Bone-Conduction ABR: Clinically Feasible And Clinically Valuable

BY JAMES W. HALL III

More than 20 years has passed since Jewett and Williston's classic publication on auditory brainstem response appeared in the journal Brain. *I remember the early ABR days of the mid-1970s when often only "special people" from the clinical staff were allowed to conduct the ABR measurements; the usual rationale was that the procedure was "just too difficult" for the mere mortal clinician.*

Times have changed! Today, ABR testing is a routine audiologic procedure, and proficiency in ABR measurements is a requirement for audiology graduate students. Although the field of auditory electrophysiology continues to expand, the ABR remains the test of choice for several clinical applications, and there continues to be new ideas and insights concerning test procedures and techniques. This month, Page Ten *will address some important issues concerning bone-conduction ABR testing.*

Who better to write an article on the ABR than someone who routinely performs this testing in the clinic, teaches ABR procedures to students and other professionals, lectures internationally, and has conducted research on this topic for the past two decades? We found such a person in James W. (Jay) Hall III, PhD, Associate Professor and Director of Audiology, Division of Hearing and Speech Sciences and Department of Otolaryngology, School of Medicine, Vanderbilt University.

Dr. Hall is no stranger to Journal *readers. He was the guest editor for the well-thumbed special issue on otoacoustic emissions published in November 1992. While Jay is perhaps best known for "The Book," weighing in at 3.7 pounds, those close to him know him as a savvy, yet inquisitive clinician who has never lost his enthusiasm for diagnostic audiology. We're fortunate that he agreed to take some time away from one of his few weekends at home to prepare this excellent "hands-on" piece for* Page Ten.

~Gus Mueller
Editor, Page Ten

Click stimuli presented by *air-conduction* are almost always entirely adequate, in fact optimal, for neurodiagnostic applications of the auditory brainstem response (ABR). However, when ABR is used to estimate hearing sensitivity in infants, very young children, and other patients who are difficult to test with conventional behavioral audiometric techniques, *bone-conduction* click stimulation may contribute additional clinically valuable information.

My experience with bone-conduction ABR dates back to 1982. I had just assumed duties as director of audiology at the University of Texas Medical School in Houston. We had immediately purchased two evoked response systems, and soon were providing a variety of auditory evoked response services in the audiologic clinic, the newborn nurseries, the intensive care units, and the operating rooms of the University Hospital.

The first chairman of the newly formed Department of Otolaryngology at the medical school was Robert Jahrsdoerfer, MD, an otologist with a worldwide reputation for expertise in the surgical repair of congenital aural atresia. Over lunch one day, Bob explained his protocol for assessment and management of children with aural atresia. Then he asked if it was possible somehow to assess the sensorineural hearing integrity of each ear in patients with bilateral congenital atresia, even patients with the classic masking dilemma and very young children who could not be tested behaviorally.

He emphasized that information on bone-conduction hearing for each ear was critical for otologic management of these patients. That is, there was no value in performing surgical repair of congenital atresia on a dead ear, and it was not appropriate to attempt surgical repair on an only hearing ear.

This conversation led to my conducting air- and bone-conduction ABR measurement on more than 100 patients with congenital atresia, along with hundreds of other children with myriad middle ear disorders, at the University of Texas and, later, at the Vanderbilt University Medical Center.

If bone-conduction ABR is so useful clinically, why don't more audiologists routinely apply the technique? At least four factors probably contribute to the clinical underuse of bone-conduction ABR:

First, test protocols that are appropriate for air-conduction stimuli will not produce quality bone-conduction ABR recordings. It is necessary to modify these test protocols to record reliable bone-conduction ABR waveforms.

Second, the strategies for analyzing and interpreting ABR waveforms and latency intensity functions with bone-conduction stimuli are distinctly different from the strategies used with air-conduction stimuli.

Third, most clinicians probably attempt to record bone-conduction ABRs initially from adult patients, even though it is much easier to obtain quality bone-conduction ABR recordings from infants and children.

Finally, it is generally assumed, incorrectly, that the same bothersome masking problems associated with bone-conduction pure-tone audiometry are also encountered in bone-conduction ABR measurement.

