disease is well established (27, 29). Although tympanometry measures are an important tool in the detection of middle ear function in the older child and adult population, these procedures have not been widely applied in normal full term neonates. Thus, the benefits of tympanometry contribute an important role as part of the test battery for this age group. The aim of this study was to compare the results of the tympanometry by utilizing probe tone frequencies of 226 and 660 Hz in normal full term neonates. A correlation between the audiological findings and various parameters of probe tone frequencies 226 and 660 Hz were addressed.

Purposes of This Study

The purposes of this study were to compare:

1. the tympanometric patterns between probe tone frequencies 226 and 660 Hz in full term neonates.

2. the amplitude admittance tympanograms between probe tone frequencies 226 and 660 Hz in full term neonates.

3. ~~the tympanometric~~ peak pressure of admittance tympanogram between probe tone frequencies 226 and 660 Hz in full term neonates.

4. the amplitude admittance tympanograms at 660 Hz between male and female full term neonates.

5. the tympanometric peak pressure of 660 Hz admittance tympanogram between male and female full term neonates.

Research Questions

This study intended to answer the following questions:

1. Was there any difference between the tympanometric patterns probe tone frequencies 226 and 660 Hz in full term neonates?

2. Was there any difference between the amplitude of admittance tympanogram at probe tone frequencies 226 and 660 Hz in full term neonates?

3. Was there any difference between the tympanometric peak pressure of admittance tympanogram at probe tone frequencies 226 and 660 Hz in full term neonates?

4. Was there any difference between the amplitude admittance tympanogram at 660 Hz in male and female full term neonates?

5. Was there any difference between the tympanometric peak pressure of 660 Hz admittance tympanogram between male and female full term neonates?

The Advantages of This Research

1. Results from this study may provide information of basic tympanometry measurements in neonates, which should be applied to the early detection of middle ear disease and hearing impairment.

2. Results of this study may be helpful as part of a pediatric test battery for evaluated the integrity of the middle ear in neonates and young infants.

Definitions

The following definitions are relevant to this study:

1. Tympanometry is a measurement of acoustic immittance in the external auditory meatus as a function of changes in air pressure within the external auditory meatus (9).

2. Tympanogram is a graphic representation of acoustic admittance or acoustic impedance as a function of ear canal pressure (9).

3. Probe tone is the acoustic signal introduced into the ear canal whose properties were compared with the signal resulting as a consequence of reflection of eardrum (30).

4. Deca Pascals (daPa), the unit of air pressure is varied positive or negative relative to ambient or atmospheric pressure and the dynamic effects of air pressure changes on the acoustic immittance properties of the middle ear transmission system are measured (23).

5. Acoustic impedance (Za in acoustic ohms) is a measure of the opposition to the flow of acoustic energy into the middle ear transmission system (23).

6. Acoustic admittance (Ya in acoustic mmhos) is a measure of the ease with which acoustic energy flows into the middle ear (23).

7. Acoustic immittance is a generic term used to refer to either acoustic impedance or acoustic admittance measurements (23).

6. Phase angle (ϕ in degrees or radians) refers to an angle between the total immittance vector and the positive real axis (23).

10. Polar notation refers to acoustic immittance is expressed as an amplitude and phase angle (23).

11. Rectangular notation refers to acoustic immittance is expressed as a complex number (23).

12. Acoustic resistance (Ra in acoustic ohms) is a real component of complex acoustic impedance (23).

13. Acoustic reactance (Xa in acoustic ohms) is the imaginary component of complex acoustic impedance and is the algebraic sum of mass reactance (Xm) and compliant reactance (-Xc) (23).

14. Acoustic conductance (Ga in acoustic mmhos) is the real component of complex acoustic admittance (23).

15. Acoustic susceptance (Ba in acoustic mmhos) is the imaginary component of complex acoustic admittance and is the algebraic sum of mass susceptance (-Bm) and compliant susceptance (Bc) (23).

16. Tympanometrric peak pressure (TPP) is a pressure at which the peak of a tympanogram occurs, and provides an estimate of the middle ear pressure (23).

CHAPTER II

REVIEW OF THE LITERATURE

This chapter presented some of the basis anatomy and physiology of the middle ear. The basic characteristics of acoustic measurements, middle ear transformer mechanism and choice of probe tone for tympanometry in neonates were focused. The use of interpreting high frequency tympanometry results in this populations has also been reviewed.

1. The Anatomy and Physiology of the Middle ear

The middle ear is an irregular, laterally compressed, air-filled space lying within the petrous portion of the temporal bone between the external auditory canal and the inner ear (Figure 1). The middle ear is part of a system of contiguous organs including:

1.1 The tympanic cavity

The middle ear also called the tympanic cavity is irregularly shaped. Located just medial to the end of the external canal, the middle ear contained air and mechanically important components. The cavity in its anterior-posterior dimension measures 15 mm at most. In the vertical dimension, the greatest distance across the cavity is also 15 mm the transverse diameter of the middle ear ranges between 2 and 6 mm. This small opening in the skull has an overall capacity of between 1 and 2 cc.

On the posterior surface of the middle ear is the mastoid antrum. This entrance to the labyrinth of mastoid cavities is a system of pneumatic cells, which apparently contributes to the acoustic resonance characteristics of the middle ear (31, 32, 34).

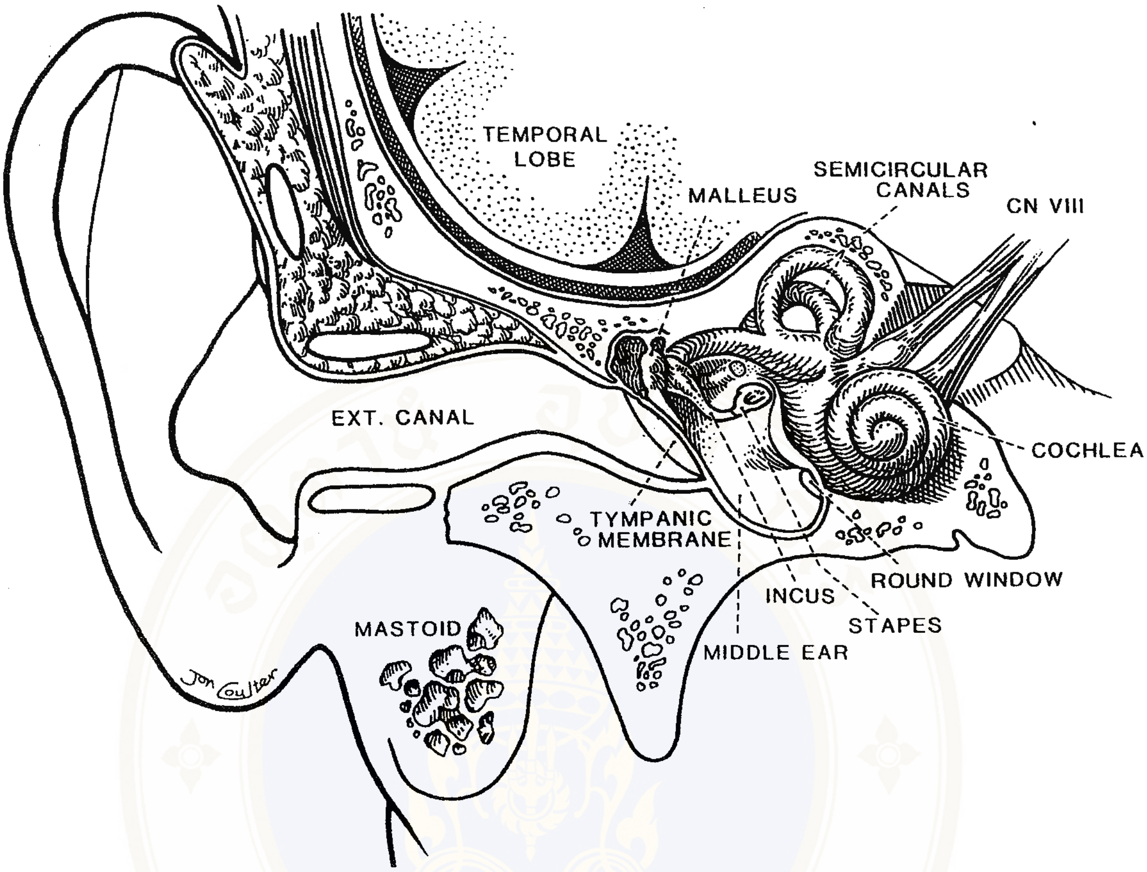


Figure 1 Illustration of relation of the middle ear to external and inner ears (31).

1.2 Eustachian tube

The eustachian tube in an infant is about half as long as that in an adult; it averages about 18 mm. The cartilaginous tube represents somewhat less than two-thirds of this distance, whereas the osseous portion is relatively longer and wider in diameter than it is in an adult. The height of the pharyngeal orifice of the infant eustachain tube is about one-half that of adult, but the width is similar. The osteum of the tube is more exposed in an infant than it is in an adult, since it lies lower in the shallower nasopharyngeal vault. The direction of the tube varies, from horizontal to an angle of about 10 degrees to the horizontal, and the tube is not angulated at the isthmus but merely narrows (31). Holborow (33) demonstrated that the medial cartilaginous lamina if infants were relatively shorter since there was less tube mass and stiffness in infant tube than there was in that of the older child and adult. The tensor tympani muscle is less efficient in infant. Sade [cited in Charles et al. (31)] reported no difference in the eustachain tube lumen of infants with and without otitis media that would support the contention that functional, not mechanical, obstruction was an importance problem in ear disease in this age group.

1.3 Ossicular chain

There are three ossicles in the middle ear. The malleus, incus, and stapes develop from the mesenchymal tissue (cartilage) at the dorsolateral end of the first two brachial arches. They form a chain for the conduction of vibrations from the drumhead to the oval window. The malleus has been referred to as the hammer because of its shape. It consists of a head and neck, the manubrium (the hammer handle), long and short (lateral) process. The manubrium is visible though the outer layer of the drumhead in a normal ear. The incus consists of a body, a short process and a long process. It articulates with the malleus laterally and has a capsule, as do all articulations. The stapes is the medial ossicle. It is the smallest of the three but the most important because it closes the oval window and its movement causes traveling waves in the perilymph, which are essential to hearing. It articulates with the long process of the incus with a movable joint. Several ligaments support the ossicles in their position within the tympanic cavity. The ossicular chain acts as a system of levers gaining an advantage in the force of acoustic impulse transmitted by the stapes to the labyrinthine perilymph of the inner ear (34).

1.4 Tympanic mucous membrane

The mucosa of the middle ear cavity is continuous with that of the nasopharnyx through the eustachain tube. It consists of ciliated columnar (respiratory) epithelium and a flatter, no conciliated epithelium. The mucosa creates a number of folds where it invests various middle ear structures (35). The tympanic membrane is the receiver and collector of acoustic pressure directed against the ear by vibratory energy in the air around us. This thin (0.07 mm), delicate, elastic, and somewhat tense portion of the ear is extremely sensitive to pressure changes, so what very minute forces acting on the membrane are sufficient to elicit action of the entire auditory mechanism. The shape of the tympanic membrane is conical, pointing medailward so that more surface area of membrane can be available without having a larger opening for a canal (34). However, Bekesy [cited in (38)] had undertaken experimental investigations to discover the relative motion of the surface regions of tympanic membrane. This showed that the surface of the membrane moved considerably more in the inferior aspect than elsewhere. This observation caused Bekesy to estimate that the effective movement of the tympanic membrane was confined to only about two-thirds of its surface (34, 38).

1.5 Middle ear muscles

The tensor tympani muscle attaches to the malleus in such a way that contraction of the muscle pulls the manubrium and the tympanic membrane medially. This has the effect of tensing both the structures and can reduce the response of the middle ear to sound stimulation. This muscle is the larger of the two middle ear muscles, being about 25 mm long with a cross-section area of 5 mm^2. In the uncontracted state, the tendon of the tensor muscle exerts a slight tensing agent to the tympanic membrane.

In opposition to the direction of stress provided by the tensor tympani muscle, the smaller stapedius muscle is oriented to pull the stapes footplate away from the oval window. This smaller muscle is only 6 to 7 mm long with a cross-section area of 5 mm^2. However, the effectiveness of its reduction of transmission of energy across the middle ear exceeds that of the tensor muscle because the stapedius muscle directly affects the stapes itself (34).

2. Middle ear Transformer mechanism

The middle ear contains several mechanisms that allow us to hear sounds whose pressures are extremely small. These mechanisms provide for a number of interrelated functions, which together meet the primary purpose of transmitting acoustically derived vibrations to the inner ear with remarkable effectiveness. Breakdown of function or structure in this portion of the ear will cause conductive impairments that can greatly reduce hearing sensitivity.

Acoustically, the middle ear acts as a lever that increases the effect of transmission of sound to the cochlear fluid. If sound was to be transmitted directly to one of the windows of the fluid filled cochlea, 99.9 percent of its energy would be reflected, and consequently only 0.1 per cent would be transmitted further. The middle ear improves the sound transmission to the oval window of the cochlea by reducing this reflection. The function of the middle ear can also be said to be that of impedance transformer changes the high impedance of the cochlear fluid into low impedance resembling of air (38). In addition, the acoustic impedance of air is 41.5 ohms and the impedance of inner ear fluid is 143,000 ohms (39, 40).

Wever et al [cited in Charles et al. (31)] reported that the middle ear mechanisms provided a means whereby airborne sounds more effectively stimulate the inner ear fluid with the aid of middle ear to overcome the potential transmission loss of 30 dB. The transmission properties of the middle ear have been studied in animal experiments and in human cadaver ears using numerous methods. Figure 2 showed how the transmission of sound via the middle ear in a cat differs from transmission of sound applied directly to one of the windows. The lower graph showed how the middle ear improves transmission in the frequency rang around 1 kHz, where it is about 30 dB, and somewhat less above and below. The transmission-taking place in the human middle ear was not likely to be very different (38, 39).

Several factors contribute to the transformer function of the middle ear. They include the areal ratio of the eardrum to the oval window, the curved-membrane mechanism of the drum, and the lever action of ossicular chain.

