Auditory neuropathy: What is it and what can we do about it?

Linda J. Hood, PhD

The Hearing Journal
Volume 51, Number 8, August, 1998
Reprinted with permission

1. What is auditory neuropathy?

Auditory neuropathy is a term presently used to describe a condition, found in some patients ranging in age from infants to adults, in which the patient displays auditory characteristics consistent with normal outer hair cell function and abnormal neural function at the level of the VIIIth (vestibulo-cochlear) nerve. These characteristics are observed on clinical audiologic tests as normal otoacoustic emissions (OAEs) in the presence of an absent or severely abnormal auditory brainstem response (ABR).

These patients are distinguished from patients with space-occupying lesions, such as VIIIth nerve tumors, or multiple sclerosis, in that radiological evaluation yields normal results and even the most peripheral responses from the VIIIth nerve are absent. Patients with auditory neuropathy require a different management approach to their auditory and communication problems from approaches used with patients with usual peripheral hearing losses.

2. Do patients with auditory neuropathy typically have other neural disorders?

Not all do, but the majority of patients have either overt or subtle neuropathies outside of the auditory system. Some patients will report symptoms of other non-auditory peripheral neuropathies, while neurologic dysfunction in other patients is revealed only upon clinical neurological examination. Some patients appear to have only an auditory abnormality.

Among the neurologic abnormalities identified in patients with auditory neuropathy are hereditary motor sensory neuropathy (HMSN, Charcot-Marie-Tooth syndrome), Friedreich's ataxia, gait ataxia, loss of deep tendon reflexes, and motor system disturbances. Most patients identified who are old enough to provide subjective reports complain first of hearing difficulty1.

3. Is auditory neuropathy a "new" hearing disorder?

No. What is new is our ability to clinically identify the disorder and distinguish it from other problems. That has become possible primarily because of the broader clinical use of otoacoustic emissions in recent years. OAE testing allows identification of those individuals with normal outer hair cell function despite showing abnormal ABRs.

Several past articles (e.g., Worthington and Peters, 1980; Kraus et al., 1984) presented the dilemma of patients with absent ABRs who were later found to have auditory function. A number of those patients may have been identified as auditory neuropathy, had OAE measurement been clinically at that time.

More recently, with the availability of OAE testing as well as evoked potential data, several studies have reported the paradoxical absence of ABRs in the presence of otoacoustic emissions1 (Starr et al., 1991; Berlin et al., 1993; Gravel and Stapells, 1993; Gorga et al., 1995; Sininger et al., 1995).

Some patients with auditory neuropathy appear, based on history and initial behavioral testing, to fit into the category of "central auditory processing disorder". However, evaluation of such patients with physiological measures sensitive to auditory nerve/brainstem disorders (i.e., OAEs and ABR) shows a more peripheral site consistent with auditory neuropathy. There also may be some hearing-impaired children and adults with previously undocumented normal outer hair responses who are being managed as having severe/profound hearing loss. While the incidence of this circumstance is unknown, persons who show no progress or perform poorly with amplification may fall into this category and be candidates for testing with OAEs (Berlin et al., 1996).

4. Are there different etiologies of auditory neuropathy?

The characteristics of auditory neuropathy most likely reflect more than a single etiology and thus the disorder(s) may more accurately be described as auditory neuropathies. However, while various etiologies of auditory neuropathy may exist, patients of all ages show a cohesive set of auditory symptoms. The pattern of normal outer hair cell function combined with abnormal neural responses shown by the ABR places the site of auditory neuropathy to the area including the inner hair cells, connections between the inner hair cells and the cochlear branch of the VIIIth cranial nerve, the VIIIth nerve itself, and perhaps auditory pathways of the brainstem.

Possible sites of auditory neuropathy include the inner hair cells, the tectorial membrane, the synaptic juncture between the inner hair cells, auditory neurons in the spiral ganglion, the VIIIth nerve fibers, or any compbination (Starr et al., 1996; Berlin et al., 1998). Neural problems may be axonal or demyelinating. Afferent as well as efferent pathways may be involved.

