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Bone Conduction Audiometry - The Good, The Bad, and The Interesting

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- - [Sherman] Hello everyone. I'm Sherman Lord and I am very happy to be here today, being asked by GSI to make this presentation on bone conduction. Over the years, I've become interested in a lot of the technical issues associated with bone conduction threshold measurement and calibration, primarily due to the number of calls we receive questioning bone vibrator calibration. When I was a clinical audiologist, many, many years ago, we used to see air-bone gaps that were unexplainable, that we wrote off mostly to collapsed ear canals, particularly when it was up in the 4,000 hertz or higher range. Unfortunately, I didn't have the use of insert earphones back then. They weren't available. The questions that we get about the accuracy of bone conduction calibration was cause for concern for me for several reasons. Most importantly, since medical management decisions are based on accurate threshold measurement, any question about calibration will impact the confidence you have as the audiologist in the test results, and any management decisions made based on those results.

I was also concerned, quite frankly, about the confidence our accounts, our clients, had in our ability to calibrate the audiometers correctly and accurately and, of course, the financial impact it was having on my business by having technicians return to check the calibration of the bone oscillator. I would say about eight, or nine, out of 10 times, we'd find that the oscillator was definitely within the tolerance allowed by the ANSI standard. As I started looking into the issue, it was a re-education on bone conduction hearing and testing, things that I had long forgotten, and, in general, the variables affecting the accuracy and reliability of bone threshold measurement, as well as tester biases that exist in the measurement of pure tone bone thresholds, reference standards to which audiometers are calibrated, and the equipment used to calibrate bone vibrators. I started looking closely at what could be done to mitigate these calls that we were receiving. The dilemma was that there was no easy answer nor was there only one answer but one conclusion I did reach is that we in the calibration business had to better educate our clients, the audiologists we served, about the contributing factors to these sometimes unexplained air-bone gaps, as well as those occasions when bone conduction and thresholds test worse than air. One thing I did learn is that many of the same issues and concerns about bone conduction testing we have today were addressed over 50 years ago by many researchers. I have two primary goals today. I want to increase your confidence in the measured bone conduction thresholds when they don't seem to make sense, and I want to discourage any tampering with the measured BC thresholds when the results don't confirm to "the way it is supposed to be." And I quote Dr. Gerald Studebaker in that because I've referred to some of his studies throughout this presentation. There are three learning objectives that we have for today. These are, we would hope that you would be able to describe at least two technical variables affecting bone conduction audiometry, describe calibration variables in bone conduction audiometry, and describe the difference between forehead and mastoid placement of the bone oscillator and determine the best placement for your patient.

These are the topics that we're going to go through today and we'll take these, of course, one at a time. We wanna start off a little bit with the history surrounding the testing and the standards that are used today for calibration. First audiometer in the US was made back in 1922 and you can actually see this here, if I could get the arrow up on the screen, and I'm not able to do that. Or am I? Hold on. There we go. Now, I have it. This is the first audiometer in the US back in 1922. It's interesting because this was only an air conduction audiometer but it did have masking capability. It was $1,500 back in that time. In today's dollars, that would equal about $23,000. 25 were sold in 1922. Soon thereafter, the audiometer shown below was manufactured and introduced commercially in 1923. It did not have bone conduction. That didn't come around until 1928. At the time, there were no published reference levels for calibration so everything had to be done psychoacoustically with normal listeners. It wouldn't be until 1936, when over 4,000 otologically normal hearing subjects were tested under the control of the US Public Health Service that audiometric zero was established. It was the data obtained in that survey that was used for the first published standard which came out in 1951 by what is now known as the American National Standards Institute. So, I want to quickly go through the three modes of bone conduction hearing, kind of a review of back in the days of Audiology 101. It's worth recalling the fact that there are contributions from the air conduction pathway when stimulating the bones of the skull, particularly if the bone conduction oscillator is placed on the mastoid bone. So, the first one we're gonna talk about is the compression, and what also is known as the distortion mode. Of course, we all know that when you vibrate the skull at either the mastoid or forehead location, you will also vibrate the temporal bone creating movement of the perilymph fluid in the cochlea due to a pressure differential that exists within the inner ear. For many years, it was thought that this pressure differential was exclusively due to the high elasticity of the round window.

But in the 1960s, it was determined that the fluid in the vestibule and semicircular canals also contributed to this pressure differential, almost like a third cochlear window. In fact, it may have a greater impact on the process than the round window. A researcher by the name of Tonndorf had experimented with cats by occluding both the oval and round windows and revealed that the bone conduction hearing was only slightly impaired. The compression mode of bone conduction dominates the frequency range above 1,500 hertz. The inertial mode is based upon Newton's first law of motion. It contributes to hearing via bone conduction stimulation due to the anatomy of the ossicular chain and it's supporting ligaments. The ossicles, as you know, are suspended in the middle of your space by ligaments and attachments at the TM. As a result, the ossicular chain vibrates independently of the skull. Therefore, when the skull vibrates, the ossicles will move in response but they lag behind the skull movement. When the ossicles do move in response to this vibratory stimulus, the stapes footplate will move in the oval window creating traveling waves in the cochlea. This is the normal mode of air conduction hearing. Therefore, bone conduction hearing does not totally bypass the middle ear and, in this case, this mode of bone conduction hearing is most dominant in the mid-frequency range but does have some effect on the lower frequencies as well. And the final mode involves the osseotympanic mode and this is the occlusion effect, essentially. When testing by bone conduction, with the non-test ear occluded with an earphone or with an insert phone, occlusion effect will occur. It will lateralize to the side of the occluded ear in the low frequencies, from 125 to 1k, and enhance bone conduction hearing levels. If the ears are not occluded, this low frequency acoustic energy will leak out of the ear and not enhance the bone conduction thresholds. So, the bottom line is that bone conduction hearing does not totally bypass the air conduction pathways, as we were told early on in our audiology training programs. We're always taught that bone conduction is simply a measure of cochlear reserve and, in many cases, we now know, or we have known for years, that that is not completely true and it does have an impact, and may have an impact, on bone conduction thresholds to some degree.