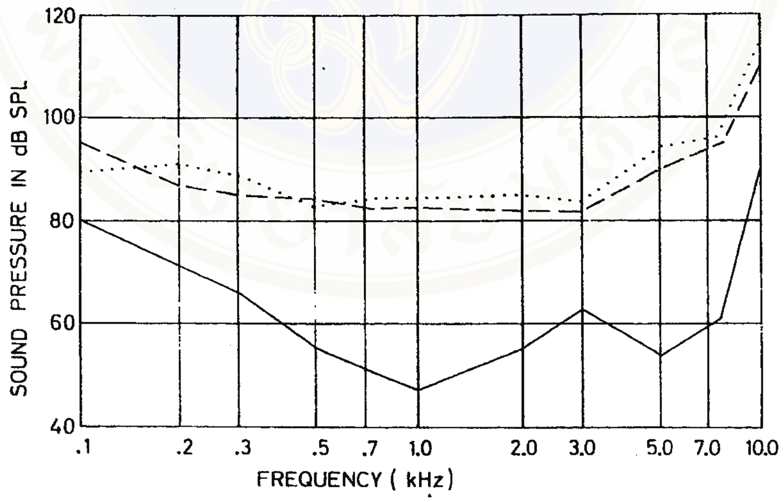


Figure 2 Sound pressure was required to obtain a certain motion of the cochlear fluid when sound reaches the tympanic membrane and the middle ear intact (solid line) compared with the case when sound reaches one cochlear window at a time (dashed line = oval window, dotted line = round window, SPL = sound pressure level) (38).

2.1 Areal ratio of the Tympanic membrane

The tympanic membrane is approximately 21 times greater in total area than is the footplate of the stapes. However, only about two-thirds of the tympanic membrane moved effective (36), it is necessary to reduce the total 21:1 ratio of areas by one-third yielding an effective size ratio of 14:1 between the tympanic membrane and the stapes footplate. This relationship can be calculated to be 22.9 dB. In effect, the greater size of the collecting surface of the tympanic membrane resulted in nearly 23 dB increases in the effectiveness of the sound transmission system to the inner ear (39, 41, 42).

2.2 Lever ratio of the Ossicular chain

Tympanic membrane vibrations are transmitted by way of the malleus to the incus. The axis of rotation of the ossicular chain is from the anterior process of the maleus through the posterior (short) process of the incus. The long process of the incus and handle of the malleus move in unison; however, the malleus handle is 1.3 times longer than the long process of the incus. This difference in length produces a 1.3:1 lever ratio or 2.5 dB of the middle ear ossicles (40, 43).

2.3 Natural resonance and efficiency

Natural resonance and efficiency refer to inherent anatomic and physiologic properties of the external and the middle ear that allow certain frequencies to pass more easily to the inner ear. The natural resonance frequency of the external auditory canal is 3,000 Hz, while that of the middle ear is 800 Hz. The tympanic membrane is most efficient in transmitting sounds between 800 and 1,600 Hz, while the ossicular chain is most efficient in transmitting sounds between 500 and 2,000 Hz. These properties produce greatest sensitivity in sound transmission between 500 and 3,000

Hz, approximately those frequencies that are most important in routine conversation (42, 43).

3. Acoustic Impedance of the Middle Ear

The main function of the middle ear is to facilitate the transmission of sound waves from air through the cochlear fluid. If sound waves act directly on the cochlear fluids, there will be a significant transmission loss of about 30 dB. This is the values of acoustic resistance (or impedance), which are determined by elasticity and density, and widely different between two medias such as air and the inner-ear fluid (34). The middle ear system serves as an impedance-matching transformer that makes it possible for the sound energy to be efficiently transmitted from the air to the cochlea (41).

Electrical analogue models of the middle ear provide a mean for understanding and predicting the response of the middle ear to a wide rang of acoustic stimuli in normal and pathologies ears. These models represent the anatomical structures of the ear by electrical components that quantitatively express the effects of mass, compliance (springiness), and resistance of each structure. The ossicles are represented as mass elements; the tympanic membrane, muscles, tendon, ligaments, and enclosed air spaces are spring elements; and friction encountered between ossicles, with in the tympanic membrane, and at the stapes-labyrinthine fluid interface are resistive elements. A block diagram of such a model is presented in Figure 3 (44).

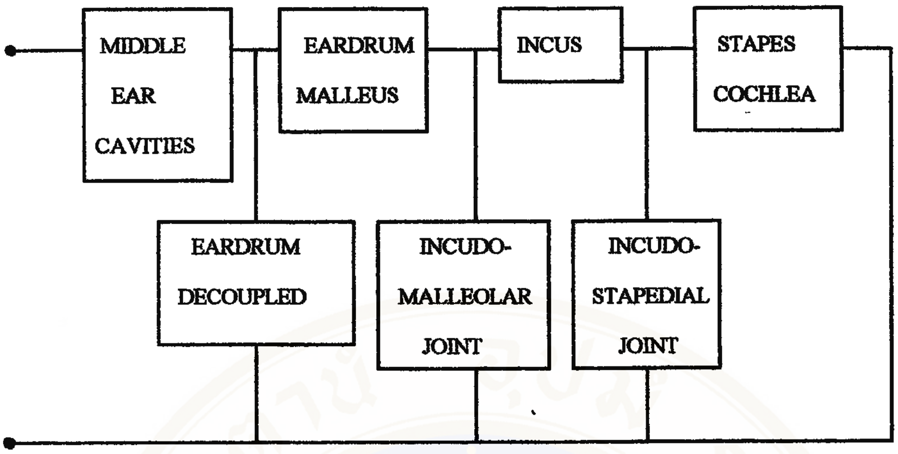


Figure 3 Functional block diagram of the human middle ear. The diagram represents one or more structures and in more complete from the model, would include a network of resistors, capacitors, and inductors (representing friction, spring elements, and mass elements, respectively). (44)

As in any other system, the impedance of the middle ear is due to its stiffness, mass and resistance. Figure 3 is block diagram of the middle ear with respect to its impedance (43). One may think of the upper row of boxes as the line of energy flow from the eardrum to the cochlea, and of the boxes coming down from them as the ways energy was shunted from the system. The first box represents the middle ear cavities, which contribute significantly to the stiffness of the system. The next two boxes, "eardrum/malleus" and "eardrum (decoupled)", should be thought of together. The former represents the proportion of sound energy transmitted from the drum to the malleus. It includes the inertia of the malleus; the elasticity of the drum, tensor tympani muscle, and malleus ligaments; and the friction caused by the strain in these structures. "Eardrum (decoupled)" is the proportion of energy diverted from the system when the drum vibrates independently the malleus, which occurs particularly at high frequencies. The labeled "incus" is the effective mass of the incus and the stiffness of its supporting ligaments. The energy lost at the two ossicular joints was represented by "incudomalleolar joint" and "incustapedial joint", which shunted energy off the main line of the diagram. The last box shows the effects of the stapes, cochlea and round window membrane contribute to the stiffness component. Most of the ear's resistance is due to the cochlea. Zislocki (44) has pointed out that a major effect of this resistance was to smooth out the response of the middle ear by damping the free oscillation of ossicular chain (41, 43, 44).

Metz [(cited in Shanks et al (29)] was the first to apply the concept of acoustic impedance to clinical audiology. Very simply, acoustic impedance is a measure of the opposition to the flow of acoustic energy into the middle ear transmission system. Conversely, acoustic admittance is a measure of the ease with which acoustic energy flows into the middle ear. Although technically incorrect, the term compliance has been used interchangeably with admittance. Acoustic immittance is a generic term used to refer to either acoustic impedance or acoustic admittance measurements that describe the opposition to sound flow through a system as. All currently available instruments measure acoustic admittance as well as in this study. The following will focus on admittance measurements.

The admittance of a system, whether electrical, mechanical or acoustical, is defined as the complex ratio of a velocity to a force. The admittance ($|Y|$) of a system can be measured by applying a known force (F) and measuring the resultant velocity (V). If the same force is applied to two objects, the object with the higher admittance will move at a faster velocity than lower admittance object (45, 46). The ear canal and middle ear transmission system contain mechanical and acoustic elements alike.

As demonstrated in Figure 4, three elements compliance, mass and friction with in a mechanicoacoustic system offer admittance [cited in Margolis et al (45)]. The time or phase relation between an applied force and the resultant velocity is different for each of three elements.

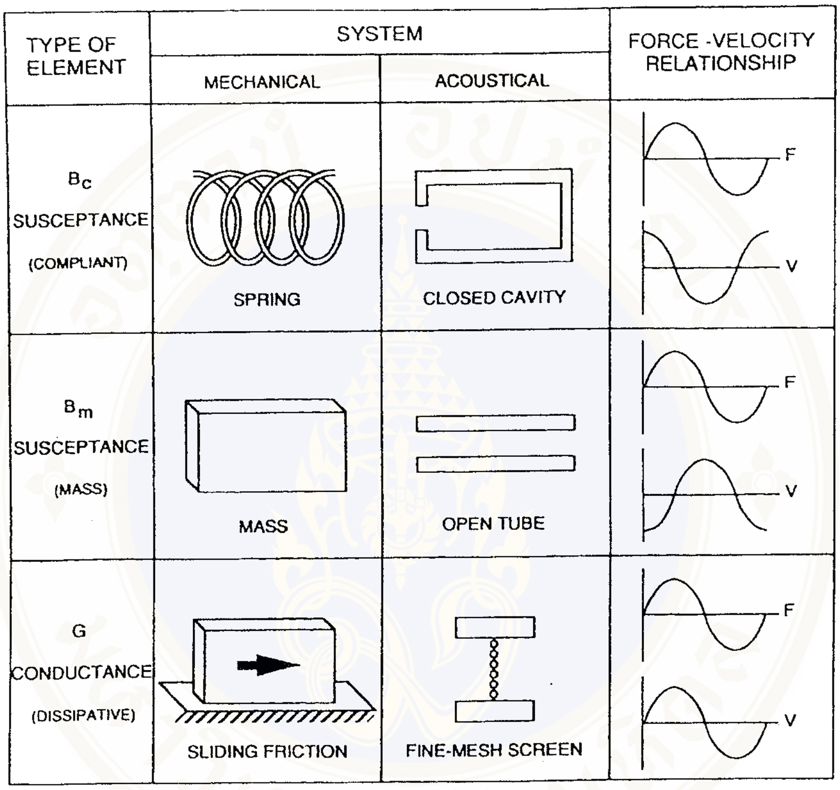


Figure 4 Diagram showing the force-velocity relationship for the three elements, compliance, mass and friction, which contributes to the admittance of a mechanioacoutic system (45).

3.1 Spring

A spring, an enclosed volume of air, is an example of compliance elements. The eardrum, ligaments and tendons in the middle ear function like mechanical springs: the enclosed volumes of air the ear canal and middle ear space represent acoustic compliances. Figure 4 depicts the force-velocity relation for a compliance element. When a maximum force is applied to compress the spring, the velocity of the spring is zero; when the force is removed, the spring will go back to its original position at a maximum velocity. The force lags the velocity by a quarter of a cycle, or by 90°. The admittance offered by a compliant (or conversely, stiff) element is called compliant susceptance and denoted Bc (46,47,48).

3.2 Mass

The pars flaccida of the eardrum, the ossicles and the perilymph in the cochlea are examples of mechanical masses; an example of an acoustic mass is a plug of air that moves as a unit in a constriction or in a narrow, open tube. The narrow lumens in the mastoid air cell system represent acoustic masses. The force-velocity relation of a mass element also is depicted in Figure 4. When a maximum force is applied to a mass element or heavy object, the velocity of the mass will be zero until the inertia is overcome. The force, then, can be withdrawn and the mass will move forward at a maximum velocity in the direction of the applied force. The force leads the velocity by a quarter of a cycle, or by 90°, for a mass element. The admittance offered by a mass element is called mass susceptance and denoted –Bm. For compliance and mass element, the applied force and resultant velocity are out-of-phase with each other, but the velocities of the two objects are in the opposite directions for the same applied force. These two elements are said to react 180° out-of-phase with each other. Compliant susceptance (Bc) and mass susceptance (-Bm) comprise the out-of-phase components of acoustic admittance (46,47,48).

3.3 Friction

The third element dissipates or absorbs acoustic energy because of friction. Mechanical friction occurs in the membranes, tendons, and ligaments of the middle ear, whereas acoustic resistance occurs because of the velocity of air. For a friction element, force and velocity are in phase. Conductance, denoted G, is the in-phase component of admittance (46, 47).

The acoustic admittance measured at the probe tip, represents the combined effects of the ear canal, all middle ear structures, and to a small extent, even cochlea; it is not simply a measure of eardrum mobility. The measured admittance depends on the stiffness, mass and friction at above offered by all these structures in the external and middle ear and on the frequency of the probe tone used to make the measurements. Because acoustic admittance is a complex vector quantity, two numbers are required for its complete specification. Figure 5 shows that the point in the complex plane can be described either in polar or in rectangular notation. In polar notation, the magnitude or length of the admittance vector (| Y |) and the angle (ø) between the vector and the x-axis are measured: | Y | is an absolute value and therefore has no sign; in contrast, phase angle (ø) can be positive (to signify a stiffness-controlled ear) or negative (to signify a mass-controlled ear). Most of the admittance instruments that incorporate a single, low frequency probe tone of 226 Hz measure only the magnitude of acoustic admittance, (| Y |). Since normal and even diseased middle ears are so stiffness dominated at low frequencies, the contributions from mass and friction are ignored. Under this conditions, the admittance vector lies along the positive susceptance axis at an angle of 90° (47).

A few commercially available instruments report the admittance data in rectangular form (Figure 5). These instruments display the out-of-phase component, acoustic susceptance (B) (the algebraic sum of mass and stiffness), and the in-phase component, acoustic conductance (G), which is related to the friction. This form of expression is most common in instruments that use high frequency or multiple frequency probe tones (45, 47, 48).

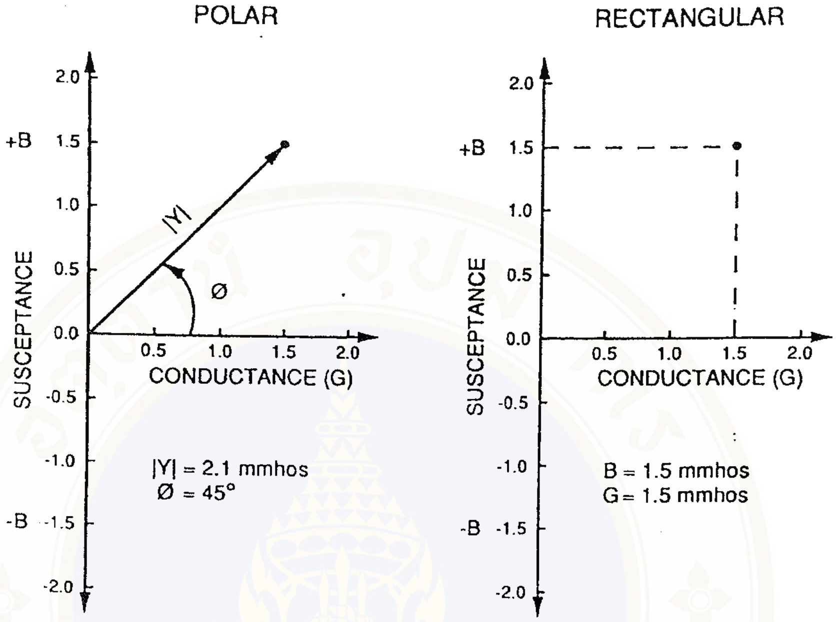


Figure 5 Complex acoustic admittance represented in polar notation [admittance magnitude (|Y|) and phase angle (ø)] and in rectangular notation [susceptance (B) and conductance (G)] (45).

