The Case for Incorporation of Wideband Immittance Testing in Newborn and Infant Hearing Screening: Practical and Theoretical Considerations, in partnership with Seminars in Hearing

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- It's my pleasure to welcome for the very first time, Dr. Hammam AlMakadma. This course is presented in partnership with Seminars in Hearing, and we'd like to thank the Editor in Chief of Seminars, Dr. Katherine Palmer. If you'd like to learn more about Dr. AlMakadma, you can read about his bio on the course registration page and at this time I'll hand the mic over to you.

- Hello, good afternoon everyone who's in EST time? My name is Hammam AlMakadma. I'm an Assistant Professor at the Department of Otolaryngology, Head and Neck Surgery, and Communicative Disorders, at the University of Louisville. A little bit about myself. My area of research is actually in this topic, the wideband acoustic imittance. So I direct the Middle Ear Diagnostic Research Lab. As well, I'm the Director of the Newborn Screening Program at the University Hospital, here in Louisville. And so the topic of today's presentation, is very much at the heart of what I do on day-to-day basis, whether it's the service side of things, versus the research side of things. The title of today's presentation is, "The Case for Incorporation of Wideband Imittance Testing in Newborn and Infant Hearing Screening: Practical and Theoretical Considerations."

And so we will talk a little bit about newborns, we'll talk a little bit about hearing screening, we'll talk a little bit about imittance testing, wideband acoustic imittance, and a little bit of related topics here and there, as well. All right, here are my disclosures. I do receive an honorarium from AudiologyOnline, to present today. I'm employed by the University of Louisville, and I don't have any other non-financial relationships to disclose. My research is currently funded, by the William Demant Foundation. The William Demant Foundation is the parent foundation of companies such as Inter Acoustics and GSI, and both of these companies dispense, or provide wideband acoustic imittance test equipment. And though I don't have any relationship, or this presentation, is not specifically focused on any of those products, I do wanna disclose that.

All right, so here are the learning outcomes. Here's what I would like for us to have achieved, by the end of this presentation. When you leave this course, my goal for you, is to be able to describe wideband absorbance, which is the most common wideband imittance measure in normal newborn infant ears. So be able to correct tries, and identify what a normal measurement looks like, as well as being able to evaluate and interpret, when the measurements are not normal, due to obstruction of the sound conduction pathway, which is a common occurrence in newborns, in the first few days of life. Second, to explain how to make appropriate recommendations for rescreening or diagnosis, using the outcomes of both wideband acoustic imittance, and hearing screening tests.

So from the title of this presentation, I'm suggesting that we should include a wideband test, along with the newborn screening testing. And so this will very much inform the way we make recommendations, and will improve outcomes of EDHI. And finally, to discuss the importance of some quality assurance techniques, such as how to ensure that you have a good acoustic seal, and that your measurements are artifact free. Okay, so in order to achieve these outcomes, we will cover a number of topics. First, we will sort of establish our context or a topic area in newborn hearing screening and EDHI programs, and why evaluation of the conductive pathway, is of particular interest to those programs. Then we will review imittance testing for this population, for newborns, and discuss why tympanometry, for example, is not a suitable test.

And then introduce our main test of interest, which is wideband imittance, as the suitable alternative. Before proceeding to discuss about clinical norms and clinical assessment and interpretation, we will need to revisit some topics in acoustics, and middle ear physiology. So a little bit of theoretical discussions there, specifically how the middle ear process sound, at different frequencies, and the underlying physical characteristics, that determine that. With just a quick sort of hint here, tympanometry

typically assesses one frequency, but our ear processes sound, at all the frequencies that we hear. And so wideband imittance testing, actually allows us to make inferences about that. We will then proceed, to discuss wideband immittance measurements, and dive into our clinical assessment, and clinical interpretation.