So we have to also talk about calibration, of course, and the impact that accurate calibration and some of the variables have, in terms of making sure that your audiometer is calibrated to the standards that are published. As mentioned earlier, the first audiometer calibration standard came out in 1951 but did not include any values for testing bone conduction. The reason was that there wasn't any device available at the time that could accurately assess the output of the bone vibrator or measure the force levels, the vibratory force levels, that were generated. Soon after that 1951 standard, audiometric data collected in the UK and Japan showed that there was a 10 dB better threshold level being measured than compared to that survey that was done in the US in the '30s. So, another survey was conducted in 1954 in the US and the results agreed with those from the 1930s again so everybody was a little bit concerned about that. So they did a third survey, this time changing the methodology used to establish threshold. These results, interestingly enough, agreed with those from the UK and Japan and were felt to be a result of a better test technique. The ASA standard was not changed until 1969 but in 1964, the ISO, the International Organization of

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Standardization, published an audiometer calibration standard based on the UK and Japan. Many audiometers in the US and other parts of the world were now calibrated to this new standard although some continued to use the 1951 standard. In 1969, a new standard came out from ANSI that was published that was similar to the '64 standard and since then, air conduction values have changed very little, with the exception of the fact that we've added insert phones and circumaural headphones to the list of approved air conduction transducers. So, the focus of this presentation, of course, is to talk about the air-bone gaps that we measure, both positive and negative, that we have a little bit difficult time explaining. It's also necessary though, as a result of that, since we're comparing air and bone, that we briefly review air conduction calibration for air conduction transducers.

Of course, just like hearing testing, proper technique and accuracy is imperative when calibration is being conducted, with proper equipment and proper training of the technicians providing this service. Interestingly, I rarely get phone calls about air conduction calibration. Usually, the calls are all about bone scores or the bone vibrator being out of calibration but you can't ignore the air conduction calibration values. These could be affected in a negative fashion because of changes that may have occurred in the calibration over time. So, we can't assume the air conduction calibration is status quo. There may be cases where air conduction is changed and bone hasn't, although I will tell you that it's much more likely that the bone oscillator drifts out of calibration over time compared to those air conduction transducers. Different calibration values are used for air conduction transducers that can also vary based upon the type of coupler being used and, if you take a look at this slide, you will see the current ANSI values for calibrating air conduction transducers with two different types of couplers, and if I can get my arrow back on the screen here. So, in the three columns that you see here, these address the three different, or actually four different types, if you consider the TDH 49 and 50 two different styles. But the three main different types of supra-aural headphones. These are the models and the values that are used to calibrate each of these is based on using a coupler that is identified as the NBS-9A. That's the National Bureau of Standards 9A, and then an International Technical Committee coupler designated as, what we call, the 318-3. Notice the different values for each of these and then, you'll also see that in the case of this 318-1, you can calibrate all four of these supra-oral headphones to these specific values because, in this particular case, this is referred to as an occluded ear simulator, as opposed to this being more of simply an acoustic coupler. It's getting into a lot of technical mumbo jumbo but, when we go out to calibrate, and this is certainly something you need to be aware as consumers, it's not a bad idea to know a little bit about what types of hardware that your technicians are using to calibrate your equipment and don't just assume that everything is being calibrated exactly as it's defined within this standard.

So, it's important to be aware of these things. This slide should be familiar to everybody in audiology. These numbers that you see here in red represent the audiometric threshold and sound pressure level that are generated for which we base the zero dBHL level on. So, in this particular case, should have left my arrow here, the audiometric threshold, the average audiometric threshold at 1,000 hertz is 7.5 dBSPL. That becomes zero dBHL on our audiogram so if you, for example, would set the dial, your dial setting of your audiometer at zero, as I said, on your audiometer, and we were measuring the output of the supra-aural headphone at that frequency, the measured value should be 7.5. When calibration is actually conducted, however, the dial setting of the audiometer is set to 70 dB as we eliminate the influence of ambient noise levels. So, our reading on the sound level meter should be 70 dB plus 7.5, or 77.5 dB. That, of course, assumes that the linearity of the attenuator is in line with what it should be. In the next slide, we're gonna take a look at the two most commonly used couplers for supra-aural and circumaural headphones. This is that NBS-9A I referred to with a supra-aural cushion placed on top of it. This weight is to mimic the headband tension. Over here on the right is a coupler that is used to calibrate and check the output of the insert type of earphones. This is similar to a hearing aid style or hearing aid test box style 2cc coupler. What's important to know about each of these is that the volume of air that exists between the diaphragm of the earphone and the end of the sound tube here is supposed to mimic the volume of air that exists when it's placed in the human ear and that's an important factor to consider because the goal is to try to replicate the acoustic impedance of the ear across the test frequency range. Unfortunately, neither of these couplers do so. Nonetheless, the ability of these two couplers to have repeatable results is very high and that is what is certainly needed in terms of calibration, is a coupler that you can use that you know will not impact the measurement capabilities so that we can get reliable and repeatable results. Bone conduction calibration is a process that's a bit more challenging. The technique requires more precision and frequent accuracy checks of the mechanical coupler, that we refer to as artificial mastoids, to measure the force levels of the bone vibrator. The first published standard for bone conduction came out in 1972 and it was based on an artificial mastoid manufactured by Beltone. That has long since disappeared from the market.