4. Clinical Applications of Tympanometry

The first tympanograms, reported by Terkilden and Thomsen in 1959 [(cited in Margolis et al (23)], were developed originally for estimating middle ear pressure. In addition, much of the terminology and many of the measurement techniques still used today were introduced in this landmark paper by Terkildsen and Thomsen. They used a probe tone frequency of 220 Hz to make the measurements, and although this probe frequency was chosen arbitrarily, a 220 Hz probe tone has persisted as the primary frequency on all acoustic immittance instruments (23, 45).

Tympanometry shapes vary markedly, depending on the admittance component measured and on the probe frequency used to make the measurements. The most commonly used tympanometric procedure is admittance magnitude (| Y |) measured at 226 Hz or low probe tone frequency. Methods of analysis used for two-component admittance measurements (acoustic susceptance and acoustic conductance) is at 678 Hz or high probe tone frequency (46, 48,49).

4.1 Low Probe Tone Frequency at 226 Hz

Figure 6 shows a typical admittance (| Y |) tympanogram recorded using a 226 Hz probe tone. Changes in acoustic admittance that are being measured as the air pressure in the sealed ear canal is varied over a maximum range of +400 to -600 daPa (1 daPa = 1.02 mm H_2O) (50). At high positive (for instance, =200 daPa) and high negative (for instance, -300 daPa) pressures, the eardrum becomes extremely stiff. At these pressures, little acoustic energy flows into the middle ear, and the admittance decreases to a minimum. As the air pressure in the ear canal approaches atmospheric pressure (0 daPa), there is an increasing in the flow of energy into the middle ear, and admittance also increases to a maximum or peak value. The maximum flow of energy into the middle ear occurs when the pressure on both sides of the eardrum are equal. The following three values demonstrated in Figure 6 can be calculated from the tympanogram: middle ear pressure, ear canal volume and peak compensated static admittance.

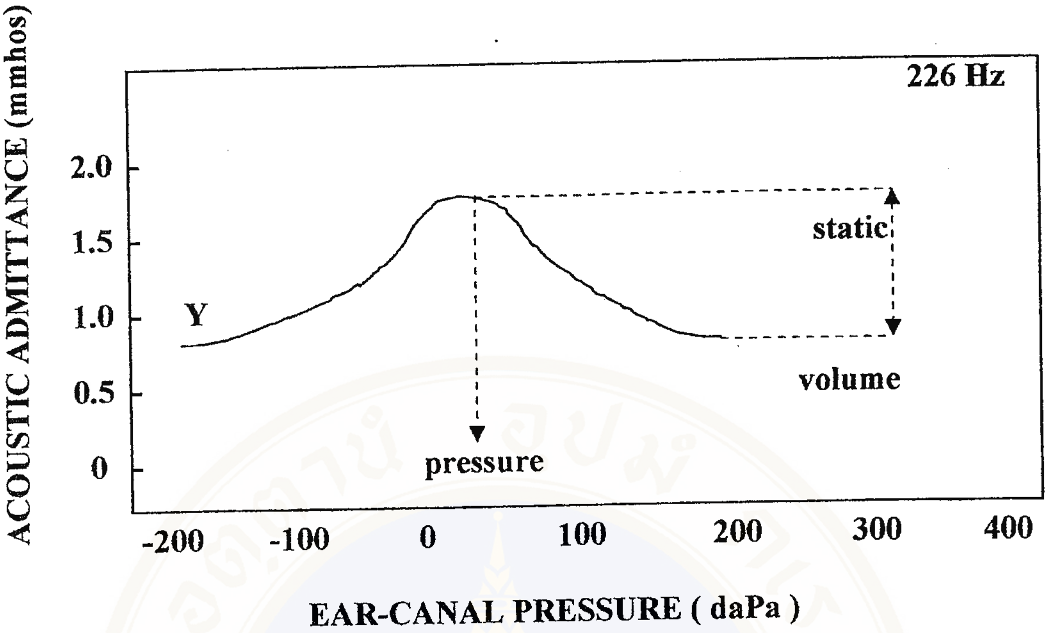


Figure 6 Tympanometric peak pressure (TPP), ear canal volume and peak compensated static admittance demonstrated on a normal 226 Hz tympanogram (47).

4.1.1 Tympanometric Peak Pressure.

The peak of tympanogram occurs when the pressure in the ear canal is approximately equal to the middle ear pressure. If the eustachain tube is functioned properly, the peak will occur near 0 daPa. However, if there is negative pressure in the middle ear, the tympanic peak will occur while a similar negative pressure corresponding to the tympanometric peak, providing an estimate of middle ear pressure. Normal middle ear pressure typically falls between +50 and -100 daPa (23, 45).

4.1.2 Physical Volume Test.

The volume of the ear canal can also be estimated from the tympanogram. The admittance recorded at the probe tip (Y_{probe}) represents the sum of the admittance of ear canal volume (Y_{ec}) and the middle ear (Y_{me}); that is,

$$Y_{probe} = Y_{ec} + Y_{me}$$

At high positive or negative pressures, however, the eardrum becomes extremely stiff and the admittance of the middle ear is recorded to 0, or $Y_{probe} = Yec + 0$. The admittance value measured at a high positive pressure (such as 200 daPa), therefore, provides an estimate of the ear canal volume only. This measurement is called the physical volume test (PVT). If the eardrum is intact, the volume estimate at 200 daPa of the ear canal only will be averaged 0.7 cm^3 in children, and to 1.1 cm^3 in adult males (8). If eardrum is perforated, the volume estimate will be >2.0 cm^3 in children and >2.5 cm^3 in adults, because that the volume now will includes the ear canal plus the middle ear space and mastoid air cell (45,30). This large volume typically averages 8 cm^3, but the maximum value that most admittance instruments will measure is 5 cm^3. A volume estimated is especially useful when a flat tympanogram is recorded.

4.1.3 Amplitude Admittance Tympanogram.

The admittance of the middle ear without the effects of the ear canal also can be estimated from the tympanogram. Recalling that the admittance recorded at the probe tip represents the sum of admittance of the ear canal and the middle ear. When the admittance of ear canal at 200 daPa is subtracted from the admittance value measured at the probe, the admittance of the middle ear alone can be determined; that is,

$$Yme = Yprobe - Yec$$

This calculation is termed peak compensated static admittance. Peak static admittance at 226 Hz averages 0.5 acoustic mmhos in children and 0.8 acoustic mmhos in adults, with 90% of normal persons falling between 0.2 and 1.4 acoustic mmhos (30). The clinical use of static admittance has been controversial because of large range of normal variability and overlap with the pathological population.

4.1.4 Tympanometric Width and Gradient.

Tympanometric width (TW) is the width of the tympanogram (in daPa) measured at half of the height from the peak to the tail (50, 51). Tympanometric gradient is a measure that refers to the slopes of the sides of the tympanogram near the region of the peak pressure.

Another calculation introduced in recent years is a measure of the slope or width of the tympanogram at the peak. Shallow or broadly peaked tympanograms have been associated with middle ear effusion (18). Several methods for calculating tympanometric gradient or width have been suggested; the tympanomeric width and gradient that are most frequently used methods are demonstrated in Figure 7 (45, 53, 54). The ASHA (51) guidelines, suggested that widths exceeding 235 daPa in infants, 200 daPa in older children, and 300 daPa in children with a high prevalence of middle ear disorders should be considered abnormal.

Figure 7A demonstrates a calculation of tympanometric width, or the ear canal pressure range corresponding to a 50% reduction in static admittance; tympanometric width is reported in daPa. Normal tympanometric width ranges from 50-150 dapa (8).

Figure 7B demonstrates a calculation of tympanometric gradient, which is defined as the change in admittance between the peak value and the mean admittance value, corresponding to a pressure interval of 50 daPa on the negative (Yn) and positive (Yp) sides of the peak. Although tympanometric width has been shown to be more sensitive than gradient to middle ear effusion, gradient is more commonly used by equipment manufacturers (54).

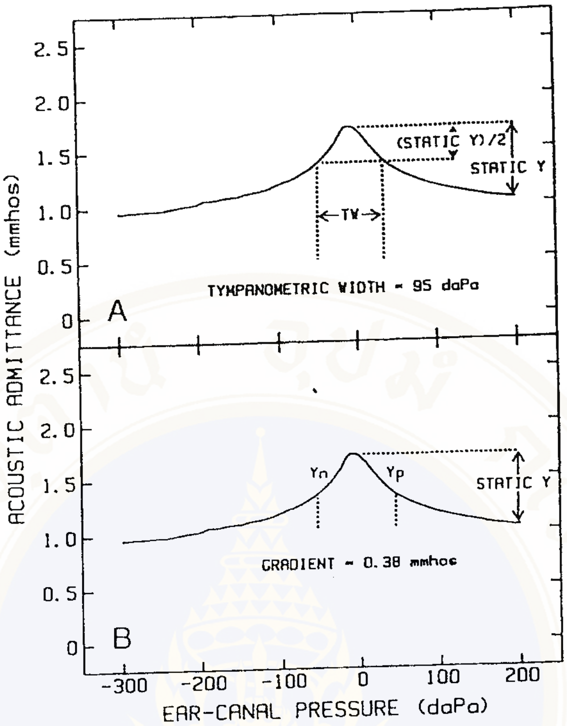


Figure 7 Calculation of tympanometric width in daPa (A) and gradient in acoustic mmhos (B) (45).

4.1.5 Type of 226 Hz tympanogram. Figure 8 demonstrated the most popular method for categorizing the shapes of 226 Hz tympanograms. Liden and Jerger (20, 21) identified the five basic types of 226 Hz tympanogram described.

Type A is a normal tympanogram. The peak admittance is normal in amplitude (that is, static) and in pressure. Peak admittance near 0 daPa is consistent with a normally functioning eustachain tube. There are two subdivisions of the Type A tympanogram.

Type As is similar to the normal tympanogram except that the peak amplitude or static admittance is reduced. This is typical of an abnormally stiff middle ear caused by otoscerosis .

Type Ad also demonstrates a normal tympanometric shape and middle ear pressure, but peak admittance is abnormally high. This increase in amplitude is associated with ossicular discontinuity or eardrum pathology, such as that found in neomembrane or tympanosclerotic plaques.

Type B is a flat tympanogram typical of middle ear effusion, eardrum perforation, patent pressure-equalization tube, or impacted cerumen. Measures of physical volume can help to differentiate among these conditions.

Type C is characterized by a peak at extreme negative pressures, typically less than -150 daPa. Recalling that the maximum transfer of acoustic energy occurs when there is a zero pressure differential across the eardrum. A negative peak on the tympanogram suggests a similar negative pressure in the middle ear (45).

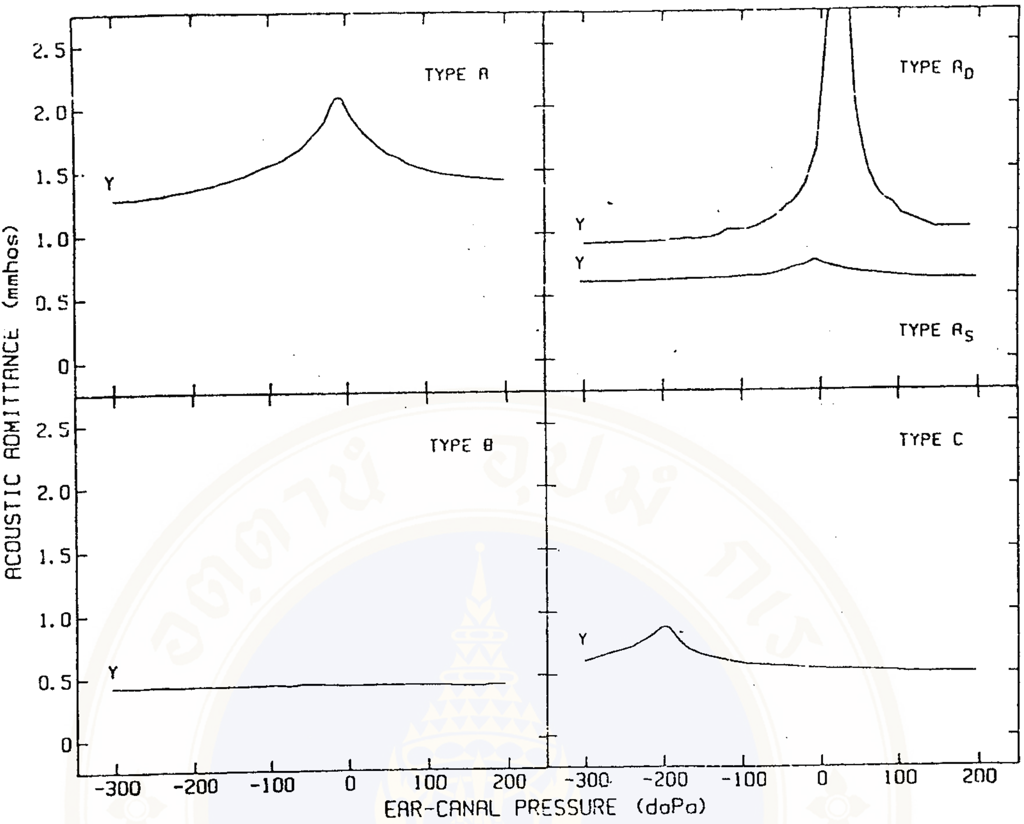


Figure 8 Five basic type of 226 Hz admittance tympanograms described by Liden (21) and Jerger (20).

