# IDENTIFICATION OF COCHLEAR / RETROCOCHLEAR PATHOLOGY IN SENSORINEURAL HEARING LOSS PATIENTS BY THE USE OF ACOUCTIC REFLEX THRESHOLDS

**MONDNATH CHOCKBOONDEE**

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Mondnath Chockboondee

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ABSTRACT

Sensorineural hearing loss (SNHL) is a type of hearing loss. The pathology of SNHL is the hair cells in the cochlea and/or the neurons of the auditory part of cranial nerve VIII. The hearing loss treatment depends on the site of the lesion. Therefore, SNHL patients have to be diagnosed using special tests that identify the sites of the lesion. These tests determine whether the lesions are in the cochlea, or the retrocochlea. The audiological diagnostic evaluations are very important for treatment. They consist of subjective and objective evaluations. Subjective evaluations require patients' cooperation. These tests can have some limitations, including a patient's cooperation level, but also less sensitivity and specificity in identifying sites of lesion. Objective evaluations, or physiological tests are an instrument designed to measure unobserved constructs. A widely used objective evaluation nowadays is the auditory brainstem response (ABR). The test does not require patients' cooperation. Several reports confirmed the sensitivity of ABR for diagnosing retrocochlear hearing loss to be as high as 98%, with a specificity of 90%. The results of ABR can give more sensitivity and specificity in identifying sites of lesion, but the test takes longer and is more expensive. The acoustic reflex measurement is another objective test. It can be used to diagnose the site of the lesion in hearing loss patients by comparing the acoustic reflex thresholds with pure tone air conduction thresholds, which is called sensation level. If the sensation level is lower than 60 dB, it means there is recruitment, which is a characteristic of cochlear hearing loss. Having a reflex threshold level elevated to greater than the $90^{th}$ percentile cutoff level is considered indicative of retrocochlear hearing loss.

The purpose of this research was to study the diagnostic accuracy on the sensitivity and specificity of the acoustic reflex test (ART) in identifying sites of lesions compared to the results of auditory brainstem response measurement (ABR). This was a retrospective study with data collection from clinical charts of sensorineural hearing loss patients who were referred by otorhinolaryngologists for ABR measurement from 2009 to 2013. The subjects consisted of 346 ears, from 232 patients (102 males, 130 females). The overall sensitivity of ART in identifying the site of lesion was 90.9% and specificity was 57.3%. However, the highest sensitivity and specificity of ART in identifying the site of lesion was 100% and 80.6% respectively in moderate SNHL (41-55 dBHL). The group of low frequency loss demonstrated highest sensitivity in identifying sites of lesion at 100% and the specificity was 75.8%.

KEY WORDS: SENSORINEURAL HEARING LOSS / SITE OF LESION /ACOUSTIC STAPEDIUS REFLEX

71 pages

การจำแนกพยาธิสภาพ Cochlear / Retrocochlear โดยใช้ Acoustic Reflex Thresholds ในผู้ป่วยประสาทหูเสื่อม
IDENTIFICATION OF COCHLEAR / RETROCOCHLEAR PATHOLOGY IN SENSORINEURAL HEARING LOSS PATIENTS BY THE USE OF ACOUCTIC REFLEX THRESHOLDS

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บทคัดย่อ

ประสาทหูเสื่อมเป็นการสูญเสียการได้ยินรูปแบบหนึ่ง สาเหตุของการสูญเสียการได้ยินมาจากความผิดปกติของเซลล์ขนในหูชั้นใน และ/หรือความผิดปกติที่เกิดขึ้นบริเวณทางเดินของเส้นประสาทการได้ยิน ดังนั้นผู้ป่วยประสาทหูเสื่อมต้องได้รับการวินิจฉัยด้วยการตรวจพิเศษเพิ่มเติมเพื่อจำแนกพยาธิสภาพว่าอยู่ในส่วนของก้นหอย (Cochlea) หรือ หลังก้นหอย (Retrocochlea) การตรวจวินิจฉัยจำแนกพยาธิสภาพที่เป็นสาเหตุของประสาทหูเสื่อม แบ่งออกเป็น Subjective evaluation และ Objective evaluation การใช้ Subjective evaluation ต้องอาศัยการตอบสนองของผู้ป่วย และการตรวจมีข้อจำกัด คือต้องอาศัยความร่วมมือจากผู้ป่วย ในการตอบสนองต่อเสียง นอกจากนั้น ค่าความไว (Sensitivity) และ ความจำเพาะในการวินิจฉัย (Specificity)น้อย ส่วนObjective evaluation เป็นการตรวจโดยอาศัยการตอบสนองทางสรีระ การตรวจที่นิยมใช้ในปัจจุบันคือ auditory brainstem response (ABR) ซึ่งมีข้อดีคือไม่ต้องอาศัยความร่วมมือของผู้ป่วยในการตอบสนองต่อเสียง และมีค่า Sensitivity และ Specificity สูงถึง 98% และ 90% ตามลำดับ แต่การตรวจ ABR มีข้อจำกัดคือต้องอาศัยเวลาในการตรวจนาน มีความยุ่งยากในการตรวจเพราะต้องติดอุปกรณ์ที่ผิวหนัง และมีราคาแพง การตรวจแบบ Objective evaluation อีกแบบหนึ่ง คือ Acoustic reflex measurement เป็นการตรวจวินิจฉัยพยาธิสภาพโดย พิจาณาค่า Sensation level คือผลต่างของ acoustic reflex thresholds กับ ค่า pure tone air conduction thresholds หากน้อยกว่า 60 dB จะแปลผลได้ว่าผู้ป่วยมีพยาธิสภาพใน Cochlea หาก Sensation level อยู่ในเกณฑ์ปกติ แต่มีการตอบสนองของ Acoustic reflex threshold สูง (มากกว่า ค่าเปอร์เซนไทล์ที่ 90 ของผู้มีการได้ยินปกติและผู้ที่มีความผิดปกติในหูชั้นใน) จะบ่งชี้ว่ามีพยาธิสภาพที่ Retrocochlea

การวิจัยนี้มุ่งศึกษา ค่าความไว (sensitivity) และ ความจำเพาะ (specificity) ของการตรวจ Acoustic Reflex Test (ART) ในการวินิจฉัยจำแนกพยาธิสภาพของหูชั้นใน ในผู้ป่วยประสาทหูเสื่อม โดยเปรียบเทียบกับผลการตรวจ Auditory Brainstem Response (ABR) จากการศึกษาข้อมูลย้อนหลัง ในเวชระเบียนของผู้ป่วยประสาทหูเสื่อม ที่โสต ศอ นาสิกแพทย์ ส่งตรวจ ABR ในช่วงปี 2552-2556 ทั้งหมด 346 หู (232 ราย) เพศชาย 102 ราย (44%) เพศหญิง 130 ราย (56%) การตรวจด้วย ART ในการวินิจฉัยจำแนกพยาธิสภาพ ได้ค่าความไว (sensitivity) 90.9% และค่าความจำเพาะ (specificity) โดยรวม เท่ากับ 57.3% อย่างไรก็ตามค่า Sensitivity และ Specificity จะสูงถึง 100% และ 80.6% ตามลำดับ ในผู้ที่มีการสูญเสียการได้ยินระดับปานกลาง (41-55 dBHL) ส่วนรูปแบบการได้ยินชนิด Low frequency loss จะให้ค่าความไว (100%) และ ค่าความจำเพาะ (75.8%) ในการจำแนกพยาธิสภาพได้ดีที่สุด

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| | |
|---|---|
| SNHL | sensorineural hearing loss |
| ABR | auditory brainstem response |
| ART | acoustic reflex threshold |
| MRI | magnetic resonance imaging |
| dB | decibel |
| HL | hearing level |
| SPL | sound pressure level (0dB nHL ≈ 45 dBSPL) |
| SL | sensation level |
| PTA | pure Tone Average |

# CHAPTER I
# INTRODUCTION

## 1.1 Background and rationale

Hearing is one of the essential five senses. Sound perception is an important sense for speech and language development. It is important after birth, and also maintains communication in a hearing society, throughout a person's life. The ear picks up sound from the environment through the ear canal. The tympanic membrane transmits vibrations to the ossicular chain, which consists of three small bones in the middle ear called the malleus, incus and stapes. From the stapes footplate, the sound travels to the cochlea via the oval window [1]. Then, the fluid in the cochlea moves and excites both the outer and inner hair cells of the basilar membrane, which transforms the mechanical motion of the pressure waves into nerve impulses. The outer and inner hair cells in the fluid inside the cochlea move and generate nerve impulses, then travel to the brain [2].

Whenever there are disorders or abnormalities in the auditory system, it may cause hearing loss which can be classified by type: conductive, sensorineural, and mixed hearing loss [2-4]. Sensorineural hearing loss (SNHL) is indicated when the air and bone conduction thresholds are elevated equal and within 10 dB of each other [5]. Patients with SNHL have a reduced ability to hear sounds. Even when speech is loud enough to be heard, it may still be unclear or muffled. The degree of loss is varied from mild, moderate, severe, to profound loss. The most important part of the sensorineural pathway is the organ of corti in the cochlea, and the neurons of the auditory part of cranial nerve VIII [6]. Abnormalities in the cochlear nerve and sensory receptors within the cochlea cause cochlear hearing loss, such as noise induced hearing loss, or Meniere's disease. Retrocochlear hearing loss is caused by diseases or disorders of the auditory system, located from the auditory nerve through the auditory cortex. These diseases and disorders include vestibular schwanoma, multiple sclerosis, and auditory neuropathy [4]. Because, the treatment of SNHL depends on the site of the lesion, SNHL patients have to be diagnosed using special tests to identify their legions' exact location [5].

The otorhinolaryngologist's evaluations are very important to diagnose the site of lesion in SNHL patients. There are subjective and objective evaluations. Subjective evaluation requires patients' cooperation. These evaluations include the short increment sensitivity index (SISI), the alternate binaural loudness balance (ABLB), tone decay, and Bekesy audiometry. These tests have some limitations, including a patient's cooperation level, and degree of hearing loss, They also have less sensitivity and specificity in identifying the site of the lesion[4]. Objective evaluations do not require a response from the patient. One widely used objective evaluation is the auditory brainstem response (ABR).

The ABR measures the electrical response from the auditory brainstem pathway to diagnose the site of the lesion in sensorineural hearing loss patients. The test does not require a patient's co-operation, and several reports confirmed the sensitivity of ABR for diagnosis of retrocochlear lesion to be as high as 98% with a specificity of 90% [7-9]. Though the results of ABR provide more sensitivity and specificity in identifying the site of the lesion, the test needs more time and the cost is rather expensive.

The acoustic immittance assessment is also an objective test used to test the immittance of the middle ear by generating variations of air pressure in the ear canal. It provides information about middle ear pathologies, and middle ear muscle contractions, due to the acoustic stimulation, called acoustic stapedius reflex [2]. This is a mechanism of the inner ear that protects itself from high intensity sound stimulations. The lowest intensity level at which this contraction is measurable is called the acoustic reflex threshold (ART) [10]. Most normal hearing people have bilateral intra-aural muscle reflex when pure tones are introduced to either ear [4]. It can be measured as ipsilateral mode when the stimulus is presented to the probe ear, which is the same ear in which the immittance change is being monitored. For the contralateral mode, it is being measured in accordance to the stimulus level presented in the ear opposite to probe ear. In normal hearing, Ipsilateral ART occurs between 85 and 100 dB SPL, and 75-100 dBHL for contralateral ART by pure tone stimulation [2].

The acoustic reflex measurement is another objective test that can be used to diagnose the site of the lesion in hearing loss patients by comparing the contralateral acoustic reflex thresholds with pure tone air conduction thresholds, which is called sensation level. The sensation level in normal hearing is 60-65 dB. If the sensation level is lower than 60 dB, it means recruitment, which is a characteristic of cochlear hearing loss. If the sensation level is more than 60 dB, and the elevated ART is either greater than 105 dBHL or is absent, it is considered to be retrocochlear hearing loss [11]. However, in the case of severe SNHL, ART is absent because the intensity of the signal is insufficient to stimulate the brainstem in order to produce the acoustic reflex [4].

Nevertheless, ABR and ART have less sensitivity and specificity in finding the tumor on the auditory nerve when compared with Magnetic resonance imaging (MRI), which is a medical imaging technique used in radiology to investigate the anatomy and physiology of the body in both health and disease. But they are recommended to be used as audiologic tests to diagnose patients who have auditory nerve disorders, such as auditory neuropathy, because the previous research showed MRI revealed at least one imaging abnormality only 64% [12, 13].

## 1.2 Statement of the problem

Although the sensitivity of ABR for diagnosing the site of the lesion is high, there are limitations of the test, including the length of the test. The ABR takes about 45-60 minutes per case. The acoustic reflex measurement test takes less time, only 10-15 minutes per case. The ART is also cheaper, and no appointment is needed. However, there have been a few researches about acoustic reflex measurements, especially in Thailand. The aim of this research is to study the diagnostic accuracy, including the sensitivity and specificity, of the acoustic reflex test in identifying the site of the lesion.

## 1.3 Purpose of the study

1.3.1 To study the diagnostic accuracy, including the sensitivity and specificity, of the acoustic reflex test in identifying the site of the lesion, compared to the results of auditory brainstem response measurement.

1.3.2 Find out the audiometric configuration, or hearing level, which will be the most sensitive, to apply the method of comparison acoustic reflex and pure tone thresholds in identifying the sites of lesions.

## 1.4 Research questions

1.4.1 What is the diagnostic accuracy on the sensitivity and specificity of the acoustic reflex test in identifying sites of lesions, when compared to auditory brainstem response measurement?

1.4.2 What is the audiometric configuration, or hearing level, most sensitive to apply the method of comparison acoustic reflex and pure tone thresholds in identifying sites of lesions?

## 1.5 Expected outcomes of the research

Acoustic reflex measurement may be used as an effective tool to identify sites of lesions, especially in cochlear hearing loss, which will improve routine clinical service by reducing test time and reducing the cost of diagnostic procedures.

## 1.6 Definition of terms

**Sensorineural hearing loss**: Formerly called perceptive loss or nerve loss, this term refers to the loss of hearing sensitivity produced by damage, or the alteration of the sensory mechanism of the cochlea, or the neural structures that lie beyond.

**Acoustic reflex thresholds** (ART): The lowest intensity at which a stimulus can produce the acoustic reflex [4].

**Auditory brainstem responses** (ABR): The Auditory brainstem response is an electrical response induced by sound; it arises from the structures within the ear, nerve, and brain [14].

**Sensitivity**: The sensitivity measures the percentage of time a test correctly identifies a site of a lesion as such; the percentage of sick people who are identified as having the condition.

**Specificity**: The specificity measures the percentage of time a test correctly rejects an incorrect diagnosis as such; the percentage of normal people who are identified as not having the condition [4].

**Positive predictive value**: The positive predictive value is the proportion of patients who are test positive, and in whom the disease is presented.

**Negative predictive value**: The negative predictive value is the proportion of patients who are test negative, and in whom the disease is absent [15-17].

# CHAPTER II
# LITERATURE REVIEW

The review of the literature relating to the present study is divided into four sections, including the anatomy and physiology of the auditory pathway, sensorineural hearing loss, auditory brainstem response, and acoustic reflex measurement.

## 2.1 Anatomy and physiology of auditory pathway

The main components of the human ear are the outer ear, the middle ear, and the inner ear (Fig 2.1). The outer ear begins at the pinna, along with the ear canal and terminates at the tympanic membrane. The pinna of outer ear serves to focus sound waves through the ear canal, and has the ability to localize sound vertically. The sound wave arrives at the tympanic membrane, and is transmitted to the middle ear. The tympanic membrane is vibrated by air pressure, and then transmitted to the ossicles. The ossicles consist of malleus, incus and stapes. The footplate of stapes set up a wave of sound pressure to the fluid of the inner ear via the oval window. The hair cells in the cochlea convert mechanical energy to neural signals to the VIIIth nerve. From the VIIIth nerve, the signal arrives at the cochlear nucleus (CN), then travels to both the right and left superior olivary complexes (SOC), and is transmitted to the inferior colliculus through the lateral lemniscus. Next, it is transmitted to the medial geniculate body, and finally to the auditory cortex. The following review of the muscle of middle ear, cochlea and the ascending pathway will demonstrate the elemental source of ART and ABR.

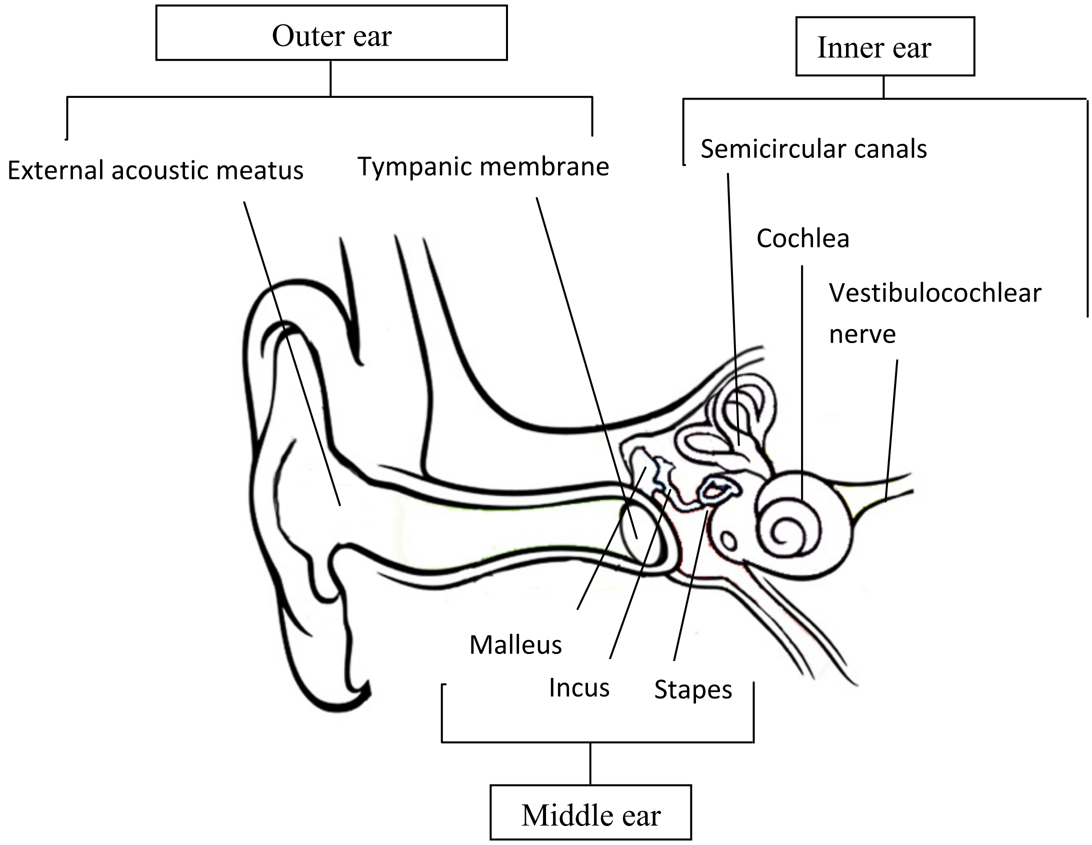



**Fig 2.1** Ear anatomy. Drawing of modified coronal section through external ear and temporal bone.

### 2.1.1 The muscle of middle ear

The middle ear contains two muscles, the stapedius and tensor tympani muscles, both of them attach to the ossicular chain.