The problem might also be related to a biochemical abnormality involving neurotransmitter release. The specific sites and mechanisms of auditory neuropathy have yet to be determined.

5. Which clinical auditory tests are most sensitive to auditory neuropathy?

Since auditory neuropathy is characterized by normal outer hair cell function and abnormal function in the region of the inner hair cells and/or auditory nerve, the appropriate auditory tests are those sensitive to cochlear and auditory nerve function.

Outer hair cell function can be evaluated by measuring otoacoustic emissions and cochlear microphonics. Clinical tests that are specifically sensitive to auditory nerve dysfunction are middle ear muscle reflexes (ipsilateral and contralateral), auditory brainstem response, masking level difference, efferent suppression of otoacoustic emissions, and to a limited extent, word recognition with an ipsilateral competing noise or message.

Of the above measures, otoacoustic emissions and the auditory brainstem response, when used together, offer insight into preneural as well as neural function in the auditory system and thus may form the most sensitive combination.

6. Can auditory neuropathy be distinguished by testing only pure-tone thresholds and speech recognition?

Pure-tone thresholds and speech recognition scores appear the least sensitive of the above-mentioned audiologic tests sensitive to auditory neuropathy. Pure-tone thresholds are quite variable in auditory neuropathy patients and can range from normal to severe or profound hearing loss ranges. Some patients show rising or unusual configurations and threshold responses may or may not be symmetric between ears. The variability in pure tone threshold patterns limits the utility of pure-tone testing to distinguish auditory neuropathy. If pure-tone thresholds and otoacoustic emissions are compared, then disagreement between the results of the two tests may provide a clue to the presence of a retrocochlear disorder that warrants further testing.

In many but not all patients with auditory neuropathy, word recognition in quiet is poorer than one would predict from the pure-tone average. In eight patients with auditory neuropathy described by Starr et al. (1996), word recognition in 12 of 16 ears was poorer than would be predicted using the norms reported by Yellin et al. (1989). Furthermore, our experience is that those patients who show some word recognition ability in quiet have great difficulty understanding speech, even sentences, when there is even a small amount of background noise. However, results again are variable and speech understanding is similarly poor with other types of retrocochlear disorders.

7. What are the results of other auditory tests in patients with auditory neuropathy?

Cochlear responses that involve outer hair cell function, which include otoacoustic emissions and cochlear microphonics, are normal. Responses that require intact auditory nerve and/or brainstem pathways, such as the middle-ear muscle reflex (MEMR), the auditory brainstem response (ABR), masking level difference (MLD), and efferent suppression of otoacoustic emissions, are abnormal.

Table 1 summarizes the expected results of standard baseline auditory tests, otoacoustic emissions, and measures sensitive to auditory nerve/brainstem disorders.

Efferent suppression of otoacoustic emissions involves the reduction in amplitude or change in phase of emissions resulting from addition of another stimulus (Collet et al., 1990; Berlin et al., 1995; Hood et al., 1996). Auditory neuropathy patients demonstrate a lack of suppression of otoacoustic emissions under any circumstances (Berlin et al., 1996), which may reflect efferent pathway dysfunction and/or a compromise of access to the efferent system resulting in a lack of efferent suppression of OAEs.

Middle latency responses are generally abnormal while late potentials (e.g., N1-P2, P300), where longer duration stimuli can be used, may be present.

Table 1. Expected test results in auditory neuropathy patients.

Pure tone thresholds:	Normal to severe/profound hearing loss (Any configuration; can be asymmetric)

Speech recognition in quiet:	Variable; slightly reduced to greatly reduced
Otoacoustic emissions:	Normal
Middle ear muscle reflexes:	Ipsilateral Absent Contralateral Absent Non-Acoustic Present
Cochlear microphonic:	Present (Inverts with stimulus polarity reversal)
ABR:	Absent (or severely abnormal)
Masking Level Difference (MLD):	No MLD (i.e., 0 dB)
Efferent Suppression of TEOAEs:	No suppression
Speech recognition in noise:	Generally poor

8. Do OAEs and ABRs test hearing?

That's an important question. Neither OAEs nor ABRs are direct tests of hearing! OAEs, which are used to evaluate outer hair cell function, represent preneural phenomena related to mechanical processes in the cochlea. The presence of OAEs in an otherwise intact auditory system is most commonly consistent with normal or near-normal peripheral hearing sensitivity. Presence of an ABR to low-intensity stimuli also is most typically consistent with good hearing sensitivity.