The second calibration standard for bone came in 1981 based on the B&K 4930 which continues to be used today for bone conduction calibration. The performance of the couplers used for this purpose are affected by temperature and humidity. Therefore, it's imperative that checking the output of the bone oscillator be conducted after the coupler has been allowed to adjust to the temperature and humidity of the area where the calibration takes place. In the case of one coupler, a temperature and humidity gauge is used to provide current readings for the technician. This improves the accuracy of the measurements. Here is the current bone conduction standard and you'll notice that we have a column for mastoid placement and forehead placement and then the difference between the two but the thing that I wanna point out in this slide is the fact that, if you look at the relationship between the values at each octave starting at 250, so going from 250 to 500 to 1,000 to 2,000, there is a pretty systematic decrease in the threshold. So it actually averages out to be about 12 dB per threshold, except when we go to 4k where there's an increase of about 4.5 dB, and this is the basis that some use to question the accuracy of the 4,000 hertz calibration value for bone conduction but we're gonna talk about that a little more later on in the presentation. One other point to make with respect to the bone conduction calibration values, these were all measured in the presence of 40 dB affected masking presented to the contralateral ear. It's important to keep this in mind if you're conducting psychoacoustic or biological checks on your audiometers for bone conduction thresholds to monitor the output between periodic physical calibrations. I recommend to all of our accounts that these measurements be conducted with the contra masker at 40 dB affected masking for a true apples to apples measurement. While the potential effect of central masking is limited and generally no more than average test/retest reliability, it is worth conducting biological checks for bone with contralateral masking being used.

Next, we're gonna take a look at the two artificial mastoids that are most commonly used now by most calibration technicians. The B&K 4930, which is over here on the left hand side of the slide, is considered the gold standard of artificial mastoids and has been around for about 50 years. It did undergo a modification in the mid 1970s and some actually believe that this is a contributing factor to this issue of the 4,000 hertz calibration standard. It's a heavy device to cart around and it must be handled with tender loving care. The Larson-Davis artificial mastoid, which we refer to lovingly as the hockey puck, is a small circular disk coupler that is placed on the opening of the 6cc coupler as you see here. Unlike the B&K, which measures force levels or vibratory force levels that are then converted into an electrical signal and then sent to the sound level meter, the Larson-Davis unit actually measures the acoustic output of the bone vibrator which is then sent to the sound level meter through the standard microphone placement in the coupler itself. Both of these attempt to replicate mechanical impedance of the human head. Some believe this is not necessary based upon what we know about the couplers we use for air conduction and, again, the most important thing that you can have is a stable and accurate device that allows for repeatable results. Okay, so enough of that stuff. So, let's talk about some of the variables from a technical standpoint that you deal with every day, in terms of the impact it can have on bone conduction threshold measurement in general and in the resultant air-bone gap and I didn't mention at the beginning of the presentation, if you do have questions that come up during this, feel free to type them in. I'll do my best to keep on eye on that part of the screen and, depending upon the question itself, I may choose to respond at that point or wait till the end. So, here we go. So, positioning of the bone oscillator. Everybody knows how important that is and it can be a challenging and frustrating process. Different patients present with different head sizes and shapes and, for the most part, we use a one size fits all bone oscillator headband.

Of course, the goal is to find the most prominent point on the mastoid, carefully place the oscillator and just hope it stays there. In some cases, it can slip from the location initially selected and when it does, we may not know that it did until testing is over and that could have an adverse effect on our bone conduction threshold, making it poorer than if it remained in the preferred location. Occasionally, as you probably all have had to do with smaller heads, you might have to rig the headband by wrapping cloth or packing foam around the center top of the headband so that it fits properly on smaller heads and, again, you know, standard operating procedure is keep hair out of the way, don't let it touch the pinna, etc. The next point is the issue of surface area or contact area with regards to the oscillator itself and the mastoid process. So, a little history here. Back in the day, and sadly to say, when I was doing audiology, we were using the B70A bone vibrator, which you see here. You can see that one of the differences between what we have today and what was back then is that the contact surface area actually was flat, sort of. There was a little bit of a curvature to it that you can probably pick up and it was designed in this way to deal with the fact that the mastoid bone is not essentially flat. But there was an effort to promote contact area that was more uniform across subjects, which this one was not and so, what came out next was called the disk style bone oscillator with this protruding circular disk which is still in use today, of course, as you all know. Within the last few years, there's been a new model introduced and that is the B81. It is capable of producing higher outputs with less distortion, which I'm gonna show you in the next slide. It looks essentially the same as the B71, meaning that it has this protruding disk but the contact area you have between the oscillator and the mastoid process, or wherever you're testing, is certainly a very important variable. So, real quick. If you look at this graph up here, we're showing the maximum output of the B81 in blue compared to the maximum output of the B71 in red. So you can see that you can get a lot more output now, a lot more maximum output from your bone oscillator than you could previously. In addition to that, and this is actually compensated, so the reduction in distortion is actually more dramatic than this slide shows but there's a drop by 25% of the distortion levels in the low frequencies at 250, and then 5% at 501.

