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# Clinical Assessment of Auditory Dysfunction

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**Many drugs, chemicals substances and agents are potentially toxic to the human auditory system. The extent of toxicity depends on numerous factors. With few exceptions, toxicity in the auditory system affects various organs or cells within the cochlea or vestibular system, with brain stem and other central nervous system involvement reported with some chemicals and agents. This ototoxicity usually presents as a decrease in auditory sensitivity, tinnitus and/or vertigo or loss of balance. Classical and newer audiological techniques used in clinical assessment are beneficial in specifying the site of lesion in the cochlea, although auditory test results, themselves, give little information regarding possible pathology or etiology within the cochlea. Typically, ototoxicity results in high frequency hearing loss, progressive as a function of frequency, usually accompanied by tinnitus and occasionally by vertigo or loss of balance. Auditory testing protocols are necessary to document this loss in auditory function.**

## Introduction

Clinical assessment of auditory dysfunction is a broad topic, potentially covering many different methods of assessment and many types of auditory dysfunction. It is well known that auditory dysfunction can be caused by literally hundreds of different problems or pathologies. Auditory dysfunction can occur as a result of peripheral or central pathologies, or it can occur as a local manifestation of some systemic disease. Auditory dysfunction can be caused by extrinsic factors (infections, drugs, trauma, tumors, neurologic diseases, metabolic diseases) or intrinsic factors (genetic, etc.). Auditory dysfunction may be congenital or acquired. If congenital, it may be genetic, with hearing loss occurring alone as in the case of Mondini's aplasia, occurring in the form of a syndrome with other abnormalities such as Usher's syndrome, or may occur as a chromosomal abnormality. It may also be congenital but nongenetic, with hearing loss occurring alone in the case of many ototoxic agents, or, occurring with a host of other abnormalities as in the case of maternal rubella, anoxia, bacterial infections and metabolic disorders. As indicated, auditory dysfunction may also be acquired, either genetic or nongenetic. If genetic, hearing loss may occur alone as in the case of familial progressive sensorineural deafness or in conjunction with other abnormalities as in the case of Alport's syndrome. If nongenetic, hearing loss may occur as a result of numerous pathologies, including inflammatory diseases, ototoxicity, neoplastic disorders, traumatic injury, metabolic disorders, vascular insufficiency, or central nervous system diseases such as multiple sclerosis.

It should be obvious from this short description that the exact cause of a specific auditory dysfunction is frequently impossible to determine. It is also of interest to note that toxic agents may cause congenital or acquired auditory dysfunction. Since this conference is concerned with target organ toxicity—in the present case, specifically the auditory system—the remainder of this paper will deal especially with this topic. It should be remembered, however, that the same clinical assessment is appropriate to a wide range of auditory dysfunctions and not specific to those caused by ototoxicity.

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## Ototoxicity

It is probably safe to say that the action of any substance on an organ or cell can be either beneficial or detrimental, depending on many factors. Some controversy continues, however, as to whether any chemical, drug or agent has a beneficial effect on the inner ear. Recent literature would indicate that nearly 200 substances have some documentation in the medical literature of ototoxicity (*1-3*). Although these cannot be described within the current space constraints, they can be separated into general categories. These include: chemicals (carbon monoxide, alcohol, nicotine, arsenic, potassium bromate, etc.); heavy metals (lead, tin, gold, mercury, etc.); antibiotics; diuretics; analgesics and antipyretics (salicylates, quinine, etc.); antineoplastics (bleomycin, nitrogen mustard, *cis*-platinum); and miscellaneous drugs (pentobarbital, hexadine). The literature on chemical or drug ototoxicity for antibiotics and diuretics is extensive. The aminoglycosides have received the majority of attention; however, other antibiotics, such as vancomycin, erythromycin, chloramphenicol, polymyxin B and ampicillin, have also been indicated as potentially ototoxic. Diuretics have also received substantial research as potentially ototoxic. Specifically, furosemide and ethacrynic acid have ototoxic properties, or at least potentiate ototoxicity. However, other diuretics such as mannitol and the mercurials may be ototoxics. Perhaps the greatest body of literature with regard to ototoxic effects concerns exposure to noise. Auditory dysfunction following noise exposure has been documented for more than 100 years.