4.2 High Frequency Probe Tone at 660/678 Hz

Vanhuyse et al (35) developed a classification scheme that counted the number of peaks (positive and negative) in the susceptance and conductance (B-G) tympanograms. This model was called Vanhuyse Model, which explained the variety of normal susceptance and conductance tympanograms recorded at high frequencies probe tone. The model demonstrated that marked alterations in the shapes of the susceptance and conductance tympanograms (Figure 9). They identified four patterns of admittance tympanograms that were classified according to the number of positive and negative peaks (extrema) exhibited in the susceptance and conductance tympanograms.

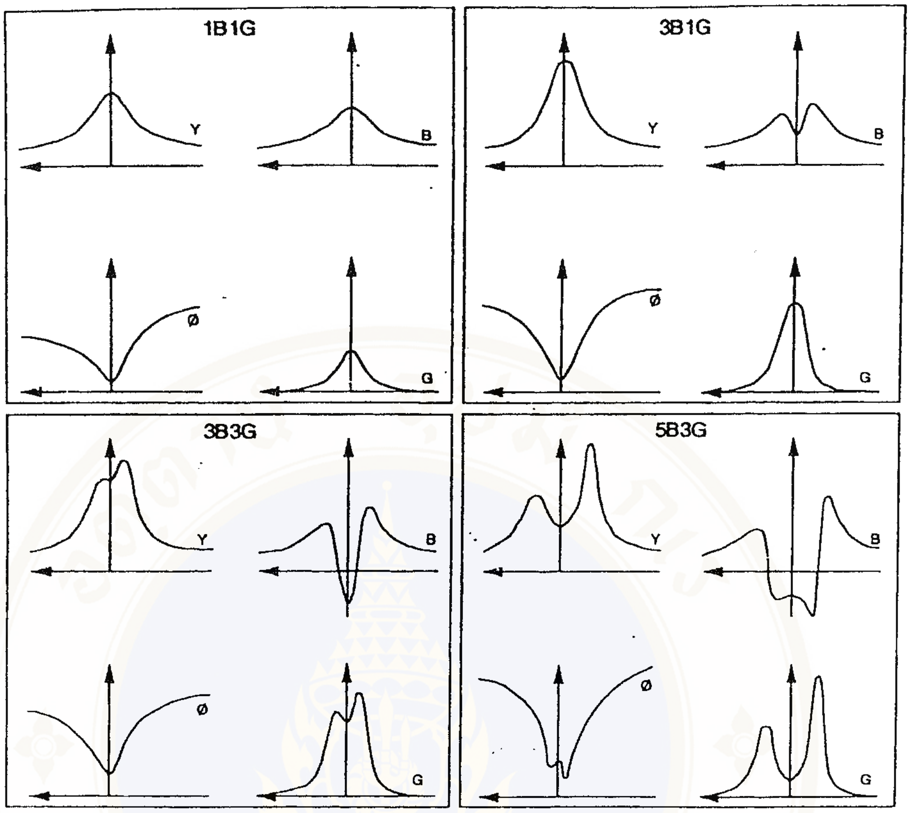


Figure 9 Four patterns of normal 678 Hz admittance (| Y |), phase angle (ø), susceptance(B) and conductance (G), tympanograms described by Vanhuyse et al (35).

4.2.1 Type 1B1G. In Type 1B1G tympanogram, both the susceptance (B) and conductance (G) tympanograms are single peaked; admittance magnitude (| Y |) and phase angle (ø) tympanograms are single peaked. Clinical experience with a normal adult population shows that the static susceptance value should be less than or equal to the static conductance value. The reverse relation is found that when susceptance is greater than conductance at 678 Hz then the ear is abnormal stiff (29).

4.2.2 Type 3B1G. In Type 3B1G tympanogram, the conductance tympanogram is single peaked, but the susceptance tympanogram has a central notch due to a positive shift in the reactance tympanogram. Although reactance remains negative for all ear canal pressures, the absolute value of reactance is less than resistance near the peak and greater than resistance at extreme ear canal pressures. The central minimum in the susceptance tympanogram corresponds in pressure location to the peak reactance. Two maximum in the susceptance tympanogram occur at pressures where the reactance and resistance tympanograms intersect. The positive susceptance maximum is higher than the negative maximum due to the asymmetry of the resistance tympanogram. When peak reactance is near zero, the admittance | Y | tympanogram also may be notched (29, 30, 52).

4.2.3 Type 3B3G. In Type 3B3G tymapnogram, the susceptance and conductance tympanograms have three extremas. This tympanometric pattern occurs when peak reactance is positive, indicating that the middle ear is mass controlled. When the ear is mass dominated, the center susceptance value falls below the tail value, or stayed differently, the peak compensated static susceptance is negative. The maximum in the conductance tympanogram occurs near the points where reactance equals zero. A notched conductance tympanogram generally occurs only in an ear which is mass controlled. The admittance tympanogram is also notched in the 3B3G pattern (29).

4.2.4 Type 5B3G. In the Type 5B3G tympanogram, the susceptance tympanogram contains five peaks and the conductance tympanogram exhibits three. The middle ear is mass controlled, and the peak reactance is greater than resistance. The maximum in the conductance tympanogram occurs at the point where reactance is zero. The maximum reactance value corresponds with the central peak in the susceptance tympanogram. The phase angle (ø) tympanogram also should develop a notch (29, 45).

Abnormal Tympanograms Shapes. Van Camp et al (55) developed the following rules for defining abnormal notching at 678 Hz:

1. The pressure difference (in daPa) between the outermost maxima exceed 75 daPa in 3B3G tympanograms, and 100 daPa in 5B3G tympanogram.
2. More complexly notch than a 5-B pattern.
3. More complexly notch than a 3-G pattern.

Figure 10 shows three examples of abnormal 678 Hz tympanograms in comparison with a normal 1B1G pattern. The corresponding | Y | tympanograms at 226 Hz also are shown to demonstrate how varied tympanometric shapes are at 678 Hz in comparison with 226 Hz. The first quadrant shows a normal 1B1G tympanogram; static susceptance is less than static conductance. The second quadrant labeled “otosclerosis” depicts abnormal stiffness at 678 Hz because static susceptance is greater than static conductance. The third quadrant, labeled “resolving ototis media”, shows a case that is abnormally mass controlled because the notch width is greater than 100 daPa. The example in the fourth quadrant, labeled “disarticulation”, is too complexly notched (greater than a 5B pattern) and again is too broadly notched (45).

4.3 Choice of Probe Tone for Tympanometry

4.3.1 Tympanometry in Adults and Children. Conventional tympanometry use to a low frequency (usually 226 Hz) probe tone. Low frequency probe tone tympanometry is a reliable indicator of many middle ear pathologies in adult and children. For example, the sensitivity and specificity of tympanometry for diagnosing middle ear effusions are 90-95% and 70-80% respectively (56,57,58). A normal low frequency tympanogram has a single admittance peak and is referred to as a Type A in the Jerger/Liden classification scheme or a 1B1G (one susceptance, B, and one conductance, G, peak) in the Vanhuyse classification scheme (55). As the tympanometry probe, tone frequency is increased and approached, the point of middle ear resonance (where mass and stiffness are equal), the shape of the tympanogram becomes more complex, and notching occurs.

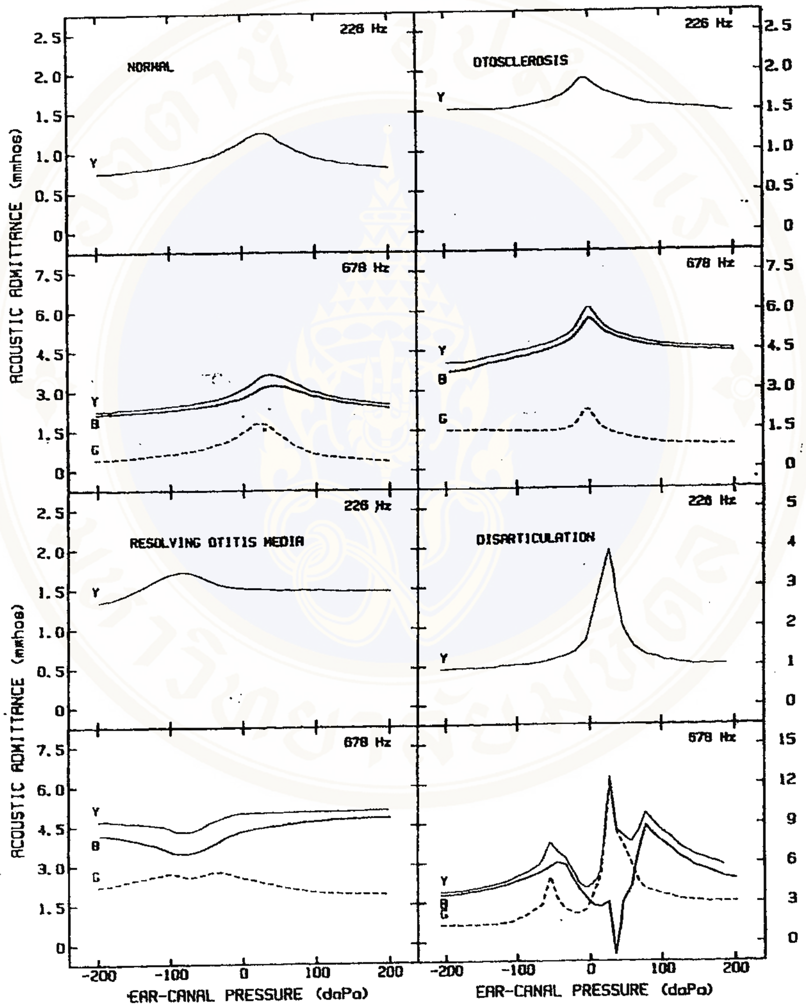


Figure 10 678 Hz susceptance (B), conductance (G), and admittance (| Y |) tympanograms in comparison with the corresponding 226 Hz admittance tympanograms in one normal and three abnormal patients with otosclerosis, resolving otitis media and ossicular disarticulation (45).

4.3.2 Tympanometry in Neonates and Young Infants. In infants' ears, there are relatively greater mass contributions to middle ear impedance. Low frequency probe tone tympanograms are therefore more likely to show notching or complex patterns in infants (17, 23, 24, 25, 56, 57).

Some insight into the physical differences between neonates and adult ears were contributed by studies that neonate tympanograms with two-component instruments were employed more than the traditional 220 (or 226) Hz probe frequency (28,64). These results suggested that (i) unlike the adult, the neonates ear was characterized by a high resistive component at 220 Hz, (ii) the impedance phase angle of the neonate ear at 220 Hz was close to 0° rather than the -70° phase angle that characterizes the adult ear, and (iii) the effect of frequency on tympanometric shapes was not predicted by the Vanhuyse model.

Holte (58) recorded normal, neonate tympanograms longitudinally over the first 4 months of life. Figures 11 and 12 present tympanograms from a normal neonate at 2 days and 93 days, respectively. At 2 days, the 226 tympanograms appear to be a 1B1G pattern. The higher conductance relative to susceptance suggests an admittance phase angle less than 45°, which would be abnormal in older children and adult. At higher probe frequencies, the conductance and susceptance tympanograms are irregular multipeaked patterns. The resistance and reactance tympanograms do not appear to be helpful in understanding the tympanometric irregularities, as they are in adult subjects with various middle ear pathologies.

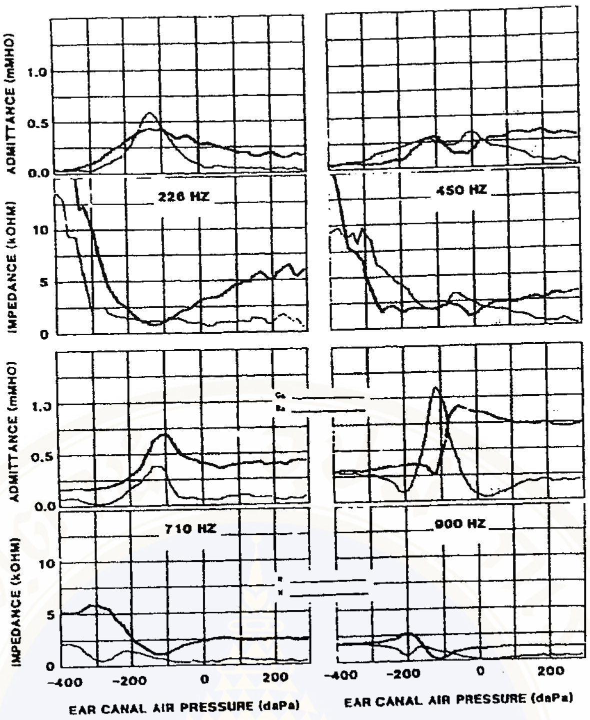


Figure 11 Admittance and impedance component tympanograms from a 2-day-old infant at four probe frequencies (58).

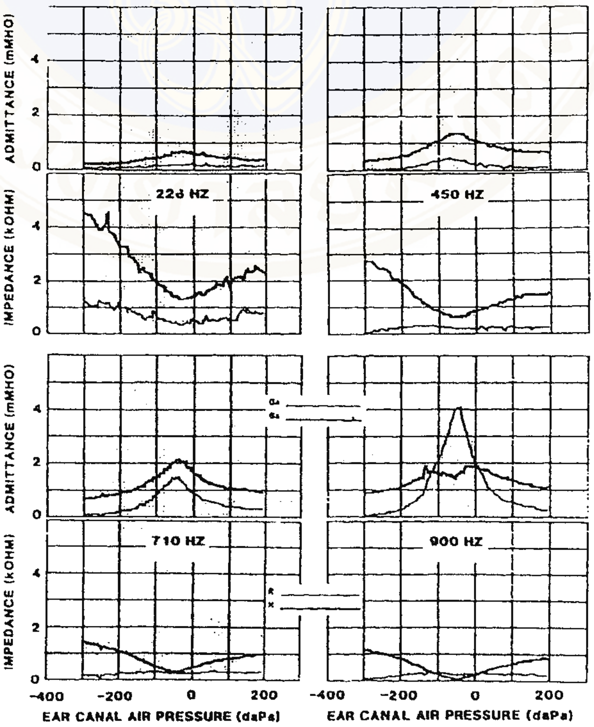


Figure 12 Admittance and impedance component tympanograms from a 4 month old infant (58).

