That doesn't make sense! – The practical realities of bone conduction audiometry

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"The calibration of my bone conduction oscillator is off" is one of the more frequent calls our service department receives. If some basic over-the-phone troubleshooting doesn't alleviate the concern, we schedule a service call to check the accuracy of the BC oscillator's output. If I were a gambler, I'd win a lot of money betting on the outcome being that the calibration is within acceptable tolerance as defined in the ANSI S3.6 standard for audiometers. Yet, these calls persist, primarily due to unexplainable air/bone gaps and the occasional bone threshold testing worse than the air threshold at the same frequency. This is a frustrating, puzzling situation, indeed; however, there are reasonable explanations that are well-documented throughout the literature.

The frequencies most often identified in these calls are 250Hz, 500Hz, and, particularly, 4KHz. Let's first address this issue in more general terms before discussing these specific frequencies later in the article.

In theory, puretone (PT) BC testing bypasses the outer and middle ears and stimulates the inner ear directly, thereby providing an estimate of sensory-neural hearing. If it were only that simple! Accurate PT BC thresholds are essential for a physician to determine an appropriate treatment plan (surgery?) Unfortunately, many of our physician colleagues reject the presence of any significant air/bone gaps that do not correlate with an otoscopic examination and/or immittance testing. The rejection of these air/bone gaps is based on a lack of understanding of the many variables that co-exist which impact the test/retest reliability of PT testing, particularly that associated with BC stimulation.

It is imperative that anyone administering and/or interpreting PT audiometry test results have a thorough knowledge and understanding of these many variables, which fall into one of the following categories:

- Modes of bone conduction stimulation
- Technical related
- Subject related
- Calibration related

Modes of BC stimulation

- Compression/distortion (skull vibration)
- Inertia (a lagging of the ossicular chain with respect to skull vibration)
- External canal or osseotympanic (vibration of the external auditory meatus) (Vento and Durrant 2009)

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Each of these contribute to the measurement of bone conduction thresholds in a unique way. The compression/distortion mode is based on a pressure differential between scala vestibuli and scala tympani as a result of the greater elasticity of the round window. In addition, experiments have demonstrated the presence of a greater pressure differential than would be expected. The theory is that this is due to the contributions of the volume of fluid within the semicircular canals.

The inertia and osseotympanic modes contribute to BC sensitivity though the conventional AC pathway. The inertia mode creates a lag in the movement of the ossicular chain relative to skull vibration causing the stapes footplate to vibrate. The osseotympanic mode causes vibration of the walls of the external meatus, once again using the conventional AC pathway to create traveling waves in the cochlea. (Vento and Durrant)

The important point here is that the conventional AC pathway can contribute to the measurement of BC thresholds.

Technical Variables

These include the following:

- Proper positioning of the BC oscillator
  Finding just the right "spot" for placement of the BC oscillator can impact the accuracy of BC threshold measurement. The oscillator must be placed on the hard surface of the mastoid bone while avoiding touching the pinna and hair. Also it is important to find a location that will allow the oscillator to remain stable during testing. Slippage off of the preferred location can lead to reduced BC hearing sensitivity.

- Mastoid vs. forehead placement
  Over 90% of BC testing is performed with mastoid placement although several studies have shown that forehead placement yields better test/retest reliability with less contributions from the middle ear to BC thresholds. However, maximum output of the BC oscillator is reduced by approximately 20dB at some frequencies with forehead placement.

- BC oscillator application force
  The tension of the BC headband will have an effect on how low BC thresholds are measured. The ANSI Standard for audiometers recommends a force of 400 grams of headband tension. Over time, all headbands lose tension and may need to be replaced. This is something that should be checked during annual equipment calibration.

- BC oscillator surface area
  BC thresholds will be lower if the BC oscillator contact surface area is larger. The B71 is the most frequently used oscillator. It has a circular disk on the face of the oscillator that has a surface area of 175mm. Proper placement on the mastoid should maximize the contact area in order to achieve the lowest BC thresholds possible.

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- Occlusion effect

Of course, everyone is familiar with the occlusion effect and the artificial lowering of bone conduction thresholds in the 250Hz-1KHz region. The occlusion effect varies based on the type of AC transducer selected. Supra-aural headphones cause a larger occlusion effect than insert phones, particularly when the insert phones are inserted deeply into the ear canal past the cartilaginous portion. This must be considered as a possible contributing factor when unexplained air/bone gaps occur in the lower frequencies.

- Proper air conduction testing techniques

Finally, proper technique in the placement of air conduction transducers must also be considered as a technical variable leading to unexplained audiometric test results. Supra-aural headphone improperly placed can lead to erroneous AC thresholds. The condition of the earphone cushions can be a contributing factor to inaccurate AC thresholds in the low frequencies. If the cushions are hard and/or cracked, the attenuation of ambient noise in the low frequencies is reduced. Insert phones should be inserted as deeply as is comfortable for the patient using the proper size in order to create an acoustically tight seal. Poorly fit foam tips can allow LF puretones to exit the ear canal much like the vent in a hearing aid or earmold.

Subject Variables

Audiometric zero (0dBHL) is the mean hearing threshold for a large group of young, normally hearing adults. As is the case in most "normal" populations, there is a certain variance in the values that generate that average level. So a normal distribution exists for both AC and BC threshold levels. With this in mind some individuals classified as have normal hearing are going to be at the extremes of the normal distribution.