We will cover practical considerations, including acoustic leaks and other artifacts to look for. And finally, we will circle back to newborn hearing screening, and demonstrate how wideband immittance outcomes, together with the hearing screening outcomes, will lead to improved UNHS, and EDHI program outcomes overall. All right, so let's start with the big picture. The objective of the Universal Newborn Hearing Screening Program, is to identify infants, with permanent congenital hearing loss early on, and once the infants are identified as having hearing loss, the goal of early hearing detection intervention, or EDHI programs, are to diagnose the type of hearing loss, and to provide an intervention, or establish an intervention plan, in a timely manner. And the timeliness piece here is very important.

It is well understood that delayed intervention, with sensory deprivation in early stages of life, results in delayed development milestones, in both language, speech, as well as cognitive development. Before newborn screening programs were mandated universally, a lot of babies with hearing loss were delayed, as far as three and a half years, and finally identified by the pediatrician at the pediatrician office. By that time, some of the delays are actually permanent. Infants may be able to catch up a little bit, but never to their normally hearing peers. So the timeliness piece is essential, For that reason, the EDHI program, there's the 1-3-6 recommendation. This is the Joint Committee and Infant Hearing Guidelines. Many of you may be familiar with this.

So what that means is by one month of age, we should identify the newborns that have a permanent, or a suspicion of a permanent congenital hearing loss. And then by three months of age, we will have diagnosed the type of hearing loss. So some kind of either

BR-based diagnosis thresholds. So that allows us to fit hearing aids for example, or determine if cochlear implants are needed. And such intervention plans, should be drafted by six months of age. So when the babies are identified by the system, and they are diagnosed and intervened by six months, six months is usually your milestone or benchmark for a timely effective outcome. In order for all of this to work, we need to identify the babies here.

There are multiple screenings that happen in this one month period of time. There's a screening that happens, possibly the first day of life in the hospital. Typically, a second screening happens in the hospital, before discharge. And if the babies continue to fail the screening, they are invited back to outpatient offices, within two weeks to one month of age to get a third screening. And the reason for that, actually has to do, with the temporary conductive obstructions in the ear. But by two months of age, by one month of age, they will have cleared. And that's the reason we invite all these babies back. So a lot of tracking has to happen, right? You need to bring back all these babies, you need to track them.

There's a lot of retesting and testing. So there's a lot of resources spent. The babies that are then identified have to be invited back to a diagnostic appointment, then to an intervention plan appointment. And unfortunately one of the inefficiencies in the system is the loss to follow up, or loss to documentation piece. It's at 40 to 50% I think, sort of the national average in the US at least. So half of the babies who are identified, or have failed their initial screening at the hospital are lost to the system somewhere in this stage, and then again here, and then again here, so that's a very big inefficiency. One of those factors that complicate this, is related to the obstructions of sound conduction, in the first few days of life.

So this is actually for today's topic. This is a stage of sort of the EDHI program, that we will focus on. We'll focus on what happens in this stage here. Any improvement we are

proposing or postulating, will actually be related to this stage. All right. So let's talk about what happens in the first couple of days of life. There's potentially a problem to our EDHI programs, and efficiency of our EDHI programs. A lot of babies are born with natural substances, in their conductive pathway, that cause an increase in the fail rate on the screening tests. All right, so let's talk about these obstructions for a second. They're naturally occurring, they're not pathological. For example, there's the vernix, which is the fatty layer that covers the baby's skin at birth.

A residual amount of it is still in the ear canal, and sometimes that's enough to cause an OAE screening to fail, or an AABR screening to fail. Newborns also have residual developmental mesenchymal tissue in the tympanic cavity, that hasn't yet resorbed by the surrounding tissue. Less commonly is amniotic fluid aspirations. This happens when the birth or the labor is distressed. Newborns may aspire some of that fluid, during the birth process, and there was evidence of those substances, in the middle ears. Otitus media or infection are less common in this population, unless we're talking about a NICU baby, all right? So these are transient in nature, they're temporary, they resolve very rapidly, after the second or third day of life.