It is an understatement and oversimplification to describe the action of any chemical, drug or other agent as complex, with potential ototoxic effects dependent on many variables. However, this is also an accurate statement. The mechanisms of action of ototoxic substances or agents may injure or embarrass the entire organ, specific cells within the organ, components of specific cells, or inhibit individual biochemical pathways. This action has been related to overall dose; duration of exposure; blood serum levels in the case of chemicals, drugs or heavy metals; general health of the subject and underlying disease; age of subject; prior exposure; renal impairment; individual susceptibility; and, of course, possible potentiation and synergistic effects of combinations of chemicals, drugs and other agents. All of these factors create a rather confusing picture with regard to true ototoxic effects and may explain, to some extent, apparent disagreements within the literature.

Auditory dysfunctions resulting from ototoxic agents usually present as tinnitus, hearing loss and/or vertigo. Cochlear damage is usually an orderly progression of hair cell loss in the organ of Corti beginning in the basal turn and progressing toward the apex. There appears first to be a consistent destruction of the inner row of outer hair cells, progressing to the outer two rows, with preservation of the inner hair cells until overwhelming toxicity occurs and eventual total destruction of the organ of Corti. Injury to other cochlear structures has been demonstrated, including: changes in the stria vasularis, suprastrial portion of the spiral ligament, pericapillary tissues of the spiral prominence, outer sulcus cells, and Reissner's membrane. In addition, vestibular damage may occur, specifically in the Type I hair cells of the cristae ampullaris and in the utricle (*4, 5*). Auditory dysfunction resulting from ototoxic agents is almost always sensorineural. In most cases, this loss is bilateral and symmetric, although there are exceptions reported in the literature. Hearing loss caused by chemical or heavy metal toxicity may show brain stem or central pathology and is usually associated with a variety of other neurologic manifestations.

## Clinical Test Battery

Clinical assessment of auditory dysfunction follows an orderly progression of tests to identify the site of disorder. While the shape of the auditory function may give information regarding possible pathology or etiology, auditory tests are designed to give primary information as to site-of-lesion. For example, auditory tests may indicate that the primary source of pathology is in the cochlea. These results, however, give no indication as to type of pathology (i.e., hair cell damage, damage to stria vascularis, rupture of Reissner's membrane, etc.), nor do they give information regarding possible etiology, since many factors, including ototoxicity, can cause damage to the cochlea. As a point of major differentiation, auditory tests are designed to separate peripheral and central auditory disorders. The major point of demarcation between peripheral and central disorders is the synapse at the cochlear nucleus, between the first- and second-order neurons. With this definition, pathologies in the external ear, middle ear, inner ear, and auditory nerve would be considered peripheral disorders and pathologies in the brain stem and cortex would be considered central disorders. Other auditory tests are designed to help differentiate site-of-lesion within the peripheral or central auditory system. As defined, auditory dysfunction in the peripheral system might be expected to show the following characteristics: ipsilateral symptoms, usual loss of sensitivity, distortion present in cochlear and auditory nerve

disorders, and abnormal adaptation or fatigue in cochlear and auditory nerve disorders. Central auditory dysfunction might be characterized by contralateral symptoms, frequently normal sensitivity, and dysfunction in ability to transmit complex stimuli. Differences in characteristics of peripheral and central auditory dysfunctions have led to development of different auditory test batteries. In peripheral testing, pure tone stimuli can conveniently be used. Central testing, however, usually requires more subtle changes in stimuli and the use of complex stimuli (*6*).

The classical peripheral auditory test battery contains tests to differentiate among conductive, cochlear and retrocochlear hearing loss. In addition, tests are available to aid in differentiating sites-of-lesion within these three major areas. A complete description of auditory tests may be found in several standard audiology textbooks (*6-8*). A typical test battery might include the following tests.