In this article, I will briefly address each of these factors and then offer practical guidelines for successful clinical application of bone-conduction ABR.

How do test protocols differ for air- versus bone-conduction ABR measurement?

Examples of test protocols used for both modes of stimulation are displayed in Table 1. Both protocols can be performed with commercially available evoked response systems. The type and location of

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the transducer are, of course, major distinctions between the two protocols. Other parameters that usually differ for air- versus bone-conduction stimulation are polarity and maximum intensity level.

For most patients, rarefaction polarity stimuli produce the clearest ABR.[1] When you present rarefaction, or condensation, polarity stimuli via insert-type earphones, you can minimize stimulus artifact by extending the acoustic tubing and locating the transducer box as far as possible from the recording electrodes. When you conduct bone-conduction stimulation, the transducer (bone oscillator) on the mastoid is relatively close to the recording electrode (on the earlobe). Therefore, a single polarity stimulus will often produce excessive measurement artifact.

To reduce this artifact, you must use an alternating polarity stimulus. Maximum effective intensity level for the bone oscillator on the mastoid is only 50 dB nHL to 55 dB nHL, compared to a maximum intensity level of 90 dB nHL to 95 dB nHL for an air-conduction stimulus. Because the maximum bone-conduction stimulus intensity level is reduced, the "dynamic range" for stimulus intensity is limited. Even for a patient with hearing threshold levels of 15 dB HL to 20 dB HL, the range of bone-conduction stimulus intensity that is effective in eliciting an ABR is on the order of 30 dB or less. Clearly, if a patient, such as a young child, has hearing threshold levels of 0 dB or even better, then the effective stimulus intensity level (e.g., sensation level) may exceed 50 dB to 55 dB, and the bone-conduction response will be more robust.

As noted below, detection of a reliable ABR Wave I is important for determining ear specificity of the bone-conduction ABR. Manipulations of stimulus parameters that enhance Wave I amplitude, such as reducing the rate of stimulation, are often useful in bone-conduction ABR measurement.[1]

A relatively low cutoff for the high-pass filter, such as 30 Hz, is an important acquisition parameter for successfully recording a bone-conduction ABR. The bone-conduction ABR appears to contain relatively more low-frequency energy than does the air-conduction ABR. Some of the bone-conduction ABR energy may be filtered out with high-pass filter settings of 150 Hz to 300 Hz, resulting in a serious reduction in response amplitude and detectability. Also, the maximum stimulus intensity level is lower for bone- than for air-conduction stimulation. Therefore, the bone-conduction ABR at maximum stimulus intensity has lower amplitude than the air-conduction ABR at maximum stimulus intensity.

You may need to do more signal averaging (more stimulus repetitions) to produce an adequate signal-to-noise level, e.g., a clearly detectable ABR with bone-conduction stimulation. You can often make a more confident identification of the ABR Wave I component if you compare the ipsilateral to the contralateral electrode arrays (Figure 1). That is, the ABR Wave I detected in the ipsilateral recording array is generated from the VIII nerve ipsilateral to the stimulus. As a near-field potential, the Wave I produced by activating the test ear should be observed only for the array that has an ipsilateral inverting electrode. Using an earlobe-inverting electrode or, if possible, a Tiptrode-style inverting electrode, will further enhance detection of the Wave I in the ipsilateral channel.

Table 1. Test protocols for recording air- versus bone-conduction auditory brainstem response (ABR). Parameters that are distinctly different for the two stimulus presentation modes are indicated by italics.

Parameter	*Air-conduction*	*Bone-conduction*
STIMULUS		
transducer	ER-3A insert earphone	B-70 bone oscillator
presentation site	ear canal	mastoid bone
type	click	click
duration	0.1 msec	0.1 msec
polarity	rarefaction	alternating
rate	21.1/sec	7.1/sec
intensity	maximum of 95 dB nHL	maximum of 50-55 dB nHL
masking	rarely required	only when Wave I is not observed in the ipsilateral electrode array
ACQUISITION		
filter settings	30 or 100 to 3000 Hz	30 to 3000 Hz
analysis time	15 msec	15 msec
prestimulus time	1 msec	1 msec
sweeps	usually 1000 to 2000	more sweeps may be needed due to low signal-to-noise ratio
*electrode arrays**	F_z-A_i	Fz-A_i and Fz-A_c

* F_z = high forehead; A_i = earlobe ipsilateral to stimulus; A_c = earlobe contralateral to stimulus ear

What are the clinical indications for bone-conduction ABR?