2.1.1.1 The stapedius muscle is the smallest of the skeletal muscles. It is innervated by the seventh cranial (facial) nerve. The body of the stapedius muscle is located in the pyramidal eminence (a prominence on the posterior wall of the tympanic cavity), and inserted into the neck of the stapes by the stapedius tendon [2]. In humans, the stapedius muscle contracts when it is stimulated by intense sound. The contraction of the stapedius muscle is a hearing protective mechanism called acoustic reflex. The stapedius stiffens the ossicular chain by pulling the stapes of the middle ear away from the oval window of the cochlea. The reflex decreases the transmission of vibrational energy to the cochlea [18].

2.1.1.2 The tensor tympani muscle is located inside of tensor tympani semicanal, within the anterior wall of the tympanic cavity. The tendon of the tensor tympani muscle bends around the cochleariform process, a curve body projection on the anterior/medial wall points into the middle ear space, and ends at the top of the malleus. The tensor tympani muscle contracts as part of a startled reaction. These are stiffened by loading the eardrum when it pulls the malleus (hammer) in toward the middle ear [18].

### 2.1.2 Cochlea

The cochlea is composed of a bony labyrinth within the inner ear that contains the cells which are responsible for the perception of sound (Fig 2.2). The sound vibration is transmitted into the oval window by the stapes footplate. The fluid in scala vestibuliu is called perilymph. It moves in a wave-like motion and propagates passed the helicotrema to the Scala tympani. Travelling waves in the perilymph leads the endolymph in the Scala media to continue vibrating, and the basilar membrane is similarly displaced [4]. The organ of Corti consists of hair cells and tectorial membrane which lie on basilar membrane. When the basilar membrane vibrates, the structure of steriocilia on the tip of the hair cells bends, and induces potential actions. At first, in the resting cell potential (no stimulation), sodium ions (Na+) is outside the cell and potassium ions (K+) is inside the cell, and is a negative voltage. When the steriocilia bends, the sodium gate is opened and Na+ influxes into the cell induces the voltage in the cell and rapidly shifts from negative to positive. Then the deflection of the stereocilia in the opposite direction is repolarized, the Na+ gate is closed and K+ gate is opened, the sodium potassium pump is then able to reestablish the resting potential, and the process of repolarization is completed. These mechanisms are called potential action, which are transmitted along the nerve fiber supply [19]. The cochlear is a tonotopic organization, and can be described by the traveling wave theory. Bekesy found that the basilar membrane is an elasticity uniform and longitudinal position. Because the basilar membrane is wider toward the top, it is most stiff at the base (near the stapes) and the least stiff at the apex. As the result of this stiffness, the basilar membrane movement is a pattern that always happens from the base to the apex, and this is called the traveling wave. The traveling wave depends on the frequencies of sound. High frequencies are represented toward the base of the cochlea and low frequencies are represented at the apex [2].

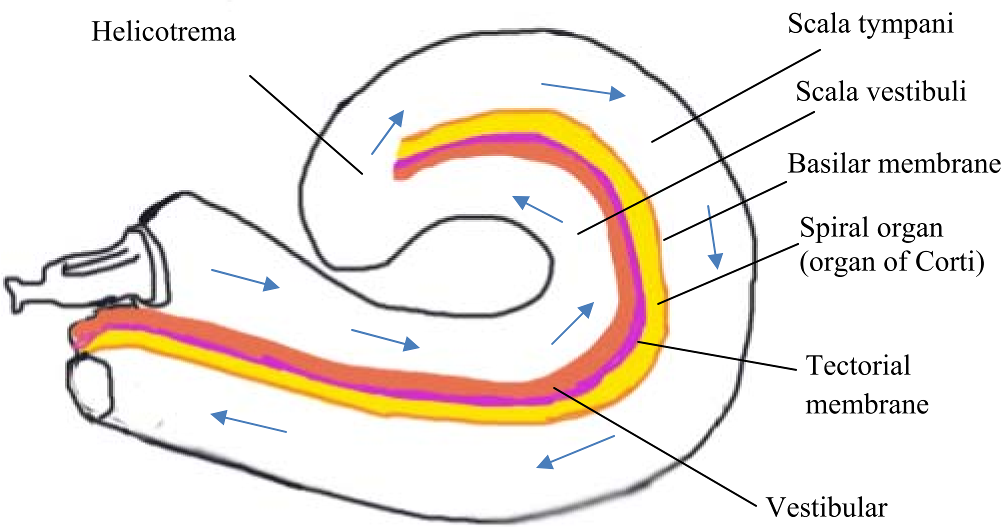



**Fig 2.2** Drawing of component of the cochlea

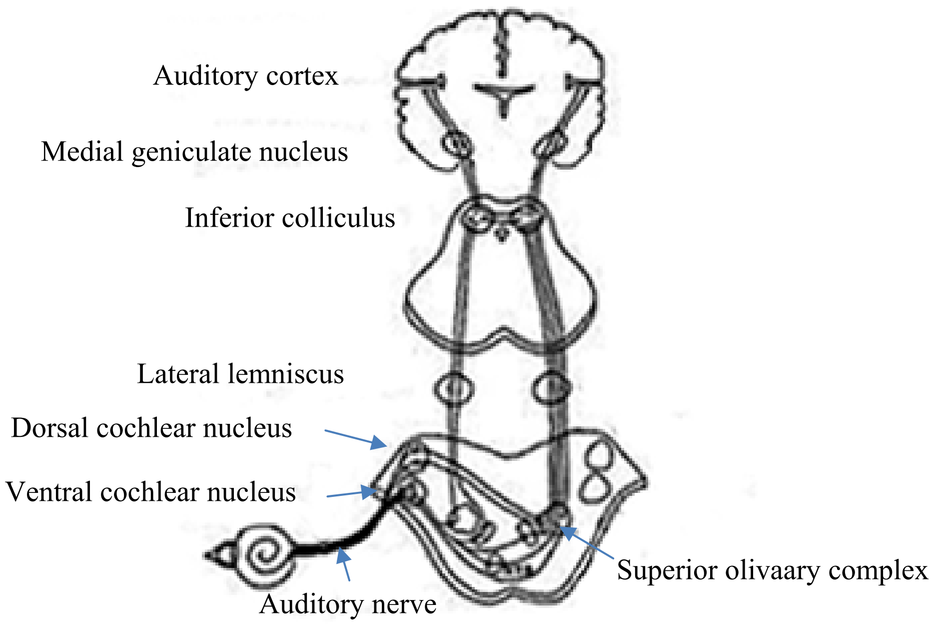



**Fig 2.3** Drawing of central auditory pathway [20]

### 2.1.3 The central auditory pathway

The central auditory pathway composes of nuclei and complex pathways that are ascending auditory signal within the brainstem (Fig. 2.3)[21].

2.1.3.1 The auditory nerve

The auditory nerve extends 17 to 19 mm passes from the modiolus of the cochlea through the internal auditory canal (IAC), and terminates at the base of the brain. The auditory nerve is one of two parts of the vestibulocochlear nerve. The other portion of the vestibulocochlear nerve is the vestibular nerve that innervates the vestibules and the semicircular canal of the inner ear; this structure transmits information about balance, and is an important component of the vestibuloocular reflex. When damage occurs, the vestibular nerve may give off the sensation of spinning and dizziness, and rotatory nystagmus. If a damaged cochlear nerve causes partial or complete deafness in the affected ear, that classification of audiogram is sensorineural hearing loss. However, a small percentage of patients with acoustic neuromas will have normal pure-tone audiogram and normal ABR findings (Telian et al, 1989). These are because of the size and position of the tumors.

2.1.3.2 The cochlear nucleus (CN)

The cochlear nucleus, also known as the cochlear nuclei, is located on the lateral surface of the brainstem that carries sound information from the cochlea via the cochlear nerve. The cochlear nucleus is divided into ventral and dorsal subdivisions. The ventral CN is divided into the anterior ventral and the posterior ventral. The ventral acoustic stria (2nd order neuron) projects fibers from anterior ventral CN to the ipsilateral superior olive, and across via the trapezoid body terminate to contralateral superior olivary. The intermediate acoustic stria ($2^{nd}$ order neuron) projects fibers from posterior ventral CN to the contralateral CN, ipsilateral dorsal CN, and contralateral inferior colliculus. The dorsal acoustic stria ($2^{nd}$ order neuron) projects from dorsal CN to contralateral of the lateral lemniscus [4].

2.1.3.3 The superior olivary complex (SOC)

The SOC is the first central auditory center to receive binaural innervation, It maintains a tonotopic organization, as the cochlea and CN. The SOC consists of three major nuclei that give third-order neurons consistency: lateral SOC, medial SOC, and the medial nucleus of the trapezoid body. The medial nucleus of the trapezoid body is a relay, carrying information from opposite CN to ipsilateral lateral SOC. The medial SOC receives input from both ipsilateral and contralateral CN, but more directly from the ipsilateral side. The lateral SOC receives direct connections from the ipsilateral ventral CN [22]. The direction of sound source is analyzed by the interaural time delay, by medial SOC, and the interaural intensity differences by lateral SOC [23]. In addition, The SOC mediates the reflex activity of the tensor tympani and stapedius muscles of the middle ear. Some of the SOC interacts with some neurons of facial nerve. High intensity sounds influence activation of the stapedial branch of the facial (VIIth) nerve. The stapedius muscles contract both ears when there is only one ear stimulation [4].

2.1.3.4 The lateral lemniscus

The lateral lemniscus, which is located on the lateral edge of the medulla and the pons, is auditory fiber, since SOC and CN reach the inferior colliculus. The ventral nucleus of the lateral lemniscus receives contralateral projections from the ventral CN and bilateral SOC, and contacts the ipsilateral inferior colliculus. The dorsal nucleus of lateral lemniscus receives bilateral lateral and medial SOC and the dorsal CN and projects to bilateral inferior colliculus. [23].

2.1.3.5 The inferior colliculus

The inferior colliculus is a midbrain structure that receives afferent stimulation from both SOC and synapse fiber to the medial geniculate body. Almost ascending and descending auditory pathways between the brainstem and forebrain synapse are within the inferior colliculus[23]. A few fibers bypass the inferior colliculus to reach the medial geniculate body directly from the lateral lemniscus. The lateral lemniscus is also an important component of the acoustic startle reflex pathway. These pathways through the lateral lemniscus correlate with aspects of the wave III to V interval of the auditory brainstem response [4].

2.1.3.6 The medial geniculate body

The medial geniculate body located in the thalamus. Most of fiber comes from the ipsilateral inferior colliculus and a few come from the lateral lemniscus. Next to this point, nerve fibers spread as the auditory radiations, and then ascend to the auditory cortex [4].

## 2.2 Sensorineural hearing loss

Sensorineural hearing loss (SNHL) reduces the ability to hear sounds. Even when speech is loud enough to hear, it may still be unclear or sound muffled. SNHL is indicated by air and bone conduction thresholds, which are both elevated and within 10 dB of each other [5]. It can be mild, moderate, or severe, including total deafness.

### 2.2.1 Clinical sign and symptoms of SNHL patients

2.2.1.1 Aural fullness

Patients often describe aural fullness as a stuffy feeling in the ear, ear pressure, or a clogged sensation. Aural fullness is associated with some diseases such as diabetes, hypertension, head and neck cancer, migraines, thyroid disease, chronic renal failure, depressive disorder, and allergic rhinitis, which might have some influence on hearing [24]. The most common cause of aural fullness is middle ear problem (56%), but it can also be caused by the inner ear problem(10.8%) [25]. Some patients (2.1%) had aural fullness caused by the inner ear problem, such as the early stage of Menière's disease [25, 26], idiopathic sudden sensorineural hearing loss (5.5%)[25, 27], and diabetes is frequently accompanied by sensorineural hearing loss [24].

2.2.1.2 Dizziness

Dizziness is a symptom in which patients complain of lightheadedness, imbalance, or spinning. A common cause of abnormal symptoms relate to vestibular systems, including metabolic, neuromuscular, and cerebrovascular [21]. However, the vestibular receptor organ is part of the inner ear, the same as the cochlea, they and have together endolymphatic fluid. Consequently, the dizziness is associated with hearing. For example, abnormal fluctuation in the amount of endolymphatic fluid is called endolymphatic hydrops, or Meniere's disease. It's characterized by vertigo, which can last for several hours [2]. Another is inflammation involving the inner ear, called labyrinthitis. The symptoms are constant vertigo that may stay for several days, with nausea, vomiting, imbalance and sudden hearing loss. Vestibular schwannoma is a benign tumor growth of the vestibular nerve (eighth nerve). The general symptoms are dizziness or imbalance, progressive hearing loss and ipsilateral tinnitus [28, 29].

2.1.1.3 Tinnitus

Tinnitus is the abnormal perception of sound. The patient may be described as having “ringing in the ears,” “head noise,” or “ear noise”. It is commonly associated with SNHL, and others with CHL, but it sometimes occurs with normal hearing [2]. Tinnitus is classified into two categories: Objective tinnitus (exogenous sounds), meaning that the examiner can actually listen, and hear the sounds the patient hears. It is caused by muscle spasms [30] or a sound that beats in time with the pulse (pulsatile tinnitus, or vascular tinnitus). Subjective tinnitus (endogenous sound) - the tinnitus is heard only by the patient. It is commonly associated with an abnormal hearing system in the inner ear. The damage, and loss, of the tiny sensory hair cells can be caused by loud noise, medications, or age [31].

2.2.1.4 Hearing loss

Hearing loss symptoms depend on the type, the degree, and the configuration of hearing loss.

1. Type of hearing loss

Sensorineural hearing loss reduces the ability to hear sounds. Even when speech is loud enough to hear, it may still be unclear. In contrast to conductive hearing loss, if the signal is loud enough to hear, they hear clearly. Therefore, the most complaints are as follows:

- Unclear speech perception or mumbling
- Difficulty hearing in noisy environments
- Difficulty understanding phone conversations
- Rather difficult to have conversations when more than one person speaks at the same time
- Always misunderstanding what people say and responding inappropriately.
- Always ask people to repeat themselves
- Frequent complaints by others that the TV is too loud

- Feeling uncomfortable while listening to loud sounds. Even though there is only a small increase in the noise levels, sound may seem much louder [32].

2. Degree of hearing loss

Degree of hearing loss refers to the severity of the loss. Table 2.1 shows one of the common classification systems. The numbers are representative of the patient's hearing level in decibels (dB HL) [33].

**Table 2.1** Level of hearing [34]

| dB HL Range | Term |
|---|---|
| 0 – 25 | Normal hearing |
| 26 – 40 | Mild hearing impairment |
| 41 – 55 | Moderate hearing impairment |
| 56 – 70 | Moderately severe hearing impairment |
| 71 – 90 | Severe hearing impairment |
| > 90 | Profound hearing impairment |

3. Configuration of hearing loss

The configuration or shape of the hearing loss refers to the extent of hearing loss at each frequency and the overall picture of hearing that is created [35]. Some typical shapes and the criteria used to describe them are shown in Table 2.2

**Table 2.2** Criteria for classifying audiometric configurations

| Term | Descriptions |
|---|---|
| Flat | ≤5dB average difference per octave |
| Gradually sloping | 6-10dB rise or fall per octave |
| Sharply sloping | 11-15dB rise or fall per octave |
| Precipitously sloping | ≥16dB rise or fall per octave |
| Rising | Better hearing at the higher frequencies |

**Table 2.2** Criteria for classifying audiometric configurations (Cont.)

| Term | Descriptions |
|---|---|
| Trough or saucer | ≥20dB more loss at middle frequencies than at 250 and 8000Hz |
| Notch Sharply | poorer at one frequency, with recovery at adjacent frequencies |

Robert s, 2009 modified from Cahart (1945) and Lloyd and Kaplan (1978) [6]

ASHA, 2005 were describing the configuration of hearing loss in three following types;

1. Hearing loss configurations are flat, indicating the same amount of hearing loss for low and high tones. Flat configuration audiogram: A hearing loss that is approximately the same at all frequencies, more or less a straight horizontal line. Sometimes it is called flat loss or flat curve. (Fig 2.4)

2. Low frequency SNHL: Better hearing at the higher frequencies. (Fig 2.5)

3. High frequency SNHL: there is little or no hearing loss in the low frequencies, but a considerable loss in the higher frequencies. (Fig 2.6) [35]

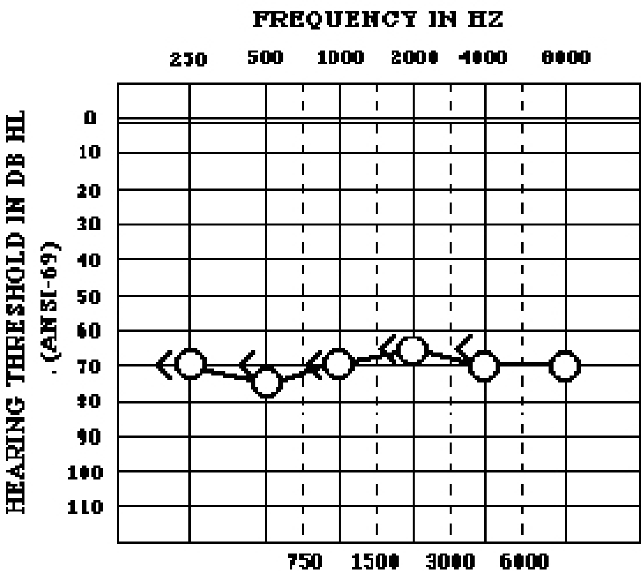



**Fig. 2.4** Flat audiogram

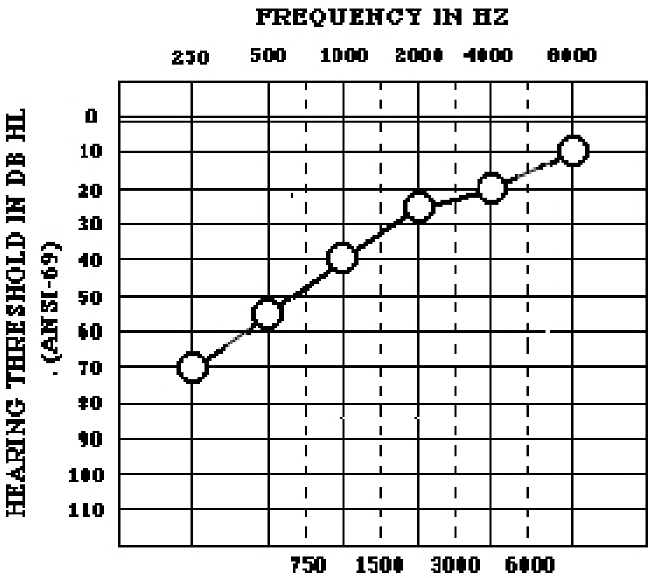



**Fig. 2.5** Low frequency hearing loss audiogram

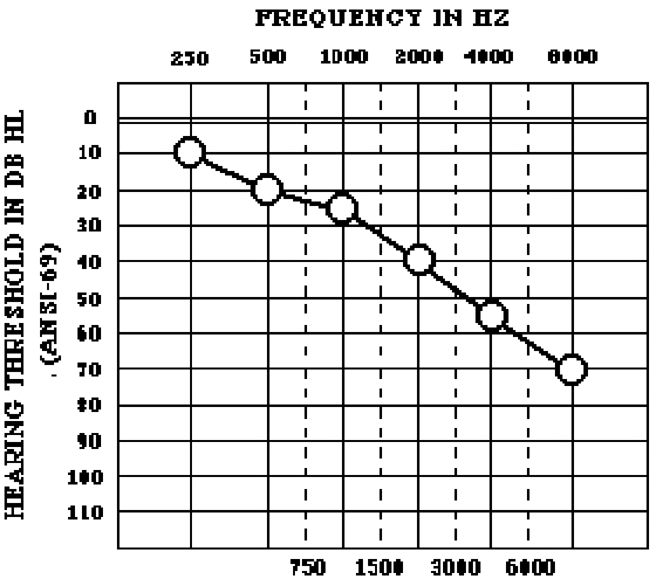



**Fig. 2.6** High frequency hearing loss audiogram [36]

### 2.2.2 Site of lesion

Pathology of SNHL is the hair cell in the cochlea or/and the neurons of auditory part of cranial nerve VIII [6].