## Pure Tone Thresholds (Air Conduction and Bone Conduction)

Pure tone air conduction testing is used to measure the sensitivity of the ear to different frequencies, when compared to normal hearing. Air conduction testing uses the entire auditory system [i.e., external ear, middle ear, inner ear, eighth cranial nerve (N VIIIth), and central nervous systems]. Pure tone bone conduction testing is used to measure the sensitivity of the ear to different frequencies when the external ear and middle ear have been by-passed and sound is transmitted directly to the inner ear, although this is an oversimplification. The difference between air and bone conduction scores is the first evidence of conductive or sensorineural hearing loss.

## Speech Reception Threshold (SRT)

SRT involves measurement of the sensitivity of ear to speech material. The speech materials generally used are spondee words (i.e., two syllable words with equal emphasis on each syllable, like baseball or airplane). The speech reception threshold should agree with the average pure tone air conduction results at 500, 1000 and 2000 Hz.

## Speech Discrimination (SD)

Speech discrimination measures the ability of a subject to transmit and understand complex stimuli (speech). Speech discrimination lists are presented at a level above threshold so that they can be heard without difficulty, usually 40 dB SL, and the patient's ability to discriminate is measured. The speech materials generally used are short, single syllable, phonetically balanced words.

## Alternate Binaural Loudness Balance (ABLB)

ABLB measures the presence or absence of loudness recruitment by having the subject balance the loudness of a standard tone in one ear with an alternating tone in the pathologic ear. The presence of loudness recruitment is measured by the growth of loudness in the pathologic ear. One contraindication of this test is that it cannot be used in bilaterally symmetrical hearing loss.

## Short Increment Sensitivity Index (SISI)

The SISI test measures the ability of a subject to detect a 1 dB change in intensity at a level 20 dB above threshold. This test can be used at any frequency in either ear, regardless of the asymmetry of the hearing loss. A positive SISI score (i.e., above 60%) is an indication of cochlear pathology. Several modifications have been made to the classic SISI procedure (*9*).

## Tone Decay (TD)

Tone decay measures the fatigue or adaptation of the auditory system to a constant stimuli. Tone decay is measured as the decay in decibels from threshold over a one minute period. A positive tone decay (i.e., greater than 25 dB) is an indication of N VIIIth disorder. Modifications to this original technique have been reported in the literature (*10-12*).

## Bekesy Tracings

The Bekesy tracings indicate threshold sensitivity measured on an automatic audiometer when the tones are pulsed and when they are continuous. Theoretically, the pathologic auditory system should show more adaptation to a continuous tone than to a pulsed tone. Particular patterns of tracings have been identified with cochlear pathology and with retrocochlear pathology. The automatic Bekesy audiometer is essentially under the control of the subject. The subject is instructed to press a button when he hears a tone and release the button when the tone disappears. In this way, the patient automatically traces his threshold for pulsed and continuous tones. Thus, the audiometer can be used in several different ways.

***Sweep Frequency.*** The audiometer automatically sweeps through frequencies from 100 Hz to 10,000 Hz, with the subject controlling the intensity. Pulse tones are used first, then continuous tones are plotted on the same audiogram, showing the amount of adaptation between pulsed and continuous tones (*13*).

***Fixed Frequency.*** The audiometer can be set for one particular frequency and threshold for pulsed and continuous tones are plotted as a function of time. The purpose is to look at the amount of adaptation occurring at one particular frequency (*13*).

***Backward Sweep.*** The audiometer can also be swept from 10,000 Hz to 100 Hz, showing whether the adaptation is a function of time or frequency (*14*).

***Most Comfortable Loudness.*** The subject is instructed to keep the tone at his most comfortable loudness, which makes this a suprathreshold test. This modification is based on the concept that abnormal adaptation first appears only at high intensities and eventually appears at lower levels, until it finally appears at threshold. Abnormal decay of a continuous tone at suprathreshold levels is an indication of N VIIIth pathology (*12*).