So that's the reason why we can get these higher outputs and it all has to do with the manner in which this new bone oscillator is constructed. Now, here's an interesting variable. Everybody knows that headbands for bone oscillators and headbands for air conduction transducers are supposed to have a certain amount of force or pressure applied when you put it in place to do hearing testing. It actually gets into really significant detail in the ANSI standard. There are many articles that have addressed this issue of headband tension, both for patient comfort, as well as the effect it has by varying the force related to the accuracy of bone thresholds. ANSI and ISO both recommend a static force of about 5.4 newtons be applied. Now, if you Google this and ask what is that in pressure, it comes out to be about 510 grams, even though if you look in the ANSI standard and the ISO standard, they define the amount of pressure at 5.4 newtons but say that 400 grams is acceptable. For those of us who are metrically challenged, which I am, 510 grams equals about 1.1 pounds of force. There doesn't to be much real documentation about why this number was chosen, although in an article by Toll and his colleagues, they suggest that Von Bekesy's work in the 1960s probably is where that came from. Also, in that same article, these folks looked at the effect varying the static force would have on threshold measurement and discovered that it had very little. In fact, using force levels ranging from 2.4 newtons to 5.4 newtons, only generated a difference of plus or minus two dB, which they felt, and they calculated, statistically was not significant. They also considered patient comfort and not surprisingly, found that the standard BC headband, which is a model P-3333 was quite uncomfortable for their subjects. A study in 1986 by Lau and others revealed that a static force of 6.4 newtons was considered painful by most of the subject in their study. It seems that a force less than 5.4 newtons would have little effect on bone conduction thresholds and make it more pleasant for the patient. The next two slides I'm gonna jump through pretty quickly.

You'd be able to go back and look at these but we're really comparing here the vibratory force of the oscillator on an artificial mastoid for the two different models shown here and you can see that the difference in the vibratory levels measured by the artificial mastoids were essentially insignificant for the two different force levels applied. The next slide is data generated from the Toll article. These are actual threshold measurements from patients with four different force levels at each of these frequencies and you can see the pattern is followed very, very nicely with very little difference. So, force level doesn't seem to be as big a deal as we once thought, certainly on the basis of this data that's presented here. Next variable in day to day testing, of course, is the occlusion effect. We all know about it. We all know the impact it has on bone thresholds at 1k and below. It's probably nothing new also to you that supra-aural headphones create the largest occlusion effect, with insert phones pretty close with standard insertion depth. If you insert the foam tip deeper, down past the cartilaginous portion, it does eliminate the occlusion effect based on data that's out there, but this is generally not practical and it can be uncomfortable for your patient. Circumaural headphones, which a lot of us refer to as high frequency phones because for years, we were only using them to test extended high frequencies above 8k, they have little or no occlusion effect in the lower frequencies. They also now can be calibrated to the audiometer across the entire frequency range and of the three transducers available, the circumaurals are the only transducers, as I said, that can test that entire range. The next slide is showing the measured occlusion effect in two different conditions. One is actually measuring it with a probe tube placed in the ear canal with an occluded and unoccluded ear canal for the three different types of transducers, and then, a full insertion depth, and I keep forgetting about this green arrow, folks, I'm sorry. So, full insertion depth here. Partial insertion depth here. You can see that the numbers for occlusion effect are significantly higher for the supra-aural headphone and much less, if not nonexistent, for the circumaural headphone and then, finally, this is measured values, measured thresholds, or a measured occlusion effect with an occluded and unoccluded ear but measuring actual threshold as a result.

And then, we have the issue of accurate air conduction thresholds which, as you all know, can be impacted by improper placement of supra-aural earphones, not getting 'em right over the opening to the ear canal, the issues of collapsing canal. In addition to that, insert phones can be impacted by not getting a good acoustic seal with the foam tip and, if you do have a breakage in that acoustic seal, you're gonna be venting off low frequencies in much the same way you would by venting a hearing aid ear mold or custom hearing aid. We already mentioned that deep insertion does reduce that but that's not very comfortable. So, in a lot of ways, when you look at the circumaural headphones, they are very attractive as an alternative to both the supra-aurals and the insert phones for testing all audiometric frequencies. One thing I wanna mention is about earphone cushions on supra-aural headphones. These look pretty bad up here in the upper left hand corner and these are not used as frequently as they used to be. These are the MX41/ARs. There are cracked and are probably much harder than the cushions are when they're brand new. You can see new MX41 cushions here. These

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need to be replaced. When our technicians go out to do calibration on an annual basis, unless there's a strong objection from the audiologist, we like to replace these yearly. They're really inexpensive and the impact they can have on low frequency thresholds, if you're still using supra-aurals, is certainly not worth the idea of not spending a little bit of money to replace them. And then, down on the bottom here, you see the most popular model of cushion that's being used today which is the model 51 but they can also become cracked and hardened over time with continual use. Okay, moving on here. Coming back to this slide that we looked at a little earlier, I just wanna make one point about this that I wanna emphasize again as we move into our next topic and that is these numbers. These numbers are averages and like averages, in order to get to an average, you have to have the individuals in your population test at higher values and lower values. So, the question is not just what the mean is, or what the average is, but what is the standard deviation about this mean, which leads us into the discussion about normal variability in air conduction, bone conduction, and air-bone gaps.