2.2.2.1 Cochlear pathology

The most common cause of cochlear hearing loss originates by hair cell damage. Hair cells are important in hearing discrimination, so SNHL patients hear unclear speech although the intensity of sound is loud enough. Another characteristic of cochlear hearing loss are the exception of pitch and loudness perception. The patient hears more than one pitch despite the same pure tone called diplacusis. Loudness recruitment means abnormal growth perception, which is rapidly increased in suprathreshold stimulus intensity [2, 37].Hearing loss occurs at any time in life, as a result of ear diseases illness and injury. The common causes are the following:

- Ototoxicity

The term ototoxicity refers to a medication or chemicals which are poisonous to the ears. The most commonly seen in practice are aspirin, loop diuretics, aminoglycoside antibiotics, and antineoplastic drugs [19]. This hearing loss is typically associated with bilateral high-frequency and tinnitus, or balance disorders.

- Head injury

The highest risk of head injury causing SNHL is a fracture of the petrosal part of temporal bone [38, 39]. The post-traumatic SNHL most often progresses within the first six months. The cause of progressive SNHL due to trauma is still ambiguous. One feasible explanation is that the initial traumatic process inflames the inner ear, and the labyrinth, and affects the cochlea at the cellular level [40].

- Noise exposure

High levels of noise (greater than 85 dB) [41], can cause noise-induced hearing loss. It depends on the loudness and the duration of noise exposure. Noise induced hearing loss is often caused by the damage and death of hair cells. Moreover, human hair cells do not regenerate. The configuration of the audiogram begins at high frequency loss, then mid, and low frequency loss respectively [42].

2.2.1.2 Retrocochlear pathology

Retrocochlea refers to the neurons of the auditory pathway, from the cochlea to the auditory cortex. The cause of retrocochlear hearing loss may occur from disease, irritation, or pressure on the nerve trunk of the central auditory pathways. Common causes of retrocochlear hearing loss include:

- Benign auditory nerve tumors arise from sheaths that cover the vestibular branch of the vestibulocochlear nerve [29].

- Multiple sclerosis (MS) is primarily an inflammatory disorder of the brain and spinal cord in which focal lymphocytic infiltration leads to damage of myelin and axons. This damage disrupts the ability of parts of the nervous system to communicate [43].

- A demyelinating disease is any disease of the nervous system in which myelin sheaths cover many nerve fibers in the central and peripheral nervous system; they accelerate axonal transmission of neural impulses. Disorders that affect myelin interrupt nerve transmission, when occur with central auditory pathway so patients have hearing disorder [44].

- Auditory neuropathy (AN), also known as Auditory Neuropathy Spectrum Disorder (ANSD) or Auditory Dyssynchrony (AD), is a variety of hearing loss in which the outer hair cells within the cochlea are present and functioning as measured by otoacoustic emissions, but poor neural synchrony of the auditory (VIIIth cranial) nerve [45] result in impaired word discrimination that is disproportionately poorer than the pure tone loss, and absent or abnormal ABR [46].

## 2.3 Auditory evaluation for diagnosis site of lesion

Indication for diagnosing the site of lesion

- Unilateral hearing problem
- Asymmetric hearing loss
- Progressive hearing loss
- Sudden-onset hearing loss
- Poor word recognition ability in quiet and/or reduced in noise
- PIPB rollover (Performance Intensity function for Phonetically-Balanced words)
- Balance disturbance

- Unexplained elevated or absent reflexes [46, 47]

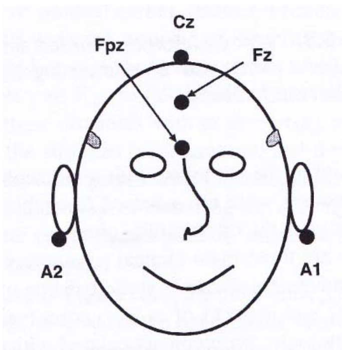
The hearing evaluations for diagnosing the site of the lesion include both subjective and objective tests. Subjective tests depend on cooperation from patients, and offer lower sensitivity and specificity. Therefore, researchers will review objective evaluations; Auditory brainstem response and Acoustic reflex measurement.

### 2.3.1 Auditory brainstem response

The Auditory brainstem response is an electrical response induced by sound; it arises from the structures within the ear, nerve, and brain at some distance from skin electrodes. The result of ABR relies on synchronous nerve firing.

2.3.1.1 Protocol test

- Electrode montage




Non inverting (Active): High forehead (Fz)

Inverting (Reference): Earlobe (A2, A1)

Ground: Low forehead (Fpz)

- Stimulus

The ABR is the response waveform of synchronized nerves occuring as the sound stimulus, short period from the onset. Most clinical use Click stimulus 0.1 ms. to diagnose site of the lesion because click stimulus gives the amplitude of wave large more than tone burst.

- Intensity

High intensity makes the amplitude of wave bigger. The intensities used were 90 dBHL or 99 dBHL (in hearing loss patient)

- Rate

Increase stimulus rates affect latency of the waveform. This prolonged, amplitude of the wave, is decreased because the high stimulus rate gets desynchronization.

- Polarity

Rarefaction provides ABR response faster latency and bigger amplitude more than condensation and alternating

- Ipsilateral & Contralateral

The results of ABR have arisen from the pathway since cochlear portion 8th cranial nerve, cochlear nucleus, superior olivary complex, lateral lemniscus and inferior colliculus. The signals transfer these pathways in stimulated ears, and cross to the contralateral at the superior olivary complex and next [48].

**Waveform generating**

The consistent components of the response are waves I to V, which originates from following (Table 2.3);

**Table 2.3** Anatomic origin of ABR waveform

| Component of ABR waveform | Anatomic origin |
|---|---|
| Wave I | The distal portion of the eight nerve |
| Wave II | The proximal portion of the eight nerve |
| Wave III | The superior olivary complex |
| Wave IV | The multiple crossing of midline for auditory fiber beyond the cochlear nucleus |
| Wave V | Lateral lemniscus termination at inferior colliculus and direct pathways from cochlear nucleus to inferior colliculus |

[14, 49]

2.3.2.2 ABR analysis and interpretation

The analysis and interpretation of auditory brainstem response includes waveform morphology, peak latency, and peak amplitude.

1. Waveform morphology

a. Response reliability and analysis criteria

Normal ABR waveforms have clear and repeatable wave components. Repeatability of at least two ABR waveforms recorded in succession with the same measurement conditions (Stimulus and parameters). The assumption of ABR measurement is time locked to the stimulus with minimal background noise and randomly distributed [50]. For ABR recordings, the assumption is often approached under the measurement conditions containing a high stimulus intensity level, low noise level, and relaxed muscle activity subject [49].

b. Waveform identification

In ipsilateral ABR (Fig 2.7), Peaks often missing in normal ABR waveforms include wave II and IV. The clear waveform morphology showed I, III and V. However, clinical experience shows that wave III is occasionally absent in normal subjects. Whether an absence of wave III, yet a normal wave I to V latency interval, is normal or abnormal, is still being debated. The missing peak relates to hearing deficits in the high frequency region. Therefore, the interpretation of ABR has to consider updated audiogram information. The fused peak is two peaks combined into a single wave complex. The peaks most often fused in normal ABR waveforms are IV and V. Edward found that about 50% of their subjects showed a single peak of IV-V; it is typically labeled as wave V [49].

In contralateral ABR (Fig 2.8), since wave I and II are electrical changes in the eighth nerve at the distal and the proximal portion in stimulated ears, so contralateral recording ABR have not got wave I and II. The cross of the hearing pathways begins at the superior olivary complex that produces wave III, then sends nerve signals to both ears. Therefore ABR has waves III to V in both ipsilateral and contralateral recording.

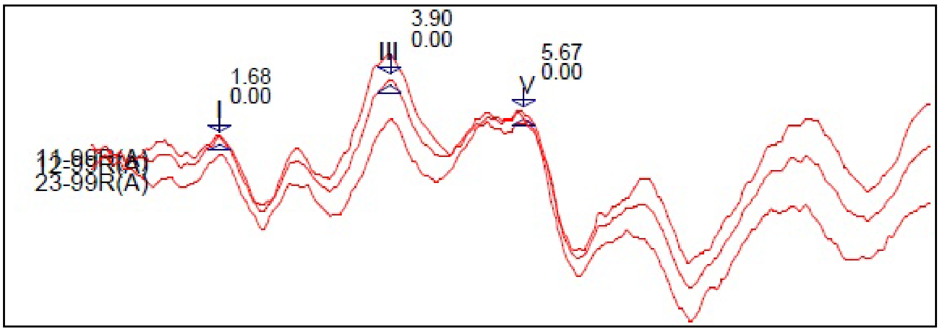



**Fig 2.7** Ipsilateral recording ABR

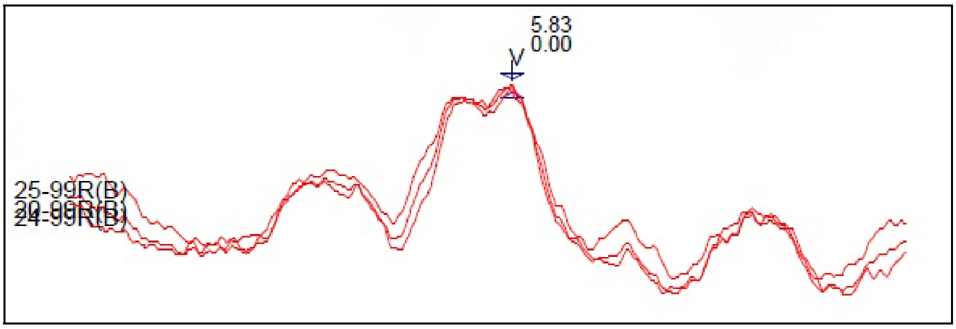



**Fig 2.8** Contralateral recording ABR

2. ABR wave amplitude

The amplitude of ABR refers to the height of a given wave component, and is measured in microvolts (μV). The amplitude depends on the amount of synchronized neural activity, and varies with the level of stimulation, hearing loss, neurologic pathology, and age.

a. Wave V amplitude

The amplitude is typically determined by differences in the magnitude of waves, compared with normal subjects. In the past, many studies examined amplitude wave V for diagnosis of retrocochlear disease and they were successful only in large tumors. However, it had a poorer sensitivity than latency measures due to several reasons, including weak electrical fields, a poor signal to noise ratio, and hearing loss. These caused smaller amplitudes than normal [46].

b. Interaural wave V amplitude comparison

The measurement is to compare the amplitude of wave V in the suspected ear to the non-suspected ear. The assumption is that there are very small differences in the amplitudes of wave V between the ears from the same individual. But its limitation in non-suspected ears is cochlear hearing loss and bilateral tumor [46].

c. Amplitude ratio

-Intraaural wave V to wave I amplitude ratio

The measurement is the ratio of the amplitude of wave V to wave I. In normal subjects, wave V is typically much greater than wave I. If the tumor occurs after eight nerve, the amplitude of Wave V decreases, and then has a small amplitude ratio. Musiek (1986) reported amplitude ratio in normal hearing and cochlear hearing loss has been less than 1. However, the sensitivity of detection of retrocochlear hearing loss by this method was 44% [46].

-Interaural wave V to wave I amplitude ratio

Compare the ratio of the amplitude of wave V to wave I between the suspected ear and the other ear. This method can improve the sensitivity and specificity, but its limitation depends on the wave I recording, and the configuration of any cochlear hearing loss in non-suspected ears [46].

3. ABR wave latencies

The most widely used ABR measure is the latency of three major peaks, consisting of wave I, III, and V. The latency of ABR is defined as the amount of time between the onset of acoustic stimulus and elicitation of response.

a. Absolute latencies

In normal ABR results, the absolute latency of wave I should occur at approximately 1.6 ms. after stimulus onset; wave III at about 3.7 ms.; and wave V at about 5.6 ms. This is for clicks presented at an intensity level of approximately 75 dB nHL [48]. Phadhana-anek studies in normal Thai subjects, reported the absolute latency of wave I, III, and V were 1.9, 3.9, and 5.7 ms. by click stimulus at 90 dBnHL. The latency measurement was highly reliable with intra-aural and interaural subjects [51].

b. Interpeak interval latencies

Coats and martin, 1978; Portmann et al, 1980, reports interpeak latencies were prolonged in tumor patients. But in sensorineural hearing loss and conductive hearing loss, they were not affected. Because of the location of the tumor on the nerve fiber ascending pathway, there is a specific delay in interpeak latencies between I and III or V. In males, normal interpeak I-V latencies are within 4.0 and 4.2 ms. and interpeak I-III latencies is within 2.0 and 2.2 ms. In females, they are slightly shorter [52].

c. Interaural interpeak latencies

Gordon and Cohen 1995 observed non- tumor ear individuals, and reported similar interpeak I-V in both ears. In tumor ears, interpeak I-V latency may be in the normal limit, but longer than for non-suspected ears. There was limitation in bilateral tumors, cause it delayed interpeak latencies on both sides [53].

In summary, the abnormal findings suggestive of retrocochlear pathology include the following;

1. Prolonged absolute latency of wave V.
2. Prolonged interpeak intervals latencies.
3. Significant difference in interaural absolute latency of wave V.
4. Significant difference in interaural interpeak latencies.
5. Significant difference in wave V latency when using slow and first click rates.
6. Poor waveform morphology or absent waveform.
7. Amplitude ratio of waves V/I less than 0.5 [54, 55].

### 2.3.2 Acoustic reflex measurement

The acoustic reflex refers to the reflexive middle ear muscle contraction, which is the protective mechanism of inner ear from high level of sound stimulation. These reflexes occur in human ears voluntarily by the following acoustic reflex pathway (Fig2.9).

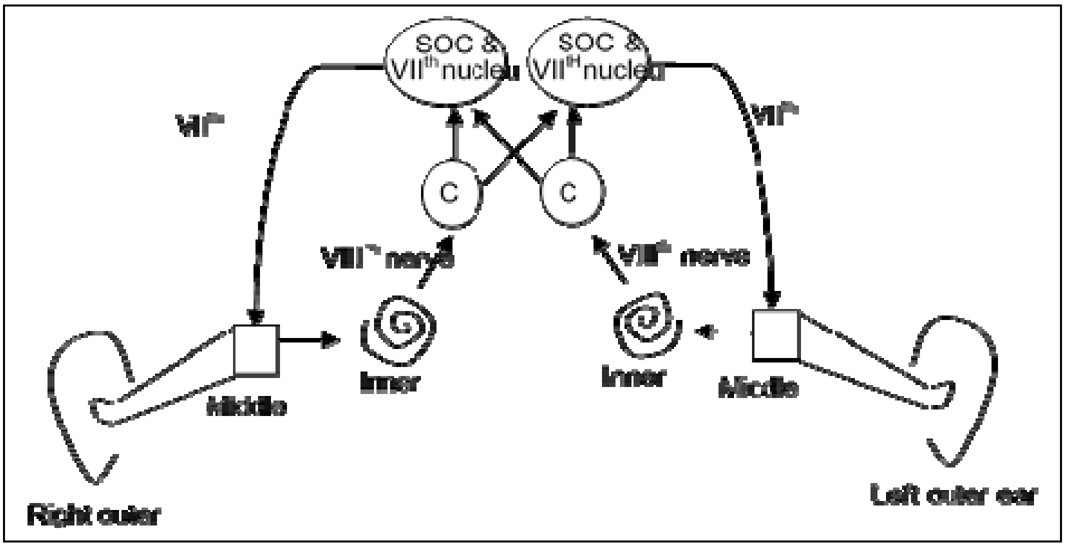



**Fig.2.9** Acoustic reflex pathway

2.3.2.1 Acoustic reflex pathway

The acoustic signal enters the outer ear, travels through the middle ear, inner ear, and the VIIIth nerve, to the brainstem. From the VIIIth nerve, the signal arrives at the cochlear nucleus (CN), then travels to both the right and left superior olivary complexes (SOC), and both the right and left VIIth nerve nuclei. The signal is sent from both the VIIth nerve nuclei to both VIIth nerves, which results in a contraction of both stapedius muscles. Thus, both stapes bones are pulled outward and downward, in a direction away from the inner ear. Their contraction has the effect of stiffening the ossicular chain, thereby reducing the amount of energy that is delivered to inner ear. Acoustic reflex responses are measured in the ear canal by using a probe stimulus to monitor admittance changes elicited by a reflex-activating stimulus [18].

2.3.2.2 ART measurement

Clinical ART measurement is made according to the American National Standards Institute for immittance instruments by the use of a 226-Hz probe tone. Ipsilateral acoustic reflex refers to contraction of stapedius muscle in the same ear as stimulated ear (uncrossed acoustic reflex) (Fig. 2.10). Contralateral acoustic reflex refers to contraction of stapedius muscle in the opposite ear as stimulated ear (crossed acoustic reflex) (Fig. 2.11).

