INTRODUCTION:

Clinical audiology has evolved new techniques and strategies to assess auditory function. Pure tone audiometry, tympanometry and acoustic reflex measurements, and word recognition scores continue to be important for hearing assessment but these measurements have been aided by other behavioral and electrophysiologic test procedures. EcochG can contribute to the diagnosis of Meniere’s disease while auditory brainstem response (ABR) offers a readily accessible and relatively inexpensive means for identifying retrocochlear auditory dysfunction. Otoacoustic emissions have become the latest addition to the clinical audiological battery because of their sensitivity and specificity of outer hair cell function. Generally speaking, diagnosis of an audiological disorder is made based on the patient’s history, physical examination, and audiological test battery results. Results obtained from testing can often be verified by other modalities. For instance an air-bone gap seen on pure tone audiometry can be confirmed by abnormal tympanogram, the typical otoscopic appearance of a retracted eardrum and its poor mobility on pneumatic otoscopy.

PURE TONE AUDIOMETRY

Pure tone audiometry is the most commonly used test for evaluating auditory sensitivity. Signals are delivered through air and bone conduction. The American National Standards Institute (ANSI) defines the threshold of audibility as the minimum effective sound pressure level of an acoustic signal producing an auditory sensation ‘in a specified fraction of trials.’ Most often, threshold is defined as the lowest signal intensity at which multiple presentations are detected 50% of the time. The auditory system is activated by acoustical and mechanical transmission of sound energy to the sensory receptors within the cochlea of the inner ear. Air conducted sound is shaped spectrally by the head and external auditory canal and is transferred mechanically by the middle ear transmission system to the cochlea. Energy is then formatted into a neural code that is projected by the auditory nerve and central pathways to the higher auditory centers of the brain. Air conduction assesses the function of the entire auditory system from the most peripheral aspect to the central portion. Air conduction testing provides little information regarding the etiology of hearing loss and specific auditory pathology. When examined in conjunction with thresholds obtained via bone-conduction testing, however, they help determine both the type and severity of the hearing loss. Bone conducted sound is transmitted directly to the cochlea – it is also important to note that the outer and middle ear contribute secondarily to the total bone
conduction response; however, most people consider bone conduction a test of sensorineural function. A bone oscillator is typically placed on the mastoid process which provides an enhanced dynamic range compared with other placements such as the frontal bone.

Pure tones are perfectly suited to test auditory acuity. They are generated by an electroacoustic or mechanical source that produces acoustic or mechanical energy that varies as a function of cycles per second. Pure tones are excellent stimuli for testing hearing because of their utility and spectral simplicity in testing cochlear elements. High frequency tones initiate traveling waves whose maximum intensity will occur at the basal end of the cochlea while a low frequency tone initiates a traveling wave whose maximum intensity will occur at the apical end of the cochlea. This allows pure tones to test for the determination of auditory function at relatively discrete portions of the cochlea.

Typically when discussing the decibel levels in the human hearing, it is necessary to define the decibel scale that is being used. Three different units are used in audiology including dB sound pressure level (SPL), dB hearing level (HL), and dB sensation level (SL). Human hearing extends from 20 to 20,000 Hz but the sensitivity at different frequencies varies in dB SPL. Humans can hear a 1000 Hz tone at about 6.5 dB SPL but hear 125 Hz only when the tone is presented at a level of 45 dB SPL and hear 10,000 Hz at about 20 dB SPL. Because the human ear is differentially sensitive, the SPL curve represents the "just audible" line. Each point on the line corresponds to threshold of human hearing and is thus arbitrarily given a value of 0 dB HL. Intensity range of human hearing extends from about 0 dB HL to approximately 130 dB (pain sensation). Decibels are quantified on a logarithmic basis and as such a 10 dB increase in level signifies a ten fold increase in sound energy. Thus, a 60 dB HL signal is actually a million times more powerful than a 0 dB HL signal. This should not be confused with percentage of hearing loss. The difference in loudness across frequencies decrease at higher intensities, so that at 100 dB SPL, all frequencies are equally loud. The ear thus functions as an equalizer at higher intensities. Sensation level refers to the hearing sensation for any one individual above their threshold values. For example, a person with a 20 dB SL at 1000 Hz indicates a level that is 20 dB louder than that patient’s admitted threshold.