## Impedance

The study of impedance in the auditory system involves an analysis of the acceptance or rejection by this system of the flow of energy per unit of time. In other words, how much is the flow of energy impeded by this particular system? A system with high impedance rejects or reflects the majority of energy, while a system with low impedance accepts or absorbs most of the energy and reflects less. Normally, there are three components which combine to determine the impedance of a particular system: resistance, stiffness, and inertia or mass. In order to accomplish this clinically, a probe is placed in the external canal and sealed. The probe emits a low frequency tone (220 Hz), and a microphone in the probe measures the reflected sound from the tympanic membrane. The amount of sound reflected gives an indication of the integrity of the external and middle ears. Normally, four measures may be made—static compliance, tympanometry, acoustic reflex threshold and acoustic reflex decay.

***Static Compliance.*** Static compliance of the middle ear is a measure of mobility. Mass (inertia), resistance (friction) and stiffness (or its reciprocal compliance) work together in a complex manner to facilitate, or impede, motion of the middle ear system, as measured at the tympanic membrane (MT). Historically, static compliance has been termed acoustic impedance or absolute impedance, although the term compliance is a more descriptive term of what is actually measured. Static compliance denotes a single number representing the mobility of the middle ear system. Tympanometry is also a measure of compliance; however, this measure is made over numerous values as the MT moves in response to changes in air pressure and, thus, is a measure of dynamic compliance.

Static compliance of the middle ear system is measured by quantifying the sound energy reflected from the MT. When the middle ear system is stiff, more energy is reflected rather than absorbed or transmitted through the middle ear. Therefore, a stiff middle ear system is said to have low compliance or high resistance. A flaccid middle ear mechanism absorbs more energy and reflects less. Therefore, this system has high compliance or low resistance.

Static compliance can be measured in terms of equivalent volume of air in cubic centimeters or in acoustic ohms. This test requires two measurements: one measurement made with the MT in a position of low compliance by exerting an air pressure of +200 mm of water in the external ear relative to the middle ear; the second measurement is made with the MT in a position of maximum compliance (normally at 0 mm of water). Neither of these two measures has any significance when taken alone. However, by subtracting one measure from the other, the external ear canal volume is effectively cancelled, thus allowing a measurement value of the middle ear mechanism. The compliance of the normal middle ear system is influenced by many variables, including age and sex. In general, however, normal static compliance values range between 0.26 and 1.5 cc. A stiff middle ear system should demonstrate a compliance value less than 0.26 cc, while a flaccid middle ear system should have a compliance greater than 1.5 cc. The normal range of absolute impedance in acoustic ohms is approximately 600 to 3000 ohms. Absolute values below 600 ohms indicate a very compliant ear, while values above 3000 ohms indicate a resistive middle ear system.

***Tympanometry.*** Tympanometry is the measurement of eardrum compliance as the air pressure is altered in the external ear relative to the middle ear. These measurements are normally recorded on a graph which represents a compliance–air pressure function, called a tympanogram. A point of significance is that the MT is at maximum compliance when the air pressure in the middle ear is equal to that in the external ear. Tympanometry can provide an indirect measure of existing middle ear

pressure by identifying the air pressure in the external canal, where the eardrum shows its maximum compliance. Subjects who have intact MTs, with no middle ear pathology and adequate eustachian tube function, will show maximum compliance at atmospheric pressure or within ± 50 mm of atmospheric pressure. Subjects with intact MTs and poor eustachian tube function will show maximum compliance at negative air pressure values. Subjects with fluid in the middle ear will usually never reach a point of maximum compliance, to the maximum of the instrumentation, while those with a resistive type middle ear pathology will show very low compliance (high stiffness or resistance) at atmospheric pressure.