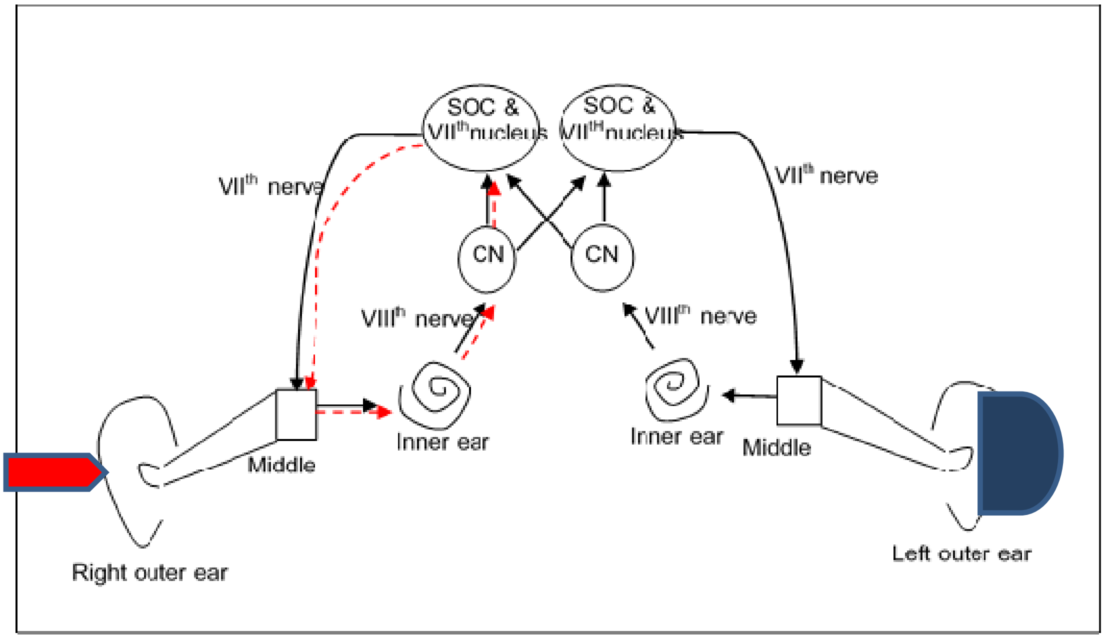



**Fig. 2.10** Diagram of ipsilateral acoustic reflex pathway

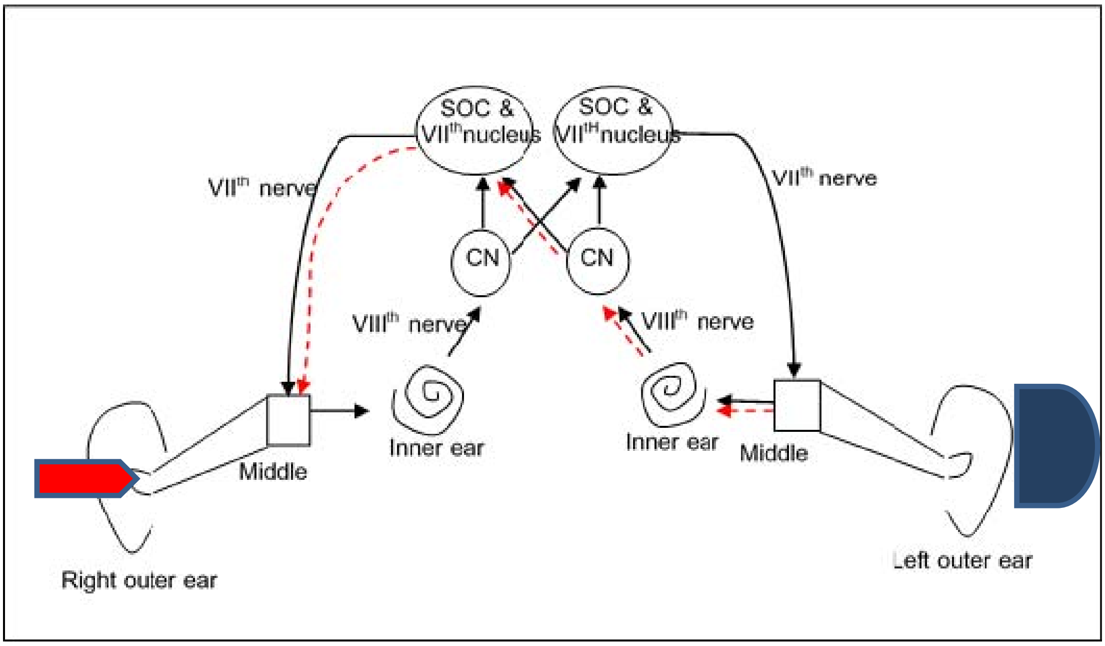
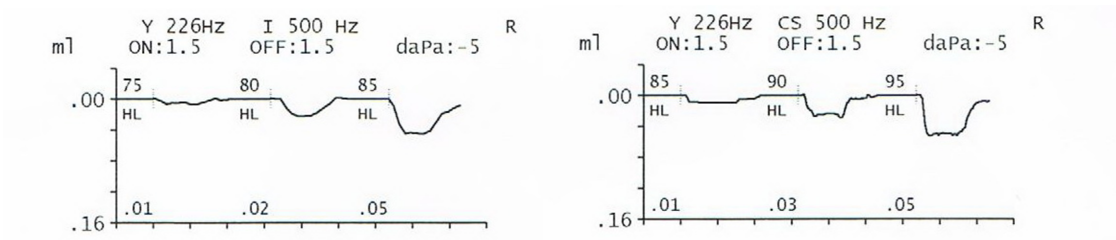



**Fig. 2.11** Diagram of contralateral acoustic reflex pathway

The sound stimuli widely used in the clinic were pure tones (500, 1000, 2000, or 4000 Hz) or a broadband noise. The ART are measured at the position of tympanometric peak pressure (TPP), which is the maximum admittance peak pressure. When reflex occurs, the admittance of the test ear decreases and demonstrate on the monitor, for example, 0.02 to 0.03 mmho., The lowest intensity level at which this contraction is measurable is called acoustic reflex threshold (ART) [10, 56]. For example (Fig. 2.12), the lowest intensity level of the right ipsilateral acoustic reflex was 80 dB HL (a) and the lowest intensity level of the left contralateral acoustic reflex was 90 dB HL (b).




(a) (b)

**Fig. 2.12** Admittance of the test ear decreases by a criterion amount in the presence of the monitor. Right ipsilateral (Fig a.) and Left contralateral (Fig. b)

**Factor absent acoustic reflex**

Acoustic reflex is protective mechanism of the ear to protect damage from loud sound. ART is presented in normal hearing people. Many kinds of ear problem inhibit ART.ART are absent by the following factors:

1. Absence stapedial tendon
2. Middle ear effusion
3. Ossicular chain disruption peripheral to stepedial tendon: anormaly of ossicle alignment
4. Otosclerosis: Fixation of stapes footplate
5. Tympanic membrane perforation
6. Abnormal middle ear pressure
7. Facial nerve lesion medial to stapedial nerve
8. Severe to profound hearing loss
9. VIIIth nerve disorders [55, 57].

**Application of ART measurement for testing the cochlear / retrocochlear pathologies**

In normal hearing, ipsilateral ART occurs between 85 and 100 dB SPL for pure tones, and contralateral ART ranges from 65 to 95 dB HL [58]. In sensorineural hearing loss patient, the ART results are classified into two pathologies [2].

1. Cochlear pathology: ART results are typically presented in ears within lower sensation level (different between contralateral ART and pure tone threshold < 60 dBHL) at the activator frequencies.

2. Retrocochlear pathology: The reflex threshold is at a normal sensation level, but the elevated reflex threshold or absent is considered indicative of retrocochlear hearing loss. For example, normal hearing with absent acoustic reflex. Reflex thresholds are considered elevated if they exceed the relevant 90th percentiles (Appendix A) because ART so high are common among ears with normal hearing and/or cochlear disorders, occurring less than 10% of the time [18, 59].

Limitation of ART is hearing level. In case of hearing loss more than 80 dB, ART is actually absent. However, in some cases, ART can be recorded in patients with hearing loss up to 95 dB HL[60]. The measurements have been a part of the standard clinical immittance test battery for decades as a cross-check with the behavioral audiogram and as a way to separate cochlear from retrocochlear pathology [61].

Cohen & Prasher, 1988, studied the value of combining auditory brainstem responses and acoustic reflex threshold measurements in neuro-otological diagnosis. Subjects were 69 patients, referred to the neuro-otological clinic on the suspicion of a retrocochlear lesion. The inclusion criteria were sensorineural hearing loss patients with hearing level better than 60 dB HL. The ABR result was positive in 100 % of cerebello-pontine angle tumor group and 90% in the brainstem group compared with ART results of 93% and 70% respectively [62]. In 1984, Shepard and Frazer reported 73% sensitivity and 90% specificity for prediction of acoustic neuroma using the ART [10].

Ferguson et al, 1996, studied the effectiveness of tests in screening cerebello-pontine angle tumors. Subjects were 237 sensorineural hearing loss patients, presenting at the ENT department. All patients were pathological confirmed by computerized tomography (CT) and magnetic resonance imaging (MRI).The results of ARTs demonstrated high sensitivity of 93% and ABR sensitivity of 88%. Although ART showed higher sensitivity than ABR, but the specificity was only 49%, which was lower than ABR specificity (78%) [63].

Many research reported that acoustic reflex thresholds depend on hearing sensitivity. Gelfand, Schwander, & Silman (1990) show the 10th, 50th, and 90th percentiles of ART at 500 Hz (Fig. 2.13), 1000 Hz (Fig. 2.14), and 2000 Hz (Fig. 2.15) for normal hearing and cochlear hearing loss patients. For example, information of patients who have thresholds 15 dBHL at 500 Hz: 10% of them have ART up to 75 dBHL, 50% have ART up to 85 dBHL, and 90% have ART up to 95 dBHL (Fig 2.13). These researches were used to decision about when an ART is elevated depend on the magnitude of the hearing loss patients. If hearing level is 50 dB at 500 Hz, presents an acoustic reflex threshold more than 100 dBHL suggested retrocochlear pathology[2, 18]. Olsen at al. applied the 90th percentile cutoff level to 30 cerebellopontine angle tumors patients. They found 83% of them had elevated ART beyond the 90th percentile level at least one activator frequency and 57% of them had elevated ART at least two activator [28].

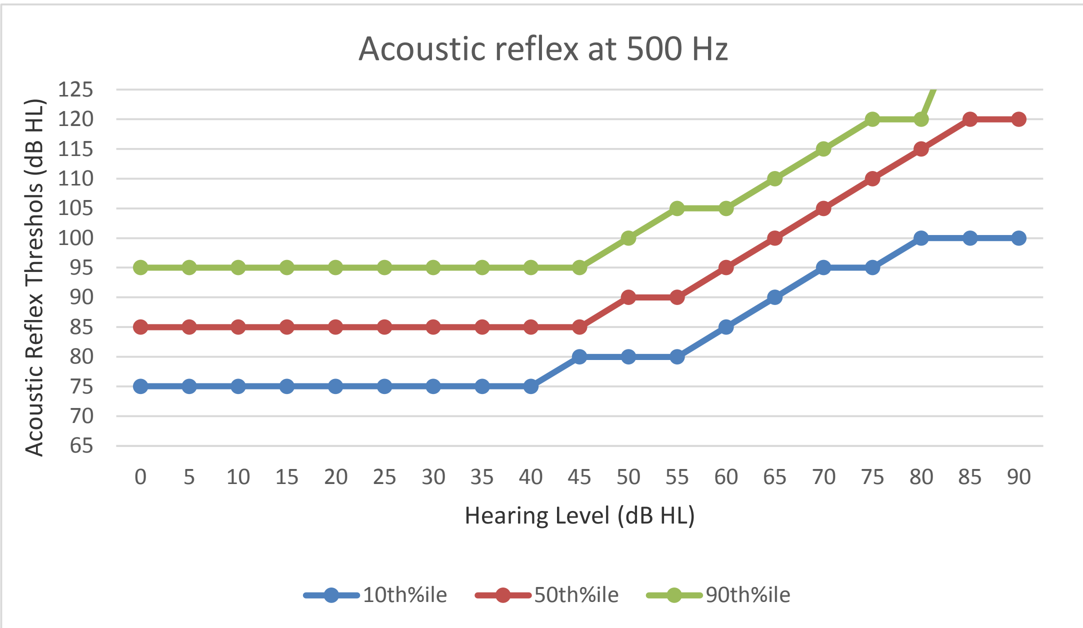



**Fig. 2.13** 10th, 50th, and 90th percentiles of acoustic reflex thresholds for 500 Hz stimulation

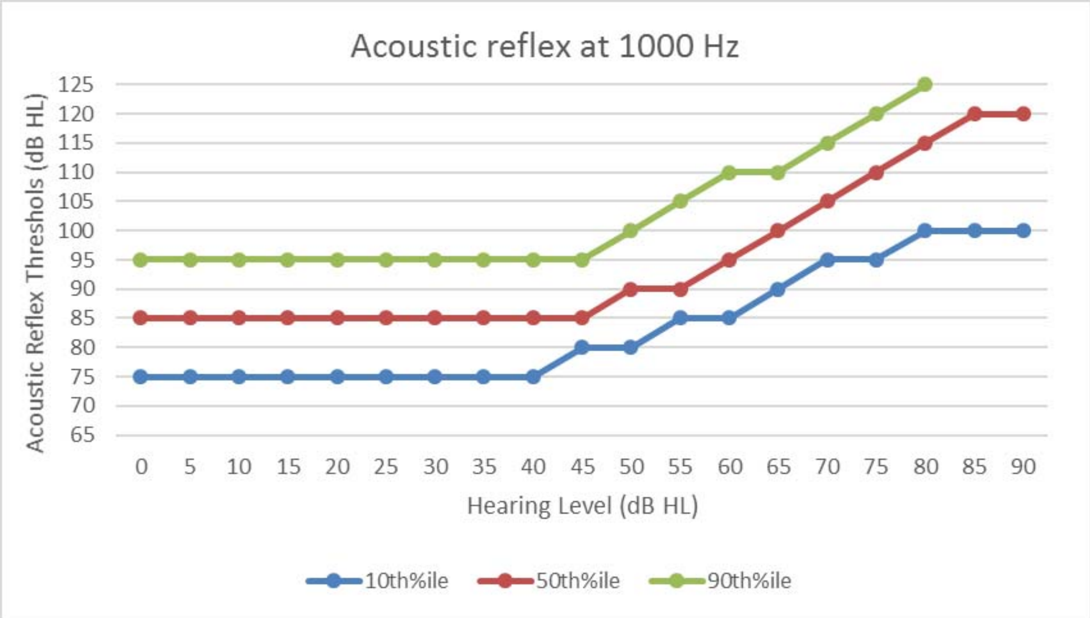



**Fig. 2.14** 10th, 50th, and 90th percentiles of acoustic reflex thresholds for 1000 Hz stimulation

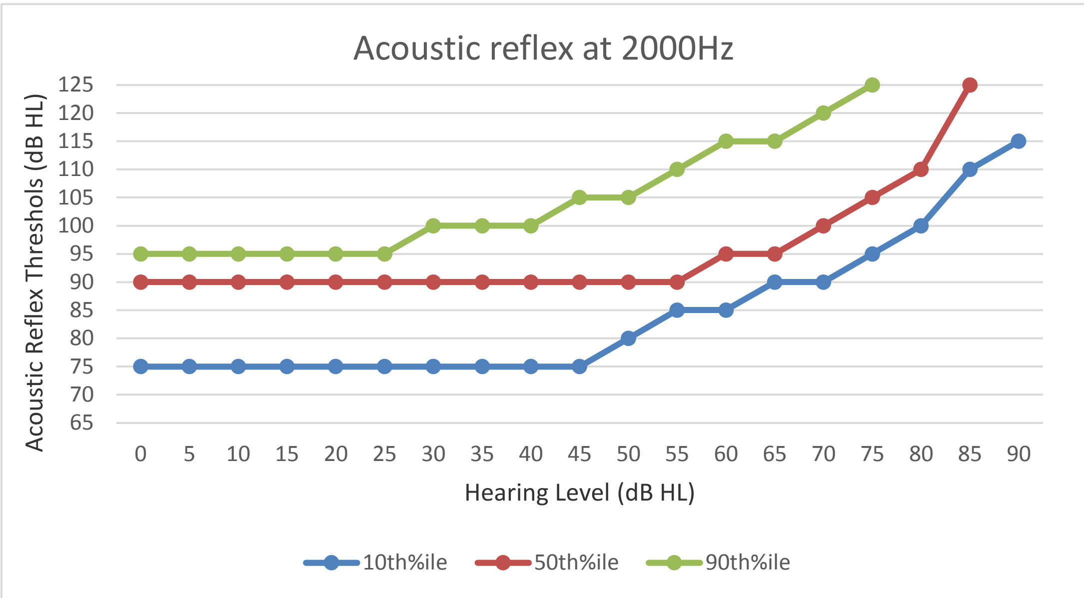



**Fig. 2.15** 10th, 50th, and 90th percentiles of acoustic reflex thresholds for 2000 Hz stimulation

# CHAPTER III
# MATERIAL AND METHODS

The goal of this study was to find the sensitivity and specificity of ART for clinical application. The study was done at Audiology clinic, the Department of communication sciences and disorders, Faculty of Medicine Ramathibodi Hospital, Mahidol University. The data were obtained from medical records of sensorineural hearing loss patients. This chapter described the subjects, instrumentation, procedures, and method in data analysis.

## 3.1 Subjects

This was a retrospective study of sensorineural hearing loss patients, who were referred by otorhinolaryngologists for ABR measurement during 2009 – 2013, total of 5 years. The subjects consisted of 346 ears from 232 patients (102 males, 130 Females), ranging age from 8 – 83 years with a mean age of 53.31 years. All patients had an updated audiogram. The difference did not exceed 3 months prior to ABR measurement. Acoustic immittance measurement recordings include tympanogram and acoustic reflex thresholds.

The exclusion criteria consisted of:

a. Normal hearing
b. Profound hearing loss
c. Tympanogram was not Type A

   Characteristic of type A tympanogram included;

   - The peak of the tympanogram within +/- 100 daPa
   - The compliance of tympanogram within 0.3 - 1.4 mmho.

d. ABR waveform could not be identified due to severe hearing loss

## 3.2 Procedures

3.3.1 All data in this study were collected by reviewing medical records and fill-in record forms for each patient.

The information included:

- Hospital number (NH)
- Age
- Chief complaint
- Audiogram: Pure tone air conduction thresholds
  Pure tone bone conduction thresholds
  Speech recognition threshold
  Speech recognition score
- Acoustic immittance measurement:
  Tympanogram
  Acoustic reflex thresholds
- Auditory brainstem response results.

3.2.2 Classified the degree of hearing impairment are based on the pure tone average for air conduction thresholds at 500, 1000 and 2000 Hz. Table 3.1 shows a commonly employed classification system for describing the severity of hearing impairment in adults.

**Table 3.1** Classification of magnitude of hearing impairment [34]

| dB HL Range | Term |
|---|---|
| 0 – 25 | Normal hearing |
| 26 – 40 | Mild hearing impairment |
| 41 – 55 | Moderate hearing impairment |
| 56 – 70 | Moderately severe hearing impairment |
| 71 – 90 | Severe hearing impairment |

3.2.3 Audiometric data was classified according to the configuration as follows;

3.2.3.1 Flat configuration audiogram: A hearing loss that is approximately the same at all frequencies, more or less a straight horizontal line. Sometimes it is called flat loss or flat curve. It is identified with a hearing Threshold difference per octave ≤ 10 dB

3.2.3.2 Low frequency SNHL: Better hearing at the higher frequencies.

3.2.3.3 High frequency SNHL: there is little or no hearing loss in the low frequencies, but a considerable loss in the higher frequencies.

## 3.3 Statistical analysis

3.3.1 A statistic package SPSS for Windows was used for data analysis:

The general information of patients, and the chief complaints of patients were calculated.