So, everybody, oh, the transitions here are a little slow. I apologize. Everybody knows what this is. This, of course, is a bell curve and this represents a normal distribution of randomly collected data from a sample population. Air conduction, bone conduction thresholds and the resultant air-bone gaps are independent and they are normally distributed variables. If you understand the bell curve and how it relates to hearing threshold, it provides a way to categorize air and bone thresholds as being within normal limits or not. We all know that, in general terms, if you're within plus or minus two standard deviations of the mean, you're gonna be in that 95% of the population, and we use that range to determine whether our test results are certainly considered normal or not. If we knew the mean of the hearing threshold level at 1k, which obviously would be zero dB, and we also knew the standard deviation, then we would be able to predict what the range is and we would be able to predict what percentage of our patients would fall within that range. In hearing testing, as I said, zero dB is set as the average at all frequencies but the variability might be smaller or larger than some frequencies compared to others. If the standard deviation is five dB at 1000 hertz, then two standard deviations would equal plus or minus 10 so our range of normal would run from minus 10 to 10 dB and, in general, that would mean that 95% of the population would test between that range with regards to being normal hearing. Bone conduction thresholds are more variable than air conduction thresholds. They're both independent of one another. In other words, the distribution of those two measurements do not depend on the other measurement. Air-bone gaps are the differences between these two normally distributed but independent variables and since they are independent, it is not possible to accurately predict these air-bone gaps on the basis of air and bone conduction values within the normal population. Back in 1967, Studebaker was one of the first to address this issue of air-bone gaps as a normally distributed variable. Using an assumed five dB standard deviation, you can predict with accuracy what percentage of normal hearing and sensorineural hearing loss population will have air-bone gaps of specified values, and that's an important point.

We're not talking about patients or subjects that have a middle ear disorder that generates a conductive loss or a mixed loss. We're talking about how this applies to normal hearing or sensorineural hearing loss patients and why we don't get air conduction or, excuse me, bone conduction values hitting air conduction. In Studebaker's study, which you'll see on the next slide, 38% of the normal hearing or sensorineural loss patients will have a least one frequency, excuse me, will have at least one frequency with a zero dB air-bone gap. So, let's take a look at the data that he found. So, very quickly. If you look at this, ah, let get me that pointer on again. If you look at this column over here, this is the measured air conduction minus bone conduction relationship. So, negative values represent conditions where the bone score was worse than air. Positive values where the bone score was better than air and then he defined ranges into which he categorized all of the results. So, if you look here at the middle, anybody who has a air-bone gap of zero falls into this range which will occur 38% of the time. Patients then will have, there will be an equal number of patients or results that will fall in the negative direction and in the positive direction. So, for example, if you get a bone score worse than air of 10 dB, in Studebaker's data, we would expect that to occur 6% of the time. In the same sense, in a non-middle ear patient, that is, normal middle ear function, you would expect to get a bone score better than air of 10 dB or greater approximately 7% of the time. If the numbers that you have in your practice don't fall within this range, then it's certainly reasonable for you to be skeptical and start thinking about is there something inaccurate with the calibration or, before you get to that point, you might wanna think about looking at other variables that could be creating and contributing to these measurements that fall out of this normal distribution that Studebaker found here. So, with all this being said, there remains some other variables that can affect the pure tone air and bone thresholds. Those that will potentially have similar effect on air and bone levels include: the sensorineural sensitivity, the patient's attention level, fatigue level and experience, and how about time? Many of you are probably in very busy practices and you have very little time to do a full audio assessment.

So, it is conceivable that the accuracy of the thresholds may not be quite as reliable when testing is done under duress of obtaining the results as quickly as possible. I can remember my experience many years ago, in a very, very busy ENT practice, that we generally needed to do air, bone and speech measurements in about 10 minutes. So it was really difficult and we were kind of trying to get as close as we could to threshold. We were good at it, and I'm sure you all are as well, but it may have an impact on test/retest reliability. Variations of head size and shape, thickness of skin, normal anatomical variations in the external auditory canal, in the middle ear system, and many of these variables are out of our control. So far, the variables that I've discussed, both technical and non-technical, they can influence measurement of the thresholds, air and bone, as well as air-bone gaps that occur as a result. So, now, what I wanna touch upon are two other variables, one non-technical and one technical, and they are the tester bias issue and the 4,000 hertz calibration value. Tester bias does exist, in scientific research, in clinical measurement, that require interpretation and they're manifested in many different ways, including the three that are displayed here on this slide and I can't seem to get my pointer. So, confirmation bias, diagnostic, and previous opinion bias. All of these can enter into interpretation when you're doing scientific research or clinical measurement. Test bias occurs during measurement of bone thresholds. No matter how much we as audiologists believe that we won't be influenced by patient history, previous test results, a physician's exam, or other test results, including the air conduction thresholds, that won't influence our decision making, they very well may do so and some of it may not be conscious decision making. The issue of tester bias was addressed in the literature, again, by Studebaker back in 1967, with respect to bone scores being worse than air and concerning the theory that bone cannot test worse than air because a loss in the part of the peripheral system cannot exceed the whole system.