The unusual characteristics of neonate tympanograms have been attributed to an incomplete development of the ear canal wall (18, 59). The tympanic ring of neonates is not yet ossified. Consequently, the ear canal wall is not rigid but move in response to ear canal pressure changes. It is unlikely that the multipeaked neonate tympanograms at 220 Hz are due to the characteristics of the ear canal for the following reasons. First, the expected effect of a compliant ear canal wall is an increase in volume as ear canal air pressure changed from negative values, providing monotonically increasing susceptance tympanograms (27). Second, Holte (58) reported that there was no relationship between the occurrence of multipeaked 226 Hz tympanograms in neonates and otoscopically observed ear canal wall mobility. It appeared that the differences between neonate tympanograms and those obtained from older infants and adults, cannot be completely attributable to the development of ear canal. It was more likely that neonate tympanograms were substantially affected by the condition of middle ear at birth. Paparella et al (60) reported that a significant degree of unresolved mesenchyme in the middle ears of infant temporal bones. This finding may explain the high resistive component of the impedance of the neonate ear.

Below 4 months of age, low frequency probe tone tympanogram is clearly immature (17). There are still maturational differences in admittance between 6 month olds and adults (28).Meyer et al (25) showed an increase in middle ear resonance in one infant who was followed longitudinally up to 200 days (almost 7 months). Above seven months of age, there was evidence that low frequency probe tone tympanometry was efficient in detected middle ear effusion (18, 61, 62). Keefe and Levi (20) reported that the acoustic response properties of the external and middle ear varied significantly over the first two years after birth. However, they have noted false negative results used conventional tympanometry in infants up to 14-16 months of ages. These infants with high frequency tympanograms were consistent with effusion that was diagnosed otoscopically following failed OAE screening. Based on current literature high frequency probe tone tympanometry should be used routinely up to at least 7 months of age (63).

4.4 Interpreting High Frequency Tympanometry Results in Neonates and Young Infants

At 800 Hz probe tone, Hirsch et al (23) found that 6 of 12 ears with flat (<0.1 mmho) admittance tympanograms and absent 800 Hz probe tone reflexes failed at 30 dBSPL of ABR screen. Zapala (64) found that infants though having normal middle ears based on OAE and ABR testing (including 39 ears with sensorineural hearing loss) had great variability of 1000 Hz admittance tympanometric shapes. All had a point of maximum admittance between +35 and -45 daPa and gradients less than 130 daPa measured using the Grason Stadler GSI 33 immittance meter. However, normal infant middle ears showed a monotonic decrease in susceptance as air pressure, was decreased from +200 to -200 daPa (65,66), but this pattern could also be seen in ears with middle ear effusion (19,63). Using a simple criterion of any peaked pattern at 678 and 1000 Hz as a "pass", Rhodes et al [(cited in Wiley et al (48)] found very poor agreement between otoscopy and tympanometry in 87 newborns (43% of ears failed otoscopy, less than 1% failed high frequency tympanometry). The three infants that failed the 1000 Hz tympanogram also failed ABR, OAE and acoustic reflex tests.

Because of the great variability of tympanogram shape, the following tympanometric criteria for middle ear "normality" have been used in high frequency tympanometry studies investigating middle ear function in infants: (i) peak 660 Hz susceptance greater than 0.4 mmho (19) or greater than 0 mmho (27), (ii) mean 660 Hz susceptance (between ± 300 daPa) greater than 0.16 mmho, (iii) notching in the 660 Hz susceptance tympanogram (19), (iv) a discernible susceptance or conductance peak at 678 or 1000 Hz (45), (v) a double peaked 1000 Hz tympanogram and a peaked 678 Hz tympanogram with the peak occurred at a pressures more than -100 daPa (29,67).

5. Test Variables in Tympanometry

Successful clinical application of tympanometry depends on an appreciation of the influences of test variables including:

5.1 Direction of Ear canal pressure Change

Tympanometric data can be obtained by varying the air pressure in the ear canal in a positive to negative (+/-) direction (descending) or in a negative to positive (-/+) direction (ascending). Both tympanometric amplitude and shape were affected by the direction of ear canal pressure changes (23, 56, 68, 69, 70). Most of these studies indicated that peak compensated static admittance was greater (impedance was lower) for tympanograms recorded in the ascending direction than in the descending direction of pressure change. Although the direction effect may be statistically significant, the change in tympanometric amplitude does not appear to be clinically significant, particularly for low frequency probe tone.

Tympanograms obtained in the ascending direction of pressure change also tend to have more complex configurations (i.e., notches), especially at higher probe tone frequencies than do tympanograms obtained in the descending direction (52,68,69,71).

Wilson and Shanks (72) reported that 38%-46% of normal adults had notched 678 Hz tympanograms when the ascending pressure direction was used, whereas only 21%-25% of the subjects had notched tympanograms when the descending pressure direction was used.

The pressure direction, also affects the shapes and values of tympanograms. For single peaked tympanograms, recording in the descending direction usually results in lower admittance (high impedance) values than the ascending direction (52). The pressure direction also affects the maximum reactance value at tympanic membrane, therefore the shapes of all other immittance tympanograms. This effect is illustrated in Figure 13 (52, 69).

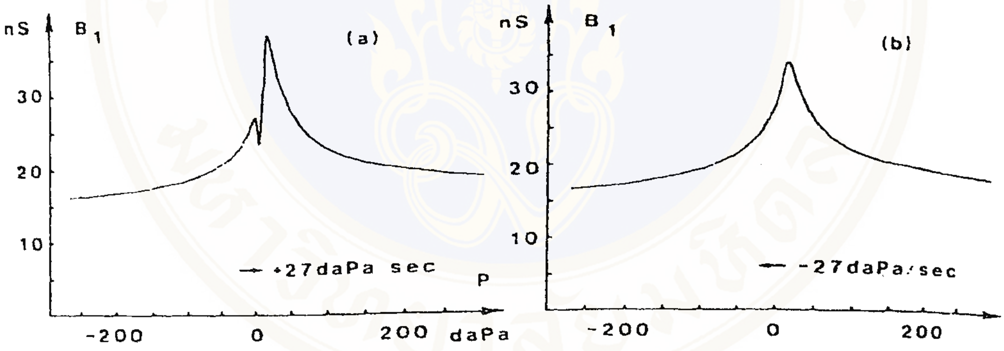


Figure 13 Susceptance tympanogram at 660 Hz recorded from the same ear, both at 27 daPa/sec, but with opposite directions of ear canal pressure change: (a) recorded ascending and (b) recorded descending (52).

5.2 Rate of Ear-canal pressure Change

In addition to direction of pressure change, rate of pressure change can affect tympanometry. The primary effect of rate is on peak static admittance; i.e. peak static admittance increase as rate of pressure change increases (70).

Thompson and Robinette (73) reported that temporal characteristics of these tympanometry varied greatly and that digital systems tended to be faster than analog devices. The temporal response of the immittance unit can confound measures of temporal characteristics (e.g. acoustic reflex response), or affect the tympanometric measures previously discussed.

Feldman et al (74) reported that higher admittance at a rate of 75 daPa/s than at 25 daPa/s; amplitude was expressed in arbitrary units and could have been affected substantially by ear canal volume.

The rate of ear-canal pressure change also can have an effect on tympanometric data. First, because of the nonlinear behavior of the middle ear, the immittance measured in the ear canal may vary with the rate of pressure change. Second, the temporal response of the recording instrument at fast rates of pressure change may produce a measurement artifact disguised as a rate effect on tympanometric measurement. These effects influence the tympanometrically measured middle ear immittance in opposite ways; the former results in higher admittance, whereas the latter produces lower admittance (23,73).

5.3 Number of Tympanometric Runs

Wilson et al (72) reported that consecutive tympanometric runs appeared to change the characteristics of tympanograms in two ways. First, the magnitudes of admittance peaks increase with an increase in the number of tympanometric runs.

Second, the shapes of tympanograms become more complex with an increased number of runs. This effect is illustrated in Figure 14. The acoustic impedance of the ear decreases with consecutive tympanometric runs.

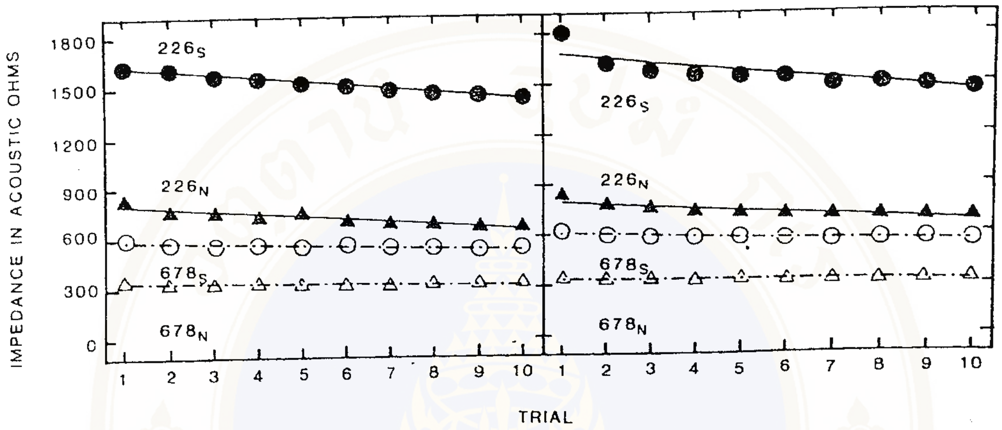


Figure 14 The acoustic impedance of the ear decreases with consecutive tympanometric runs (72)

The amplitude and complexity of admittance tympanograms for a constant probe position indrawn as the number of successive tympanometric runs increases. Changes in conductance and susceptance peak amplitude of 15%-30% across successive tympanometric recorded have been reported (72, 74, 75). These studies reported that the greatest change in amplitude occurred during the first three to five tympanometric runs. The incidence of notched also increased with successive tympanometric runs. These findings have been attributed to change in the viscoelastic properties to the tympanic membrane (75).

5.4 Subjects variables

Sprague et al (77) reported that tympanometric shapes seen in infants were differenced from those seen in adults. In adults with healthy middle ear systems, virsually all tympanograms recorded at 226 Hz showed the type of 1B1G. In infants, by contrast, the 1B1G pattern was the least common. In stead, up to 83% of the susceptance (B) tympanogram recorded from infants under the age of 130 hours showed notch tympanogram. The tympanometric patterns seen in infants also included irregular shapes, B and G peaks occurred at different pressure locations, and monotonically rising acoustic susceptance tympanogram. As infant age group, they showed fewer complex tympanometric shapes for the 226 Hz tympanograms (17, 77).

Holte et al (17) reported that, by the age of 2 months, healthy infants yielded tympanograms at 226 Hz showed that the 3B3G patterns, and by the age of 4 months, all of infants yielded tympanograms showed 1B1G. Because the infant ear canal was cartilaginous, it cannot be modeled as a hard wall cavity as it adults. Consequently, the models that have been developed for adult ears mat not apply. More data are needed on the ears of infants with confirmed middle ear disease before we know the best way to distinguish normal from pathological ears in this important group of patients (17).

Some of the variability in amplitude values tympanogram can be attributed to variability across different clinical populations. There are significant differences in amplitude admittance tympanogram by gender; woman have lower amplitude values than men (40, 79, 80). There are also significant changes in amplitude values with age; children have lower amplitude values than adults (81).

In addition, Wiley et al [cited on (40)] suggested that after adulthood, however, the amplitude of tympanogram values do not change significantly with age through the age of 90 years, although the gender difference remains.

5.5 Instrument effect

As the rate of pressure change increases, the rate of immittance change increases, and thus, the recorded device is more likely to lag the rapidly changed signal that has been measured. The temporal response of recorded device is more likely to lag the rapidly changing signal being measured. If the temporal response of the recorded device is slower than the rate of signal-level change being measured, then an increase in rate will reduce the amplitude of tympanometric peaks and artifactually decrease the admittance estimate. The manufacturer for each instrument should specify the maximum rate of immittance change that can be recorded accurately.

Most available studies on rate of ear canal pressure change are performed using commercially available instrument capable of changing pressure at rates of 12-75 daPa/s (68, 69, 72, 75, 76). New screening instruments, however, are being introduced as various vary pressure at rates up to approximately 600 daPa/s. These high rates of pressure change have great clinical appeal to those testing infants and children and to those involved in screening programs (76).

CHAPTER III

MATERIALS AND METHODS

1. Subjects

The subjects for this study were 80 full term neonates born from the postpartum ward at Ramathibodi hospital (40 male and 40 female) with age ranged from 2 to 7 days after birth. Al subjects were considered as full term neonates diagnosed by skilled pediatrician and based on a gestational age of greater than 37 weeks. All subjects needed to pass normal responses on the TEOAEs testing in both ears to verity normal middle ear and inner ear function (56,81).

Newborn neonates who had any risk factors of hearing impairment by criteria of Joint committee on Infant Hearing, 1991(6): (Appendix A were excluded from this study).

2. Instruments

The instruments used in this study were:

2.1 Acoustic Immittance Instrument-Virtual 310

2.2 The Otodynamic OAEs analyzer, model ILO 096 V5.

3. Method

All subjects' parents underwent an interview for all pertinent case history informations and signed in consent forms permitting their babies to serve as subjects.

All measurements, which obtained for approximately 60 minutes were performed in a sound treated room at Ramathibodi Hospital. All normal newborn babies were received an otoscopic examination and TEOAEs testing. During measurements of TEOAEs and tympanometry, they were placed in supine position on a comfortable bed while they were naturally asleep after feeding or in a quiet state, in order to reduce restlessness.

