Welcome to our Marc Page Ten. Spring i nearly here and it' time to think about new and exci- ing things. Let's see, what can we pull from the audiologic world? How about…bone-conduction testing! Yes, that bone-conduction testing, but just wait, sometimes old is new!

It was over 70 years ago when Bekesy's experiments laid the foundation for bone-conduction measurements. It was over 50 years ago that Carhart wrote about the clinical applications and, among other things, reported the observation of a "notch." Once a mainstay of clinical testing, bone conduction has assumed a lesser role since immittance has become routine. But when you do need it, it just might involve your most important diagnostic decision of the day!

While it may not be the hippest test to hit the audiologic streets in 2005, if there is one person who can make it exciting it's this month's guest author, **James W. Hall III**, PhD. And don't be surprised if you learn something about this old test that will make your next clinic day go a little more smoothly.

Dr. Hall is a clinical professor and chief of the Division of Audiology in the Department of Communicative Disorders in the College of Public Health & Health Professions at the University of Florida in Gainesville.

He keeps busy with a clinical practice, sometimes even hanging out with his pal SAL. Mostly, however, his clinic time is involved with auditory electrophysiologic recordings in infants, the assessment and management of adult patients with tinnitus, or evaluating children with auditory processing disorders. He also is teaching on campus and distance-learning doctor of audiology students, and conducting clinical research. Jay often leaves Gainesville to give workshops at various audiology conferences around the country, and also internationally.

You of course are familiar with the many books that Jay has written. He's currently spending his "free time" completing the new *Handbook of Auditory Evoked Responses*, the second edition of that well-known, 3-pound tome. While Jay usually is writing about the latest innovation in electrophysiologic testing, I think you'll enjoy his clinical tips on the following pages concerning our old standby, bone conduction.

Gus Mueller
Page Ten Editor

The clinical challenges of bone-conduction measurement

By James W. Hall III

Hall

1 You're almost old enough to know the history of bone-conduction testing, aren't you?

Hey, in the world of bone conduction, I'm just a kid! But you don't have to be old to know history. One of my favorite audiology textbooks in graduate school is my now well-worn copy of *Hearing Measurement: A Book of Readings,* edited by Ventry, Chaiklin, and Dixon.[1] Although it was published in 1971, I still consult this collection of 54 carefully selected journal articles, which covered all that an audiologist of that time really needed to know about clinical procedures.

Eight of the ten articles in the second part, "Measurement of pure-tone thresholds," pertain to bone-conduction mechanisms and experimental findings or to clinical procedures, with such big-name authors as Raymond Carhart, Don Dirks, Gerald Studebaker, and Juergen Tonndorf. The final two papers—one by Tom Tillman, the other by Jim and Susan Jerger—are on the sensorineural acuity level (SAL) test.

2 But now that we all do immittance and OAEs routinely, is bone-conduction testing still necessary?

In this era of managed care and healthcare cost containment, when every clinical minute counts, we shouldn't perform any audiologic procedure that adds nothing to the diagnosis and does not contribute to patient outcome. If aural immittance findings (tympanometry and acoustic reflexes) are entirely normal and, especially, if OAEs are well within normal limits, then bone-conduction pure-tone audiometry has no clinical value. It's a waste of precious clinical time and an unnecessary clinical expense. However, for patients who lack these criteria for normal middle ear function, bone-conduction audiometry is definitely in order.

3 Is it possible for a patient to have a conductive loss, yet still have a normal tympanogram and acoustic reflexes at normal HL values?

That pattern of findings is possible, but highly improbable. The etiology that comes to mind immediately is a very specific form of traumatic damage to the ossicular chain involving a crus of the stapes. However, there's no good reason to stubbornly perform bone-conduction audiometry if the patient has normal findings for immittance measures and OAEs and doesn't have a history of head injury.

By the way, in case you don't know what "crus" means, it's the singular version of "crura," which is derived from the Latin word for legs. A crus is a leg, or an anatomic structure that resembles a leg. See, you learn something every day.

4 Thanks for the etymology lesson, but let's get back to audiology. Am I correct in assuming that the challenges of bone-conduction measurement involve masking?

Mastering the technique of masking has certainly challenged generations of audiology students. For the experienced clinician, however, one of the real challenges is defining, confidently and accurately, ear-specific bone-conduction thresholds in patients with bilateral conductive hearing loss when effective masking requires high levels of noise.