He states, and I quote, "fails to take into consideration the very real subject "of measurement variability "and implies an exactitude of measurement "which cannot be achieved in practice." He goes on to state that those who review these modified audiograms, and what he meant by that is adjusting the actual thresholds to not show bone scores worse than air, so not reporting what is actually measured, become even more convinced that bone cannot be worse than air and the circle is thus completed. Many physicians don't understand, many physicians don't understand the variability that exists when measuring air and bone thresholds and the resultant relationship between these two variables, the air-bone gap. Therefore, if we fudge the data so as not to have our competency questioned by a physician, we are reinforcing the notion that bone scores cannot be worse than air at any time. Continuing with some of the Studebaker data, he clearly demonstrated that, not only can bone occasionally test worse than air, but that you can predict it, which we've already gone over. Many audiologists aren't comfortable reporting bone worse than air and I just spoke to one actually the other day. One of the concerns is their accuracy is being questioned, their competency is being questioned and if they're told that these types of things can't happen, then it might cause them to record the bone score at the level of the air. Margolis and colleagues reviewed audiometric test result databases at five different centers. The analysis included 2.4 million threshold determinations from approximately 722,000 subjects. Three of the five database sets used manual testing. Two other database sets used automatic threshold testing. An analysis of an annual result showed an under-representation of negative air-bone gaps suggesting that these were not being recorded as measured. This figure that you see here shows the distribution of air-bone gaps at five frequencies from a dataset obtained via manual audiometry which are these dashed lines, versus a normal distribution obtained through automated audiometry. You can see that the variability is less using the manual method and the distribution is skewed in a positive direction, particularly here at 4,000 hertz. Not too many negative air-bone gaps.

You can also see that the percentage of zero dB air-bone gaps is much greater than Studebaker predicted. Margolis compared air-bone gaps obtained from 10 patients with normal hearing and that with sensorineural hearing loss and that's going to be displayed here. In the slide on the left, these are estimates of the variability of air and bone conduction thresholds after assessing duplicate audiograms from two different audiologists on the same patients. Standard deviations of five dB and seven dB were used for air and bone conductions respectively, bone conduction thresholds respectively. The figure on the right shows the predicted air-bone gaps, both positive and negative, that would have occurred as a result. In this case, you can see that a zero dB air-bone gap is only occurring about 21% of the time in this study. That is much different and much lower than that of Studebaker. You can also see that positive and negative air-bone gaps of 10 dB occur approximately 22% of the time when combined and 15 dB more about 16% of the time. Now, granted, this was a smaller population than used in the previous studies but you can still see that we would expect pretty much an equal number of positive and negative air-bone gaps to occur. So, what happens if you occur air-bone gaps obtained through manual audiometry with those obtained using the automated method? So, if you look at the next slide, actually I'm sorry this is not the case. This is looking at, first of all, this is the previous slide. This is the same that appeared on the previous slide. The figure on the left compares the distribution of air-bone gaps obtained on 11 patients via manual testing with sensorineural hearing loss, and this was done by an experienced expert audiologist. The squares are those obtained by the audiologist here compared to the predicted levels here and, again, you see a much higher percentage of zero dB air-bone gaps and a skewing to the positive direction of air-bone gaps with very few negative air-bone gaps in this case. The next slide will show a comparison of air-bone gaps obtained with manual audiometry, that's presented here in the maroon color, with automated audiometry in the purple color. With the exception of 1,000 hertz, the automated procedure yielded larger air-bone gaps compared to thresholds obtained manually. Is this tester bias? Some believe it is.

Of course, if you look at 4,000 hertz, the air-bone gap measured here, both manually and in the automated format, have many audiologists, physicians, and calibration technicians scratching their heads on a daily basis. More on that in a few minutes. So, to summarize tester bias and the air-bone gap. Margolis' study in 2016 with several colleagues confirmed the findings of Studebaker nearly 50 years earlier that air-bone gaps are a normally distributed measurement affected by two other independent measures with normal variability. What is also revealed is that tester bias does seem to influence the reporting of audiometric test results, especially bone conduction thresholds. Audiologists are much more likely to report bone conduction thresholds, to inaccurately report bone conduction thresholds, when they don't seem to match up with expectations and others are questioning the accuracy of the testing. This can lead to misinterpretation of the results and perpetuate two myths: that bone conduction testing should equal air conduction in cases of normal hearing and sensorineural hearing loss, and that negative air-bone gaps don't occur. For many reasons, recording of thresholds as measured should never come into question and just one more comment about this presumed idea of tester bias. With the use of automated methods for performing air, bone, and speech testing increasing, the implication of that is that users of these automated systems will have to reset their expectations to reflect the true variability of threshold measurements, unaffected by tester bias. This will most definitely be a learning curve involved in this transition. So, let's take a look at this audiogram. Probably similar to audiograms you see on a fairly regular basis. Most of us would expect the bone score at 4,000 hertz to equal that there. And I'll get this over here. So you can see we have mask thresholds for bone showing air-bone gaps only at 4,000 hertz. Interesting, you see here a bone score five dB worse than air which we would expect to see about 24% of the time in a normal hearing and sensorineural hearing loss patient based on the data that we've already covered. Unexplainable air-bone gaps at 4k is the source of much head scratching, as I said, and the number one reason we receive calls about bone conduction calibration.