Air conduction audiometry measures pure tone thresholds at discrete frequencies for each ear and then plotting these thresholds on an audiogram. Thresholds are determined using 5-dB step changes that allow moment-to-moment changes in sensitivity. Air conduction thresholds are obtained from 250 Hz to 8000 Hz at octave intervals. Interoctave intervals are tested when successive octave thresholds differ by 20 dB. Bone conduction testing is performed by placing a vibrator on the skull, usually at the mastoid process which allows sufficient vibratory force to stimulate the ear. The mastoid seems to be the location of choice for bone conduction measurement although both the forehead and mastoid offer distinct advantages and disadvantages. The mastoid requires less energy to stimulate thresholds thus it is often used. Bone conduction testing involves finding threshold values at octave intervals from 250 Hz to 4000 Hz. Testing below 250 Hz or above 4000 Hz is difficult because of the physical limitations of bone conduction vibrators. Occluding one or both ears during bone conduction stimulation increases the intensity of sound delivered to the covered ear, principally at 1000 Hz and below. Initial measurements during bone conduction testing should be done with both ears uncovered to avoid threshold artifacts. Thresholds are measured by obtaining a first positive response then the intensity is lowered in 10 dB steps until no responses are seen. All ascending series of tone presentations are made in 5 dB steps. Threshold is defined at the minimum hearing level at which response occurs 50% or more of the time.
**SPEECH AUDIOMETRY**

The information derived from pure tone air conduction and bone conduction audiometric tests is helpful yet speech audiometry is necessary to completely assess basic auditory function. Speech audiometric techniques present standardized samples through a calibrated system in order to measure an aspect of hearing ability. Spondaic or spondee words are the speech stimuli used to obtain the speech reception threshold (SRT). A spondee is defined as a two-syllable word spoken with equal stress on both syllables and is excellent choice for determining threshold in speech because it is easy to understand at faint hearing levels. Standardized word lists now include 36 spondees grouped into two lists of 18 words that are phonetically dissimilar and homogeneous in terms of intelligibility. Most audiologists measure speech thresholds using monitored live voice and use 5-dB increments. Familiarization with the spondee words should occur before testing commences because the familiarization results in an SRT that is 4 to 5 dB better than that obtained without prior knowledge. Criterion for the SRT is the lowest hearing level at which 50% of the words are identified. The first spondee is presented at the lowest hearing level setting and usually no response occurs. Then the examiner ascends in 10 dB steps until a correct response is identified. Spondee threshold is the lowest hearing level at which half of the words are identified correctly followed by at least two ascending series. Word recognition or speech discrimination testing has been used to qualify speech understanding difficulty and possibly provide information about site of injury in the auditory system. Phonetically balanced (PB) monosyllabic word lists exist and allow the determination of word recognition. Word lists were developed which minimized the difficulties in assessment of patients with limited vocabularies and those that were unfamiliar with the words. This component of the basic hearing test battery is not a threshold measure but the test is administered suprathreshold (about 30 to 50 dB above threshold). A list of 20 or 50 words may be used and the percentage correct is identified. A word recognition score of 90% or higher is considered normal while scores below this value indicate a problem with word recognition. Patients with a conductive hearing loss frequently show excellent speech discrimination scores when test stimuli are sufficiently loud. Patients with cochlear lesions have poorer discrimination scores and those with retrocochlear lesions tend to have even poorer speech discrimination abilities even with normal auditory pure-tone thresholds.