5 Can I assume you are alluding to the dreaded "masking dilemma"?

Yes, I am. Resolving the masking dilemma remains a problem, especially for the vast majority of practitioners who continue to rely on the conventional bone-conduction technique.

6 What do you mean by "conventional bone-conduction technique"? What other technique is there?

By conventional BC measurement, I mean the presentation of pure-tone signals to one mastoid with a bone-conduction oscillator while masking noise is delivered to the other (non-test) ear, often using outdated supra-aural earphones. The likelihood of crossover of masking noise from the non-test ear to the test ear can be reduced by the use of deeply seated insert earphones that produce higher inter-aural attenuation than supra-aural earphones. The masking dilemma will remain, however, with a moderate to severe degree of conductive hearing loss where one finds, "Enough masking is too much masking."

As for other techniques, there are the sensorineural acuity level or SAL technique, the ABR evoked by bone-conduction signals, and the bone-conduction auditory steady-state response (ASSR).

7 I've encountered the masking dilemma myself. What steps do you take first in your clinical practice to resolve the dilemma in serious conductive hearing loss?

That's a no brainer. I use a proven technique that's an oldie but a goodie—a blast from the past. I go straight to my pal SAL.

8 That is an oldie! So old, in fact, that I've never used it. What advantage does the SAL procedure have over conventional bone-conduction audiometry?

The sensorineural acuity level (SAL) procedure offers several advantages over conventional bone-conduction measurements. With this technique, masking noise is delivered to both ears via bone conduction, with the bone oscillator located on the forehead. The essence of the masking dilemma—crossover of the masking noise to the test ear—is immediately eliminated.

There's also a very practical advantage for the busy audiologist. The SAL procedure is performed with earphones on both ears or, better yet, with insert earphone cushions within each ear canal. This eliminates the repeated need to run into the sound booth to reposition the bone oscillator on the mastoid of the test ear and the earphone for masking on the non-test ear.

9 My memory is a little vague on exactly how to do the SAL test. Can you provide a little refresher?

I understand, a lot of people skipped that class in graduate school. First of all, some simple norms need to be collected in the clinic. Here are the steps for normative data collection:[2]

- ❖ Gather a small group of normal-hearing subjects, maybe 8 to 10 people.
- ❖ Determine air-conduction thresholds in quiet for each ear for four test frequencies (500, 1000, 2000, and 4000 Hz) and for spondee words.
- ❖ Determine air-conduction thresholds with maximum narrowband and speech-masking noise presented via bone conduction for the same frequencies and spondee words. By maximum I mean go up to equipment limits for bone conduction. This will usually be around 55 to 60 HL.
- ❖ Calculate the average normal "shift" in air-conduction thresholds from the quiet condition to the noise (via bone conduction) condition, again for the same four pure-tone frequencies and spondee words. The normal shift caused by the bone-conduction noise is usually about 55 to 60 dB.
- ❖ Prepare a sheet for recording the above information for patients.

Then, with patients, you follow a similar protocol:

- ❖ For the four test frequencies and spondee words, measure air-conduction thresholds in quiet for each ear.
- ❖ Measure air-conduction thresholds for these frequencies and spondee words with maximum narrowband and speech-masking noise presented to the forehead via bone conduction (the same HL level you used for collecting your norms).
- ❖ For each test frequency (500, 1000, 2000, and 4000 Hz) plus spondee words, calculate the patient's "shift" in air-conduction thresholds from the quiet condition to the noise (via bone conduction) condition.
- ❖ Subtract for each frequency and the spondee word signal the difference between the patient's air-conduction thresholds with BC noise versus the normal "shift." The difference is the patient's air-bone gap in dB.
- ❖ For each test frequency and the spondee word signals, subtract the estimated air-bone gap from the patient's air-conduction thresholds.

10 The SAL technique is slowly coming back to me. Could you summarize a few typical sets of findings encountered clinically?

The three most straightforward examples are a normal-hearing person, someone with a pure-conductive hearing loss, and a patient with a sensory hearing loss. The normal-hearing person is just like each of the subjects in the normative group. Since the cochlea is normal, all of the bone-conduction noise is effective as a masking signal. Pure-tone thresholds with the bone-conduction noise are equivalent to the normal shift. That is, they are shifted maximally by the bone-conduction noise masking the normal cochlea, so there is no air-bone gap (i.e., it's "0 dB").