But this two to three days is the timeframe, within which babies are discharged from the hospital. So unfortunately, that's the time we have to do our hearing screening. And as a result we get a lot of referrals that are not permanent congenital hearing loss. Not the main target of newborn screening programs, or EDHI programs. And that adds burden to the system. So the impact of such obstructions, on OAE and screening tests, is that when we get those babies back within two weeks or one month, we find that 76 to 92% of them will pass the test, even though they failed in the first two days of life. And what that tells us is that fail was temporary, because of all these conductive obstructions.

So as you can imagine, this is very cost inefficient. There's a cost burden there. There's also the burden that I mentioned before of tracking, making sure the babies come back, which a lot of them don't. And it is one of the reasons that contributes to the delay. Unfortunately, only 67% of the identified children, received intervention by six months of age for the CDC census, all right? So this is not great. This means that this very expensive universal screening program, has an efficiency rate, as far as time is concerned, of 67%. So what do we wanna do about it? What am I proposing here? Remember, I'm trying to make a case for immittance testing, so I'm trying to sell you on something here.

Okay, let's summarize what we talked about. The impact of transient conductive obstructions. It basically is that we have a lot of failed screening tests. And that's a problem, because there is no way for us to determine at the time of birth, that the fail in a screening test, is in fact due to a conductive component. It could be sensory neural, it could be conductive. If you were ever in involved in screening or counseling parents of new babies or newborns, you probably say, "Well they failed the test today. We don't know why they failed it. We'll test you again tomorrow, before you leave the hospital." And then the second day, you'll say, "Well, we're not really sure, so we want you to come back in two weeks to one month, so we can make sure one more time."

So it's an extremely inefficient process. There is this mass indiscriminate screening, that we do for everybody, repeated screenings, until finally at some point in two weeks to one months, we no longer suspect that it's due to conductive. So might there be a benefit of including an immittance test at birth? What if we're actually able to determine at a time of screening that a fail is due or not due to a conductive obstruction, right? This can really improve our referral and retesting paradigms, right? So instead of large scale repetition, indiscriminate screening on everybody, we may be able to intentionally and deliberately target different newborns, either for rescreening, if they have

conductive pathology, or conductive obstruction present, sorry, not pathology, just conductive obstruction present.

Or more importantly, we may be able to expedite, or directly refer someone to diagnostics, get ahead of the timeline, avoid any sort of stages where we might lose a baby, and just send them directly to diagnosis, if we determine that this baby has normal sound conduction, but they continue to fail the screening, okay? So this is the referral paradigm, that we're trying to improve here. Consider these two questions, I kinda just answered those, but let's just consider them one more time. What if the baby refers on an OAE or a AABR screening test, but their sound conduction is normal? Okay, well this suggests that a fail, is not actually due to conductive obstructions. It may actually be due to a sensorineural hearing loss.

And so sensorineural hearing loss is permanent, this is a very high value baby. We don't wanna lose this baby to the system. There's no need to repeat their tests two more times, before we send them to diagnostics. We could just directly refer 'em to diagnostics. On the other hand, what if the baby refers on the screening test, but the sound conduction is abnormal, or slightly abnormal, right? Then we may consider more intentionally rescreening of the baby. This will obviously save us costs, allow us to counsel the parents better instead of saying, "Well, I don't know." It could be, or it could not be. All right, so now that I hopefully convinced you, that incorporating newborn immittance tests is of benefit, why should we consider wideband testing instead of tympanometry?

All right, well there are multiple reasons why tympanometry is not actually suitable, as an immittance test tool in newborns. The first of those reasons, has to do with the technical assumptions, underlying tympanometry measures. And those assumptions do not hold true in newborns, because of the immaturities in the ear canal walls. So let's elaborate this point a little bit, okay? As background, you may recall that one of

the reasons that tympanometry requires pressurization, is to calibrate admittance units in mmho, to volume units in milliliter, or 1cc. For this to work, when we introduce extreme pressures, like a positive pressure or negative pressure, at the tail point of the tympanogram, the tympanic membrane is completely immobilized, and the ear canal becomes pretty much, for all intents and purposes, a rigid close-ended cavity.