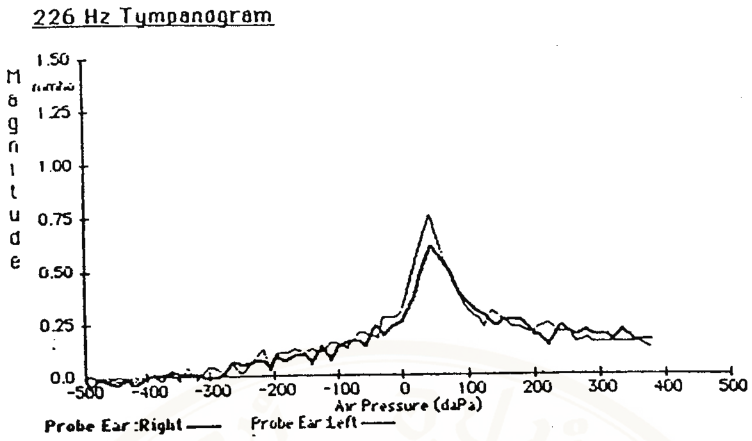
3.1 TEOAEs recording

Transient Evoked Otoacoustic Emissions (TEOAEs) screening hearing threshold were performed using the Otodynamic Analyzer ILO 96 V-5 . The Quick Screen mode was used in response analysis within a time window from 2.5 to 12.5 msec after the stimulus onset. The stimulus was a click with an electrical duration of 80 µs. The gain of the ILO 96 OAE system was adjusted to present stimuli at a peak level of 80 ± 3 dBSPL. The neonate probe (No. 8IA711006) with an appropriate size of a rubber probe tip was sealed into the ear canal. The probe fit was evaluated by measuring the adequacy of the stimulus across the frequency rang of 0.5-5 kHz. The acoustic stimulus waveform were recorded in the ear canal and displayed in a check probe fit routine first. A good fit was achieved when there was minimal noise leakage into the meatus as indicated by noise bar. When the probe tip was judged to be good enough, the stimulus spectrum was a smooth, rounded curve extending across 1 to 4 kHz. The artifact rejection level was adapted to the recording conditions for each ear varying between 43 and 52 dBSPL. During the measurement the stability of the stimulus and the probe fit was indicated on the screen by a green light. If the light turned red, the probe was refitted or the measurement restarted. Two hundreds and sixty sweeps were averaged for each recording (56,81). On the response screen of the ILO96, the response reproducibility was displayed. Reproducibility values were calculated for the whole response and for individual frequency bands. For this study, the reproducibility value was recorded for 5 frequencies: 1000, 1500, 2000, 3000, and 4000 Hz. A determination of a pass for TEOAEs was made by 2 different methods, reproducibility and signal-to-noise (S/N) ratio. A "pass" in TEOAEs screening was defined as a reproducibility value of greater than 50% in 3 of the 5 frequencies (2,3,4 kHz) and was referred to as TEOAE REPRO. An S/N ratio of greater than or equal to 3 dB above the noise floor at 3 of 4 frequencies was defined as a pass for that ear and was referred to as TEOAE S/N . If reproducibility was not obtained after the acquisition of 260 subsets, this constituted a "fail"(56,81).

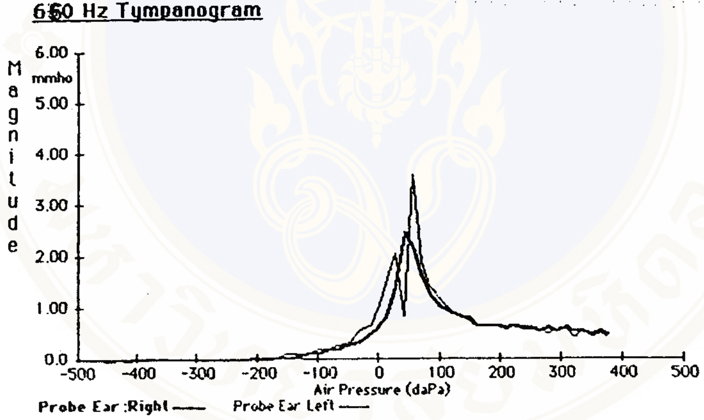
3.2 Tympanometric measurements

Tympanometry was performed using the clinical acoustic immittance instrument (Virtual 310) with probe tone frequencies of 226 and 660 Hz. The instrument was calibrated at 226 and 660 Hz in hard-walled cavities, supplied by the manufacturer (0.5, 2.0 and 5.0 cm^3). The intensity of the probe tone produced constant ear canal pressure at 85 dBSPL. All tympanograms were obtained in ascending direction (-500 daPa to +400 daPa) of pressure change at rate of 125 daPa/second. If the test could not be performed then the probe tip would be removed or reinserted and another measurement was attempted. Tympanometric tests were obtained with the higher probe tone frequency of 660 Hz using the same protocol as in 226 Hz probe tone tympanometry . Data from the admittance (Y) tympanograms were using 226 probe tone. Susceptance (B) and conductance (G) tympanograms were obtained for analysis and classified according to the Vanhuyse model (35).

For tympanometry recording, tympanometric data were collected from neonates during short intervals in which the neonate's movements were limited. After the probe was inserted into the neonates ear canal, a 226 Hz admittance tympanogram was obtained. At the starting of the tympanogram, the equivalent ear canal volume was measured between the tip of probe and tympanic membrane. The measuring range was from 0 to 4.5 ml. The admittance was estimated by subtracting the amplitude value at + 400 daPa from the peak admittance. The pressure range used in this instrument was -500 to +400 daPa.. Tympanograms were labeled according to the number of extrema in the two components admittance tympanogram. For example 1B1G designate single-peaked susceptance (B) and conductance (G) tympanograms, and 3B1G designate a notched susceptance (B) and a single-peaked conductance (G) tympanogram (Figure 15,16).

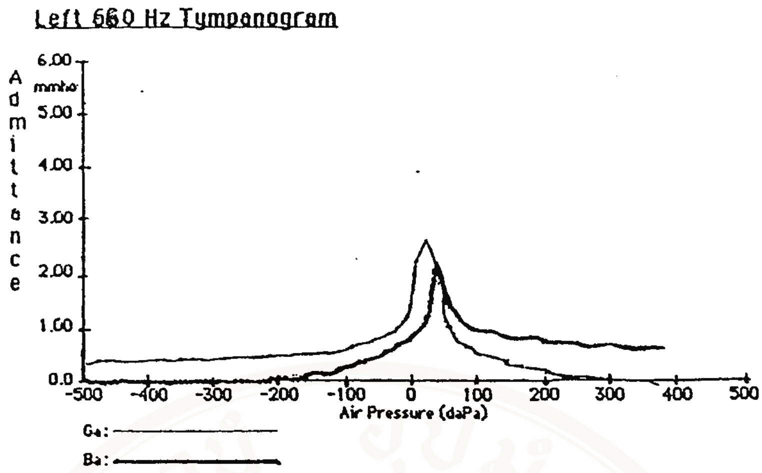


right ear 1Y left ear 1Y

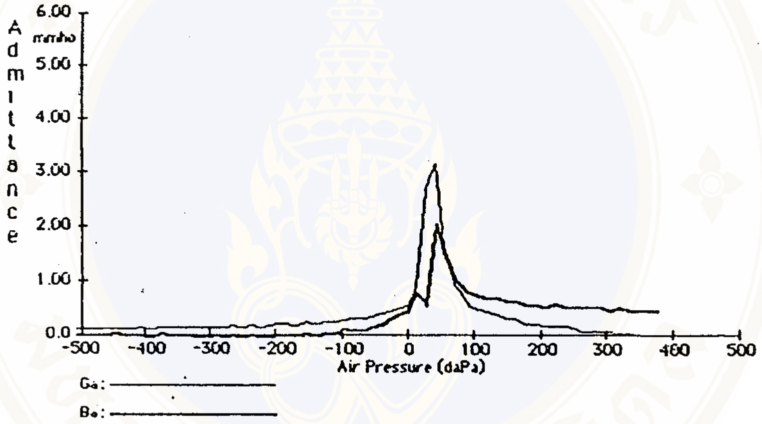


right ear 1Y left ear 3Y

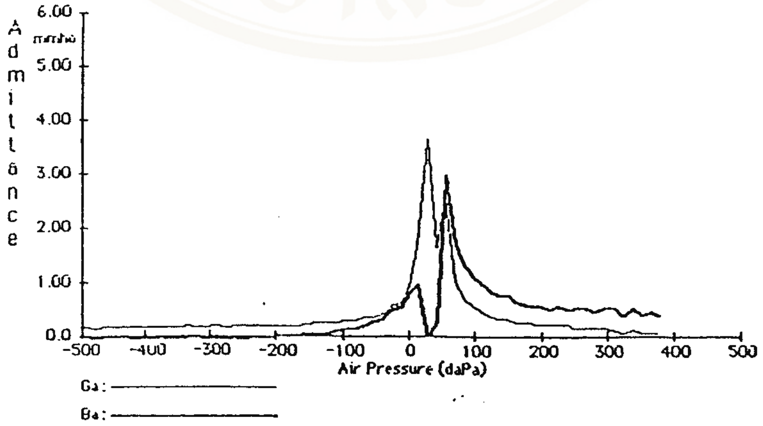
Figure 15 The example of patterns admittance tympanogram recording at probe tone frequency of 226 (upper)and 660 Hz (lower) (37).



1B1G



3B1G



3B3G

Figure 16 The example of patterns susceptance-conductance (B-G) tympanogram recording at probe tone frequency of 660 Hz (37).

5. Criteria Used to Ensure a Valid Recording

5.1 226 Hz Tympanograms: The criterias include (51,81)

5.1.1 tympametric peak pressure > -200 daPa

5.1.2 static acoustic admittance > 0.2 mmho

5.1.3 equivalent ear canal volume > 0.2 mmho

5.1.4 tympanometric width < 235 daPa

5.2 660 Hz Tympanograms: The criterias include (40,45,46,52)

5.2.1 no more than five B and three G peaks

5.2.2 the G peaks must fall within the B peaks

5.2.3 < 75 daPa in 3B3G, <100 daPa in 5B3G

6. Data Analysis

In this study the statistical package, SPSS for window version 9, had been used for data analysis.

6.1 Percentages were used for describing the tympanometric patterns.

6.2 Mean and standard deviations (SD) were used for analysis of the amplitude of tympanogram and tympanometric peak pressure.

6.3 The paired t-test was used in comparison of the different of the amplitude tympanogram and the tympanometric peak pressure when using probe tone frequency of 226 and 660 Hz in the same ear.

6.4 The t-test was used for comparison the different of the amplitude and tympanometric peak pressure of tympanograms obtained form full term male and female neonates.

CHAPTER IV

RESULTS

The purposes of this study were to investigate the tympanometric pattern, amplitude of admittance tympanogram and tympanometric peak pressures between probe tone frequency of 226 and 660 Hz in normal full term neonates.

The tympanometric measurements were performed in both ears of 80 normal full term neonates of which 40 were male (80 ears) and 40 were female (80 ears). The overall age ranged from 1 day to 7 days; the means age were 2.48 days (SD= 0.71); and 2.31 days (SD= 0.90) for male and female subjects, respectively.

1. The Tympanometric patterns at probe tone frequency of 226 and 660 Hz in normal full term neonates

Table 1 showed the percentage of the tympanometric patterns at probe tone frequency of 226 Hz in 80 normal full term neonates. The tympanometric patterns can be classified into two patterns, according to a modified Vanhuyse et al (52) model. Pattern 1 showed a single peaked; pattern 2 showed notched tympanogram. In polar notation, the record showing single peaked tympanogram (1Y) was 43.8%, and notched tympanogram (3Y) was 56.2 %. In rectangular notation, the record showing single peaked tympanogram (1B1G) was 26.3% and notched tympanogram was 73.7%

(3B1G 35.6% and 3B3G 38.1%). However, 5B3G type tympanogram was not found in this study.

Table 1 Percentage (number of ears) of the tympanometric patterns Y, B, and G tympanograms in normal full term neonates (160 ears) at probe tone frequency of 226 Hz.

Tympanometric patterns	**1B1G**	**3B1G**	**3B3G**	**5B3G**	**Total**
1Y	26.3% (42)	17.5% (28)	0	0	43.8% (70)
3Y	0	18.1% (29)	38.1% (61)	0	56.2% (90)
Total	26.3%(42)	35.6%(57)	38.1%(61)	0	100% (160)

Table 2 showed the percentage of the tympanometric patterns at probe tone frequency of 660 Hz in 80 full term neonates. The tympanometric patterns can be classified into both single peaked and notched tympanogram. In polar notation, the record showing single peaked tympanogram (1Y) was the most frequently 66.3% and notched tympanogram (3Y) was 33.7%. In rectangular notation, the record showing single peaked (1B1G) was 59.4% and notched tympanogram was 33.7% (3B3G 18.1% and 3B3G 22.5%).

Table 2 Percentage (number of ears) of the tymapnometric patterns Y, B, and G tympanograms in normal full term neonates (160 ears) at probe tone frequency of 660 Hz.

Tympanometric patterns	1B1G	3B1G	3B3G	5B3G	Total
1Y	59.4 % (95)	6.9 % (11)	0	0	66.3 % (106)
3Y	0	11.2 % (18)	22.5% (36)	0	33.7% (54)
Total	59.4% (95)	18.1% (29)	22.5% (36)	0	100% (160)

Table 3 showed the patterns of Y, B and G tympanograms in male and female full term neonates of 160 ears at probe tone frequency of 660 Hz. In polar notation, the percentage of a single peaked tympanogram (1Y) at probe tone frequency of 660 Hz in male and female neonates were 65% and 67.5% ,and notched tympanogram (3Y) were 35% and 32.5% , respectively. In rectangular notation, the percentages of single peaked (1B1G) in male and female neonates were 55% and 63.8%, and notched tympanogram were 44.9% and 36.3% (3B1G 21.3%, 15% and 3B3G 23.7%, 21.2%), respectively.

Table 3 Percentage (number of ears) of the tympanometric patterns in male and female full term neonates (160 ears) at probe tone frequency of 660 Hz.

Tympanometric Patterns	**Sex**	**1B1G**	**3B1G**	**3B3G**	**Total**
1Y	Male	55% (44)	10% (8)	0	65% (52)
	Female	63.8% (51)	3.7% (3)	0	67.5% (54)
3Y	Male	0	11.3% (9)	23.7% (19)	35% (28)
	Female	0	11.3% (9)	21.2% (17)	32.5% (26)
Total	Male	55% (44)	21.3% (17)	23.7% (19)	100% (80)
	Female	63.8% (51)	15% (12)	21.2% (17)	100% (80)

2. The Amplitude of admittance (Y) tympanogram at probe tone frequencies of 226 and 660 Hz in full term neonates.

Table 4 showed the mean, SD and range of the admittance tympanogram at probe tone frequencies of 226 and 660 Hz in full term neonates (160 ears). The mean , SD and range of the amplitude of admittance Y tympanogram at probe tone frequency 226 Hz in full term neonates were 0.72 ± 0.23 and 0.30-1.50 mmho, respectively. The mean amplitude (±SD) of the Y, B, and G tympanograms at probe tone frequency of 660 Hz in full term neonates were 0.42 ± 0.13, 0.40 ± 0.19 and 0.76 ± 0.22 mmho, respectively. The range of the Y, B-G tympanograms at probe tone frequency of 660 Hz in full term neonates were 0.20-0.75, 0.01-0.90 and 0.02-1.40 mmho, respectively.

Table 4 Mean, SD and range of amplitude of the Y, B-G tympanograms in full term neonates at probe tone frequencies of 226 and 660 Hz.