3.3.2 A statistic package Stata for Windows was used for data analysis:

The sensitivity, specificity, positive predictive value and negative predictive value of Acoustic reflex threshold in sensorineural hearing loss patients were investigated from a two-by-two table (Table 3.2). These are analyses in all patients and subgroup belong PTA and classification of hearing loss.

**Table 3.2** Two-by-two table

| **Result of diagnostic tests (Acoustic reflex threshold)** | **Results of Gold standard Test (ABR)** | |
|---|---|---|
| | **Retrocochlear pathology** | **cochlear pathology** |
| **positive test** | True positive (a) | False positive (b) |
| **negative test** | False negative (c) | True negative (d) |

Recording ART results Positive test: Sensation level more than 60 dB and elevated above the ninetieth percentile cutoff level (Appendix A) at or absent ART at least one frequency.

Negative test: Sensation level lower than 60 dB at least one frequency at 500-4000 Hz

Recording ABR results Positive test: Retrocochlear pathology

Negative test: Cochlear pathology

True positive (a) = Positive both ART and ABR

False positive (b) = Positive ART but negative ABR

False negative (c) = Negative ART nut positive ABR

True negative (d) = Negative both ART and ABR

**Formula of calculation**

$$Sensitivity = \frac{True\ positive}{True\ positive + False\ negative} = \frac{a}{a + c}$$

$$Specficity = \frac{True\ negative}{False\ positive + True\ negative} = \frac{d}{b + d}$$

$$Positive\ predictive\ value = \frac{True\ positive}{True\ positive + False\ positive} = \frac{a}{a + b}$$

$$Negative\ predictive\ value = \frac{True\ negative}{True\ negative + False\ negative} = \frac{a}{a + b}$$

# CHAPTER IV
# RESULTS

The purpose of this study was to find out the diagnostic accuracy, on the sensitivity and specificity, of the acoustic reflex test in identifying the site of lesions (cochlea/retrocochlea), and compare it to the results of the auditory brainstem response measurement. The positive predictive value and negative predictive value in the ART results for SNHL patients were also calculated. The data was collected from clinical charts of sensorineural hearing loss patients, who were referred by otorhinolaryngologists for ABR measurement during 2009 – 2013.

The results of the study were analyzed according to the following categories:

4.1 General information

4.2 Chief complaint

4.3 The sensitivity, specificity, positive predictive value, and negative predictive value of the acoustic reflex tests, for identifying the sites of lesions, were compared to the results of the auditory brainstem response measurements in SNHL patients.

4.4 The sensitivity, specificity, positive predictive value and negative predictive value of the acoustic reflex test, for identifying the sites of lesions, were compared to the results of auditory brainstem response measurements for each hearing level, and audiometric configuration of SNHL patients.

## 4.1 General information

Of the total number of 813 patients who were referred for ABR testing during 2009-2013, 393 (48.3%) patients had no acoustic immittance measurement results. There were only 232 (28.5%) patients (346 ears) who met the inclusion criteria. The study's subjects included 102 males and 130 females, with an age range of 8 – 83 years, a mean age of 53.31 years, and a standard deviation of 15.48.

The hearing level was classified by pure tone average (PTA) at 500-2000 Hz (Table 4.1). Most of the subjects (32.4%) had normal pure tone averages, but hearing loss at high frequencies. 23.4% had mild hearing loss (26-40 dBHL). 19.1% had moderate hearing loss (41-55dBHL). 18.2% had moderately severe hearing loss (56-70 dBHL). 6.9% had severe hearing loss (71-90 dBHL). According to the configuration of the audiogram, most of the subjects (47.4%) had high frequency loss, 42.8% had flat audiogram, and 9.8% had low frequency loss.

Seven patients (7 ears) demonstrated abnormal ABR results as unilateral retrocochlear hearing loss. Two patients (4 ears) demonstrated bilateral retrocohlear hearing loss, as shown in Table 4.1. There were variety of hearing levels, except moderately severe loss in the retrocochlear group. Most of the patients had moderate hearing level (4 ears). For the cochlear hearing loss group, most of them had PTA 0-25 dBHL and 26-40 dBHL.

**Table 4.1** Classification of SNHL patients with cochlear / retrocochlear lesion according to hearing level

| **PTA (dBHL)** | **Cochlear HL (ears)** | **Retrocochlear HL (ears)** | **Total** | |
|---|---|---|---|---|
| | | | **(ears)** | **(%)** |
| 0-25* | 109 | 3 | 112 | 32.4 |
| 26-40 | 78 | 3 | 81 | 23.4 |
| 41-55 | 62 | 4 | 66 | 19.1 |
| 56-70 | 63 | 0 | 63 | 18.2 |
| 71-90 | 23 | 1 | 24 | 6.9 |
| Total | 335 | 11 | 346 | 100 |

* Hearing loss at high frequency

When considering the audiometric configuration, most of them (6 ears) had high frequency loss and four had flat audiogram. Only one ear had low frequency loss (Table 4.2). For the cochlear hearing loss group, most of them had high frequency loss and flat audiogram.

**Table 4.2** Classification of SNHL patients with cochlear / retrocochlear lesion according to configuration of audiogram

| Configuration | Cochlear HL (ears) | Retrocochlear HL (ears) | Total | |
|---|---|---|---|---|
| | | | (ears) | (%) |
| High frequency loss | 158 | 6 | 164 | 47.4 |
| Flat audiogram | 144 | 4 | 148 | 42.8 |
| Low frequency loss | 33 | 1 | 34 | 9.8 |
| Total | 335 | 11 | 346 | 100 |

## 4.2 Chief complaint

Subjects in this study had a variety of symptoms. The most common complaint was tinnitus (26.72%), then fullness sensation (24.57%), hearing loss (20.26%), dizziness (6.04%), and 22.41% of the subjects had two or more symptoms combined. (Table 4.3)

The ABR results showed 9 patients who had retrocochlear hearing loss. Most of the patients' chief complaints with their cochlear and retrocochlear hearing loss were single symptoms, as shown in Table 4.3.

## 4.3 Agreement of the test for identification of retrocochelar hearing loss

The results of the investigation of nine retrocochlear hearing loss patients are described in Table 4.4. Only one case did not have the MRI result but there was agreement of ABR and ART results. Most of the retrocochlear hearing loss patients (90.9%) (10 in 11) demonstrated the agreement of ART and ABR results. 80% (8 in 10) demonstrated the agreement of ART and MRI results. 70% (7 in 10) of patients demonstrated the agreement of ABR and MRI results. 70% (7 in 10) of patients demonstrated the agreement of ABR, ART and MRI.

**Table 4.3** The chief complaint of sensorineural hearing loss patients

| Chief complaint | Retrocochlear HL (cases) | Cochlear HL (cases) | Total (cases) | Total (%) |
|---|---|---|---|---|
| 1 symptom | | | | |
| Tinnitus | 2 | 60 | 62 | 26.72 |
| Aural fullness | 1 | 56 | 57 | 24.57 |
| Hearing loss | 2 | 45 | 47 | 20.26 |
| Dizziness | 1 | 13 | 14 | 6.04 |
| 2 symptoms | | | | |
| Aural fullness and Hearing loss | 2 | 9 | 11 | 4.74 |
| Aural fullness and Dizziness | - | 4 | 4 | 1.73 |
| Aural fullness and Tinnitus | - | 11 | 11 | 4.74 |
| Tinnitus and Hearing loss | 1 | 10 | 11 | 4.74 |
| Tinnitus and Dizziness | - | 11 | 11 | 4.74 |
| Hearing loss and Dizziness | - | 1 | 1 | 0.43 |
| 3 symptoms | | | | |
| Dizziness, Tinnitus, and Hearing loss | - | 2 | 2 | 0.86 |
| Dizziness, Tinnitus, and Aural fullness | - | 1 | 1 | 0.43 |
| Total | 9 | 223 | 232 | 100 |

**Table 4.4** Agreement of the test for identification of retrocochelar hearing loss

| Ears | ART | ABR | MRI | ART& ABR | ART& MRI | ABR& MRI | ABR& ART&MRI |
|---|---|---|---|---|---|---|---|
| 1 | +ve | +ve | Cyst arachnoid | yes | yes | yes | yes |
| 2 | +ve | +ve | Vestibular aqueduct syndrome | yes | yes | yes | yes |
| 3 | +ve | +ve | Vestibular aqueduct syndrome | yes | yes | yes | yes |
| 4 | +ve | +ve | Mild small vessel disease | yes | yes | yes | yes |
| 5 | +ve | +ve | Small microbleed | yes | yes | yes | yes |

**Table 4.4** Agreement of the test for identification of retrocochelar hearing loss (Cont.)

| Ears | ART | ABR | MRI | ART& ABR | ART& MRI | ABR& MRI | ABR& ART&MRI |
|---|---|---|---|---|---|---|---|
| 6 | +ve | +ve | Small microbleed | yes | yes | yes | yes |
| 7 | +ve | +ve | Benign neoplasm | yes | yes | yes | yes |
| 8 | +ve | +ve | No structural abnormality of brain | yes | no | no | no |
| 9 | +ve | +ve | No structural abnormality of brain | yes | no | no | no |
| 10 | -ve | +ve | No structural abnormality of brain | no | yes | no | no |
| 11 | +ve | +ve | Do not test | yes | NA | NA | NA |

## 4.4 Sensitivity, specificity, positive predictive value and negative predictive value of the acoustic reflex test in identifying site of lesion compared to the results of auditory brainstem response measurement in SNHL patients.

The sensitivity, specificity, positive predictive value, and negative predictive value of the acoustic reflex tests were calculated according to program stata version 13.1. Table 4.5, a two-by-two table showed positive and negative ART and ABR in SNHL patients. There were 11 ears which were diagnosed as retrocochlear hearing loss by the use of ABR. 10 of those ears showed a positive ART (True positive). 1 ear showed a negative ART (False negative). In contrast, of the 335 ears with cochlear hearing loss, 192 ears showed a negative ART (True negative). 143 ears showed a positive ART (False positive).

The sensitivity, specificity, positive predictive value, and negative predictive values of ART in SNHL patients were 90.9%, 57.3%, 6.5%, and 99.5%

respectively. The sensitivity results showed that if ABR suggested retrocochlear pathology, there was a 90.9% chance of ART correctly identifying it. The specificity results indicated that there was a 57.3% chance of ART being negative for cochlear pathology. The positive predictive value showed that there was a 6.5% chance, if the ART was positive, that the patient actually had retrocochlear pathology. The negative predictive value showed that there was 99.5% chance, if the ART was negative, the patient actually had cochlear pathology. (Table 4.6)

**Table 4.5** Two-by-two table of the ART and ABR in SNHL patients

| Acoustic reflex threshold | Diagnosis test : Auditory brainstem response | |
|---|---|---|
| | Positive : Retrocochlear HL | Negative : Cochlear HL |
| Positive : Elevated or absent ART | 10 | 143 |
| Negative : Present recruitment | 1 | 192 |

**Table 4.6 Sensitivity, specificity, positive predictive value, negative predictive value in identifying site of lesion in SNHL patients**

| Sensitivity (%) | Specificity (%) | Positive predictive value (%) | Negative predictive value (%) |
|---|---|---|---|
| 90.9 | 57.3 | 6.5 | 99.5 |

## 4.5 The comparison of sensitivity, specificity, positive predictive value and negative predictive value of the acoustic reflex test in identifying site of lesion compared to the results of auditory brainstem response measurement according to hearing level and audiometric configuration of SNHL patients.

Table 4.7, a two-by-two table showed positive and negative ART and ABR in each PTA hearing level.

Table 4.8, a two-by-two table showed positive and negative ART and ABR in each configuration of audiogram.

**Table 4.7** Two-by-two table of the ART and ABR according to PTA

| Hearing level (dBHL) | Acoustic reflex threshold | Diagnosis test : Auditory brainstem response | |
|---|---|---|---|
| | | Positive : Retrocochlear HL | Negative : Cochlear HL |
| 0-25 | Positive : Elevated or absent ART | 3 | 83 |
| | Negative : Present recruitment | 0 | 26 |
| 26-40 | Positive : Elevated or absent ART | 2 | 33 |
| | Negative : Present recruitment | 1 | 45 |
| 41-55 | Positive : Elevated or absent ART | 4 | 12 |
| | Negative : Present recruitment | 0 | 50 |
| 56-70 | Positive : Elevated or absent ART | 0 | 8 |
| | Negative : Present recruitment | 0 | 55 |
| 71-90 | Positive : Elevated or absent ART | 1 | 7 |
| | Negative : Present recruitment | 0 | 16 |

**Table 4.8** Two-by-two table of the ART and ABR according to audiometric configuration

| Configuration | Acoustic reflex threshold | Diagnosis test : Auditory brainstem response | |
|---|---|---|---|
| | | Positive : Retrocochlear HL | Negative : Cochlear HL |
| Flat | Positive : Elevated or absent ART | 3 | 27 |
| | Negative : Present recruitment | 1 | 117 |
| High frequency | Positive : Elevated or absent ART | 6 | 108 |
| | Negative : Present recruitment | 0 | 50 |
| Low frequency | Positive : Elevated or absent ART | 1 | 8 |
| | Negative : Present recruitment | 0 | 25 |

The sensitivity, specificity, positive predictive value, and negative predictive values of ART in SNHL patients were calculated according to each hearing level, but in the group of 56-70 dBHL, the number could not be calculated due the absence of retrocochlear hearing loss. For sensitivity identification according to hearing levels 0-25dBHL, 26-40 dBHL, 41-55 dBHL, and 71-90 dBHL, if ABR suggested retrocochlear pathology, there was a chance of ART correctly identifying at 100%, 66.7%, 100%, and 100% respectively. The specificity of the hearing level group 0-25dBHL, 26-40 dBHL, 41-55 dBHL, and 71-90 dBHL, the chance of ART being negative in cochlear pathology patients were 23.9%, 57.7%, 80.6%, and 69.6% respectively. The positive predictive value of the hearing level group 0-25dBHL, 26-40 dBHL, 41-55 dBHL, and 71-90 dBHL, if the ART was positive, the chance that the patient actually had retrocochlear pathology was 3.5%, 5.7%, 25%, and 12.5% respectively. The negative predictive value means if the ART was negative, the patient actually had cochlear pathology. The negative predictive value of cochlear pathology according to hearing level were 100%, except for the hearing level 26-40 dBHL, where the negative predictive value was 97.8% (Table 4.9).

The sensitivity, specificity, positive predictive value, and negative predictive values of ART in SNHL patients were calculated according to the configuration of the audiogram. The sensitivity of the high frequency loss and low frequency loss were 100%. For the group of flat audiograms, the sensitivity was 75%. For the groups of flat audiograms, low frequency loss, and high frequency hearing loss, the specificity was 81.3%, 75.8%, and 31.6% respectively. The positive predictive value, according to the configuration of the audiogram, for those with low frequency loss, was 11.1%. For flat and high frequency loss, the audiogram was 10%, and 5.3% respectively. The negative predictive value, according to the configuration of audiogram, high frequency loss was 100%, low frequency loss was 100%, and the flat audiogram was 99.2% (Table 4.9).

**Table 4.9** Sensitivity, Specificity, Positive predictive value, and Negative predictive value in identifying site of lesion according to hearing level and audiometric configuration in SNHL patients

| | **Sensitivity (%)** | **Specificity (%)** | **Positive predictive value (%)** | **Negative predictive value (%)** |
|---|---|---|---|---|
| PTA (dBHL) | | | | |
| 0-25 * | 100 | 23.9 | 3.5 | 100 |
| 26-40 | 66.7 | 57.7 | 5.7 | 97.8 |
| 41-55 | 100 | 80.6 | 25 | 100 |
| 56-70 | ** | ** | ** | ** |
| 71-90 | 100 | 69.6 | 12.5 | 100 |
| Configuration of audiogram | | | | |
| Flat audiogram | 75 | 81.3 | 10 | 99.2 |
| Low frequency loss | 100 | 75.8 | 11.1 | 100 |
| High frequency loss | 100 | 31.6 | 5.3 | 100 |

* Hearing loss at high frequency

** Could not be calculated due to absent of retrocochlear hearing loss patient

# CHAPTER V
# DISCUSSION

The purpose of this study was to find out the diagnostic accuracy, on the sensitivity and specificity, of acoustic reflex tests in identifying the sites of lesions (cochlea / retrocochlea), compared to the results of auditory brainstem response measurement. The positive predictive value and the negative predictive value of ART results, in SNHL patients, were also calculated.

The research data included 346 ears with sensorineural hearing loss, from 232 patients (102 males, 130 females). The age range was 8 to 83 years old, with the mean age of 53.31 years.

## 5.1 General information

The total of patients who were referred for ABR testing during 2009-2013, only 420 (51.6%) of them had ART results. Since ABR have a high sensitivity and specificity in identifying site of lesion [7-9], while the ART in identifying site of lesion was less sensitivity and specificity. It might be the reason why the ENT choose the diagnostic test with better sensitivity and specificity. However, in this study the ART demonstrated high sensitivity and specificity in identify site of lesion in specific conditions such as low frequency loss and moderate sensorineural hearing loss patients.

The results showed that subjects with retrocochlear pathology had a range of hearing levels that included normal PTA with high frequency, mild, and moderate. There was only one case with severe hearing loss, except 56-70 dBHL (Table 4.1). Most of the subjects had mild to moderate hearing levels. This was because common retrocochlear pathology usually develops over months, or years. Common retrocochlear pathology is associated with mild impairment of hearing levels, and slowly progressive loss [64]. The retrocochlear hearing loss is the result of damage to neural structures, beyond the cochlea to auditory cortex. It is caused by diseases, irritation, or pressure on the nerve trunk. Another common cause of it is a tumor [64, 65]. The nature of retrocochlear pathology is a progressive high frequency, unilateral, or asymmetric, SNHL (95% of patients). However, hearing loss depends on the size and location of the lesion. In summary, differentiating retrocochlear pathology by using only audiometry may not be an appropriate investigation. There is a need for further audiologic diagnostic battery tests [66].

## 5.2 Chief complaint

Most retrocochlear hearing loss patients demonstrated a unilateral hearing loss or asymmetrical hearing loss, which is the first sign to be ruled out in retrocochlear pathology [46, 47]. However, retrocochlear pathology, in the early stage, perhaps shows no significant hearing loss. But some patients complained of tinnitus in the affected ear, dizziness, aural fullness, or unclear speech perception. In this study, most of the patients' complaints were single symptoms, either tinnitus, aural fullness, dizziness, or hearing loss.

However, in this study there were only 11 ears with retrocochlear hearing loss, with variety of symptoms, which could not be summarized as representative of the whole group.

## 5.3 Agreement of the tests for retrocochlear pathology identification

The magnetic resonance imaging (MRI) has been approved to be the most effective tool for diagnosing retrocochlear pathology. But the limitation of MRI is that it is an expensive procedure, and there is a long queue for the procedure. Therefore, the pathological diagnosis of the site of lesion should begin with simple a process. The diagnosis should take less time and be less expensive. Then, patients who demonstrated positive results should be referred for a clinical MRI.