I can't tell you how many times I've got that call about, "There must be a problem "with my bone oscillator "because I'm getting these air-bone gaps at 4k "that I can't explain." Observation suggests that this started back after the 1981 standard was released when it was using the B&K artificial mastoid and whether these numbers were based on the modified version or the one prior to the modification. This has led some to believe that the issue is a result of inaccurate reference threshold, an inaccurate calibration value. Early on, there was concern that this anomaly was secondary to acoustic radiation from the bone vibrator so that the patient was actually hearing the signal via the air conduction pathway. Collapsed canals was another possibility. However, when insert phones became more popular, this phantom air-bone gap continued to appear. It's not inconceivable that the bone vibrator has drifted out of calibration. Those things happen, we know that. Of the transducers in use today, it is by far the most fragile. Considering that on any given day, it is placed on and off a patient dozens of times, it will be jostled about, bumped, and occasionally dropped. That can certainly change the output at one or more frequencies and that is why it is important, and I keep stressing this, it's important to monitor the bone vibrator via biological testing and listening checks between physical calibrations. So, let's take a look at this in a little more detail. Collapsed canals, I think that most of us know that collapsed canals can be problematic with supra-aural headphones and you probably have experienced this in your career, mostly at 4,000 hertz. Collapsing ear canals do not happen when using insert phones or circumaural headphones. The use of these latter two types of air conduction transducers solved the problem of the unexplained air-bone gap. So, we don't think collapsed canals is causing that phantom air-bone gap. What about acoustic radiation? That idea, the idea that an unoccluded test ear's bone conduction thresholds could be enhanced through air conduction pathway by acoustic radiation from the bone vibrator has been investigated in great detail. Many studies comparing bone conduction thresholds with and without the test ear occluded showed that there was little or no change in the bone conduction threshold between the two conditions, and with the advent of insert earphones, the unexplained 4,000 hertz air-bone gap remained. But the two graphs shown here, the two graphs shown here offer compelling evidence that acoustic radiation does exist but, at the same time, doesn't enhance the bone conduction thresholds.

So, real quick. The top graph here shows, and if you ignore everything below 2,000, the top graph here, in green, shows the measurement with the ear occluded, and the bottom graph with the ear unoccluded and you can see that, or excuse me, I have that reversed. The top graph with the ear unoccluded, the bottom with the ear occluded. This is done on a probe microphone system. It is measuring the SPL in the ear canal with and without occlusion, and you can see that there is a definite impact of acoustic radiation being picked up in the ear canal. When you move the oscillator up to the forehead, there's still a little bit of acoustic radiation but significantly less but, again, regardless of what we're seeing here with mastoid placement, the bone conduction thresholds don't get any better. So acoustic radiation, probably not the cause of the 4,000 hertz air-bone gap. What about the calibration? This is kind of like the elephant in the room. Several well known researchers in our field and including Dr. Robert Margolis who has published extensively on this and also happens to be a member of the working committee, questions the accuracy of the 4,000 hertz calibration value. He and his colleagues make a compelling argument. Part of his argument is based upon research that was done in the '50s that showed a systematic reduction in bone conduction threshold as frequency increased, and you can see that here. If you look at this dark line, this is from a study in the '50s by Corliss and colleagues that showed a systematic, again, reduction in bone conduction threshold as a function of frequency. The dash line that you see which is perfectly straight is the minus 12 dB per octave line, and finally, or I should say the dotted line, the dashed line, represent the force levels that are part of the ANSI and ISO standard, and everything is pretty consistent until you get to 4k where the reference value and the standard is 14.1 dB higher than what is reported in the Corliss study back in 1959.

This reduction in threshold, which, again, occurs at a rate of 12 dB per octave, means that as you increase frequency from one octave to the next, the amount of force level to reach the bone conduction hearing threshold decreased at the same rate. But if you look at the calibration values, again, you can see that that's not the case. If this systematic reduction is applied to 4,000 hertz, the calibration value in the standard, the ANSI and ISO standard, should be 21 dB but it is 35.5. This inconsistency in the documented roll off could be contributing to the unexplained air-bone gap at 4,000 hertz in some cases. The figure on this slide shows exactly that, in terms of the relationship between this roll off and this standard. So, now that we've explored these things and, in this case, I put a question mark because I'm not sure whether this is the reason but, as I said, there are some compelling, there is some compelling evidence that this definitely could be contributing. So, what do we do as clinicians? Well, we could do nothing and just follow the status quo but this might require some education of your physician colleagues that you work closely with so that they don't begin to question test accuracy and your competence. You can maintain the calibration, as defined by the ANSI standard, and use a correction factor but that is similar to the next suggestion which would be to ask your calibration vendor to adjust the force level at 4,000 hertz to compensate for the presumed difference that exists. But this could be problematic with regards to meeting federal and state regulations if you are working under those guidelines. Or you may simply decide not to test bone at 4,000 hertz. None of these are ideal but under the current circumstances, these are the only options. New normative data for bone thresholds could be collected and submitted to ANSI and ISO for review and to consider changing the 4,000 hertz RETFL. There has been talk of trying to do so. So, the dreaded 4,000 hertz air-bone gap does exist. It could be secondary to a conductive loss. It's unlikely, if there aren't other air-bone gaps on the audiogram, that 4,000 would be strictly related to a middle ear disorder but there have been suggestions that changes in middle ear transmission properties can reduce air conduction thresholds secondary to the loss of inertial bone conduction, but there doesn't seem to be agreement on that.