Tympanogram	**Probe tone Frequency (Hz)**	**Amplitude (mmho)**	
		Mean± SD	**range**
Y	226	0.72 ± 0.23	0.30-1.50
Y	660	0.42 ± 0.13	0.20-0.75
B	660	0.40 ± 0.19	0.01-0.90
G	660	0.76 ± 0.22	0.02-1.40

Table 5 showed the mean and SD of the amplitude of Y tympanogram in male and female full term neonates (160 ears) at probe tone frequency of 226 and 660 Hz. The mean and SD of amplitude Y tympanogram at 226 Hz in male and female neonates were 0.70 ± 0.20 and 0.74 ± 0.25 mmho, respectively. The mean and SD of amplitude Y, B ,and G tympanogram at 660 Hz in male full term neonates were 0.42 ± 0.13, 0.39 ± 0.18 and 0.76 ± 0.23 mmho, respectively. The mean and SD of amplitude Y, B ,and G tympanogram at 660 Hz in female full term neonates were 0.42 ± 0.13, 0.41 ± 0.19 and 0.75 ± 0.22 mmho, respectively.

Table 5 Mean and SD of the amplitude admittance tympanogram (mmho) in male and female neonates at probe tone frequencies of 226 and 660 Hz

Tympanogram	Probe tone Frequency (Hz)	Amplitude (mmho)	
		Male Mean ± SD	Female Mean± SD
Y	226	0.70 ± 0.20	0.74 ± 0.25
Y	660	0.42 ± 0.13	0.42 ± 0.13
B	660	0.39 ± 0.18	0.41 ± 0.19
G	660	0.76 ± 0.23	0.75 ± 0.22

Table 6 showed the comparison of the mean values for the amplitude of Y tympanogram at probe tone frequencies of 226 and 660 Hz. The paired t-test showed a significant difference for the amplitude of Y tympanogram between the probe tone frequency 226 and 660 Hz in full term neonates at p-value < 0.01.

Table 6 Comparison of the mean values for the amplitude of Y tympanogram between probe tone frequencies of 226 and 660 Hz in full term neonates.

Probe tone frequency		t-value	df	p-value
226 Hz Mean± SD	660 Hz Mean ± SD			
0.72 ± 0.23	0.42 ± 0.13	17.6**	159	0.000

**significant at p < 0.01

3. The tympanometric peak pressure of admittance tympanogram at probe tone frequency of 226 and 660 Hz in full term neonates.

Table 7 showed the mean of TPP admittance tympanogram at probe tone frequency of 226 and 660 Hz in male and female full term neonates. The mean and SD of TPP admittance Y tympanogram at probe tone frequency 226 Hz in male and female full term neonates were 75.85 ± 47.83 and 79.68 ± 45.79 daPa, respectively. The means and SD of TPP Y, B, G tympanogram in male full term neonates were 143.78 ± 113.99, 138.13 ± 89.80 and 61.25 ± 79.77 daPa, respectively. In addition, the mean and SD in female full term neonates were 136.40 ± 114.59, 143.69 ± 79.26 and 42.25 ± 75.29 daPa, respectively.

Table 7 Mean and standard deviation of tympanometric peak pressure (daPa) admittance tympanogram at probe tone frequencies of 226 and 660 Hz in male and female neonates.

Tympanogram Type	Probe tone frequency (Hz)	TPP (daPa)	
		Male Mean ± SD	Female Mean ± SD
Y	226	75.85 ± 47.83	79.68 ± 45.79
Y	660	143.78 ± 113.99	136.40 ± 114.59
B	660	138.13 ± 89.80	143.69 ± 79.26
G	660	61.25 ± 79.77	42.25 ± 75.29

Table 8 showed the comparison of the mean tympanometric peak pressure for Y tympanogram at probe tone frequency of 226 and 660 Hz. The mean of TPP of Y tympanogram at probe tone frequency of 226 Hz was less than the mean TPP of Y tympanogram at probe tone frequency of 660 Hz. The paired t-test showed a significant difference of TPP admittance tympanogram between probe tone frequency of 226 and 660 Hz of full term neonates at p-value < 0.01.

Table 8 Comparison of the mean values for tympanometric peak pressure (daPa) of Y tympanogram at probe tone frequency of 226 and 660 Hz in full term neonates.

Probe tone frequency				
226 Hz **Mean ± SD**	**660 Hz** **Mean ± SD**	**t-value**	**df**	**p-value**
77.76 ± 46.71	140.09 ± 113.99	-7.37**	159	0.000

**significant at p < 0.01

4. The comparison of Amplitude Y, B, G tympanograms at probe tone frequency of 660 Hz between male and female neonates.

Table 9 showed the means and SD of the amplitude Y, B, G tympanograms at probe tone frequency of 660 Hz in male and female neonates. The t-test showed no significant difference between means amplitude of Y, B and G tympanogram at probe tone frequency 660 Hz in male and female full term neonates.

Table 9 Comparison of the mean values for amplitude (mmho) Y, B, G tympanogram at probe tone frequency 660 Hz between male and female full term neonates.

Tympanogram	Male	Female			
	Mean±SD(mmho)	Mean± SD(mmho)	t-value	df	p- value
Y	0.42 ± 0.13	0.42 ± 0.13	0.000	158	1.000
B	0.39 ± 0.18	0.41 ± 0.19	-0.729	158	0.467
G	0.76 ± 0.23	0.75 ± 0.22	0.202	158	0.840

5. The Comparison of the tympanometric peak pressure of Y, B, G tympanogram at probe tone frequencies of 226 and 660 Hz between male and female full term neonates.

Table 10 showed the means , SD and range of tympanometric peak pressure (TPP) admittance (Y) tympanogram at probe tone frequency of 226 and 660 Hz in full term neonates (160 ears). The mean, SD and range of TPP admittance Y tympanogram at probe tone frequency 226 Hz were 77.76 ± 46.71 and (- 37)-197daPa, respectively. The means and SD of TPP admittance Y, B, G tympanogram at probe tone frequency of 660 Hz were 140.09 ± 113.99, 140.91 ± 84.47 and 51.75 ± 77.90 daPa, respectively. In addition, the ranges of TPP at 660 Hz were -239 to +347, -100 to+340 and -200 to +260daPa, respectively.

Table 10 Mean, standard deviation and range of Tympanometric Peak Pressure (daPa) of tympanogram at probe tone frequencies of 226 and 660 Hz in full term neonates.

Tympanogram	Probe tone frequency (Hz)	TPP (daPa) Mean± SD	TPP (daPa) range
Y	226	77.76 ± 46.71	-37 to +197
Y	660	140.09 ± 113.99	-239 to +347
B	660	140.91 ± 84.47	-100 to +340
G	660	51.75 ± 77.90	-200 to +260

Table 11 showed the comparison of the mean TPP of Y, B, and G tympanogram at probe tone frequency of 660 Hz between male and female neonates. The t-test showed no significant difference of the mean TPP Y, B, and G tympanogram at probe tone frequency 660 Hz in full term neonates.

Table 11 The comparison of the mean values for tympanometric peak pressure (daPa) of Y, B, G tympanogram at probe tone frequency 660 Hz between male and female full term neonates.

Tympanogram	Male Mean ± SD (daPa)	Female Mean ± SD (daPa)	t-value	df	p-value
Y	143.78 ± 113.99	136.40 ± 114.59	0.408	158	0.684
B	138.13 ± 89.80	143.69 ± 79.26	- 0.415	158	0.678
G	61.25 ± 79.77	42.25 ± 75.29	1.549	158	0.123

CHAPTER V

DISCUSSION AND CONCLUSION

This study was conducted to investigate the tympanometric configurations recorded in 80 full term neonates, which 40 were males and 40 were females, at the age ranged from 2 to 7 days after birth. The characteristics of tympanometry were focused on tympanometric patterns, amplitude of tympanogram and tympanometric peak pressure (TPP) from the neonatal ear.

1. The tympanometric patterns at probe tone frequency 226 and 660 Hz in full term neonates

The results in table 1 and 2 showed both a single-peaked and notched tympanogram at probe tone frequency 226 Hz in normal full term neonates was used. The single peaked (1Y) was 43.8% (70 ears) and notched tympanogram (3Y) was 56.2% (90 ears), respectively. In addition, the single-peaked tympanogram mostly found when a 660 Hz probe tone in normal full term neonates was used. The percentage of Y tympanogram, single peaked was 66.3% (106 ears) and notched tympanogram was 33.7% (54 ears), respectively. These findings agreed with Sprague et al (77). They obtained tympanogram and acoustic reflexes in 44 neonates, 24-130 hours old who had normal neonates. These finding implied that notched tympanograms were typical of neonatal ears for a 220 Hz probe tone. A single peaked tympanogram was mostly found for a probe frequency of 660 Hz.

Himmelfarb, Popelka, and Shanon (25) reported that the resistive and reactive component of acoustic impedance were important for accurate characterization of tympanogram observed in neonatal ears. They defined six categories of component acoustic admittance tympanograms with 50% of 63 ears having double peaked or notched tympanograms for a 220 Hz probe tone and 71% of the ears having shallow peaks for acoustic conductance when a 660 Hz probe tone was used.

Notched tympanograms can occur under two circumstances (74). First, acoustic reactance (XA) is stiffness controlled, but its absolute value is less than acoustic resistance (RA) near ambient pressure and greater than RA at high pressures. Alternatively, double peaks are observed when XA is mass controlled near ambient pressure and stiffness controlled at high pressures. Acoustic reactance is mass controlled when the depth of the notch is the lowest point on the 220 Hz tympanograms. In the present study was not only the lowest point on the tympanogram but actually exceed the negative scale of the recorder. Such extrema nothing did not occur for the 660 Hz probe tone. The deep notches for the 220 Hz tympanograms suggest mass dominated system in the neonate at 220 Hz. In contrast, the single peaked tympanogram typically observed for the 660 Hz probe tone indicates a stiffness dominated system at 660 Hz. Changes from mass to stiffness dominated occur as a system passes though a resonant frequency (77).

Tympanograms recorded from normal full term neonates differ in many respects from those of older children and adults. This study was in agreement with those of Holte et al. (17), Paradise, Smith and Blustone (19). These investigators observed normal 226 Hz tympanogram in the presence of observable otitis media, casting doubt on the diagnostic accuracy of tympanometry in the infant. This has been attributed to the compliant ear canal of the newborn with its incomplete tympanic ring ossification (19, 20). In addition, Holte et al (26) measured the pressure related changes of the ear canal wall, and suggested that the observed tympanometric patterns were caused by characteristic of neonatal middle ear, rather than external ear. Paradise, Smith, and Bluestone (19) found that a little diagnostic valued for 220 Hz tympanograms from infants less than 7 months of age. These investigators analyzed acoustic compliance tympanograms for a 220 Hz probe tone and found similar tympanometric patterns for infants with middle ear effusion and for infants with normal middle ears. The presence of a resonance near 220 Hz in the neonatal ear might explain the low sensitivity of 220 Hz tympanograms to changes caused by middle ear effusion especially if the low frequency resonance is an ear canal effect.

In infants, there may be mesenchyme clinging to the ossicles that would also affect middle ear mass (17, 77). Acoustic friction in the middle ear comes from the tympanic membrane, tendons and ligaments, the narrow passages between the middle ear cavity and the mastoid, and the viscosity of the perilymph and the mucous lining of the middle ear cavity (52). Therefore, in neonate and young infant ears were relatively greater mass contributions to middle ear impedance. Low frequency probe tone tympanograms were more likely to show notching or complex patterns in this age group.

2. The amplitude of admittance tympanograms at 226 and 660 Hz probe tone in normal full term neonates

2.1 The amplitude of admittance tympanogram

The result in Table 4, 5 showed the mean, SD and range of admittance tympanograms at probe tone frequency of 226 and 660 Hz. At 226 Hz, the amplitude of Y tympanogram was 0.72 (± 0.23) mmho and range was 0.30-1.50 mmho, respectively. At 660 Hz, the amplitude of Y tympanogram was 0.42 (± 0.13) mmho and range was 0.20-0.75 mmho, respectively. The comparison of mean values for the amplitude Y tympanogram between probe tone frequency of 226 and 660 Hz was showed in Table 6. The amplitude of Y tymoanogram in 226 Hz was significantly higher than that of 660 Hz probe tone frequency. The results of this study were similar to Himelfarb and Popelka (25). They obtained acoustic conductance and susceptance tympanograms at 220 and 660 Hz in 34 neonates. The neonates were categories into three groups (8-24 hours, 24-60 hours, and 60-96 hours). The mean static values and SD for peak Y tympanogram were 0.81, 0.65, and 0.71 at 226 Hz, and 0.48, 0.71, and 0.72 at 660 Hz, respectively. In addition, this study agreed with that of Keefe et al (28). They reported that even single frequency admittance tympanometry might be effectively measured in neonates at frequencies higher than 266 Hz, because the acoustic influence of the lack of rigidity of the ear canal wall was less important at higher frequencies.

Single peaked high amplitude tympanograms that were characterized by increased Y tympanogram could result from pathologic conditions that added mass to the middle ear system. As mass increases, high amplitude vector tympanograms may notch.

Susceptance and conductance are affected differently by probe frequency, applied ear canal pressure, and maturation (18, 25, 32, 35, 63).

2.2 The Amplitude of admittance tympanogram in male and female full term neonates

The Table 9 showed no significant difference of the mean values of amplitude Y, B, G tympanogram at 660 Hz probe tone between male and female full term neonates at p-values > 0.05. No comparison data of the amplitude admittance tympanogram between genders was reported in neonatal subjects. However, the effects of gender on amplitude of tympanogram were reported in adult subjects (79, 80). Jerger and Mauldin (79), Zwislocki and Feldman (80), they reported significant differences in Y tympanogram by gender. They found that woman had lower Y tympanogram values than those of men. In addition, Margolis and Hellter (81) found that significant change in Y tympanogram with age; children had lower Y tympanogram than adults.