At Vanderbilt University Medical Center, we record bone-conduction ABR whenever there is audiometric evidence or clinical findings suggesting, or at least consistent with, possible middle ear disorder. Audiometric evidence includes abnormal tympanograms, abnormally delayed ABR Wave I latencies at high air-conduction stimulus intensity levels, and absence of detectable otoacoustic emissions (OAE). Clinical evidence includes obvious craniofacial deformities (e.g., aural atresia), otologic disease, and syndromes and other disorders (e.g., mental retardation) associated with middle ear disease.

In general, you should routinely perform bone-conduction ABR whenever air-conduction ABR findings are abnormal, and there is any suggestion of possible middle ear disease. The current audiologic test battery for assessing auditory status should include bone-conduction ABR, along with other electrophysiologic procedures, such as otoacoustic emissions.

How do ABR waveforms differ with air- versus bone-conduction stimulation?

Because stimulus intensity levels are less than about 50 dB nHL, the bone-conduction response, especially the Wave I component, has lower overall amplitude and, usually, somewhat poorer morphology. Also, the response is generally less synchronous than the expected air-conduction ABR, probably because with transient stimuli the bone-conduction mode of stimulation is less effective than the air-conduction mode of stimulation.

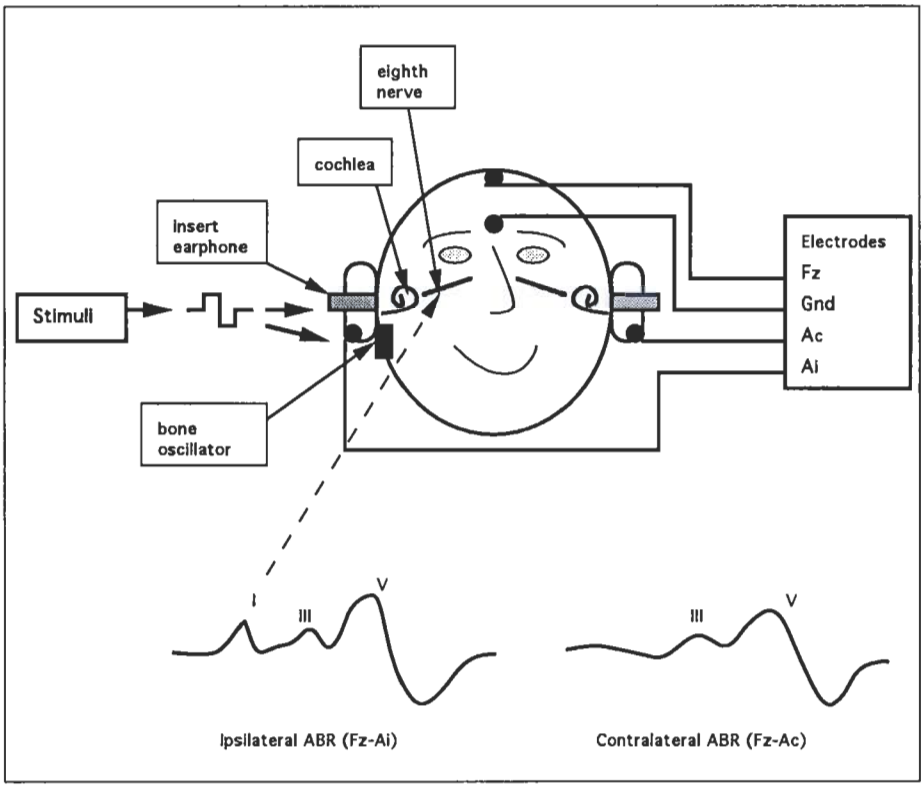

Figure 1. Schematic illustration of bone-conduction ABR measurement, including electrode arrays and generation of ABR Wave I by VIII nerve ipsilateral to the bone-conduction stimulation.