Acoustic reflex threshold measurement has been accepted as a reliable test, and the most powerful differential diagnosis of the site of lesion [57]. The sensitivity of ART in identifying sites of lesions was 86-93%[4]. In this study, ART and ABR demonstrated results in agreement, up to 90.9%. The agreement of ART and MRI was 80%, and the agreement of ABR and MRI was only 70% (Table 4.4). In the literature review, there have been comparative studies of the agreements of the tests, and appropriate number of known specific lesions [4, 14], which was different from our study. However, the results of the study showed a rather high percentage of agreement between ART, ABR and MRI, thus making the ART become a more valuable audiometric diagnostic battery test.

## 5.4 The diagnostic accuracy on the sensitivity and specificity of the acoustic reflex test in identifying site of lesion compared to the results of auditory brainstem response measurement

From Table 4.6, the sensitivity, specificity, positive predictive value, and negative predictive value, when combining abnormal ART with abnormal ABR, was 90.9%, 57.3%, 6.5%, and 99.5% respectively. The high sensitivity suggested that the ART is suitable to be the primary diagnosis pathology in sensorineural hearing loss patients. Although the specificity and positive predictive value in identifying retrocochelar pathology is less, it was suggested that if there was abnormal ART, the patients should be referred for further investigation. As for the high percentage of negative predictive value, this means the normal results confirm the patients did not have the retrocochlear pathology.

There were various sensitivity and specificity ART results by many authors, ranging from 70-93 % and 49-86% respectively [4, 62, 63]. Our study showed similar results of sensitivity and specificity according to the previous studies.

### 5.5 The comparison of sensitivity, specificity, positive predictive value and negative predictive value of the acoustic reflex test in identifying site of lesion compared to the results of auditory brainstem response measurement according to hearing level of SNHL patients.

The sensitivity, specificity, positive predictive value, and negative predictive values of ART in SNHL patients were calculated according to different hearing levels (Table 4.9). The highest sensitivity, specificity, positive predictive value, and negative predictive values of ART were found in the range of 41-55 dBHL (moderate level). This study correlated with Cohen & Prasher, 1988 that the ART results showed high percentage (93%) of cerebello pontine angle tumor group in SNHL < 60 dB [62]. The acoustic reflex measurement required acoustic stimulation of 70-95 dBSL in normal hearing. For sensorineural hearing loss patients, the acoustic reflex threshold varied, depending on the site of lesion, and degree of hearing loss. In cases of cochlear hearing loss, the sensation levels were lower than 60 dB. If the sensation level was greater than 60 dB, and the acoustic reflex threshold was greater than 105 dBHL, it was considered indicative of retrocochlear hearing loss. However, the maximum limitation of acoustic stimulus was available at 115-120 dBHL. In case of severe hearing loss, it is often limited by both hearing level, and the stimulus level that could not be compared [2, 59, 67].

The explanation about acoustic reflex threshold in sensorineural hearing loss patients was also referred to in the study by Gelfand et al; The acoustic reflex thresholds were increased according to hearing loss level [2, 18]. 90th percentile of severe sensorineural hearing loss patients demonstrated acoustic reflex thresholds at the maximum stimulus level. Hence the sensation level could not be calculated.

### 5.6 The comparison of sensitivity, specificity, positive predictive value and negative predictive value of the acoustic reflex test in identifying site of lesion compared to the results of auditory brainstem response measurement according to audiometric configuration of SNHL patients.

The sensitivity, specificity, positive predictive value, and negative predictive value of ART in SNHL patients were calculated according to the configuration of the audiogram (Table 4.9). In the group of flat audiometric configuration, the sensitivity in identifying sites of lesions was 75%, but the specificity was rather high (81.3%). This means that if the results were negative, the patients did not have retrocochlear pathology. In another configuration, the group of low frequency loss patients also showed high sensitivity (100%) and specificity (75.8%). In group of high frequency loss, the results showed high sensitivity but low specificity (31.6%) in identifying site of lesion. This is probably false positive results. According to study by Gelfand,1990 there was 12.2% of normal hearing and cochlear hearing loss patients demonstrated elevate ART above the ninetieth percentile [67]. However, the consideration of audiometric configuration alone in identifying site of lesion might not be possible. In some cases, the degree of hearing loss had to be taken into consideration. So far, there has not been any research conducted in this issue.

# CHAPTER VI
# CONCLUSIONS

1. Subjects with retrocochlear pathology had a range of hearing levels, including normal PTA with high frequency, mild, moderate, and one case of severe hearing loss, except 56-70 dBHL.

2. Subjects with retrocochlear pathology had a variety of chief complaints regarding their symptoms; Most of the chief complaints was a single symptom, either tinnitus, aural fullness, dizziness, or hearing loss (at least 1 symptom).

3. There was agreement between ART and ABR results in identifying sites of lesions up to 90.9%, while the agreement of ART and MRI was 80% and the agreement of ABR and MRI was only 70%.

4. The sensitivity, specificity, positive predictive value, and negative predictive value of diagnosing sites of lesions by using ART in sensorineural hearing loss was 90.9%, 57.3%, 6.5%, and 99.5% respectively.

5. According to hearing level, the range of 41-55 dBHL demonstrated the highest sensitivity (100%) and specificity (80.6%) in identifying sites of lesions.

6. The group of low frequency loss demonstrated highest sensitivity in identifying sites of lesion at 100% and the specificity was 75.8%. Flat loss also showed high sensitivity (75%) and specificity (81.3%) in identifying site of lesion.

## Recommendations from this study

1. It is recommended that the ART is suitable for primary diagnosis of cochlear / retrocochlear hearing loss in all SNHL patients.

2. Hearing level and audiometric configuration should be taken into consideration in order to get more accurate results in identifying site of lesion in sensorineural hearing loss patients.

3. Explanation of the results to the patients should be done with caution, because positive ART results did not always means retrocochlear pathology.

4. Further study should be focused on the sensitivity and specificity of identifying sites of lesions, according to hearing levels, while controlling the number of subjects equally, for cochlear and retrocochlear hearing loss patients. Moreover, it should be focused on acoustic reflex threshold, combined with acoustic reflex decay. It may increase sensitivity and specificity in identifying sites of lesions.

# REFERENCES

1. Zamora A. Anatomy and Structure of Human Sense Organs [monograph on the Internet]. Scientific Psychic; 2014 [cited 2014 Nov 6]. Available from: http://www.scientificpsychic.com/workbook/chapter2.htm.
2. Gelfand SA. Essentials of Audiology. 2nd ed. New York: Thieme Medical Publishers; 2001.
3. American Speech Language Hearing Association [homepage on the Internet]. Type of hearing loss; c1997-2014 [updated 2014; cited 2014 Nov 6]. Available from: http://www.asha.org/public/hearing/Types-of-Hearing-Loss/
4. Martin F, Clark JG. Introduction to Audiology. 8th ed. Boston: Allen and Bacon; 2003.
5. Roeser R, Buckley K, Stickney G. Audiology: Diagnosis. New York: Thime medical publishers; 2000.
6. Robert S, Peggy N. Puretone evaluation. In: Katz J, Medwetsky L, Burkard R, Hood L, editors. Handbook of clinical audiology. 6th ed. US: Lippincott Williams & Wilkins; 2009. p. 30-49
7. Flood L, Brammer R, Graham M, Kemink J. Pitfalls in the diagnosis of acoustic neuroma. Clinical otolaryngology and allied sciences. 1984;9(3):165-70.
8. Harner S, Laws E. Diagnosis of acoustic neuroma. In: Harner S, Laws E, editors. Neurosurgery. 1981. p. 373-9.
9. Moffat D, Hardy D, Baguley D. Strategy and benefits of acoustic neuroma searching. J Laryngol Otol. 1989:51-9.
10. Emanuel D, editor. Acoustic reflex threshold patterns [monograph on the Internet]. Audiology online; 2013 [cited 2014 Jan 14]. Available from: http://www.audiologyonline.com/articles/acoustic-reflex-threshold-art-patterns-875
11. Sanders J, Josey A, Glasscock M, Jackson. The acoustic reflex test in cochlear and eighth nerve pathology ears. Laryngoscope. 1981:787-93.

12. Roche J, Huang B, Castilo M, Bassim M, Adunka O, Buchman C. Imaging characteristics of children with auditory neuropathy spectrum disorder. Otol Neurotol. 2010;31(5):780-8.
13. Roush P. Auditory Neuropathy Spectrum Disorder (ANSD) [Internet]. Brighton. The university of north carolina chapel hill; 2008 [cited 2014 Jul 15]. Available from: https://www.phonakpro.com/content/dam/phonak/b2b/ pediatrics /webcasts/brighton/brighton_2008_-_patricia_roush.pdf
14. Cohen M, Prasher D. The value of combining auditory brainstem responses and acoustic reflex threshold measurements in neuro-otological diagnosis. Scand Audiol. 1998:153-62.
15. Altman DG. Practical statistics for medical research. New York: Chapman & Hall; 1992.
16. Chamnijarakit T. Apply statistic in medicine. Bangkok: Chulalongkorn University ; 1997.
17. Euasirirattanapaisan K. The compaison of the vestibular evoked myogenic potential between difinite meniere's disease patients and normal healthy adults. Thai: Mahidol University; 2009.
18. Gelfand SA. The acoustic reflex. In: Jack Katz LM, Robert Burkard, Linda Hood, editors. Handbook of clinical auditory. 6th ed. Philadelphia: Lippincott Williams & Wilkins; 2009. p. 189-221.
19. Adunka O, Buchman C. Otology, Neurotology, and Lateral Skull Base Surgery. New York: Thieme Medical publishers; 2011.
20. DNBhelp [Internet]. Acoustic neuroma and hearing loss; 2010 [updated 2011; cited 2014 Jun 14]. Available from: https://dnbhelp.wordpress.com/ otology/
21. College of liberal Arts [Internet]. The central auditory system; 2012. [updated 2012; cited 2014 Jun 14]. Available from: http://homepage.psy.utexas.edu /homepage/class/psy394U/hayhoe/perception/Chapt.%203-%20Central% 20Auditory%20System%20copy.pdf
22. Glasscock M, Jackson C, Josey A. The ABR handbook auditory brainstem response. 2nd ed. New York: Thieme Medical Publishers; 1987.

23. Rungesamuelson C, Friedland D. Anatomy of the auditory system. In: Paul W Flint BHH, editors. Cummings Otolaryngology head & neck surgery. 5th ed. China: Mosby elsevier; 2010. p. 1831-7.
24. Panchu P. Auditory acuity in type 2 diabetes mellitus. Int J Diabetes Dev Ctries. 2008;28(4):114-20.
25. Park MS, Lee HY, Kang HM, Ryu EW, Lee SK, Yeo SG. Clinical Manifestations of Aural Fullness. Yonsei Med J 2012;53(5):985-91.
26. Tokumasu K, Fujino A, Naganuma H, Hoshino I. Initial symptoms and retrospective evaluation of prognosis in Menière's disease. Acta Otolaryngol Suppl. 1996;524:43-9.
27. Westerlaken BO, Stokroos RJ, Dhooge IJ, Wit HP, Albers FW. Treatment of idiopathic sudden sensorineural hearing loss with antiviral therapy. Ann Otol Rhinol Laryngol. 2003(112):993-1000.
28. Hunter L, Ries D, Levine R. Safety and clinical performance of acoustic reflex tests. Ear and hearing. 1999;20(6):506-14.
29. Lazar M. Acoustic neuroma (vestibular schwannoma) & facial nerve tumors2015. [updated 2015; cited 2015 Feb 13]. Available from: http://www.neurosurgerydallas.com/2_1_6_2.php.
30. American Academy of Otolaryngology- Head and Neck Surgery [homepage on the Internet]. Alexandria: The Association; 2015 [updated 2015; cited 2015 Feb 13]. Tinnitus. Available from: http://www.entnet.org /content/tinnitus
31. WebMD [homepage on the Internet]. The association.c1995-2015 [updated 2014 March 12; cited 2015 Feb 13]. Tinnitus: Ringing in the ears. Available from: http://www.webmd.com/a-to-z-guides/ringing-in-the-ears-tinnitus-topic-overview
32. WebMD [homepage on the Internet]. The association. c1995-2015 [updated 2014 March 12; cited 2015 Feb 13]. Hearing loss. Available from: http://www.webmd.com/a-to-z-guides/hearing-loss-causes-symptoms-treatment?page=2#2

33. American Speech Language Hearing Association [homepage on the Internet]. Hearing loss; c1997-2014 [updated 2014; cited 2014 Nov 6]. Available from: http://www.asha.org/public/hearing/Hearing-Loss/
34. Silman S, Silverman C. Auditory diagnosis. San diego: Academic press; 1991.
35. American Speech Language Hearing Association [homepage on the Internet]. Type degree and configuration of hearing loss; c1997-2014 [updated 2014; cited 2014 Nov 6]. Available from: http://www.asha.org/uploadedFiles /aud/Info SeriesHearingLossTypes.pdf
36. Bauman N, editor. Kinds of Hearing Losses [monograph on the Internet]. Stewartstown; Center for Hearing Loss Help; c2006-2015 [cited 2014 Fed 9]. Available from: http://www.hearinglosshelp.com/articles/kindsof hearinglosses.htm.
37. Buus S, Florentine M. Growth of loudness in listeners with cochlear hearing losses: recruitment reconsidered. JARO. 2001(3):120-39.
38. Bergemalm P. Progressive hearing loss after closed head: a predictable outcome injury. Acta Otolaryngol Suppl. 2003;123:836 –45.
39. Wennmo C, Svensson C. Temporal bone fractures. Acta Otolaryngol Suppl.1989;468:379 – 83.
40. Davidson H. Imaging of the temporal bone. Magn Reson Imaging Clin N Am. 2002;10:573-613.
41. American Speech Language Hearing Association [homepage on the Internet]. Noise; c1997-2014 [updated 2014; cited 2014 Nov 6]. Available from: http://www.asha.org/public/hearing/Noise/
42. National Institute on Deafness and Other Communication Disorder [homepage on the Internet]. Noise-Induced Hearing Loss; [updated 2014; cited 2014 Nov 6]. Available from: http://www.nidcd.nih.gov/health/hearing/pages/ noise.aspx
43. Compston A, Coles A. Multiple sclerosis. Lancet [serial on the Internet]. 2008 [cited 2014 Nov 20 ]; 372 (9678) :1502-17. Available from: http://www.sciencedirect.com/science/article/pii/S0140673608616207
44. Brian R Apatoff, editor. Overview of Demyelinating Disorders [monograph on the Internet]. New Jersey: Merck Manuals; 2015 [cited 2015 Feb 13].

Available from:http://www.merckmanuals.com/professional/neurologic-disorders/demyelinating-disorders/overview-of-demyelinating-disorders

45. The Audiology Awareness Campaign [homepage on the Internet]. Auditory Neuropathy & Auditory Dys-Synchrony; c2007-2010 [cited 2015 Jan 29]. Available from: http://www.audiologyawareness.com/hearinfo neuropathy.asp
46. Don M, Kwong B. Auditory brainstem response: differential diagnosis. In: Katz J BR, Hood L, editor. Handbook of clinical auditory. 6th ed. Philadephia: Lippincott Williams & Wilkins; 2009. p. 265-92.
47. American Academy of Otolaryngology-Head and Surgery [homepage on the Internet]. Alexandria: The Association; 2015 [updated 2015; cited 2015 Feb 13]. Clinical Indicator: Auditory Brainstem Response. Available from: https://www.entnet.org/Practice/upload/Auditory-Brainstem-Response-CI.pdf
48. Hood L. Clinical applications of the auditory brainstem response. San Diego: Singular Publishing Group; 1998.
49. Hall J. New handbook of auditory evoked responses. Boston: Pearson Education; 2007.
50. Hoth S. Reliability of latency and amplitude on values of auditory evoked potential. Audiology. 1986;25:248-57.
51. Phadhana-anek M. Auditory brainstem response (ABR): A normative study in Thai normal hearing adults: Mahidol University; 1985.
52. Elberling C, Parbo J. Reference data for ABRs in retrocochlear diagnosis. Scand Audiol. 1987(16):49-55.
53. Gordon M, Cohen N. Efficacy of auditory brainstem response as a screening test for small acoustic neuromas. Am J Otol. 1995(16):136-9.
54. Stantriphob T. Stacked auditory brainstem response (Stacked ABR): A normative study in Thai normal hearing adults: Mahidol University; 2010.
55. Hall J, Mueller G. Audiologists' desk reference. London: Singular Publishing; 1997.
56. Clark J, editor. Acoustic (stapedius) reflexes [monograph on the Internet]. Johannesburg; 2004 [cited 2015 6 Apr]. Available from:

https://vula.uct .ac.za/access/content/group/27b5cb1b-1b65-4280-9437 a9898ddd4c40/Acoustic%20_stapedius_%20reflexes.pdf.

57. Grason-Stadler. Middle ear analyzer. Reference instruction manual. Madison; 2008.
58. Bess F, Humes L. Acoustic reflex measurement. 3rd ed. US: Lippincott Williams & Wilkins; 2003.
59. Wilber L. The measurement of middle ear function. In: Feldman A, Wilber L, editors. Acoustic impedance and admittance Acoustic reflex measurement procedures, interpretations and variables. 1976.
60. Sesterhenn G, Breuninger H. The acoustic reflex at low sensation levels. Audiology. 1976; 15(6):523-33.
61. Schairer K, Feeney MP, Sanford C. Acoustic reflex measurement. Ear Hear. 2013: 34: 43-7.
62. Cohen M, Prasher D. The combined effect of acoustic reflex thresholds and brainstem auditory evoked potentials in neuro-otological diagnosis. Scand Audiol. 1988:153-62.
63. Ferguson M, Smith P, Lutma M, Mason S. Efficiency of tests used to screen for cerebello-pontine angle tumors: a prospective study. British Society of Audiology. 1996:159-76.
64. Jung T, Nissen R. Otologic Manifestations of Retrocochlear Disease. 2001.
65. Zarenoe R. Tinnitus in Patients with Sensorineural hearing loss (Dissertation). Sweden, Linkoping University; 2012. 49p.
66. Hirsuch B, Durrant J, Yetiser S, Kamerer D, Martin W. Localizing retrocochlear hearing loss. Am J Otolaryngol. 1996;17:537-46.
67. Gelfand S. Acoustic Reflex Thresholds in Normal and Cochlear-Impaired Ears: Effects of No-Response Rates on 90th Percentiles in a Large Sample. Journal of Speech and Hearing Disorders. 1990;55:198-205.