***Acoustic Reflex Threshold.*** The stapedial muscle contracts reflexively when the ear is stimulated with a sufficiently loud sound. In normal ears, the acoustic reflex can be elicited with stimulation at sensation levels of 70 to 95 dB. Contraction of the middle ear muscles decreases the compliance of the MT. This contraction occurs bilaterally. In the demonstration of the acoustic reflex, the sudden change in the relative compliance of the middle ear created by the muscle contractions is utilized. If the acoustic signal is sufficiently loud to elicit the bilateral acoustic reflex, the resulting contraction of the stapedius muscle in the probe ear will suddenly decrease the compliance at the MT synchronously with the presentation of the stimulus and this change in relative compliance can be observed as a sudden deflection in the balance meter. The acoustic reflex can be elicited by either contralateral stimulus presentation or ipsilateral stimulus presentation at approximately the same stimulus levels. Also, the reflex may be elicited with pure tone stimuli or with noise.

***Reflex Decay.*** Reflex decay is a truly remarkable phenomenon. In normal ears, contraction of the middle ear muscles to an auditory stimulus of 1000 Hz or lower can be maintained for up to 45 sec without obvious decay, fatigue or adaptation. In subjects with retrocochlear lesions and some cochlear lesions, the reflex appears normal when first turned on. When the acoustic stimulus is sustained, however, reflex amplitude declines and may eventually disappear. Klockoff and Anderson et al. (*15*, *16*) advocate the use of reflex decay as an indicator of VIIIth nerve lesions. These authors have reported a decay in the acoustic reflex for patients with VIIIth nerve pathology when a stimulus is presented at a reflex sensation level of 10 dB for 10 sec. When a stimulus is presented in this manner, the amplitude of the reflex decays to a level of 50% or less of the original amplitude in less than 10 seconds. The same results have been found in normal ears at 4000 Hz, and to a lesser degree at 2000 Hz. No decay is observed in normal ears at 500 and 1000 Hz, however.

## PI-PB Function

The PI-PB (performance versus intensity for phonetically balanced words) function test, a special use of speech discrimination, simply refers to the discrimination test given at several different intensities. In the case of cochlear pathology, the function should reach a plateau with increased intensity and remain there, while in VIIIth nerve pathology, the discrimination score becomes worse at high intensities (*17*).

## Central Auditory Dysfunction

Tests for central auditory dysfunction will not be discussed in this presentation. The reader is referred to several excellent texts describing these tests (*18*, *19*). The majority of tests used to identify central auditory dysfunction use complex stimuli like speech because changes in the central nervous system are usually subtle. In general, the speech material is changed in some way to reduce its redundancy and increase its ability to detect subtle changes. Tests have been designed which alter speech stimuli in many ways. These include: submerging the speech material in a background of noise; combining the speech material with a competing message of different speech material, either in the contralateral or ipsilateral ear; filtering the speech material to reduce its intelligibility; interrupting the speech material; accelerating the speech material; presenting different frequency bands of speech to different ears; and, presenting two different speech messages simultaneously to the two ears (dichotic speech). Some toxic substances effect the central nervous system more than the peripheral system. These include carbon monoxide and heavy metals. In these cases, complete clinical assessment would include central auditory tests.

## Brain Stem Tests

Several more recent auditory tests appear to show promise in enhancing the clinical assessment of auditory dysfunction. The most prominent appears to be the auditory brain stem evoked response (BSER, BER or ABR). This is one of several evoked responses that have been identified in the auditory system. At present, the following responses have been identified: auditory nerve response (latency 1-4 msec); brain stem or fast responses (latency 2-12 msec); middle responses (latency 12-50 msec);

sonomotor or muscle responses (latency 10-50 msec); slow auditory responses (latency 50-300 msec); and contingent negative variation (CNV) (latency 300-600 msec).

One of the more stable evoked potential measures is the brain stem response. This is a series of vertex-positive waves following a click or tone burst with latencies from 1 to 10 msec (*20-26*). To date, seven different waves have been identified and associated with various nuclei in the auditory brain stem system (*21, 27*). The most prominent and visible wave of this series occurs with a latency of approximately 6 msec and is called the V wave (*28-30*). It is assumed to originate in the inferior colliculus and is a good candidate for assessing the higher auditory frequency responses occurring in the basal turn of the cochlea. Other waves have been ascribed to the auditory nerve (wave I), cochlear nucleus (wave II), trapezoid body (wave III), lateral limniscus (wave IV) and medial geniculate (wave VI). The utility of the brain stem response as a clinical tool seems to be enhanced since the response is extremely stable, is not unusually affected by state of sleep, can be recorded from unconscious patients, shows a maturational development, can be recorded in a relatively short period of time and includes waves which are associated with various nuclei in the auditory system of the brain stem (*31, 32*).