**CLINICAL MASKING**

During testing of pure tone and speech audiometric assessment, instances can occur in which the obtained responses represent the performance of the nontest ear rather than the test ear. Failure to recognize this occurrence and deal with it appropriately can result in erroneous interpretation of the audiometric data. Consider the results of the audiogram that realistically can occur when testing a person who has normal hearing in one ear and no hearing in the other ear. Hearing sensitivity may be normal for one ear (say the left ear) and thresholds may range from 50 to 60 dB for the right ear (ear without hearing). This air conduction of the right ear actually represents the so-called shadow curve that often occurs during air conduction testing when a large sensitivity difference exists between the ears. What actually happens is that right ear air conduction responses result from the pure tone stimuli that activate the left ear. This results from crossover hearing. A so-called shadow curve develops because the skull and intracranial contents partially impede the transmission of sound from one ear to the other during air conduction testing. In this example of actual profound right-ear hearing loss, the responses obtained with air-conducted tones to the impaired side represent a shadow of the better ear. This illustrates the concept of interaural attenuation which refers to the reduction in sound when it crosses from one ear to the other. This crossover phenomenon occurs principally through bone conduction. The interaural attenuation of air conducted tones varies from 40 dB to 80 dB depending on whether ear insert or headphones are
being used and also on the frequency being tested (greater interaural attenuation at higher frequencies). Interaural attenuation values tend to be smaller for the lowest frequency regions than for the higher frequency regions. Interaural attenuation values for bone conduction occur at about 0 dB so it is prudent to mask the non-test ear when thresholds vary between ears. One other consideration is the bone conduction threshold of the non-test ear which may be lower than the air conduction threshold of the non-test ear. If the air conduction threshold of the test ear exceeds the bone conduction threshold of the non-test ear by a value greater than interaural attenuation, masking should be employed. It is not sufficient simply to compare the air conduction hearing levels between ears to determine if crossover hearing is taking place – you must take into account the bone conduction threshold of the non-test ear. Isolation of the non-test ear can be accomplished with the use of masking noise. The modern audiometer is equipped to provide narrow bands of masking noise centered around the frequencies selected for pure tone testing. Speech spectrum noise is available for masking during speech audiometry. The use of narrow band noise is based on the critical band concept. Only energy contained in a restricted band of frequencies centered around the test tone contributes to the masking of that tone. Noise or energy outside this band plays no masking role but does contribute to overall loudness of the masking tone. Narrow bands of noise are more efficient than broad band noises because the provide more masking at a given overall level. Narrow band noises are less loud because the energy is integrated over a small band of frequencies. The overall goal will provide the largest shift in threshold with the least intense noise. The plateau method is often employed in clinical masking. Basically, the non-test ear is masked by progressively greater amounts of sound until the threshold of the test ear does not continue to increase. This indicates the "true" threshold of the test ear and masking may be discontinued. Occasionally, masking is necessary but not possible with cases of bilateral conductive or mixed hearing loss. This refers to the masking dilemma when bone conduction thresholds are within normal limits and the air conduction thresholds exceed interaural attenuation. In these cases, unmasked thresholds represent the responses of the non-test ear whereas masked air conduction may appear worse than they actually are.

**ACOUSTIC IMMITANCE**

Impedance refers to the opposition of the flow of energy through a system. An acoustic wave strikes the eardrum of the normal ear and a portion of the signal is transmitted through the middle ear to the cochlea while the remaining part of the wave is reflected back out the external canal. The reflected energy forms a sound wave traveling in an outward direction with an amplitude and phase that is dependent upon the opposition encountered at the tympanic membrane. The energy naturally is greatest when the middle ear system is stiff or immobile. On the other hand, an ear with ossicular chain interruption will reflect considerably less sound back into the canal because of reduced stiffness. The measurement of acoustic immitance at the tympanic membrane has become an important diagnostic tool to identify the presence of fluid in the middle ear, evaluate eustachian tube and facial nerve function and predict audiometric findings. Tympanometry, and threshold of the acoustic reflex commonly comprise the acoustic immitance test battery. Tympanometry reflects the mobility of the middle ear when air pressure is varied from +200 to – 400 daPa. A normal tympanogram for an adult has a peak pressure point between – 100 and +40 daPa which means that the middle ear functions optimally at or near ambient pressure. Tymps that peak at a point below the accepted range of normal pressures suggest malfunction of the middle ear pressure-equalizing system. This malfunction might be due to eustachian tube malfunction, early or resolving serous otitis media or acute otitis media. The amplitude of the tympanogram gives additional information about the compliance or elasticity of the system. A stiff middle ear (ossicular chain fixation) is represented by a shallow amplitude while an ear with an interrupted ossicular chain is represented by a tympanogram with a steep amplitude (indicating low
impedance). Acoustic immittance also provide the physician with information about the volume of air medial to the probe. In general, ear canal volumes range from 0.5 to 1.0 ml in children and 0.6 to 2.0 ml in adults. Volume measurements greater than these suggest tympanic membrane perforation or a patent pressure equalization tube.

The acoustic reflex threshold (ASR) is defined as the lowest possible intensity needed to elicit a middle ear muscle (stapedius) contraction. This contraction causes a temporary increase in the middle ear impedance. Acoustic stimulation to one ear or the other will elicit a muscle contraction in both ears. In the normal ear, contraction of middle ear muscles occurs with pure tones ranging from 65 to 95 dB HL. The neural network of the acoustic reflex is located in the lower brainstem. Several studies have shown that the threshold of the contralateral acoustic stapedius reflex (ASR) is 80 to 85 dB HL for frequencies ranging from 500 to 4000 Hz. Ipsilateral reflex thresholds might be slightly lower owing to the different stimulus transducers. Also increasing bandwidth tends to decrease the threshold for the ASR. Adaptation occurs with continuous stimulation which leads to a decrease in the strength of stapedius contraction. In normal hearing persons, adaptation tends to occur at high frequency tones while lower frequency tones and broad-band noise have very little adaptation.