# APPENDICES

# APPENDIX A

**Acoustic reflex threshold 90th percentile cutoff values as a function of hearing level at 500, 1000, and 2000 Hz [13]**

Gelfand, Schwander and Silman (1990)

| Hearing Threshold (dB HL) | 90th Percentile Acoustic Reflex Threshold Norm (dB HL) | | |
|---|---|---|---|
| | 500 Hz | 1000 Hz | 2000 Hz |
| 0 | 95 | 95 | 95 |
| 5 | 95 | 95 | 95 |
| 10 | 95 | 95 | 95 |
| 15 | 95 | 95 | 95 |
| 20 | 95 | 95 | 95 |
| 25 | 95 | 95 | 95 |
| 30 | 95 | 95 | 100 |
| 35 | 95 | 95 | 100 |
| 40 | 95 | 95 | 100 |
| 45 | 95 | 95 | 105 |
| 50 | 100 | 100 | 105 |
| 55 | 105 | 105 | 110 |
| 60 | 105 | 110 | 115 |
| 65 | 110 | 110 | 115 |
| 70 | 115 | 115 | 120 |
| 75 | 120 | 120 | 125 |
| 80 | 120 | 125 | NR |
| 85 | NR | NR | NR |
| ≥90 | NR | NR | NR |

# APPENDIX B
# RAW DATA

| ID | Age (yrs) | Gender | Symptom | | | | Degree of hearing loss | | Immittance measurement | | | | ABR | | Configuration | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Vertigo | Dullness | Tinnitus | Hearing loss | Rt | Lt | Tymp (Rt) | Tymp (Lt) | ART (Rt) | ART (Lt) | Rt | Lt | Rt | Lt |
| 1 | 81 | Female | No | yes | No | yes | Moderately severe | Moderately severe | A | Other | 1 | * | 1 | * | F | F |
| 2 | 68 | Female | No | No | No | yes | Moderate | Normal | A | A | 1 | * | 1 | * | L | * |
| 3 | 57 | Female | No | No | yes | yes | Mild | Mild | Other | A | 2 | * | 1 | * | F | F |
| 4 | 49 | Female | No | No | No | yes | Normal | Normal | A | A | 1 | * | 1 | * | H | * |
| 5 | 33 | Male | No | yes | No | No | Normal | Moderately severe | A | A | * | 1 | * | 1 | * | L |
| 6 | 24 | Male | No | No | yes | No | Normal | Normal | A | A | 1 | 1 | 1 | 1 | H | H |
| 7 | 69 | Male | No | No | yes | No | Normal | Mild | A | A | * | 1 | * | 1 | * | L |
| 8 | 60 | Female | No | yes | No | No | Mild | Moderately severe | Other | A | 2 | * | 1 | * | F | F |
| 9 | 24 | Female | No | yes | No | No | Moderately severe | Normal | A | Other | 1 | * | 1 | * | L | * |
| 10 | 48 | Female | No | yes | No | No | Mild | profound | A | A | 1 | * | 1 | * | H | * |
| 11 | 50 | Female | No | No | No | yes | Normal | Moderately severe | Other | A | * | 1 | * | 1 | * | L |
| 12 | 80 | Male | No | yes | No | No | Moderate | Moderately severe | A | A | 1 | 1 | 1 | 1 | F | F |
| 13 | 67 | Male | No | yes | No | No | Normal | Moderate | A | A | 2 | 2 | 1 | 1 | H | H |
| 14 | 57 | Male | No | yes | No | No | Mild | Moderately severe | A | A | 2 | 1 | 1 | 1 | H | F |
| 15 | 67 | Female | No | No | No | yes | Moderately severe | Mild | Other | A | 1 | * | 1 | * | F | H |
| 16 | 61 | Male | yes | yes | No | No | Mild | Normal | A | A | 2 | 2 | 1 | 1 | F | H |
| 17 | 58 | Female | No | No | yes | No | Moderate | Normal | Other | A | 1 | * | 1 | * | L | * |
| 18 | 57 | Female | No | yes | No | yes | Mild | Mild | Other | A | 2 | * | 1 | * | H | H |
| 19 | 26 | Female | No | No | No | yes | severe | Normal | A | A | 1 | * | 1 | * | F | * |

1 =negative result, 2=positive result, *= exclusion criteria, F= F loss, L=Low frequency loss, H=High frequency loss

| ID | Age (yrs) | Gender | Symptom | | | | Degree of hearing loss | | Immittance measurement | | | | ABR | | Configuration | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Vertigo | Dullness | Tinnitus | Hearing loss | Rt | Lt | Tymp (Rt) | Tymp (Lt) | ART (Rt) | ART (Lt) | Rt | Lt | Rt | Lt |
| 20 | 60 | Female | No | No | yes | No | Normal | Normal | A | A | 2 | 2 | 1 | 1 | H | H |
| 21 | 36 | Male | No | No | yes | yes | Moderately severe | Normal | A | A | 1 | * | 1 | * | F | * |
| 22 | 57 | Male | yes | No | yes | No | Normal | Moderate | A | A | 1 | 1 | 1 | 1 | H | F |
| 23 | 57 | Male | No | No | No | yes | Mild | Normal | A | A | 2 | * | 1 | * | F | * |
| 24 | 82 | Female | No | No | No | yes | Moderately severe | Moderately severe | A | A | 2 | 2 | 1 | 1 | F | F |
| 25 | 50 | Female | No | No | No | yes | Mild | Moderate | A | A | 2 | 1 | 1 | 1 | H | F |
| 26 | 71 | Male | No | No | No | yes | severe | Normal | A | A | 2 | 2 | 1 | 1 | H | H |
| 27 | 48 | Female | No | yes | No | No | Mild | Moderately severe | A | Other | 2 | * | 1 | * | F | F |
| 28 | 56 | Female | No | yes | No | No | Mild | severe | A | A | 2 | 1 | 1 | 1 | F | F |
| 29 | 79 | Male | No | No | No | yes | Moderate | Mild | A | A | 2 | 2 | 1 | 1 | H | H |
| 30 | 35 | Male | No | yes | No | No | Normal | Normal | A | A | 2 | 1 | 1 | 1 | H | H |
| 31 | 12 | Male | No | yes | No | No | Moderate | Normal | A | A | 1 | * | 1 | * | F | * |
| 32 | 63 | Male | No | No | yes | No | Mild | Normal | A | A | 2 | 1 | 1 | 1 | H | H |
| 33 | 63 | Male | No | No | yes | No | Moderate | Mild | A | A | 2 | 2 | 1 | 1 | H | H |
| 34 | 34 | Male | No | No | yes | No | Normal | Moderate | A | A | * | 1 | * | 1 | * | L |
| 35 | 44 | Female | No | No | yes | No | Normal | Moderately severe | A | A | * | 1 | * | 1 | * | F |
| 36 | 67 | Female | yes | No | No | No | Normal | Moderately severe | A | A | 2 | 1 | 1 | 1 | H | F |
| 37 | 49 | Female | No | No | yes | No | Normal | severe | A | A | * | 1 | * | 3 | * | F |
| 38 | 74 | Female | No | No | yes | yes | Normal | severe | A | A | 2 | 2 | 1 | 1 | H | H |
| 39 | 72 | Female | No | yes | No | No | Moderate | Moderately severe | A | A | 1 | 1 | 1 | 1 | F | F |
| 40 | 57 | Male | yes | No | No | No | Mild | Moderately severe | Other | A | * | 1 | * | 1 | * | F |
| 41 | 57 | Female | No | yes | No | yes | Moderate | Normal | A | A | 1 | * | 1 | * | F | * |
| 42 | 68 | Male | No | No | yes | No | Moderately severe | Moderately severe | A | A | 1 | 1 | 1 | 1 | F | F |

1 =negative result, 2=positive result, *= exclusion criteria, F= F loss, L=Low frequency loss, H=High frequency loss

| ID | Age (yrs) | Gender | Symptom | | | | Degree of hearing loss | | Immittance measurement | | | | ABR | | Configuration | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Vertigo | Dullness | Tinnitus | Hearing loss | Rt | Lt | Tymp (Rt) | Tymp (Lt) | ART (Rt) | ART (Lt) | Rt | Lt | Rt | Lt |
| 43 | 72 | Female | No | No | No | yes | severe | Moderate | A | A | 2 | * | 1 | * | F | * |
| 44 | 62 | Female | yes | No | yes | No | Normal | Moderate | A | A | * | 1 | * | 1 | * | F |
| 45 | 50 | Female | No | No | No | yes | severe | Normal | A | A | 1 | * | 1 | * | F | * |
| 46 | 65 | Female | yes | No | No | No | Normal | Normal | A | A | * | 1 | * | 1 | * | H |
| 47 | 66 | Female | No | No | yes | yes | Mild | Moderate | A | A | 2 | 1 | 2 | 1 | H | F |
| 48 | 53 | Female | No | yes | yes | No | Normal | Moderate | A | A | * | 1 | * | 1 | * | H |
| 49 | 52 | Male | No | No | No | yes | Normal | Mild | A | A | 1 | 1 | 1 | 1 | F | F |
| 50 | 14 | Female | No | No | No | yes | Moderately severe | Moderately severe | A | A | 1 | 1 | 1 | 1 | F | F |
| 51 | 50 | Female | yes | yes | No | No | Moderate | Normal | A | A | 1 | * | 1 | * | L | * |
| 52 | 57 | Female | No | yes | No | No | Normal | Normal | A | A | 2 | 2 | 1 | 1 | H | H |
| 53 | 21 | Male | yes | No | No | No | Normal | Normal | A | A | 2 | * | 1 | * | H | * |
| 54 | 67 | Male | No | No | No | yes | Moderate | Moderately severe | A | A | 1 | 1 | 1 | 1 | F | F |
| 55 | 71 | Female | No | No | No | yes | Normal | Moderately severe | A | A | * | 1 | * | 1 | * | H |
| 56 | 69 | Male | yes | No | yes | yes | Mild | Moderately severe | A | A | 2 | 1 | 1 | 1 | F | F |
| 57 | 17 | Female | No | yes | No | yes | Normal | Moderate | A | A | * | 2 | * | 2 | * | H |
| 58 | 51 | Male | No | No | No | yes | Normal | severe | A | A | 2 | 1 | 1 | 1 | H | F |
| 59 | 41 | Female | yes | No | No | No | Normal | Moderate | A | A | * | 1 | * | 1 | * | L |
| 60 | 41 | Female | No | yes | No | No | Moderate | Mild | A | A | 2 | 2 | 1 | 1 | F | F |
| 61 | 59 | Female | No | No | yes | No | Moderate | Normal | A | A | 2 | * | 1 | * | H | H |
| 62 | 30 | Male | No | yes | No | yes | Normal | Moderately severe | A | A | * | 1 | * | 1 | * | L |
| 63 | 66 | Female | yes | No | No | No | Normal | Moderate | A | A | * | 1 | * | 1 | * | L |
| 64 | 76 | Male | No | No | No | yes | Mild | Mild | A | A | 2 | 1 | 1 | 1 | H | H |
| 65 | 76 | Male | No | No | yes | No | Moderately severe | Moderate | A | A | 1 | 1 | 1 | 1 | F | F |

1 =negative result, 2=positive result, *= exclusion criteria, F= F loss, L=Low frequency loss, H=High frequency loss

| ID | Age (yrs) | Gender | Symptom | | | | Degree of hearing loss | | Immittance measurement | | | | ABR | | Configuration | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Vertigo | Dullness | Tinnitus | Hearing loss | Rt | Lt | Tymp (Rt) | Tymp (Lt) | ART (Rt) | ART (Lt) | Rt | Lt | Rt | Lt |
| 66 | 44 | Female | No | yes | No | No | Normal | Moderately severe | A | A | * | 1 | * | 1 | * | H |
| 67 | 73 | Female | No | No | yes | No | Moderately severe | Normal | A | A | 1 | 2 | 1 | 1 | F | H |
| 68 | 57 | Male | yes | yes | yes | No | Mild | Moderately severe | Other | A | * | 1 | * | 1 | H | F |
| 69 | 58 | Male | yes | No | yes | No | Normal | Moderately severe | A | A | 2 | 1 | 1 | 1 | H | F |
| 70 | 55 | Male | No | yes | yes | No | Normal | severe | A | A | * | 1 | * | 1 | * | F |
| 71 | 61 | Male | No | No | yes | No | Mild | Normal | A | A | 1 | 1 | 1 | 1 | H | H |
| 72 | 50 | Male | No | yes | No | No | Moderate | Normal | A | A | 2 | 2 | 1 | 1 | H | H |
| 73 | 8 | Female | No | No | No | yes | Mild | Moderate | A | A | 2 | 2 | 2 | 2 | H | L |
| 74 | 52 | Female | yes | No | yes | yes | Moderately severe | Normal | A | A | 2 | * | 1 | * | F | * |
| 75 | 80 | Male | No | No | yes | yes | Moderate | Moderate | A | A | 1 | 1 | 1 | 1 | F | F |
| 76 | 21 | Female | No | No | yes | No | Normal | Normal | A | A | * | 2 | * | 1 | * | H |
| 77 | 52 | Female | yes | No | No | No | Normal | Normal | A | A | 1 | 1 | 1 | 1 | H | H |
| 78 | 48 | Male | No | No | yes | No | Normal | Mild | A | A | 1 | 1 | 1 | 1 | H | F |
| 79 | 55 | Female | yes | No | No | No | Moderate | Mild | A | A | 1 | 2 | 1 | 1 | F | H |
| 80 | 64 | Male | No | yes | No | No | Normal | Moderate | A | A | 2 | 1 | 1 | 1 | H | F |
| 81 | 54 | Female | No | yes | No | No | Moderate | Normal | A | A | 2 | * | 1 | * | L | * |
| 82 | 74 | Male | No | yes | No | No | Moderate | Moderately severe | A | A | 1 | 1 | 1 | 1 | F | F |
| 83 | 52 | Male | No | yes | No | No | Normal | Moderate | A | A | 1 | 1 | 1 | 1 | H | L |
| 84 | 68 | Male | No | No | No | yes | Moderately severe | Mild | A | A | 1 | 2 | 1 | 1 | F | L |
| 85 | 49 | Female | No | yes | No | No | severe | Normal | A | A | 2 | * | 1 | * | F | * |
| 86 | 59 | Female | No | No | yes | No | Normal | Normal | A | A | 2 | 1 | 1 | 1 | H | H |
| 87 | 59 | Female | No | No | No | yes | Moderately severe | Normal | A | A | 2 | * | 3 | * | H | * |
| 88 | 57 | Male | No | No | yes | No | Normal | Normal | A | A | 2 | 2 | 1 | 1 | H | L |

1 =negative result, 2=positive result, *= exclusion criteria, F= F loss, L=Low frequency loss, H=High frequency loss

| ID | Age (yrs) | Gender | Symptom | | | | Degree of hearing loss | | Immittance measurement | | | | ABR | | Configuration | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Vertigo | Dullness | Tinnitus | Hearing loss | Rt | Lt | Tymp (Rt) | Tymp (Lt) | ART (Rt) | ART (Lt) | Rt | Lt | Rt | Lt |
| 89 | 27 | Female | No | yes | No | No | Normal | Mild | A | A | * | 1 | * | 1 | * | L |
| 90 | 64 | Female | No | No | No | yes | Moderate | Mild | Other | A | 1 | * | 1 | * | F | F |
| 91 | 27 | Male | yes | No | yes | No | Moderately severe | Normal | A | A | 1 | * | 1 | * | H | * |
| 92 | 56 | Female | No | No | yes | No | severe | Normal | A | A | 2 | * | 1 | * | H | * |
| 93 | 56 | Female | No | No | No | yes | Moderately severe | Mild | A | A | 1 | 1 | 1 | 1 | F | F |
| 94 | 69 | Male | yes | No | yes | No | Normal | Moderate | A | A | 2 | 1 | 1 | 1 | H | F |
| 95 | 55 | Female | No | yes | yes | No | Mild | Normal | A | A | 1 | * | 1 | * | F | * |
| 96 | 49 | Female | No | yes | No | No | severe | Normal | A | A | 2 | * | 1 | * | L | * |
| 97 | 58 | Female | No | No | yes | No | Normal | Moderately severe | A | A | 2 | 2 | 1 | 1 | H | H |
| 98 | 58 | Male | No | No | yes | No | Mild | Moderately severe | A | A | 1 | 1 | 1 | 1 | H | F |
| 99 | 41 | Male | No | No | No | yes | Moderate | profound | A | A | * | 1 | * | 2 | * | H |
| 100 | 54 | Female | No | No | yes | No | Normal | Mild | A | Other | * | 1 | * | 1 | H | F |
| 101 | 52 | Female | No | yes | No | No | Mild | Normal | A | A | 2 | * | 1 | * | F | * |
| 102 | 56 | Male | yes | No | yes | No | Normal | Moderate | A | A | 2 | 1 | 1 | 1 | H | F |
| 103 | 29 | Female | No | No | yes | No | Moderately severe | Normal | A | A | 1 | * | 1 | * | F | * |
| 104 | 47 | Male | No | yes | No | No | Mild | Normal | A | A | 1 | * | 1 | * | H | * |
| 105 | 48 | Female | No | No | No | yes | Normal | Moderately severe | A | A | * | 1 | * | 1 | * | F |
| 106 | 50 | Male | No | yes | No | No | Normal | Moderately severe | A | A | 2 | 1 | 1 | 1 | H | F |
| 107 | 28 | Male | No | No | yes | No | Normal | Normal | A | A | 2 | 2 | 1 | 1 | H | H |
| 108 | 73 | Female | No | No | yes | No | Normal | Normal | A | A | 2 | 2 | 2 | 1 | H | H |
| 109 | 73 | Male | No | No | yes | No | Mild | Normal | Other | A | 2 | * | 1 | * | H | H |
| 110 | 26 | Female | No | No | No | yes | Normal | severe | A | A | * | 2 | * | 1 | * | F |
| 111 | 35 | Female | No | yes | No | No | Normal | Normal | A | A | * | 1 | * | 1 | * | L |

1 =negative result, 2=positive result, *= exclusion criteria, F= F loss, L=Low frequency loss, H=High frequency loss

| ID | Age (yrs) | Gender | Symptom | | | | Degree of hearing loss | | Immittance measurement | | | | ABR | | Configuration | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Vertigo | Dullness | Tinnitus | Hearing loss | Rt | Lt | Tymp (Rt) | Tymp (Lt) | ART (Rt) | ART (Lt) | Rt | Lt | Rt | Lt |
| 112 | 63 | Female | No | yes | No | No | Normal | severe | A | A | 2 | 1 | 1 | 3 | H | F |
| 113 | 56 | Male | No | No | No | yes | severe | Normal | A | A | 2 | * | 3 | * | F | * |
| 114 | 24 | Female | No | No | No | yes | Normal | Moderately severe | A | A | 2 | 1 | 1 | 1 | H | H |
| 115 | 55 | Female | No | yes | No | No | Normal | Normal | A | A | 1 | 2 | 1 | 1 | H | H |
| 116 | 83 | Male | No | No | No | yes | Normal | Moderately severe | A | A | 2 | 1 | 1 | 1 | H | F |
| 117 | 44 | Male | No | yes | No | No | Normal | Normal | A | A | 2 | 2 | 1 | 1 | H | H |
| 118 | 57 | Female | yes | No | yes | No | Moderate | Normal | A | A | 1 | * | 1 | * | L | * |
| 119 | 33 | Female | No | No | yes | No | Mild | Moderate | A | A | 1 | 1 | 1 | 1 | H | F |
| 120 | 33 | Male | No | No | No | yes | Moderately severe | Normal | A | A | 1 | 2 | 1 | 1 | F | H |
| 121 | 70 | Female | No | No | yes | No | Normal | Normal | A | A | * | 1 | * | 1 | * | H |
| 122 | 39 | Female | No | No | yes | No | Mild | Mild | A | A | 2 | 2 | 1 | 1 | L | F |
| 123 | 42 | Male | No | yes | No | No | Normal | Normal | A | A | 2 | * | 1 | * | L | * |
| 124 | 53 | Female | No | No | yes | No | Normal | Normal | A | A | 2 | 2 | 1 | 1 | H | H |
| 125 | 53 | Male | yes | No | No | No | Normal | Normal | A | A | 2 | 2 | 1 | 1 | H | H |
| 126 | 78 | Male | No | No | yes | No | Moderately severe | Moderate | A | C | 1 | * | 1 | * | F | F |
| 127 | 70 | Female | No | No | yes | No | Moderately severe | Normal | A | A | 1 | 2 | 1 | 1 | F | H |
| 128 | 68 | Male | No | yes | No | No | Moderate | Mild | A | A | 1 | 1 | 1 | 1 | F | F |
| 129 | 51 | Male | yes | No | yes | No | Normal | Moderate | A | A | * | 1 | * | 1 | * | L |
| 130 | 16 | Female | No | No | No | yes | Normal | Mild | A | A | * | 1 | * | 1 | * | F |
| 131 | 75 | Male | No | No | No | yes | Moderate | Normal | A | A | 2 | 2 | 1 | 1 | F | H |
| 132 | 46 | Female | No | No | yes | yes | Normal | Mild | A | A | * | 1 | * | 1 | * | F |
| 133 | 53 | Male | No | No | No | yes | severe | Normal | A | A | 1 | * | 1 | * | H | * |
| 134 | 57 | Female | No | No | yes | No | Mild | Normal | A | A | 2 | * | 1 | * | H | * |