The latencies of the various waves of the brain stem evoked response are extremely stable from test to test in the same subject and between subjects. In fact, the standard deviations around these mean latencies range from 0.1 to 0.3 msec (*33, 34*). In addition, the latency changes in a predictable manner as the intensity of the stimulus is increased or decreased. This latency versus intensity relationship makes the BSER a valuable tool in assessing hearing function of difficult to test subjects. For example, the mean latency of the V wave in normal hearing subjects at 70 dB above threshold is approximately 5.5 msec. As intensity is decreased to 10 dB above threshold, the latency increases to approximately 8.0 msec (*35*). Therefore, a measure of the latency of the V wave in a difficult to test subject would give some estimate of the subject's threshold for that particular stimulus. In addition, the latency of the various waves of the BSER, particularly the V wave, have been shown to exhibit recruitment (*35*). The presence of this phenomenon can give a good indication as to whether the pathology is of cochlear origin or not. It would appear that this technique holds considerable promise in evaluating performance with hearing aids in difficult to test subjects or subjects too young to respond in conventional manner. It would seem possible to predict the gain of the amplification system by measuring the latency of the V wave with and without amplification.

Another important aspect of the BSER is the neural transmission time. This is a measure of the latency between the I wave (i.e., primary auditory nerve) and the other waves, giving a measure of the travel time in the auditory brain stem system. This measure has proved valuable in assessing the site of pathologies in the brain stem, such as acoustic tumors, multiple sclerosis and brain stem vascular and neoplastic lesions. In very young children, this transmission time is also delayed, probably due to incomplete maturation or myelination of the central auditory pathways. This latency reaches normal adult values, however, around one year of age. Increased neural transmission time in older children or adults with normal latencies for the I wave may be an indication of lack of maturation, demyelinating pathologies or the presence of space occupying lesions, etc.

Another potentially important addition to the auditory test battery for clinical assessment is the use of high frequency audiometry. This measurement of auditory function in the frequencies from 8000 Hz to 20,000 Hz has potential significance to both clinical and research testing. Changes in high frequency auditory thresholds have been described as an early indication of ototoxic effects of certain drugs and noise exposure (*36-38*). This procedure has been used by several investigators; however, it is not yet completely accepted as a clinical measure because of difficulties in instrumentation (*39-41*). This procedure, with adequate and stable instrumentation, could serve as a valuable function in detecting early auditory dysfunction.

## Clinical Assessment

As previously stated, clinical assessment of auditory dysfunction usually includes a progressive battery of tests designed to indicate site-of-lesion. The first order of priority is to determine the amount of auditory dysfunction, if any, and the extent of this dysfunction. This is normally accomplished with pure tone thresholds for various frequencies, speech reception thresholds, and speech discrimination scores. Assuming an auditory dysfunction is present, the second order of priority is to determine if this dysfunction is conductive, sensorineural, mixed or central. A mixed-type hearing loss has components of both conductive and sensorineural origin, since these types of hearing losses are not mutually exclusive. This is normally accomplished with pure tone bone conduction thresholds and the impedance test battery. For a conductive hearing impairment,

pure tone bone conduction thresholds should be normal or near normal in the presence of abnormal pure tone air conduction thresholds. Speech reception thresholds should agree within ± 10 dB of average air conduction thresholds at 500, 1000 and 2000 Hz, and speech discrimination should be normal (90-100%). The impedance test battery should show abnormal static compliance (either resistive or compliant, depending on the nature of the hearing loss), tympanometry should be abnormal (showing a very compliant system, a very resistive system, negative pressure or the presence of middle ear effusions, depending on the site and type of dysfunction), acoustic reflex should be absent (depending on extent of conductive hearing loss), and acoustic reflex decay will obviously not be measured if the reflex is absent. Reports in the literature have indicated that a very mild conductive hearing loss will cause the absence of the acoustic reflex in the affected ear (*42*). At this point, a specific treatment protocol is indicated since the majority of conductive hearing losses can be medically or surgically treated. Also, there is no concrete evidence of conductive hearing losses resulting from ototoxicity.