The ASR is usually absent in patients with middle ear disease. This occurs because of two reasons. A conductive loss in the stimulated ear reduces the effectiveness of the eliciting stimulus. A conductive loss as small as 20 dB may be sufficient to elevate the ASR beyond the range of the measurement system. Second, the middle ear pathology may decrease the acoustic admittance. When the tympanogram is flat, the stapedius may be incapable of changing the middle ear admittance sufficiently to be detected by the measuring equipment. A patient who has otosclerosis may have a normal tympanogram, but because of the rigidly fixed stapes, stapedial contraction is difficult to detect. With cochlear hearing loss, the ASR often occurs when the impaired ear is stimulated at a level of 60 dB or less indicating loudness recruitment but with losses above 60 dB, the chance of observing an acoustic reflex threshold decreases. With retrocochlear lesions, the ASR may be abolished. A small intracanalicular vestibular schwannoma may abolish the reflex or may have more subtle effects. The findings of an elevated ASR in the presence of normal hearing or mild sensorineural hearing loss plus a normal tympanogram suggest retrocochlear pathology. Theoretically brainstem lesions may abolish the reflex without affecting the pure tone audiogram. Cases have been reported in which the ipsilateral reflexes remain normal while the contralateral reflexes are abnormal, presumably because of a midline lesion of the brainstem affects only the decussating reflex pathways. ASR measurements may be useful in determining the site of a seventh nerve lesion. A lesion distal to the stapedial branch would not be expected to affect the ASR whereas a more proximal lesion could abolish the reflex. Acoustic reflex decay measures the ability of the stapedius muscle to maintain sustained contraction. During this test, a signal is presented 10 dB above the acoustic reflex threshold for 10 seconds. If the response decreases to one half or less of its original amplitude within 5 seconds, the response is considered abnormal and indicative or retrocochlear pathology. Normal ears may have reflex decay at higher frequencies so 500 and 1000 Hz are most often used.

**ELECTROCOCHLEOGRAPHY**

ECochG can be defined as a method of measuring stimulus-related potentials (neuroelectric events) of the most peripheral portions of the auditory system. Electric potentials include the cochlear microphonic, the summating potential (SP), and the compound action potential (AP). Information from these potentials, particularly the SP and AP, can be useful in assessing patients who have Meniere’s
disease and in those patients who require intraoperative monitoring of the peripheral auditory structures. EcochG uses recording electrodes that are placed close to the cochlea and auditory nerve. For clinical purposes, the electrode must be located on the promontory wall of the middle ear, on the tympanic membrane or in the external auditory meatus. Generally noninvasive electrodes placed on the tympanic membrane are sufficient to generate electric potentials. Although the amplitude of the response obtained with the tympanic membrane surface electrode is attenuated when compared with a transtympanic needle recording, its ease of placement and noninvasive nature make up for this disadvantage. The primary measure is the amplitude of the SP and AP response components. Latency is not important in these measurements as in ABR. Among individual subjects, the absolute amplitudes of SP and AP vary considerably among subjects. A more common approach uses the SP-AP amplitude ratio. An abnormal ratio is one that is greater than or equal to 0.45 which suggests meniere’s disease. It is theorized that hydrops affects the elasticity of the basilar membrane and contributes to the increased amplitude of the SP relative to that of the AP. In addition, EcochG can enhance wave I of the ABR especially in patients with severe high frequency hearing loss and in whom wave I is difficult to detect by surface recording techniques.