If the patient's hearing loss is entirely conductive, that is, the cochlea is functioning normally, then the bone-conduction masking noise will also produce the maximum shift in pure-tone hearing thresholds. Of course, the final pure-tone thresholds in noise will be very elevated since they are affected by the conductive hearing loss plus the bone-conduction masking of the cochlea. Subtracting the normal shift for bone-conduction noise from the pure-tone thresholds and for speech thresholds in the noise condition leaves the air-bone gap at that frequency. For example, for a patient with a 40-dB conductive loss, pure-tone thresholds with BC noise will be approximately 90 dB HL. Subtracting the norms for the bone-conduction noise shift, i.e., 90 dB – 50 dB, leaves 40 dB. That's the air-bone gap. Subtracting it from the air-conduction pure-tone thresholds (40 dB – 40 dB) and the estimated bone-conduction hearing thresholds are 0 dB, confirming a normal cochlea and a pure conductive hearing loss.

Finally, with a sensory hearing loss, not all of the bone-conduction masking noise is effective. That is, the patient with a sensory hearing loss will not even perceive some of the noise. Therefore, there is less than a 50-dB shift from the pure-tone threshold levels in quiet versus those with bone-conduction masking. Using the same degree of hearing loss as we did for the conductive hearing loss example (40 dB HL), bone-conduction masking of 50 dB will produce a shift in pure-tone thresholds of only 10 dB (50 dB of bone-conduction masking – 40 dB of sensory hearing loss). So the pure-tone and speech thresholds with bone-conduction noise are about 50 dB. Subtracting the normal shift from the thresholds obtained with bone-conduction masking (50 dB - 50 dB) yields an air-bone gap of 0 dB. The hearing loss is entirely sensory.

11 Do I need any special equipment to perform the SAL?

All you need is an audiometer capable of presenting narrowband and speech-noise signal via bone conduction, calibrated insert earphones, a bone oscillator dedicated for SAL procedure (the high-level noise will affect calibration of the oscillator), and an adjustable headband for forehead bone oscillator placement.

12 So why don't more practitioners apply the SAL clinically?

I've been asking myself that for 30 years! I can only speculate that the university professors instructing audiology students did not regularly work in otolaryngology clinical settings where serious conductive hearing losses are commonplace. I should mention that there also are some clinical instructors who question the accuracy of the SAL technique in some patients, citing, for example, longstanding concerns about the failure of the SAL to account for the occlusion effect.[3,4]

As you can tell, I disagree with this. The SAL technique provides valuable clinical information and plays a unique role in clinical audiology when performed with insert earphones and used as a supplement to conventional bone-conduction measurements for confirming ear-specific information on sensory hearing thresholds.

For the audiologic assessment of a patient with bilateral otosclerosis or aural atresia, to cite two examples, the masking dilemma is no mere esoteric, academic exercise. It is a real problem that must be solved before decisions on surgical management can be made. Yet, with few exceptions, most recent audiology textbooks barely mention the SAL procedure. One exception is a chapter about clinical masking I wrote with the late Jay Sanders that includes a how-to description of the SAL technique complete with an example of the record form noted above.[5]

In case you want to learn more about the SAL technique, I loaded on my department web site (www.phhp.ufl.edu/ cd/facultypresentations) a PowerPoint presentation review of the topic from a hearing measurements course in our AuD program.

13 Well, it sounds as if the old SAL test still has some life left in her. Are there any other tricks in your bag for dealing with the clinical challenges (limitations) of BC audiometry?

Yes, three to be precise. One is the audiometric Weber test, a very simple technique that anyone can perform before or after bone-conduction pure-tone measurements. Although it's been around for years, the audiometric Weber remains on the fringe of clinical practice. It's really just the old Weber test performed with an audiometer instead of tuning forks.

The bone oscillator is placed on the forehead and the patient is instructed to lateralize the sound, i.e., point to the ear where the sound is heard. Then, pure tones (250, 500, and 1000 Hz) are delivered via bone conduction at a modest intensity level (about 20 dB above unmasked or bone-conduction thresholds for the apparently better cochlea). For each test frequency, the patient will lateralize the signal to the better hearing ear for sensory hearing loss, and the poorer hearing ear for conductive hearing loss. In a matter of minutes, the audiologist can begin the process of differentiating among conductive, sensory, and mixed hearing losses for each ear.

14 Wow, the Weber test is from the 1800s! You do like history. Give Friedrich my regards! What are the other two procedures?