Should auditory tests indicate a sensorineural hearing loss, the third order of priority is to delineate between cochlear and retrocochlear involvement. In the case of sensorineural hearing loss, pure tone air conduction thresholds should be abnormal, although they may vary from normal to total deafness in retrocochlear lesions. Pure tone bone conduction thresholds should agree reasonably well with air conduction, indicating no involvement of the external or middle ear. Speech reception threshold should agree with average pure tone thresholds and speech discrimination will usually be abnormal. In the case of cochlear involvement, speech discrimination will usually vary between 50 and 90%, while it is not unusual of retrocochlear involvement to show speech discrimination scores much lower than 50%. The impedance test battery will usually show specific types of patterns for cochlear and retrocochlear involvements. In both cases, static compliance and tympanometry should be normal since there is presumably no middle ear involvement. Cochlear involvement, usually accompanied by loudness recruitment, will normally show the presence of an acoustic reflex if the hearing loss does not exceed 75 to 85 dB. One indication of cochlear involvement is the presence of acoustic reflexes at abnormally low levels (*42*). If the reflex is present in cochlear hearing loss, it will normally show no significant decay. Retrocochlear lesions, on the other hand, will frequently present with an absence of reflex, even in the presence of sufficient hearing to elicit this reflex. If the reflex is present in retrocochlear lesions, it usually decays abnormally.

The use of the classic diagnostic test battery is also helpful in distinguishing between cochlear and retrocochlear lesions. Usually the tests which indicate an abnormal sensitivity to changes in loudness (ABLB, SISI, and to some extent the Bekesy) will show abnormal results in cochlear lesions. The ABLB will normally show the presence of loudness recruitment in the affected ear and the SISI will show a high percentage of small intensity increments detected (greater than 60%). In classical retrocochlear lesions, these tests are usually normal, since abnormal sensitivity to loudness changes is associated with cochlear pathology. Tests which show abnormal adaptation, such as the tone decay and to some extent the Bekesy, will show no abnormal tone decay (less than 25 dB) and a Type II Bekesy tracing. Retrocochlear lesions will normally indicate abnormal fatigue or adaptation on the tone decay (greater than 25 dB) and show Type III or Type IV Bekesy tracings. The performance versus intensity function for speech discrimination (PI-PB) also shows unique results for cochlear and retrocochlear lesions. For cochlear lesions, this function will normally reach a maximum discrimination and plateau or show a very slight decline. For retrocochlear lesions, however, this function will usually reach a maximum, although at a low discrimination level, and show a severe decline or roll-over as intensity is increased.

The brain stem evoked response has become one of the most reliable tests in differentiating cochlear and retrocochlear lesions. In conductive hearing losses, the results are often quite variable, since it may be difficult to present stimuli at sufficient levels to elicit adequate responses. In cochlear lesions, especially those exhibiting loudness recruitment, BSER results are usually normal and may even show a decreased latency when compared to the level of stimulation. In retrocochlear lesions, the BSER usually indicates abnormal latency measures, especially for waves III, IV and V. This test is obviously useful in indicating other types of lesions in the brain stem which might alter amplitude of response or latency of response. These may include space occupying lesions and demyelinating lesions. Table 1 shows the relationship between various auditory tests used in clinical assessment and their expected results in conductive, cochlear, and retrocochlear pathologies.