**AUDITORY BRAINSTEM RESPONSE**

The ABR is the most widely used auditory evoked potential procedure. The ABR represents a farfield recording of neuroelectric activity of the eighth nerve and brainstem auditory pathways that occurs over the first 10 to 15 milliseconds after a suitable sound stimulus has been delivered to the ear. It is considered a farfield recording because of the relatively large distance between the recording electrodes on the scalp and the actual generators of response in the brainstem. The most effective way to evoke the ABR is with a simple acoustic click although tonal stimuli can also be used. The acoustic energy of a click stimulus is most prominent between the frequencies of 2000 to 4000 Hz. Rate of stimulus presentation generally is slower for neurodiagnostic purposes and faster for hearing threshold estimation. The ABR is characterized by five to seven vertex positive peaks occurring over the first several milliseconds following stimulus presentation. These peaks represent synchronous neural discharge located at various way stations along the auditory pathway. It is generally accepted that waves I and II arise primarily from the auditory nerve, wave I from the distal component and wave II from the more proximal component. The intracranial generators are more complicated but wave III may represent the cochlear nucleus, wave IV the superior olivary complex and wave V the lateral lemniscus. Signal averaging and bandpass filtering are used to better configure the response and allow for a robust wave V (necessary for hearing sensitivity and neurologic applications). The ABR is unaffected by state of sleep, pharmacologic agents and only minor differences exist in the ABR between men and women; women have a slightly shorter latency for wave V and a larger wave V amplitude than men. From birth to 2 years of age, both absolute and interwave latency decrease by about 1.5 to 2 milliseconds – from that point on, the ABR remains relatively constant. The ABR can be used to test newborn infants or difficult-to-test children. It allows an assessment of the integrity of the neural elements from which estimates of hearing can be derived. When used for hearing threshold estimation, component wave V generally is tracked with decreasing sound intensity until it can no longer be observed. The click evoked ABR threshold is generally 10 to 20 dB poorer than behavioral measures of hearing sensitivity for frequencies in the range of 1000 to 4000 Hz. Latency of response and stimulus intensity can be used to plot a graph which may also give a clue as to the nature of the hearing loss (conductive or sensorineural).
The ABR is uniquely sensitive to lesions of the eighth cranial nerve and brainstem auditory pathways. This means of testing can be used and the following characteristics of the response may be evaluated and compared to normal findings: interwave latency (wave I-III and wave I – V), interaural latency difference (wave V), absolute latency, presence or absence of wave components, amplitude ratio (V/I) and overall morphology. Among these, the most valuable are measures of interwave latency and interaural latency difference of wave V. Interwave latencies reflect the time necessary for neural information to travel from one generator site to another. Any disorder that disrupts this synchronous neural flow will cause a prolongation in the interwave latency measure. However wave I is not easily seen because of some degree of peripheral hearing loss. At this point, it becomes necessary to evaluate the interaural latency difference of wave V to document retrocochlear pathology. Generally interpeak latencies such as I-III or I-V are considered the most sensitive measures of retrocochlear involvement however when wave I is absent (when a hearing loss exceeds 40 to 45 dB at higher frequencies), interaural latency difference of wave V becomes more important. It is important to note that increased I-III intervals are almost uniformly associated with retrocochlear pathology but increased I-V intervals may be associated with sensory noise-induced hearing loss.

**OTOACOUSTIC EMISSIONS**

Researchers reported the presence of audiofrequency energy in the ear canal of subjects with normal functioning ears. These emissions occurred as energy leakage from the cochlear traveling wave released from the cochlea and transmitted through the ossicular chain to the ear canal. Evidence has accumulated that such acoustic energy leakage is the biomechanical property of the healthy, functioning cochlea – in particular, the outer hair cells. It is thought that the active motility of outer hair cells serves as an amplifier of the displacement of the cochlear partition resulting in various forms of otoacoustic emissions (oae) as by-products that are detectable at low intensities. Both spontaneous and evoked emissions have been identified with approximately 96% to 100% of normal ears having evoked emissions and 35% of normal ears having spontaneous emissions. The procedure involves presentation of an acoustic stimulus to the ear which is then monitored for energy in the ear canal. A probe is fitted into the ear canal and measurement of a single averaged emission may take no longer than 30 seconds in a quiet adult. Transient evoked emissions are identifiable only from cochleae in which threshold hearing is more sensitive than 30 to 40 dB. These emissions are also frequency specific so when a cochlear site of lesion affects only frequency-specific areas, the emission will have no energy in the frequency region that coincides with the frequency-specific hearing loss. Compared to evoked potential measurements, one of the advantages of oae is the simple and brief patient preparation and examination. There is little intrasubject variability in otoacoustic emission measurements and such measurements are stable over several years for any one ear. Finally, conductive losses greater than about 30 dB HL does prevent measurement of cochlear emissions. Features which make this modality useful as a screening tool in infants include the fact that 96 to 100% of adults show evidence of an evoked emission, the procedure is noninvasive, test time is short, cochlear hearing loss exceeding 30 dB HL is identifiable from emission measurements and the measurement equipment and actual testing are not costly.

**CENTRAL AUDITORY FUNCTION**

Clinicians have noted that certain patients tend to respond poorly to auditory information in relation to their audiometric thresholds. Some patients have difficulty when several people are speaking at the same time, at a party, or when background noise is present. Comprehension can be a problem in those patients with neurologic disorders even though hearing is normal. Behavioral tests of central
Auditory function can be classified according to the manner of stimulus presentation. Categories include monotic tests (where a single stimulus is presented to one ear at a time or tests in which two stimuli are presented to one ear) and dichotic tests (in which the same stimulus is applied to the two ears). Testing can also be monaural where only one ear is tested or binaural two ears are stimulated simultaneously. A cochlear hearing loss affects measures of brainstem and cortical function while a brainstem lesion affects measures of cortical function.

BIBLIOGRAPHY

5. Head & Neck Surgery - Otolaryngology, Bailey, Ch. 130, 1998