Just basically a cavity with a fixed volume essentially. And this allows it, the probe then, to present a preferably a low frequency tone, and estimate 1 mmho of admittance, at that frequency, it's actually related to volume units, and calibrated in the ear, right? So this is kind of like an important calibration piece. There's obviously other reasons why we do this estimation that we exploit this clinically, when we estimate the ear canal volume, as you know, there's clinical applications for that. We might be able to identify tympanometry peak pressure, at different pressures. These are all sort of clinical pros or perks that we get with pressurization of the ear. But essentially the pressurization is a technical prerequisite that allows us to perform this very simple calibration method, and makes tympanometry work, okay?

So this works well in adults at 226 Hz. Low frequency tone makes admittance very much related to volume, and their ear canals are rigid, they're bony, no problem. All the assumptions hold true. This is not true however, in newborns. Their ear canals are completely cartilaginous. Those ear canals are very flexible, and when we introduce negative pressure, they tend to collapse. When we introduce positive pressure, they tend to distend. There were actually studies that measured this with video otoscopy. And so the assumption that we're calibrating in a rigid cavity, no longer holds true. To complicate this a little bit more, as you know with babies this young, we typically use 1,000 Hz tone, instead of 226 Hz tone. And this is not always going to lead to a perfect correspondence, between admittance units and volume units, so even our units are not exactly calibrated correctly.

Related to these or as a consequences of these, our clinical utility has always kind of been limited, given those limitations, it's kind of a happy coincidence, that these measures work in the first place. But there remains a lot of variability, in the way we approach norms for those frequencies. Some people go by tympanometric shape, the notching. Do you compensate at the positive tail, the negative tail, and the clinical accuracy is not where it needs to be. A third limitation of tympanometry. And this third reason is more general to even adults, even when all these assumptions hold true, is that it's just a limited slice or piece of information. A tympanometry measures the response of the ear canal admittance, oh excuse me, the admittance in the ear canal of the middle ear at a single frequency typically, 226 Hz in adults, 1,000 Hz in babies, but our ears hear at all audible frequency, a wide range of frequencies.

And so the only thing typically, that we can evaluate with tympanometry, is the middle ear compliant, hyper compliant. Hypercompliant where we're only thinking about stiffness of the middle ear. But there are other properties or physical characteristics, acoustic characteristics of the middle ear, that we cannot evaluate, because we're only looking at one frequency. All right, so luckily we do have an alternative immittance tool for newborns, and that's wideband acoustic immittance. Thanks to advanced calibration techniques, so that the calibration, is actually a little bit more complicated, than simply getting a measurement in a cavity and corresponding a volume unit to a admittance unit. But this technical advancement, allows us, to not require pressurization, so we get those measurements at ambient pressure.

We don't have to pressurize the ear, so here's one issue that's already resolved. Because of this advanced calibration technique, we can also assess at a wide range of frequencies. We can basically instantly test, introduce a broadband stimulus as our probe stimulus, instead of a single probe tone, like 226 Hz. Typically, it's a click or a chirp, that present in the ear, and we get a broad spectrum measurement from the middle ear. This allows for a very comprehensive evaluation of the middle ear, and the

inferences that we can make, go beyond just an assessment of compliance or stiffness, right, like an AS or an AD. We can learn more things about the middle ear, such as in addition to stiffness, mass, right?

Is there more mass loading than normal? Is mass composition normal or not normal? The resonant properties, right? At which frequency do the resonance happen? How big is the resonance peak and the response, right? All of these things we can glean from or infer, based on a wideband measurement. Another advantage is with this one simple quick measurement, the systems can compute multiple measures for us. The most common one is wideband power absorbance. I'll introduce this in a few slides, is the sort of increasingly adopted measure, in clinical research and for clinical application. But we could also measure impedance, admittance, all over a wide range of frequencies, right? Impedance, admittance, impedance phase, we can look at those things too.