1 =negative result, 2=positive result, *= exclusion criteria, F= F loss, L=Low frequency loss, H=High frequency loss

| ID | Age (yrs) | Gender | Symptom | | | | Degree of hearing loss | | Immittance measurement | | | | ABR | | Configuration | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Vertigo | Dullness | Tinnitus | Hearing loss | Rt | Lt | Tymp (Rt) | Tymp (Lt) | ART (Rt) | ART (Lt) | Rt | Lt | Rt | Lt |
| 135 | 65 | Female | No | No | yes | No | Normal | Normal | A | A | 2 | 1 | 1 | 1 | H | F |
| 136 | 36 | Female | No | yes | No | No | Normal | Normal | A | A | 2 | 2 | 1 | 1 | H | H |
| 137 | 59 | Female | No | yes | yes | No | Mild | Normal | A | A | 1 | 2 | 1 | 1 | H | H |
| 138 | 63 | Female | No | yes | No | No | Mild | Normal | A | A | 2 | 2 | 1 | 1 | F | H |
| 139 | 56 | Female | No | No | yes | No | Normal | Moderate | A | A | * | 1 | * | 1 | * | H |
| 140 | 62 | Male | No | yes | No | No | Normal | Mild | A | A | 2 | 1 | 1 | 1 | H | L |
| 141 | 47 | Male | No | yes | yes | No | severe | Normal | A | A | 1 | * | 1 | * | F | * |
| 142 | 46 | Male | yes | No | No | No | Normal | Normal | A | A | 2 | * | 1 | * | H | * |
| 143 | 66 | Male | No | yes | yes | No | Mild | Moderate | A | A | 2 | 1 | 1 | 1 | H | F |
| 144 | 44 | Female | No | yes | No | No | Mild | Normal | A | A | 2 | * | 1 | * | H | * |
| 145 | 49 | Female | No | yes | No | No | Normal | Moderately severe | A | A | * | 1 | * | 1 | * | H |
| 146 | 50 | Male | No | No | yes | No | Normal | severe | A | A | 2 | 1 | 1 | 3 | H | F |
| 147 | 49 | Male | No | No | yes | No | Normal | Mild | A | A | 2 | 1 | 1 | 1 | H | H |
| 148 | 34 | Female | No | No | yes | No | Mild | Normal | A | A | 2 | * | 3 | * | L | * |
| 149 | 57 | Male | yes | No | No | No | Moderate | Moderate | A | A | 2 | 2 | 2 | 2 | F | F |
| 150 | 48 | Male | No | No | yes | No | Normal | Normal | A | A | 1 | 2 | 1 | 1 | H | H |
| 151 | 42 | Female | yes | No | yes | No | Moderate | Moderate | A | A | 1 | 1 | 1 | 1 | F | F |
| 152 | 79 | Female | No | yes | No | No | severe | Moderate | A | A | 1 | 1 | 1 | 1 | F | F |
| 153 | 67 | Female | No | No | No | yes | profound | Mild | A | A | * | 1 | * | 2 | * | F |
| 154 | 69 | Male | yes | yes | No | No | Normal | Normal | A | A | 2 | 2 | 1 | 1 | H | H |
| 155 | 65 | Female | yes | No | yes | No | Normal | Mild | A | A | 1 | 1 | 1 | 1 | H | F |
| 156 | 62 | Female | No | No | yes | No | Moderate | Moderate | A | A | 1 | 1 | 1 | 1 | F | F |
| 157 | 75 | Male | No | yes | No | yes | Moderately severe | Normal | A | A | 1 | 2 | 1 | 2 | F | H |

1 =negative result, 2=positive result, *= exclusion criteria, F= F loss, L=Low frequency loss, H=High frequency loss

| ID | Age (yrs) | Gender | Symptom | | | | Degree of hearing loss | | Immittance measurement | | | | ABR | | Configuration | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Vertigo | Dullness | Tinnitus | Hearing loss | Rt | Lt | Tymp (Rt) | Tymp (Lt) | ART (Rt) | ART (Lt) | Rt | Lt | Rt | Lt |
| 158 | 47 | Female | No | No | No | yes | Normal | Normal | A | A | 2 | 1 | 1 | 1 | F | F |
| 159 | 55 | Female | No | No | yes | No | Normal | Mild | A | B | * | 1 | * | 1 | * | F |
| 160 | 52 | Female | yes | No | No | No | Normal | Normal | A | A | * | 2 | * | 1 | * | H |
| 161 | 74 | Male | No | No | yes | No | Moderate | Normal | A | A | 1 | 2 | 1 | 1 | H | H |
| 162 | 55 | Male | yes | No | yes | No | Normal | severe | A | A | * | 1 | * | 1 | * | F |
| 163 | 62 | Female | No | yes | No | yes | Moderate | Normal | A | A | 1 | * | 1 | * | F | * |
| 164 | 30 | Male | No | yes | No | yes | Mild | Mild | A | A | 1 | 1 | 1 | 1 | F | F |
| 165 | 68 | Male | No | No | No | yes | Normal | Normal | A | A | 2 | 2 | 1 | 1 | H | H |
| 166 | 62 | Male | No | No | yes | No | severe | Moderate | A | A | 2 | 2 | 2 | 1 | F | H |
| 167 | 33 | Male | No | No | yes | No | Normal | Normal | A | A | * | 2 | * | 1 | * | H |
| 168 | 78 | Male | No | yes | No | No | Moderately severe | Mild | A | A | 1 | 1 | 1 | 1 | F | F |
| 169 | 47 | Female | No | No | yes | yes | Normal | Mild | A | A | * | 1 | * | 1 | * | F |
| 170 | 52 | Female | No | yes | No | No | Normal | Moderately severe | A | A | * | 1 | * | 1 | * | H |
| 171 | 45 | Male | No | No | yes | No | Normal | Normal | A | A | * | 1 | * | 1 | * | H |
| 172 | 42 | Female | No | No | yes | No | Mild | Normal | A | A | 1 | * | 1 | * | F | * |
| 173 | 76 | Male | No | No | No | yes | Moderately severe | Normal | A | A | 2 | 2 | 1 | 1 | F | H |
| 174 | 61 | Female | No | yes | No | No | Normal | Normal | A | A | 2 | 2 | 1 | 2 | H | H |
| 175 | 58 | Female | No | No | yes | No | Normal | Mild | A | A | 2 | 1 | 1 | 1 | H | H |
| 176 | 30 | Male | No | No | yes | yes | Mild | Normal | A | A | 1 | 2 | 1 | 1 | F | H |
| 177 | 52 | Male | No | No | No | yes | Normal | Moderately severe | A | A | * | 1 | * | 1 | * | F |
| 178 | 61 | Female | No | No | yes | No | Moderate | Mild | A | A | 2 | 2 | 1 | 1 | L | L |
| 179 | 46 | Female | No | yes | No | No | Moderate | Normal | A | A | 1 | * | 1 | * | F | * |
| 180 | 59 | Male | No | yes | No | No | Normal | Moderately severe | A | A | 1 | 1 | 1 | 1 | H | F |

1=negative result, 2=positive result, *= exclusion criteria, F= F loss, L=Low frequency loss, H=High frequency loss

| ID | Age (yrs) | Gender | Symptom | | | | Degree of hearing loss | | Immittance measurement | | | | ABR | | Configuration | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Vertigo | Dullness | Tinnitus | Hearing loss | Rt | Lt | Tymp (Rt) | Tymp (Lt) | ART (Rt) | ART (Lt) | Rt | Lt | Rt | Lt |
| 181 | 52 | Female | No | No | yes | No | severe | Moderate | A | A | 1 | 1 | 1 | 1 | F | F |
| 182 | 22 | Female | No | No | yes | No | Normal | Mild | A | A | 2 | 1 | 1 | 1 | H | H |
| 183 | 68 | Female | No | No | yes | No | Normal | Mild | A | A | 2 | 1 | 1 | 1 | H | F |
| 184 | 62 | Female | No | No | No | yes | Normal | severe | A | B | * | 1 | * | 1 | H | F |
| 185 | 24 | Female | yes | No | No | No | Mild | Mild | A | A | 1 | 1 | 1 | 1 | H | H |
| 186 | 54 | Male | No | yes | No | No | Normal | Normal | A | A | 2 | 2 | 1 | 1 | H | H |
| 187 | 52 | Female | No | yes | No | No | Normal | Moderate | A | A | * | 1 | * | 1 | * | L |
| 188 | 58 | Male | No | No | No | yes | severe | Normal | A | A | 2 | 2 | 3 | 1 | F | H |
| 189 | 55 | Female | No | No | yes | No | Normal | Normal | A | A | 2 | * | 1 | * | H | * |
| 190 | 49 | Female | No | No | yes | No | Normal | Normal | A | A | 2 | 2 | 1 | 1 | H | H |
| 191 | 46 | Male | No | No | yes | No | Normal | Normal | A | A | * | 1 | * | 1 | H | H |
| 192 | 23 | Male | No | No | yes | yes | profound | Normal | A | A | * | 2 | * | 1 | * | H |
| 193 | 13 | Male | No | No | No | yes | profound | Moderately severe | A | A | * | 1 | * | 1 | * | F |
| 194 | 58 | Female | No | No | yes | No | Mild | Mild | A | A | 2 | 1 | 1 | 1 | H | F |
| 195 | 46 | Female | yes | yes | No | No | Mild | Mild | A | A | 1 | 1 | 1 | 1 | L | L |
| 196 | 53 | Male | No | yes | yes | No | Mild | Mild | A | A | 1 | 2 | 1 | 1 | H | H |
| 197 | 73 | Male | No | No | yes | No | Mild | Normal | A | A | 1 | * | 1 | * | F | * |
| 198 | 64 | Female | No | No | yes | No | Moderate | Moderate | A | A | 2 | 1 | 1 | 1 | F | F |
| 199 | 43 | Male | No | yes | yes | No | Normal | Moderate | A | A | * | 1 | * | 1 | * | L |
| 200 | 52 | Male | No | No | No | yes | Moderately severe | Normal | A | A | 1 | * | 1 | * | F | * |
| 201 | 54 | Female | No | No | yes | yes | Normal | severe | A | A | 2 | 2 | 1 | 3 | H | F |
| 202 | 70 | Male | No | yes | No | No | Normal | Normal | A | A | 2 | 2 | 1 | 1 | H | H |
| 203 | 46 | Female | No | yes | No | No | Mild | Normal | A | A | 2 | * | 1 | * | F | * |

1 =negative result, 2=positive result, *= exclusion criteria, F= F loss, L=Low frequency loss, H=High frequency loss

| ID | Age (yrs) | Gender | Symptom | | | | Degree of hearing loss | | Immittance measurement | | | | ABR | | Configuration | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Vertigo | Dullness | Tinnitus | Hearing loss | Rt | Lt | Tymp (Rt) | Tymp (Lt) | ART (Rt) | ART (Lt) | Rt | Lt | Rt | Lt |
| 204 | 73 | Female | No | yes | No | yes | profound | Mild | A | A | 2 | 1 | 3 | 1 | * | F |
| 205 | 74 | Female | No | yes | yes | No | Normal | Normal | A | A | 2 | 2 | 1 | 1 | H | H |
| 206 | 59 | Female | No | No | yes | No | Normal | Mild | A | A | * | 1 | * | 1 | * | H |
| 207 | 50 | Female | No | yes | No | No | Moderately severe | Moderate | A | A | 1 | 1 | 1 | 1 | F | F |
| 208 | 51 | Female | No | yes | No | yes | Moderately severe | Normal | A | A | 1 | * | 1 | * | F | * |
| 209 | 51 | Male | No | yes | No | No | Moderate | profound | A | A | 1 | * | 1 | * | F | * |
| 210 | 45 | Male | No | No | yes | No | Mild | Normal | A | A | 1 | 2 | 1 | 1 | H | H |
| 211 | 34 | Female | No | No | yes | No | Moderately severe | Normal | A | A | 1 | * | 1 | * | F | * |
| 212 | 43 | Female | No | yes | No | No | Normal | Moderate | A | A | * | 1 | * | 1 | * | F |
| 213 | 62 | Female | No | No | No | yes | Mild | Moderately severe | A | A | 1 | 2 | 1 | 1 | H | H |
| 214 | 55 | Female | No | yes | No | yes | severe | Normal | A | A | 1 | 2 | 1 | 1 | H | H |
| 215 | 52 | Male | No | yes | No | No | Normal | Mild | A | A | * | 1 | * | 1 | * | L |
| 216 | 39 | Male | No | yes | No | No | Mild | Normal | A | A | 2 | * | 1 | * | F | * |
| 217 | 62 | Male | No | No | No | yes | Normal | severe | A | A | 2 | 1 | 1 | 1 | H | F |
| 218 | 52 | Male | No | No | yes | yes | Moderately severe | Moderately severe | A | A | 1 | 1 | 1 | 1 | F | F |
| 219 | 45 | Female | No | yes | yes | No | severe | Normal | A | A | 1 | * | 1 | * | F | * |
| 220 | 55 | Female | No | No | No | yes | Normal | Mild | A | A | 2 | 1 | 1 | 1 | H | L |
| 221 | 58 | Female | No | yes | No | No | Moderate | Normal | Other | A | 1 | * | 1 | * | L | * |
| 222 | 50 | Male | No | yes | No | No | Mild | severe | A | A | 1 | 1 | 1 | 1 | H | F |
| 223 | 71 | Female | yes | No | No | No | Normal | Mild | A | A | 2 | 2 | 1 | 1 | H | H |
| 224 | 17 | Female | No | No | No | yes | Moderately severe | Moderately severe | A | A | 2 | 2 | 1 | 1 | F | F |
| 225 | 66 | Female | No | yes | No | No | Mild | Moderate | A | A | 2 | 2 | 1 | 1 | H | H |
| 226 | 66 | Female | No | yes | yes | No | Mild | Normal | A | A | 1 | 2 | 1 | 1 | L | H |

1 =negative result, 2=positive result, *= exclusion criteria, F= F loss, L=Low frequency loss, H=High frequency loss

| ID | Age (yrs) | Gender | Symptom | | | | Degree of hearing loss | | Immittance measurement | | | | ABR | | Configuration | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Vertigo | Dullness | Tinnitus | Hearing loss | Rt | Lt | Tymp (Rt) | Tymp (Lt) | ART (Rt) | ART (Lt) | Rt | Lt | Rt | Lt |
| 227 | 58 | Male | yes | No | No | yes | severe | Normal | A | A | 1 | * | 1 | * | F | * |
| 228 | 54 | Male | No | yes | No | No | Normal | Normal | A | A | 1 | 1 | 1 | 1 | H | H |
| 229 | 10 | Male | No | No | No | yes | Moderately severe | Mild | A | A | 1 | 2 | 1 | 1 | F | F |
| 230 | 78 | Male | No | No | No | yes | Moderately severe | Moderate | A | A | 1 | 1 | 1 | 1 | F | F |
| 231 | 57 | Female | No | No | yes | No | Moderate | Normal | A | A | 1 | * | 1 | * | F | * |
| 232 | 57 | Female | No | No | yes | No | Moderately severe | Moderately severe | A | A | 1 | 1 | 1 | 1 | F | F |

1 =negative result, 2=positive result, *= exclusion criteria, F= F loss, L=Low frequency loss, H=High frequency loss

# APPENDIX C

คณะแพทยศาสตร์โรงพยาบาลรามาธิบดี มหาวิทยาลัยมหิดล
๒๗๐ ถนนพระราม ๖ แขวงทุ่งพญาไท เขตราชเทวี กทม. ๑๐๔๐๐
โทร. (๐๒) ๒๐๑-๑๐๐๐

**Faculty of Medicine Ramathibodi Hospital, Mahidol University.**
270 Rama VI Road, Ratchathewi, Bangkok 10400, Thailand
Tel. (662) 201-1000

**Documentary Proof of Ethical Clearance**
**Committee on Human Rights Related to Research Involving Human Subjects**
**Faculty of Medicine Ramathibodi Hospital, Mahidol University**

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**MURA2014/221/N1**

| | |
|---|---|
| **Title of Project** | Identification of Cochlear Pathology in Sensorineural Hearing Loss Patients by the Use of Acoustic Reflex Thresholds |
| **Protocol Number** | ID 04-57-27 |
| **Principal Investigator** | Miss. Mondnath Chockboondee |
| **Official Address** | Communication Sciences and Disorders<br>Faculty of Medicine Ramathibodi Hospital<br>Mahidol University |
| **New Title 1:**<br>**(Approval : 29/05/2015)** | Identification of Cochlear/Retrocochlear Pathology in Sensorineural Hearing Loss Patients by the Use of Acoustic Reflex Thresholds |

***The aforementioned project has been reviewed and approved by the Committee on Human Rights Related to Research Involving Human Subjects, based on the Declaration of Helsinki.***

| | |
|---|---|
| **Signature of Chairman**<br>**Committee on Human Rights Related to**<br>**Research Involving Human Subjects** | ......Pratak Oprasert......<br>Prof. Pratak O-Prasertsawat, M.D. |
| **Date of Approval** | April 10, 2014 |
| **Duration of Study** | 4 Months |

# BIOGRAPHY

| | |
|---|---|
| **NAME** | Miss. Mondnath Chockboondee |
| **DATE OF BIRTH** | 6 September 1988 |
| **PLACE OF BIRTH** | Bangkok, Thailand |
| **INSTITUTIONS ATTENDED** | Mahidol University, 2006-2009<br>Bachelor of Science<br>(Communication Disorders)<br>Mahidol University, 2012-2015<br>Master of Science<br>(Communication Disorders) |
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| **PRESENTATION** | The 34th National Graduate Research Conference |