It is also likely that the relatively low-intensity bone-conduction stimulation produces an ABR that is dependent on activation of a broader region of the cochlea than is the case with the high-intensity air-conduction stimulus. In any event, each component is less well formed and distinct with bone-conduction stimulation than it is with air-conduction stimuli. In addition, bone-conduction stimulus artifact is usually more troublesome. The ABR waveform for bone-conduction stimulation at maximum stimulus intensity levels (about 50 dB nHL) should appear similar to the ABR waveform for air-conduction stimulation at 50 dB nHL or less.

In patients with conductive hearing loss, ABR latencies are markedly delayed for air-conduction stimulation. The conductive component effectively attenuates the stimulus energy before it reaches the cochlea. Bone-conduction ABR latencies are not delayed by this conductive attenuation. As a result, the ABR latency-intensity functions in conductive hearing loss are distinctly different for air-conduction stimulation than for bone-conduction stimulation (Figure 2). On the other hand, no ABR air- versus bone-conduction latency gap is observed in sensory hearing loss.

If my initial experiences with bone-conduction ABR in a few adults have been less than positive, should I still attempt to apply bone-conduction stimulation in ABR assessment of children?

Yes, definitely. As I noted earlier, sensorineural hearing threshold levels in the 1000 Hz to 4000 Hz region may be considerably better for a normal-hearing infant or young child (0 dB HL or even -10 dB HL to -20 dB HL) than for an adult (10 dB HL to 20 dB HL). Consequently, bone-conduction intensity levels that are defined relative to normal behavioral thresholds for the click stimulus may actually be 15 dB to 20 dB *less* intense for some apparently normal-hearing adults and 20 dB to 30 dB *more* intense for the young child. As a result, bone-conduction ABRs, including the Wave I component, are larger in amplitude and considerably more distinct in younger patients. It is sometimes possible in pediatric patients to record a clear and reliable ABR for stimulus intensity levels as low as 0 dB nHL or 5 dB nHL.

Of course, you can't expect to record a textbook-perfect bone-conduction ABR from every patient. At best, bone-conduction ABR measurement requires more test time. Also, compared to air-conduction ABRs, bone-conduction ABR waveforms tend to be noisier, not as well formed, and less reliable.

Sadly, I've discovered a number of technical snags and pitfalls. For example, I often have difficulty maintaining a consistent bone oscillator placement (and a constant stimulus intensity level) with a young and restless infant, particularly if I'm holding the oscillator with one hand while operating the evoked response system with the other—all in a darkened room! Still, the information gained from bone-conduction ABR makes it well worth the effort.

If I don't use masking, or masking cannot be applied effectively, in bone-conduction ABR, how do I know the the ABR findings are ear-specific?

There is one main reason why it is easier to identify an ear-specific response with bone-conduction ABR than with bone-conduction pure-tone audiometry. With pure-tone audiometry, the behavioral responses for the test ear are indistinguishable from those for the non-test ear. However, when you perform bone-conduction ABR, the generator for the response (test ear versus non-test ear) can often be unequivocally determined.

The ABR Wave I is near-field response. It is detected best with an electrode located as close as possible to its generator, i.e., the distal, or cochlear, end of the VIII cranial nerve. If you can clearly observe the ABR Wave I in the waveform recorded with an ipsilateral electrode array (Figure 1), then the response is unequivocally arising from the test ear. Therefore, any manipulations of measurement parameters that increase

Wave I amplitude are useful in confirming an ear-specific bone-conduction ABR. However, if you observe only an ABR Wave V component in the waveform, you cannot confidently determine test ear without applying adequate masking to the non-test ear. Observing a Wave I component in both the ipsilateral and the contralateral electrode arrays confirms direct stimulation of the test ear, and also cross-over stimulation of the non-test ear.

CONCLUSIONS

When Gus Mueller asked me to write an article for *Page Ten*, I considered literally dozens of clinical ABR and otoacoustic emissions topics. I selected bone-conduction ABR for two main reasons: (1) It's a technique that can help you make important audiologic management decisions in clinically challenging patients, and (2) it's a technique you can perform with any commercially available evoked response system. My experience suggests the following general conclusions.