Okay, so this is our new test. Some of you may have had exposure to this, some might need a little bit of elaboration. So I'm going to provide, a little bit of background information, that will prepare us to interpret wideband measures, right? A lot of us are used to maybe looking at ear bone gaps at four frequencies, or tympanometry at one frequency, to test this and the way it functions. So it behooves us to just take a step back, and think about the middle ear function over a wide range of frequencies, and how that relates to the physical characteristics, of the normal middle ear. And that will serve as basis or background, for discussing wideband middle ear immittance tests.

Okay, so to think about that, the first thing we need to think about is when we think about how the middle ear processes sound from frequencies. Well let's just think about any object that vibrates right. Middle ear is an object that vibrates, we can all agree on that. It has mass, it has elasticity, and the mass and elasticity allows it to vibrate, okay? So why do different objects vibrate at the frequency that they do? This happens to be

called the frequency, the natural frequency or the resonant frequency. And so different objects by their physical makeup have a preference to vibrate at a particular frequency and a preference to not vibrate others, right? And so you may be familiar with the term impedance.

Impedance basically are how the physical properties, of a vibrating object, hinder sound vibrations. So if you're not at the resonant frequency, the sound is being impeded below the resonance, and impeded above the resonance. And this tells us a lot about the physical properties. Okay, so if we were to hold a metallic object, and disturb that object, it's going to give you a sharp sound. And if you were to maybe hit on like a piece of wood, it's gonna give you a more basey sound, right? Different objects do have a tendency to vibrate at different frequencies, and that has to do, with how much mass and elasticity they have. I have a little bit of math here, please don't let this throw you off.

It's not really the scope of our presentation, to go into much depth here, but just to highlight, Z is impedance and it has two terms in it. It has resistance and reactance. Reactance is the X. These are the two ways that a vibrating object, can impede sound, can impede vibrations. R is resistance. Basically, it's dissipation of sound, and other forms of energy. So if there's friction, for example, the sound is converted to heat, and this is not frequency dependent, it's vibrations that are just lost, lost across the board, at all frequencies, okay? So R is not frequency dependent, and it's just sound that's being lost or dampened. X on the other hand or reactance is related to the way the object vibrates in compression, and when it compresses, it stores energy, and then it releases energy into motion, and then the elastic forces again store that energy back, and bring it back towards the equilibrium, right?

So that storage and release of energy is what reactance is. And that piece is very much dependent on frequency. There are two sub components to reactance. There's mass

reactance and stiffness reactance, and typically reactance will impede high frequency, if it has a large mass, and it will impede low frequency if it has large stiffness. So let's think about this for a second. Okay, this is a little bit more intuitive than you think it is. I'm going to skip to the next slide here. When you look at this figure at the bottom, this shows basically a vibrating system, with a representation of stiffness as a spring, a representation of mass as this kind of like block here, and friction is sort of just surface friction here, okay?

So if you have a large mass on a vibrating object, it's gonna be hard to accelerate and decelerate, a very big mass very fast, okay? Think back to Newtonian mechanics. When something has a large mass it requires a lot of force. And so what's going to happen, the acceleration and deceleration will be slower, okay, because of the mass, and that slower vibration translates to low frequency, okay? So something that has a large mass, is going to impede high frequencies. It does not like to vibrate at high frequencies, and as a result it will vibrate, preferably at low frequencies. It will be tuned or resonate at low frequencies, all right? That's mass. If an object is very stiff versus very elastic, the elastic object can move big distances around the equilibrium, but it's very stiff.

It's gonna stay kind of like around the equilibrium and it's gonna vibrate kind of fast around its resting point, right? So a stiff object will impede low frequencies, because it does not like to do these big displacements, and it will resonate or have natural tuning at the high frequencies. Okay, let's talk about a more intuitive example. This might be more relatable. If you're trying to tune a strings of a guitar, as you increase the tension or the stiffness, you're going to impede the low frequency, and the tuning will become more high frequency, right? So as you're tensing, the string is gonna go, , right? It's now tuned to a higher frequency, because you're impeding the lows. On the other hand, if you have a thick string of a guitar, versus a thin string of a guitar.