The ABR is actually a test of neural synchrony and its use in evaluating hearing is dependent upon the ability of neurons to maintain precise timing and respond synchronously to external stimuli. Presence of an ABR to low-intensity stimuli is most typically consistent with good hearing sensitivity. If there is a loss of timing or onset sensitive neural units, demyelination, or a loss of cues for temporal onset of signals, then responses may be desynchronized, compromising the ability to record an ABR (Starr et al., 1991; Berlin et al./ 1996).

Thus, while neither OAEs or the ABR is really hearing tests, under appropriate , both can give us information about function of the peripheral auditory system. This is especially useful in cases when behavioral testing is impossible. Both OAEs and ABRs are very useful in the early identification of peripheral hearing loss, as well as auditory neuropathy, and allow initiation of appropriate clinical intervention prior to behavioral confirmation of hearing sensitivity.

9. How can otoacoustic emissions be normal and yet patient reports hearing difficulty?

Again, it is important to remember that otoacoustic emissions relate to the mechanical function of the outer hair cell system. While mechanical cochlear function is important to the normal function of the cochlea, it is insufficient by itself for hearing to occur. Inner hair cell function is also necessary to activate the sensory processes that transmit incoming information to the auditory nerve and central auditory system.

10. If absence of the ABR is characteristic of auditory neuropathy patients, then why are "waves" sometimes present in ABR recordings?

The cochlea generates electrical responses which are most commonly measured using electrocochleography (ECochG). One of the cochlear potentials is the cochlear microphonic, an electrical response occurring just prior to the ABR. This response is generally small in surface-recorded responses (e.g., ABR), but is more evident when insert earphones are used and the stimulus artifact is separated in time from the biological response. In patients without an ABR, the cochlear microphonic may be larger and in infants the cochlear microphonic may even continue over several milliseconds (Berlin et al., 1998).

11. How can I distinguish the cochlear microphonic from the ABR?

Cochlear microphonics follow the characteristics of the external stimulus. The direction of the cochlear microphonic will reverse with changes in polarity of the stimulus. Comparison of responses obtained with positive (condensation) and negative (rarefaction) polarity stimuli shows an inversion of the peaks of the cochlear microphonic waveform. Neural responses such as the ABR may show very slight latency shifts with polarity changes but they will not invert. Thus, cochlear and neural components can be distinguished based on whether or not the peaks reverse with the stimulus. Use of alternating polarity stimuli is not helpful since the cochlear microphonic will cancel and not be visible in the averaged response.

Another difference between cochlear and neural responses is the effect of intensity on response latency. ABR waves increase in latency and decrease in amplitude with stimulus intensity decreases. In contrast, the cochlear microphonic does NOT increase in latency as the stimulus intensity decreases. Thus comparison of response latency at various intensities can be used to distinguish cochlear from neural responses.

A third difference between cochlear and neural responses relates to the effects of masking on the response. Cochlear microphonics do not change in latency with masking presented to the same ear while the compound action potential (CAP; Wave I of the ABR) shows amplitude reduction and latency increases during simultaneous masking to the same ear (Dallos, 1973). For an in-depth discussion of this topic and examples of responses showing these characteristics, the reader is referred to Berlin et al. (1998).

12. Are there certain risk factors for auditory neuropathy?

Currently, specific risk factors for auditory neuropathy are not clearly understood. As more patients are identified and reported, patterns may become more evident. A number of infants with auditory neuropathy have a history of major neonatal illnesses including hyperbilirubinemia and other risk factors (Stein et al., 1997; Deltenre et al., 1997; Berlin et al., 1998). Auditory neuropathy is also associated with other non-auditory peripheral neuropathies. Siblings have been identified with auditory neuropathy, suggesting underlying genetic factors as well.