- By following an appropriate test protocol, you can record reliable bone-conduction ABRs from patients for estimating their sensorineural hearing status.
- Bone-conduction stimulation is most likely to generate robust ABR waveforms from infants and young children with normal sensorineural hearing.
- A reliable bone-conduction ABR is usually not detected in patients who have sensorineural hearing loss exceeding 30 dB HL to 40 dB HL.
- By closely analyzing ABR waveforms for ipsilateral versus contralateral electrode arrays, especially identification of a reliable Wave I component in the ipsilateral array, you can obtain ear-specific information on sensorineural hearing status without using contralateral masking.
- Comparing the stimulus intensity levels that produce equivalent Wave V latency values for air- and for bone-conduction stimulation on a latency-intensity function graph enables you to estimate the air-bone gap in patients with suspected middle ear disease and conductive hearing loss.

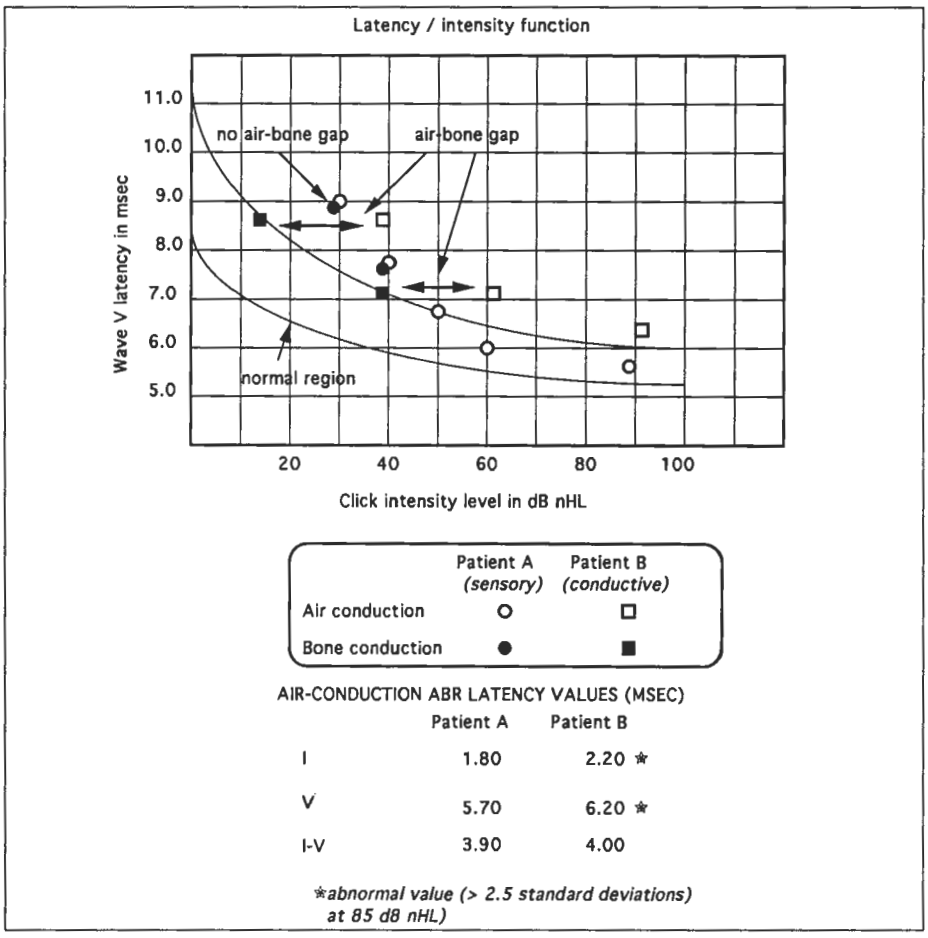

Figure 2. Latency-intensity functions for air- versus bone-conduction ABR for an infant with mild sensorineural hearing loss (A) and a patient with a mild conductive hearing loss (B).

REFERENCE

1. Hall JW: *Handbook of Auditory Evoked Responses*. Needham, MA: Allyn & Bacon, 1992.