As they go up in thickness, now the thick string, is gonna give you a very basey sound, right? like this, because the mass of that dense string, is impeding the high frequency. So it wants to vibrate at a lower pitch, okay? Hope that makes sense. All right, so these two entities, mass reactance and stiffness reactance, the XM and the XS, actually are countering each other, all the time. And at one frequency, their effect will cancel each other out. You see there's a negative sign here. Okay, at that frequency, is where you're going to get the resonance, and it varies for different objects, depending on their natural mass, and their natural stiffness composition, okay? And again, if you have something that's has a lot of mass, this point where they cancel each other, is going to be at a very low frequency, or perhaps an object that has a lot of tension in it.

This point where that resonance happens, where this term cancel itself out, happens at a very high frequency. Okay, bring it back to the middle ear. The middle year is a vibrating object. It has mass and reactance, sorry, it has mass and stiffness in it, and it has resistance elements. So it has reactance and resistance elements. So anytime you see this fork symbol here, this represents a reactance element. Anytime you see this sort of loop element here, this represents a resistance elements, right? And so if you think about the ligaments, and the joints of articulation, all these have sort of elastic elements in them, and they can either be stiff, or they can be compliant, and the bones themselves have density, right?

And if you think about it, if any of those properties change, let's say you have otosclerosis or you have cholesteatoma with mass loading or something like this it's going to change the way that ear vibrates, that impedance is going to increase, either at the low or high frequencies, and reduce sound conduction of those frequencies. All right, so now that we talked about this, let's think about what happens what day, okay? This is the function of the middle ear, all right? Let me very, very quickly explain what we're looking at. Let's look at the top graph here. This shows the gain of the middle ear, across a wide range of frequencies going from a hundred hertz to 10,000 Hz here.

And as you can see, the middle ear does not provide equal gain or frequency. It actually provides very optimal gain at this peak point here. And this peak points happen to be where Z or impedance is lowest, right? And whenever Z is lowest or impedance is lowest, that's our frequency of resonance. And this happens to be around 1,100 H. This measurement was obtained in cadaver adult ears. So what these researchers did was actually kind of like real ear put in like a microphone deep near the TM, and then they have a laser interferometer behind the stapes or the oval window. So they have an input point and an output point, and a difference between the output and the input produced the gain, okay?

So the middle ear's not a perfect conductor of sound. It prefers to vibrate this mid frequency point, all right? What happens at low frequencies? At low frequencies impedance is greater, because of the natural stiffness, in all these sort of elements that we talked about, right? All these joints, all these ligaments, that natural stiffness is what causes gain to be reduced, in the low frequencies, all right? At higher frequencies it's mass reactance. So it's the natural mass elements, that make it difficult for the middle ear, to vibrate at these sounds, all right? So this is not something, we're used to looking at clinically. If you think about tympanometry like a 226 H, 226 Hz is somewhere here just one slice, one piece, and it only tells us about stiffness.

It doesn't tell us about any of this, right? So wouldn't it be great if we had a clinical measure, that actually allows us to do that? Well luckily we do. We don't have to perform surgery on everybody, to get output and input measurements like this study did. Luckily wide band acoustics immittance, allows us to do this measurement. So very quickly before I explain anything, I'm going to show you this here. Doesn't this bear resemblance to the previous graph, right? Can't you see how we have like a peak, and then you have a reduced response here, and reduced response here. It's very

much similar to the gain graph that we looked at before. And what we have at the top here is absorbance.