Both are electrophysiologic responses evoked by bone-conduction signals. One is the bone-conduction ABR, which has been around for more than 25 years.[6,7] I'm sure you'll be fascinated to learn that less than a year after Jim Jerger and the late Larry Mauldin published one of the first articles on bone-conduction ABR in 1979,[6] another paper appeared describing an adaptation of the SAL technique to ABR measurement.[8] The auditory steady-state response (ASSR) can also be evoked with bone-conduction stimulation.[9]

15 I've never recorded an ABR with bone-conduction stimulation. Is it complicated?

Not really. With the proper protocol,[2,10] the technique is quite straightforward. You might recall I made this very point back in 1994 in a Page Ten article entitled "Bone conduction ABR: Clinically useful and clinically feasible."[11]

Briefly, the ABR is generated with click signals presented via a bone oscillator placed on the mastoid, rather than with earphones. However, waveform analysis is really the same as it is for air conduction. The initial goal is to record a clear Wave I component in the waveform recorded with an electrode array that is ipsilateral to the stimulus ear, that is, with one (the inverting) electrode on the earlobe or within the ear canal on the side that is stimulated. The Wave I of the ABR is generated at the distal (cochlear) end of the auditory nerve. It will be detected by the electrode located on the ear that is stimulated, but not by an electrode on the opposite ear. Therefore, the presence of a Wave I in the ipsilateral electrode array verifies the test ear. And when a Wave I is clearly identified, masking of the non-test ear is not necessary.

16 Wait a minute! Are you saying I can perform an audiologic procedure without worrying about masking? That *is* good news. You mentioned the ASSR earlier. How is it better than the bone-conduction ABR technique you just sold me on?

Well, it's really a case of good news, bad news. The good news is that the amplitude and, usually, the frequency-modulated pure-tone ("steady state") signals used to evoke the ASSR offer a degree of frequency specificity that is not possible with bone-conduction ABR recordings. The clinical advantage is the ability to estimate air-bone gaps for the lower frequency region where, of course, they are most often found in conductive hearing loss.

Additional good news is that maximum bone-conduction intensity levels are 15 to 20 dB higher for the steady-state signals employed in recording the ASSR than for the very brief duration (transient) signals used to evoke the ABR. Also, clinical ASSR devices use automated response-detection algorithms so the practitioner doesn't need to develop special skills in waveform analysis and interpretation.

17 That's all very encouraging. What's the bad news?

Well, for starters, the steady-state signals delivered to the mastoid at relatively high intensity levels generate considerable electrical artifact, which may interfere with ASSR measurement and even affect the accuracy of thresholds estimations. Also, the automated ASSR analysis feature has a distinct down side. That is, the anatomic marker for determining ear specificity with the ABR (e.g., the Wave I detected with visual inspection of the ABR waveform recorded with an ipsilateral electrode array) is lacking for the ASSR. So, it's necessary with bone-conduction ASSR to mask the non-test ear. That, unfortunately, brings us back to the masking dilemma.

18 I see. Then how do you verify ear-specific results with the ASSR?

There are two options to assure ear-specific ASSR findings. One is to mask the non-test ear, much as you do with conventional bone-conduction audiometry. Of course, you'll face the same concerns and questions about adequate masking that have plagued us for years. The other option is to adapt the SAL technique to ASSR measurement. Barbara Cone-Wesson and colleagues reported positive results with this strategy in a study of the ASSR conducted with a series of infants ranging in age from 3 to 13 weeks.[11]

19 Did I hear you correctly? Is it really possible to estimate the air-bone gap with infants using the ASSR?

Certainly. That's probably the biggest single clinical advantage of the bone-conduction ASSR and ABR techniques. Auditory electrophysiology measures can be applied clinically with patients of all ages, including infants and young children. Of course, for young children, sedation is required to achieve a sufficiently quiet state and to eliminate contamination of the responses with movement artifact.

20 So, it seems that you're saying non-traditional bone-conduction testing is something I should be thinking about. Is that right?

Absolutely. Don't get me wrong. I'm delighted when immittance and OAE results tell me I can skip bone-conduction audiometry altogether. But for those tough cases in the clinic, you need to pull out your best test procedures—whatever you need to get accurate, ear-specific audiometric information. Remember, the location of those BC symbols you place on the audiogram just might influence the next day's surgery schedule!

I guess now you can appreciate why I enjoy spending much of my clinical time recording ABRs and ASSRs in the diagnostic assessment of children at risk for hearing loss. My patients are always well behaved (sleeping like babies) and I don't need to worry about masking!

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