Finally, studies have shown an increasing air-bone gap as sensorineural hearing loss increases at 4,000 hertz and I'm gonna show you that here. So I have two graphs here. One shows changes in the air-bone gap as the hearing loss increases. You're looking at this along the X axis. This is the amount of air-bone gap on the vertical axis. Very little difference from normal hearing to a moderate degree of sensorineural loss but look at 4k. Look at the air-bone gaps that exist in subjects who had a five to 10 dB hearing level, it was about 10 dB on average, and as you increase the hearing loss, again, sensorineural hearing loss, you're up to 22.1 dB at 4,000 hertz. So, it does seem to suggest that, as one hearing level increases or becomes poorer at 4,000 hertz, there is a much higher probability that you're going to see an air-bone gap at that frequency. It doesn't seem to affect the lower frequencies in the same way so very interesting in terms of the data that has been put out there about this ongoing concern. Finally, I wanna get to mastoid versus forehead placement. Colleagues of mine know that I'm an advocate for forehead placement for a variety of reasons. Many early studies regarding bone conduction promoted the use of forehead placement over mastoid for a variety of reasons, yet, widespread placement of the bone vibrator on the forehead never caught on. In fact, over 90% of the audiologists in the US use mastoid placement for bone conduction testing. Recently, there has been renewed interest in forehead placement for two reasons, publication of RETSPLs for the circumaural headphones, which I've already mentioned, and an increase in the use of clinical, automated audiometers for performing air and bone conduction tests and, since there may be times when mastoid placement is advantageous, today's clinical audiometers will hold RETSPLs for both mastoid and forehead placement. All it takes is a quick button push or mouse click to change the calibration values applied. So, what are some of the advantages of forehead placement? Well, there's a larger surface area. We don't have to be as concerned about a slight shift in the bone conduction oscillator in terms of what effect it will have on threshold.

There's better test/retest reliability. There's reduced intra-subject variability and there's less contribution from the middle ear and the issue of acoustic radiation is pretty much not a concern even though we've debunked the idea that it even has an effect. Some of the more practical reasons for doing it include the fact that the occlusion effect is eliminated, you can position the circumaurals on both ears when you're testing bone which means you don't have to go back in, in between ears, when you're doing bone testings to switch the oscillator over to the other mastoid, which certainly saves time. Looking at this graph over here to the right, or this chart, you will see that, in this particular case, this was a study comparing bone thresholds for five male and five female normal hearing subjects, and two males with sensorineural hearing loss. These are standard deviations comparing bone vibrator location of mastoid and forehead at five frequencies average for both ears for male and female subjects. The two bars on the far right report an overall standard deviation for these results not specific to gender and not specific to frequency. As you can see, the standard deviations are essentially the same with some minor differences between location by frequency. When time is an issue, forehead bone vibrator placement with circumaural headphones may certainly be worth considering. Okay, that brings us to the end and I wanna open this up to any questions at this point. Unbelievably, I got that done in an hour which up until this morning, in my rehearsals, I haven't been able to do so. So, are there any questions that you have at this point? I'd be happy to do my best to answer them or, if you do have questions and we can't get to them, Audiology Online will send them off to me through GSI and I'll be happy to respond. I have one here: "Do you need to use a leather headband "or a conventional headband for forehead placement?" That's a great question. The automated system that is being used right now uses a Velcro headband that has different adjustment site points on it that allow you to meet the requirements for tension that the metal headband is used when you use mastoid placement.

If you Google this on the internet, you will see a product that comes out of South Africa that uses these huge enclosed headphones. They're a little different looking than the circumaurals we use in the US, but they have created an attachment that uses the metal headband that is attached to the top of the headphone band itself. I've also seen folks just use a regular headband that we use day in and day out for mastoid placement where they kind of put it over the back of the person's head toward the occipital area. The only issue with that is, it's more likely to shift and move off of the headband and it's gonna be affected much more by the size of the patient's head. And the actual, that Velcro band that I mentioned to you, actually goes by the name of AMBAND which is spelled A-M-B-A-N-D. That is a commercially available product, by the way. Another question, actually from the same person: "The main barrier to using circumaural "and forehead bone conduction transducer combination "is the lack of circumaural RETSPLs "in the Verifit or hearing aid manufacturers. "Any thoughts on this?" You know, I don't, and actually you bring up a good point and you know, that is certainly a question that I will address to my colleagues at Audioscan. I don't have a good answer but if you email me at slord, or actually, yeah, slord, S-L-O-R-D, @midlantictech.com, spelled M-I-D-L-A-N-T-I-C-T-E-C-H, I will be happy to get back to you with an answer.

- [Laura] We're in?

- [Man] Good to hear.

- [Laura] Hi there, this is Laura Prigge from Grason-Stadler. It looks like Sherman was disconnected so I think that what we'll do is end the course. I do see that we do have another question that is: "How can we monitor changes in the output "of an audiometer for different transducers?" And I think that that is actually, for sure, one of the easiest ways you can do it is biologic testing because otherwise you would have to have the calibration equipment in your office and, you know, a calibration technique for that. So, the easiest and, I think, most practical way to do that would be through biologic testing and that's one of the things that, for sure, is recommended with audiometric testing. Thank you for that question and with that, because we have lost our presenter, I do believe that we will end the webinar but thank you so much for coming and, again, if you have additional questions, please type them into the section in Audiology Online and we will be sure to pass those along to Dr. Lord. Thanks so much. Everybody have a great day.

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