13. Can auditory neuropathy be unilateral?

While most cases of auditory neuropathy identified to date are bilateral (though often asymmetric), a few patients have been reported with unilateral auditory neuropathy. These patients display normal auditory function in one ear and the pattern of results consistent with auditory neuropathy in the other ear. Functionally, patients with unilateral auditory neuropathy appear similar to patients with other types of unilateral hearing loss. At present, the management approach in these cases is similar to that used in other more common types of unilateral hearing loss, such as

directing speech to the normal ear and maximizing the signal-to-noise ratio.

14. Is the hearing loss progressive or does hearing ability ever fluctuate?

Progression in hearing thresholds is observed in some patients, though it is not a characteristic of all patients. We have noted progressive hearing loss particularly in some of our patients with hereditary motor sensory neuropathy (Charcot-Marie-Tooth disease) (Berlin et al., 1994). Other patients demonstrate stable threshold responses over many years. So, progressive hearing loss is not necessarily a characteristic of auditory neuropathy. Whether or not progression occurs may depend on the underlying etiology.

Some cases of fluctuating hearing loss associated with auditory neuropathy have been reported. Starr and Sininger (personal communication) are following two siblings who show symptoms of auditory neuropathy accompanying fever with normal auditory function between periods of increased temperature. Gorga et al. (1995) reported a patient with fluctuations in hearing sensitivity, felt to be related to an auto-immune disorder, where OAEs remained intact while the ABR was affected.

15. How is auditory neuropathy different than other retrocochlear or central auditory disorders?

While any disorder of the auditory neural pathways from to VIIIth nerve to the cortex might be defined as an auditory neuropathy, the current use of the term relates specifically to more peripheral portions of the auditory pathways in the area between the outer hair cells and brainstem. Auditory neuropathy differs from other disorders affecting the VIIIth nerve, such as a vestibular Schwannoma, in that there is no space occupying lesion and radiological findings are normal.

While patients may display characteristics of central auditory processing problems (e.g., inattention, missing some information, inconsistencies in responses, etc.), peripheral measures such as middle-ear muscle reflexes and the ABR are abnormal in auditory neuropathy while function at the brainstem level is more often normal in patients with classic central auditory processing disorders.

16. Are there situations where auditory neuropathy could be misdiagnosed?

Yes. Identification of auditory neuropathy presents a particular diagnostic problem in infants and children where the incidence of otitis media is higher than in older children and adults. If middle ear problems prevent evaluation of otoacoustic emissions, then it may be possible to evaluate outer hair cell function using cochlear microphonic measurement since this response appears less vulnerable to mild middle-ear problems than are OAEs (Berlin et al., 1998). In addition to the complicating factor of middle ear problems, it is conceivable that a patient could have a co-existing peripheral hearing loss which could affect the ability to measure otoacoustic emissions.

As an additional technical/procedural note, we always complete OAE testing prior to completing ABR testing in patients who are sedated. During deep sleep, the middle ear may develop positive pressure over time which could alter middle ear mechanics and reduce otoacoustic emission amplitude.

17. Do patients with auditory neuropathy have trouble communicating in everyday situations?

Yes. Our adult patients with auditory neuropathy display some awareness of sound around them, but generally are unable to discriminate speech sounds

sufficiently to understand speech. In some patients, this difficulty may be related to neural timing problems (e.g., Starr et al., 1991) that may limit the ability to follow rapid transitions of normal speech. Patients with either some residual hearing ability or later-onset progressive auditory neuropathies tend to rely heavily on lipreading to supplement whatever auditory information is available to them. While reception of speech is difficult, patients generally have normal sounding speech and vocal qualities, suggesting an intact monitoring system.

A major dilemma involves the development of communication abilities in infants and young children identified with auditory neuropathy. These children do not have the advantage of accurate auditory information to help them discriminate and learn appropriate speech and language patterns. Since speech and language develop largely through repetition of heard patterns, active intervention, as discussed below, is critical.