This variance can also contribute to not only unexplained air/bone gaps but also bone thresholds testing worse than air at the same frequency. Regardless, it is important to record these results as measured and not fudge the data to accommodate one's expectations of outcome. Assuming the technical variables that can contribute to unexplained test results are considered, then threshold measurements should be recorded as measured. This is also the only way to document a possible calibration issue if these occur on every patient.

There are changes in the middle ear that can contribute to AB gaps as one ages, including increased flaccidity of the TM and loosening of the ossicular chain. This contributes to AB gaps, particularly at 4KHz.

Calibration Variables (and the phantom 4KHz air/bone gap)

The importance of an accurate calibration of your audiometer transducers cannot be understated and should only be performed by an experienced technician with proper training, equipment, and test couplers. Since most audiometer calibrations are completed

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on an annual basis, what can one do during the interim period to ensure that audiometer transducers remain within the acceptable calibration tolerance standard?

One way is to perform regular biological checks by measuring both air and bone conduction thresholds on a colleague or someone in your office that has normal hearing. Establishing baseline audiometric thresholds to which future measures can be compared allow audiologists to monitor the performance of the audiometer on a regular basis. Thresholds should fall within the acceptable test/retest tolerance of +/- 5dB. If that tolerance is exceeded then concern about a change in the calibration of the specific transducer should be questioned. Also, any "trend" observed when testing patients is an indication of a possible calibration issue. When either or both of these changes is observed, you should contact your calibration vendor right away.

Remember that the ANSI Standard for audiometers is a consensus document that provides average values to which the output of audiometric transducers are calibrated. In fact, the BC calibration values were modified in the ANSI S3.6 2004 standard so that they were equal to the international standard, thus creating uniformity throughout the world. It is secondary to this modification that some believe contribute to these unexplained discrepancies between AC and BC thresholds in normal hearing and SNHL patients.

Now what about that unexplainable air/bone gap at 4KHz? I feel your pain! The concern about an unexplained air/bone gap at 4KHz has been around for a long time. It has been addressed in several published articles as you will see below, but yet it still exists.

No one factor causes this air/bone gap. In fact, it is more likely a combination of two or more factors. An article published in the Journal of Speech and Hearing Research in 2012 (Nondahl et al) states that the 4KHz ABG may reflect a combination of aging and other factors and not the presence of abnormal middle ear function. Let's not forget the potential for skull variations and difficulty placing the bone oscillator on the mastoid process for some patients. Collapsing canals when using supra-aural cushions have always been a common source for a 4KHz ABG. It is very rarely related to equipment malfunction.

But it can be related to the ANSI calibration offset recommended at 4KHz. The accuracy of this particular value has been questioned by many scholars in the acoustics and audiology fields for many years. But as an equipment vendor, it is our job to calibrate to the ANSI standard for audiometers. Otherwise, we put you at risk to have the accuracy of your measurements brought into question.

As mentioned, there have been many published articles addressing the issue of air-bone gaps at 4KHz. The Nondahl et al articles review several of these articles and the theories as to its presence. The reasons discussed include chance (Studebaker, 1967); air-borne radiation from the bone vibrator (Shipton et al, 1980; Frank & Holmes, 1981); wax, healed perforations, or "loosening of the middle-ear system" (Marshall et al, 1983); ear-canal collapse due to the use of supraaural rather than circumaural cushions (Randolf & Schow,

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1983); and an erroneous reference-equivalent threshold force level at 4kHz (Margolis, 2010).

As mentioned earlier in this article, please keep in mind that air bone gaps represent the comparison of two normally distributed variables (air conduction and bone conduction thresholds). That alone will occasionally create unexplained air bone gaps. (See the article entitled "The Audiologist's Dirty Little Secret".

Here are several findings from a study conducted at the University of Minnesota by Dr. Robert Margolis:

- Normal-hearing participants had small air-bone gaps at 0.5, 1.0, and 2.0 kHz (-1.7 to 0.3 dB) and larger air-bone gaps at 4 kHz (10.6 dB).
- SNHL participants had small air-bone gaps at 0.5, 1.0, and 2.0 kHz (-0.7 to 1.7 dB) and a larger air-bone gap at 4 kHz (14.1 dB).
- The 4-kHz air-bone gap grew with air-conduction threshold from 10.1 dB when the air-conduction threshold was 5-10 dB HL to 21.1 dB HL when the air-conduction threshold was greater than 60 dB.
- With the 4-kHz RETFL (Reference Equivalent Threshold Force Level) corrected by the average SNHL air-bone gap, the relationship between RETFL and frequency is linear with a slope of - 12 dB per octave. Conclusions: The 4-kHz air-bone gaps for listeners with SNHL could be avoided by adjusting the 4-kHz RETFL by - 14.1 dB.

Unless you are measuring air/bone gaps on every patient with normal hearing or a SNHL, it probably is not a calibration issue. And remember to perform regular biological calibrations on one or two of your office staff (young with normal hearing) and monitor their bone thresholds at 4KHz to make sure it is not changing more than the expected test-retest variability.

Our goal is to ensure your equipment meets the required testing standard, therefore, if you feel that the calibration of one or more of your transducers is "off", please contact your local e3 office for their advice and support.

References

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