As indicated earlier, the majority of ototoxic substances or agents have their direct effect on various parts of the cochlea, with the noted exceptions. While clinical assessment cannot differentiate between various pathologies or etiologies affecting

**Table 1. Hearing tests used in clinical assessment and expected results for conductive, cochlear and retrocochlear lesions.**

| | Type of hearing loss | | |
|---|---|---|---|
| | Conductive | Cochlear | Retrocochlear |
| Pure tone thresholds | | | |
| Air conduction | Abnormal | Abnormal | Variable |
| Bone conduction | Normal | Abnormal | Variable |
| Speech reception threshold | Abnormal | Abnormal | Variable |
| Speech discrimination | Normal | Abnormal | Abnormal |
| Impedance battery | | | |
| Static compliance | Abnormal | Normal | Normal |
| Tympanometry | Abnormal | Normal | Normal |
| Reflex threshold | Absent | (?) Abnormal | Absent/Decay |
| Reflex decay | N/A | Normal/Absent | Absent/Abnormal |
| *Diagnostic battery* | | | |
| ABLB | Normal | Abnormal | Normal |
| SISI | Normal | Abnormal | Normal |
| Tone decay | Normal | Normal | Abnormal |
| Bekesy | Type I | Type II | Type III or IV |
| PI-PB | No rollover | Plateau | Rollover |
| Brain stem evoked response | Variable | Normal/Variable | Abnormal |

the cochlea, results should indicate cochlear pathology in the presence of ototoxic substances or agents. The shape of the audiometric function frequently can give an indication of toxic damage to the inner ear. Noise exposure, for example, usually has a characteristic audiogram with the greatest loss at 3000, 4000 or 6000 Hz, while ototoxicity from drugs or chemicals shows a progressive hearing loss as a function of frequency, frequently severe in nature. This hearing loss is usually accompanied by tinnitus and occasionally by vertigo.

In clinical assessment of auditory dysfunction, including that caused by ototoxicity, several points should be made. In this section, descriptions such as frequently, usually and normally are used repeatedly. This has not resulted from lack of vocabulary, but because of the variability in auditory tests. Review of the pertinent literature indicates that any single auditory test, taken alone, shows the classic result in 60–90% of cases (*6, 43-45*). This means that a relatively high percentage of subjects (10-40%) may show retrocochlear signs on some tests with cochlear lesions, or, cochlear signs in the presence of retrocochlear lesions. In addition, the nature of the lesion itself may cause damage in more than one anatomical area. An acoustic tumor, for example, which should indicate a retrocochlear lesion, may also compromise the blood supply to the cochlea, causing cochlear damage. In this case, the test results would be quite variable and show indications on various tests of both cochlear and retrocochlear lesions. The first point, therefore, is that the entire test battery should be considered in the assessment with less weight to the results of a single test. The percentage of false positive and false negative results drops significantly when expected results are found on two, three or four of the tests in the battery. The second point is that test results should be interpreted in conjunction with a detailed case history. While an auditory test battery may give an indication as to the site of the lesion, the case history and other pertinent data may shed light on the possible etiology.

The third major point in clinical assessment of auditory dysfunction, particularly in the case of ototoxicity, is the development of adequate testing protocols. Toxic effects on the human auditory system are quite variable and the presence and extent of damage depends on many parameters. Toxic effects may occur immediately, as in the case of many diuretics, occur within days, with various drugs and chemicals, or occur over years, in the case of heavy metal toxicity and noise exposure. In addition, decrease in auditory function may continue for months after the toxic substance has been removed. Therefore, hearing assessment to detect changes in auditory sensitivity should be on a regular basis, depending on the substance or agent involved. In the case of aminoglycosides, diuretics, certain other antibiotics, and antineoplastics, testing should probably occur on a weekly basis while the subject is on the drug and monthly, up to six months, after cessation of the drug. In the case of analgesics and antipyretics, monthly to quarterly testing is probably adequate. Exposure to noise or heavy metal toxicity may require annual testing, although testing for heavy metal toxicity may depend on the blood levels of the heavy metal. It is also obvious that pre-exposure assessment would be ideal, to separate changes in auditory function attrib-

uted to the ototoxic agent from pre-existing auditory dysfunction and to serve as a baseline for comparison of changes in auditory function. However, in many cases of life-threatening illness or infection, documented decreases in auditory function resulting from the therapy may be purely academic.

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