3. Tympanometric peak pressure of admittance tympanogram in normal full term neonates

3.1 Tympanometric peak pressure at probe tone frequency of 226 and 660 Hz

The mean peak pressure, SD and range showed in Table 10. This study found that tympanometric peak pressure occurred at positive pressures for ascending pressure changes for all three admittance components at both probe frequency. In addition, this study, there was a significant difference of the tympanometric peak pressure at 226 and 660 Hz in full term neonates as showed in Table 8. These findings agreed with those of Shank and Wilson (69), and Wilson et al (68). They concluded that tympanomeric peak pressure was mostly found at the positive pressure with ascending pressure changes. In addition, the difference in peak pressure for the two probe tone frequencies of pressure change increased. Theses results were in agreement with the data of Vancamp et al (52) and Dacraemer et al (78) reported that the pressure shift was independent of the rate pressure change. A shift in tympanometric peak pressure that was related to the direction of pressure change in the ear canal had been observed in normal human subject [cited in Vancamp et al.(52)] . The peak was shifted toward positive when the ear canal pressure was swept from ascending direction, and was shifted toward negative pressure when the ear canal pressure was swept from descending direction. This effect was related to the viscoelastic properties of the tympanic membrane and middle ear structure (78). In addition, Creten et al (80) reported that the change in tympanometric peak pressure with the direction change had been attributed to two sources, the instrument and middle ear (tympanic membrane with connected middle ear structures). In this study, the pressure shifts occurred with increasing probe tone frequency. Because of the middle ear, effect was not proportional to the velocity of change of the deformation in the tympanic membrane, which was a common feature of soft biological tissue like the tympanic membrane (52, 73, 76, 77).

3.2 Tympanometric peak pressure at probe tone frequency of 660 Hz in male and female neonates

The results in Table 7 showed that the means TPP of Y, B, G tympanograms at probe tone frequency 660 Hz in male were 143.78, 138.13 and 61.25 daPa, respectively. The mean TPP of Y, B, and G tympanograms in female were 136.40, 143.69 and 42.25 daPa, respectively. There was no significant difference for TPP of Y, B, and G tympanograms at probe tone frequency of 660 Hz between male and female full term neonates as showed in Table 11. However, there were very little information regarding TPP among gender in infants and young children. Paradise et al. (19) studied the tympanograms obtained were compared with otoscopic findings in subjects age ranging from 10 day to 5 years 11 months. They concluded that sex categories identified no significant differences in the correlations between tympanometric patterns and tympanometric peak pressure for presence or absence of effusion. In adult, Magolis et al. (45) reported that there were interaural or gender differences in static acoustic admittance, tympanometric width, tympanometric peak pressure, or resonant frequency in normal adult subjects.

Conclusions

The purposes of this study were to investigate the difference of the tympanic patterns of tympanogram, the amplitude of admittance tympanogram and tympanometric peak pressure at probe tone frequencies 226 and 660 Hz in full term neonates. The correlation between the amplitude admittance and tympanometric peak pressure tympanogram from male and female full term neonates was also investigated. The finding of this study was discussed according to data reported in the literature. The results from this study suggested the following conclusions:

1. This study showed a percentage of tympanometric patterns that notched tympanogram (3Y) was most characteristic of the full term neonates when probe tone frequency of 226 Hz (56.2%, 90 ears) was used. The single peaked tympanogram (1Y) was mostly found when used probe tone frequency of 660 Hz (66.3%, 106 ears).

2. The mean of amplitude Y tympanogram at probe tone frequency of 226 Hz was 0.72 (±0.23) mmho. The mean of amplitude Y, B, and G tympanogram at probe tone

frequency of 660 Hz were 0.42 (±0.13), 0.40 (±019) and 0.76 (±0.22) mmho, respectively.

3. The comparison of the amplitude Y tympanogram between probe tone frequency of 226 Hz showed a significant difference higher than probe tone frequency 660 Hz in normal full term neonates at p-value<0.01.

4. The comparison of amplitude Y, B, G tympanogram at probe tone frequency of 660 Hz between male and female full term neonates showed no significant different (p> 0.05).

5. The mean of TPP for Y tympanogram at probe tone frequency of 226 Hz was 77.76 (±46.71). The mean of TPP admittance Y, B, G tympanogram at probe tone frequency of 660 Hz was 140.09 (±113.99), 140.91 (±84.47) and 51.75 (±77.90) respectively.

6. The comparison of the mean TPP of Y tympanogram between probe tone frequency of 226 Hz showed a significant difference larger than probe tone frequency 660 Hz in normal full term neonates at p-value< 0.01.

7. The comparison of the mean TPP of Y, B, G tympanogram at probe tone frequency of 660 Hz between male and female full term neonates showed no significant different (p > 0.05).

Recommendations

The recommendations from this study concerning further research and application are as follows:

1. Further high frequency tympanometry 660 Hz studies are recommended in different age groups and middle ear pathologies.

2. Further studies are needed that the acoustic reflexes might aid in the interpretation of neonatal tympanograms and help determine the clinical value or assessment of middle ear effusion in young infants.

3. In order to use tympanometry to assess the status of the middle ear in neonates and young infants, additional research is needed to develop a model for classifying and interpreting the patterns recorded in this population.

4. High frequency probe tone 660 Hz tympanometry should be used to confirm or exclude the presence of middle ear effusion in neonates and young infant.

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APPENDIX

A. Exclusion criteria

In 1994, The US Joint Committee on Infant Hearing made recommendations for the identification, diagnosis and management of hearing loss in early infancy (6). The recommendations included a list of risk criteria in neonates (birth-28 days) include the following;

1.) Family history of hereditary childhood sensorineural hearing loss.

2.) In utero infection such as cytomegalovirus, rubella, syphilis, herpes and toxoplasmosis.

3.) Craniofacial anomalies including those with morphological abnormalities of the pinna and ear canal.

4.) Birth weight less than 1,500 grams.

5.) Hyperbilirubinemia at a serum level requiring exchange transfusion.

6.) Ototoxic medications, including but not limited to the amino glycosides, used in multiple courses or in combination with loop diuretics.

7.) Bacterial meningitis.

8.) Apgar scores of 0-4 at 1 minute or 0 to 6 at 5 minutes.

9.) Mechanical ventilation lasting 5 days or longer.

10.) Stigmata or other findings associated with a syndrome known to include a sensorineural and/or conductive hearing loss.

Table A-1 Descriptive data of amplitude and tympanometric peak pressure by using probe tone frequency of 660 Hz in male full term neonates.

Number	Age (day)	Amplitude (mmhos)			TPP (daPa)		
		Y	B	G	Y	B	G
M1	2	0.3	0.3	0.75	108	110	-20
		0.7	0.4	1.05	-9	100	-20
M2	3	0.4	0.3	1.1	-37	-40	-40
		0.4	0.4	1.1	-94	-100	-100
M3	2	0.4	0.48	0.7	79	80	-50
		0.3	0.38	0.75	-40	80	-60
M4	2	0.5	0.7	0.8	282	320	240
		0.5	0.6	0.8	258	330	200
M5	3	0.5	0.4	0.8	-65	-60	-100
		0.4	0.2	1	-61	-50	-60
M6	2	0.4	0.5	0.85	173	200	50
		0.4	0.2	0.9	173	100	50
M7	2	0.6	0.65	0.8	-9	-10	-10
		0.6	0.65	1	51	50	50
M8	3	0.3	0.2	0.8	258	110	150
		0.5	0.2	0.9	230	130	200
M9	2	0.3	0.26	0.7	173	140	140
		0.4	0.2	0.75	202	110	100
M10	2	0.4	0.4	0.7	258	260	20
		0.4	0.25	0.7	108	140	-40
M11	2	0.6	0.9	1.2	197	300	-30
		0.2	0.25	0.85	197	200	200
M12	3	0.4	0.7	1.2	169	150	20
		0.6	0.6	1.1	79	300	80
M13	2	0.4	0.2	0.7	230	110	140
		0.5	0.7	1.05	343	340	80
M14	3	0.6	0.6	0.9	202	160	160
		0.5	0.75	0.95	197	290	-30
M15	2	0.3	0.25	0.6	230	200	110
		0.3	0.35	0.75	314	80	80
M16	2	0.4	0.4	0.9	51	160	-70
		0.4	0.4	0.6	197	170	170
M17	2	0.6	0.6	0.9	79	200	160
		0.5	0.4	0.8	282	160	100
M18	2	0.5	0.4	0.9	197	110	70

		0.5	0.65	0.9	230	270	170
M19	2	0.3	0.3	0.8	-37	80	-100
		0.3	0.35	0.7	84	80	-10
M20	4	0.3	0.2	0.9	-37	100	60
		0.6	0.35	0.75	18	160	110
M21	2	0.5	0.65	0.54	253	240	140
		0.6	0.4	0.75	-9	140	80
M22	2	0.4	0.6	0.9	112	170	20
		0.4	0.6	0.85	197	270	50
M23	2	0.5	0.4	0.65	253	100	100
		0.6	0.2	0.7	347	170	100
M24	2	0.4	0.14	0.45	98	140	80
		0.3	0.3	0.45	-9	20	100
M25	2	0.4	0.2	0.75	282	100	80
		0.4	0.2	0.55	282	180	140
M26	2	0.4	0.45	0.75	108	270	30
		0.5	0.4	0.7	79	100	70
M27	2	0.2	0.3	1	108	110	-40
		0.3	0.1	1	282	140	220
M28	3	0.6	0.4	0.2	230	120	70
		0.5	0.3	0.02	51	160	90
M29	3	0.4	0.65	0.9	169	250	170
		0.2	0.3	0.6	286	200	110
M30	3	0.5	0.12	0.1	230	20	110
		0.4	0.1	0.25	258	140	100
M31	2	0.6	0.65	0.75	51	50	20
		0.3	0.2	0.55	-32	50	-30
M32	3	0.3	0.2	0.65	18	150	20
		0.4	0.2	0.7	230	50	20
M33	2	0.3	0.4	0.65	108	110	30
		0.2	0.3	0.7	56	70	50
M34	5	0.4	0.3	0.75	18	50	20
		0.4	0.5	0.9	79	180	10
M35	4	0.5	0.45	0.62	79	80	80
		0.3	0.38	0.6	253	260	100
M36	2	0.6	0.5	0.4	79	170	50
		0.7	0.4	1	79	100	80
M37	3	0.5	0.25	0.8	256	140	40
		0.5	0.2	0.75	314	160	160
M38	3	0.1	0.4	1	230	140	-10

		0.3	0.4	0.75	79	150	60
M39	3	0.4	0.3	0.45	79	130	40
		0.6	0.65	0.7	230	230	170
M40	2	0.2	0.25	0.8	319	130	60
		0.3	0.4	0.9	108	110	-50

Table A-2 Descriptive data of amplitude and tympanometric peak pressure by using probe tone frequency of 660 Hz in female full term neonates.

Number	Age (day)	Amplitude (mmhos)			TPP (daPa)		
		Y	B	G	Y	B	G
F1	2	0.5	0.35	0.55	169	100	50
		0.3	0.14	0.6	51	200	260
F2	2	0.6	0.75	0.75	23	35	50
		0.3	0.12	0.6	-9	110	0
F3	7	0.3	0.2	0.58	-9	140	100
		0.3	0.25	0.58	18	100	-4
F4	2	0.3	0.2	0.52	173	140	170
		0.3	0.25	0.16	258	180	110
F5	2	0.3	0.4	0.75	51	60	-80
		0.4	0.4	0.52	136	140	80
F6	3	0.5	0.34	0.5	282	160	100
		0.6	0.4	0.42	51	200	-10
F7	3	0.5	0.48	0.75	79	80	80
		0.4	0.2	0.22	286	110	70
F8	2	0.3	0.16	0.46	-4	130	50
		0.3	0.18	0.54	-32	200	30
F9	2	0.4	0.22	0.73	286	130	130
		0.5	0.4	0.78	51	50	50
F10	2	0.2	0.3	0.85	282	110	-100
		0.3	0.46	1	1120	110	10
F11	2	0.4	0.2	1.2	-89	180	-90
		0.4	0.2	0.7	-51	100	50
F12	2	0.5	0.6	1	173	260	0
		0.5	0.54	0.9	79	80	60
F13	2	0.4	0.54	1.02	51	80	10
		0.4	0.5	1	56	100	40
F14	2	0.4	0.35	0.75	282	100	10
		0.5	0.54	0.9	230	300	100
F15	2	0.6	0.8	1.2	51	80	40
		0.75	0.8	1.4	51	100	40
F16	2	0.4	0.7	0.9	282	340	40
		0.5	0.5	0.75	136	140	0
F17	2	0.4	0.3	0.85	319	160	-10
		0.4	0.02	0.7	258	120	140
F18	2	0.4	0.2	0.6	314	110	130

		0.3	0.25	0.6	286	170	80
F19	3	0.3	0.4	0.7	136	130	20
		0.5	0.4	0.8	197	120	150
F20	3	0.3	0.2	0.7	282	180	80
		0.3	0.4	0.7	173	160	160
F21	4	0.6	0.52	1	18	30	20
		0.5	0.3	0.7	258	170	-40
F22	2	0.3	0.1	0.75	51	-10	-10
		0.6	0.7	0.9	230	290	160
F23	2	0.3	0.4	0.8	79	100	20
		0.7	0.6	0.75	202	100	60
F24	2	0.7	0.6	0.62	230	130	50
		0.5	0.4	0.52	230	130	70
F25	2	0.4	0.2	0.8	-37	120	-40
		0.4	0.5	0.7	112	100	-100
F26	2	0.5	0.6	0.8	60	300	20
		0.4	0.4	0.7	250	80	-30
F27	2	0.4	0.4	0.75	51	120	20
		0.4	0.5	0.75	51	50	20
F28	2	0.3	0.4	0.8	-37	-40	-40
		0.4	0.5	0.85	79	80	0
F29	2	0.6	0.7	0.35	79	80	50
		0.4	0.25	0.9	282	60	-90
F30	2	0.5	0.12	0.75	230	150	110
		0.5	0.4	0.75	230	170	70
F31	3	0.4	0.52	1.1	51	200	20
		0.3	0.7	1	51	220	20
F32	2	0.5	0.75	0.9	197	290	20
		0.4	0.45	0.5	282	230	160
F33	2	0.3	0.4	0.9	110	110	-70
		0.3	0.4	1	202	200	0
F34	2	0.5	0.5	0.75	230	50	20
		0.5	0.6	0.8	51	200	20
F35	2	0.7	0.9	0.9	253	300	60
		0.7	0.8	0.9	79	300	20
F36	2	0.3	0.5	1	79	70	30
		0.4	0.25	0.85	230	160	80
F37	2	0.5	0.6	1	79	140	80
		0.3	0.35	0.8	136	140	40
F38	2	0.4	0.25	0.45	497	70	70

		0.4	0.14	0.4	230	50	70
F39	2	0.2	0.2	0.7	-239	300	-200
		0.3	0.3	0.6	258	310	80
F40	3	0.3	0.4	0.75	230	250	200
		0.4	0.02	0.7	286	200	200

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