18. What recommendations can I make about appropriate management for these patients?

In infants and young children who have not developed speech and language through auditory channels, the most important consideration is facilitation of the development of language. Since input to the auditory system and processing of auditory stimuli is most likely compromised, alternative input methods may be most helpful.

We recommend use of a visual communication system that follows the grammatical structure of English such as signed English or cued speech (Berlin et al., 1998). The choice of method is usually related to local resources. The goal is to expose children to conversation as it normally occurs in the home and in daily activities by allowing them to "eavesdrop" on all conversations among family members. The selection of a visual communication method that follows English, rather than of American Sign Language, is based on the possibility that auditory function may improve. If the ability to utilize auditory information does improve, then spoken language can be assimilated into a language system that already follows English language structure.

In patients who have already developed spoken language, the goal is to maximize the available auditory information and provide supplementary cues to speechreading. Since some patients are able to understand some speech in quiet surroundings but generally show much difficulty in background noise, enhancing the signal-to-noise ratio may be helpful. Training to improve speechreading skills may also be beneficial.

In addition to auditory and speech-language considerations, patients should be evaluated by a neurologist or pediatric neurologist to identify and manage any neurological abnormalities. And, of course, close collaboration with the patient's otolaryngologist, pediatrician, and/or general physician are important components of comprehensive care of these patients.

19. Do hearing aids, FM systems, or cochlear implants help?

Until the underlying etiologies of auditory neuropathy are better understood, the appropriateness of using hearing aids and cochlear implants is difficult to determine. Adult patients with auditory neuropathy generally report that hearing aids are of little or no benefit. Some patients find FM systems helpful in situations where enhancement of signal-to-noise ratios allow use of residual hearing for speech understanding.

Hearing aids are being tried to a limited extent in some children with auditory neuropathy. If the clinician or a parent strongly wishes to try a hearing aid to enhance awareness of sound, then we recommend high

quality, low gain, wide dynamic range compression hearing aids. This approach is intended to minimize any deleterious effects of amplification on otoacoustic emissions until the importance of maintaining otoacoustic emissions in these patients is better understood. Use of more powerful hearing aids for limited time periods or in one ear only is being tried by some centers where trial with stronger amplification is desired. If hearing aids are tried, frequent monitoring of otoacoustic emissions for either temporary or permanent effects on OAEs should be part of the management program.

The potential benefit of cochlear implants is still an open question. If the underlying etiology of the auditory neuropathy in a particular patient is cochlear in origin (i.e., the inner hair cells and/or the hair cell-nerve juncture) and neural function is intact, then a cochlear implant may be potentially beneficial. In cases where the underlying etiology involves neural function, then the anticipated results with a cochlear implant may be less predictable based on current experience.

Unfortunately, we do not yet have a way to determine the specific involvement of either cochlear (inner hair cell) or neural sites in individual patients. Until the underlying etiology of a patient's auditory neuropathy can be determined and performance with cochlear implants or hearing aids is better understood, we take a cautious approach to their use in auditory neuropathy patients.

20. Do patients with auditory neuropathy ever get better ..... or worse?

In adult patients, hearing generally seems to either remain stable, show fluctuation (as in cases of temperature sensitivity or auto-immune disorders), or progressively worsen (as in some patients with HMSN).

In infants, both decline in hearing and improvements in auditory function have been observed (e.g., Berlin et al., 1998; Stein et al., 1996). Some newborns who display normal OAEs and absent ABRs may show improvement if neuromaturation is the underlying problem. In these cases, as the neural system matures, the ABR may improve. Other cases have been reported where auditory function, reflected in development of speech and language, develops over a longer period of time. Still other infants and young children have shown a progressive decrease in auditory responsiveness.

Until the etiologies underlying auditory neuropathy can be identified and distinguished clinically, it will be impossible to make accurate predictions about changes in auditory ability. For now, changes - either improvement or decline - can be ascertained only through long-term follow-up.

Acknowledgments:

Support for studies related to auditory neuropathy research at Kresge Hearing Research Laboratory has been provided by NIH National Institute on Deafness and Other Communication Disorders, Kam's Fund for Hearing Research, American Hearing Research Foundation, National Organization for Hearing Research, Deafness Research Foundation, Kleberg Foundation, Oberkotter Foundation, and Louisiana Lions Eye Foundation.

References:

Berlin CI, Bordelon J, St. John P, Wilensky D, Hurley A, Kluka E, Hood LJ. 1998. Reversing click polarity may uncover auditory neuropathy in infants. *Ear and Hearing* 19:37-47.

Berlin CI, Hood LJ, Cecola RP, Jackson DF and Szabo P. 1993a. Does

Type I afferent neuron dysfunction reveal itself through lack of efferent suppression? *Hearing Research* 65:40-50.

Berlin CI, Hood LJ, Hurley A, Wen H, Kemp DT. 1995. Binaural noise suppresses click-evoked otoacoustic emissions more than ipsilateral or contralateral noise. *Hearing Research* 87:96-103.

Berlin CI, Hood LJ, Hurley A, Wen H. 1996. Hearing aids: Only for hearing-impaired patients with abnormal otoacoustic emissions. Chapter in Berlin CI (Ed), *Hair Cells and Hearing Aids*. San Diego: Singular Publishing Group, Inc.

Collet L, Kemp DT, Veuillet E, Duclaux R, Moulin A, Morgon A. 1990. Effect of contralateral auditory stimuli on active cochlear micro-mechanical properties in human subjects. Hearing Research 43:251-262.

Dallos P. 1973. *The Auditory Periphery*. New York: Academic Press, Inc.

Deltenre P, Mansbach AL, Bozet C, Clercx A, Hecox KE. 1997. Auditory neuropathy: A report on three cases with early onsets and major neonatal illnesses. *Electroencephalography and Clinical Neurophysiology* 104:17-22.

Gorga MP, Stelmachowicz PG, Barlow SM, Brookhouser PE. 1995. Case of recurrent, reversible, sudden sensorineural hearing loss in a child. *Journal of the American Academy of Audiology* 6:163-172.

Gravel JS, Stapells DR. 1993. Behavioral, electrophysiologic and otoacoustic measures fro a child with auditory processing dysfunction: Case report. *Journal of the American Academy of Audiology* 4:412-419.

Hood LJ, Berlin CI, Hurley A, Cecola RP, Bell B. 1996. Contralateral suppression of click-evoked otoacoustic emissions: Intensity effects. *Hearing Research* 101:113-118.

Kraus N, àzdamar à, Stein L, Reed N. 1984. Absent auditory brainstem response: Peripheral hearing loss or brain stem dysfunction? *Laryngoscope* 94: 400-406.

Sininger YS, Hood LJ, Starr A, Berlin CI, Picton TW. 1995. Hearing loss due to auditory neuropathy. *Audiology Today* 7:10-13.

Starr A, McPherson D, Patterson J, Don M, Luxford W, Shannon R, Sininger Y, Tonokawa L, Waring M. 1991. Absence of both auditory evoked potentials and auditory percepts depending on timing cues. *Brain* 114:1157-1180.

Starr A, Picton TW, Sininger YS, Hood LJ, Berlin CI. 1996. Auditory neuropathy. *Brain* 119:741-753.

Stein LK, Tremblay K, Pasternak J, Banerjee S, Lindemann K. 1996. Auditory brainstem neuropathy and elevated bilirubin levels. *Seminars in Hearing* 17, 197-213.

Worthington DW, Peters JF. 1980. Quantifiable hearing and no ABR: Paradox or error? *Ear and Hearing* 1:281-285.

Yellin MW, Jerger J, Fifer RC. 1989. Norms for disproportionate loss in speech intelligibility. *Ear and Hearing* 10:231-234.

Berlin CI, Hood LJ, Hurley A, Wen H: Contralateral suppression of otoacoustic emissions: An index of the function of the medial olivocochlear system. *Otolaryngol-Head Neck Surg* 1994;100:3-21.

Last update March 31, 2000 by Richard P. Bobbin, PhD

While every efffort is made to ensure that this information is up-to-date and accurate, the statements found on this page are for informational purposes only

Department Home

contact webmaster I disclaimer I privacy policy