Simply absorbance is how much power is absorbed, and it's very much related to vibrations. If the system is vibrating in response to sound, it's absorbing that power, and converting it into vibrations, right? So power absorbance is the most common WAI measure. We'll refer to it as wideband absorbance for short or WBA. And essentially it's the ratio of absorbed power relative to how much power there was in the stimulus that we presented, okay? Given that we present a broadband stimulus, we get absorbance at every frequency, okay? As I mentioned before with wideband acoustic immittance, we can get other measures, We for example, we can actually estimate impedance, and impedance phase. And one of the remarkable things here, is at this point, where we have high absorbance, where we think the resonant frequency is, actually corresponds to the lowest point of impedance, which is kind of what we said before, and a phase point of zero and when phase is zero or something is vibrating in phase, that's typically a sign of resonance, okay?

So this is all good and great. We actually have FDA-approved commercially available systems that allows us to do this. Both the Interacoustics Titan and the GSI's Tympstar Pro, now allow you to do wideband measurements. So if you have any of those devices, you could purchase a module that allows you to do this. And the Mimosa Acoustics HearID device, they have another device, that's specific for newborns as well. They also are available commercially, okay? So the examples I showed you here, and in the previous slides were from adults. So just to serve as a theoretical background. Next we will begin to talk about newborns, and the normal responses in newborns, and how interpret measurements. Okay, so we do have this great tool at our disposal.

Let's now circle back and talk about newborns. All right, here is the normal response in newborns. And right off the bat, you can see that there are some differences, from adult response. So let's go slowly and talk about this response here. Again, you have absorbance on the Y-axis, and absorbance goes from zero to one or zero to 100%, 'cause we're talking about the proportion of the stimulus. So 0% of the stimulus being absorbed, 100% of the stimulus being absorbed here. For example, if I were to point to this point here, absorbance is 0.9, this means that 90% of acoustic power was absorbed. In other frequency it's low, it's about 30%, all right? Okay, so let's very much characterize, what we're seeing here.

We have this major peak in the middle, okay? So where we have the biggest peak, typically as we said, this is where the resonance happens. This is where impedance is lowest. And you can see our biggest peak, is around 2,000 Hz. Typically, that occurs in newborns, between 1,000 and 2,000 Hz. So there's a little bit of variability, between subjects here. This is a lower frequency, than where it would happen in adults. In adults, the absorbance peak occurs here. And that's because the adult auditory system, peripheral auditory system, is a little bit stiffer. All those cartilaginous parts, are a little bit more ossified. The tympanic membrane's a little bit more stiff, the tympanic air cavity is bigger, so that kind of translates into overall higher stiffness.

But the immature newborn system, the peak is a little bit lower here. There's a secondary resonance here, has to do with the cavity. This is not as important diagnostically, there aren't big differences in this frequency range, between normal/abnormal ear. So typically it's this peak that we're interested in. Okay, so to tie this back to what we talked about, if this is where the resonance happens, and impedance is lowest at higher frequencies, it's the natural mass elements, that make this absorbance lower here, and at low frequencies is the natural stiffness that's making this lower here. Okay, peculiarly, we have this rising peak here. Okay, so

anytime you have increased absorbance, it means something in the ear is vibrating, in response to sound at those frequencies, right?

Or resonating to those sounds. This peak is not present in adults, it's only present in newborns and infants, up to three months of age. In some studies could be up to six months of age, okay? And this very much is the ear canal wall vibrating to sound, all right? So very much has to do with the immaturities that we talked about, that were very problematic for tympanometry. We could actually characterize this here. So because the ear canal walls are completely cartilaginous, they actually resonate or absorb some of the sound, and vibrate in response to these tones here, and this translates into higher absorbance. So that's kind of cool. If you have this present in your measurement, it means that you're inserting the probe tip correctly.

There's no obstruction of sound. It's kind of nice to see this when you're measuring, You know you're performing your measurements correctly. All right, so let's talk about the shaded area. The shaded area is our norms. So the 10th percentile is the bottom of the shade here, and the 90th percentile is the top end. And basically what this means, is this edge here, it means that only 10% of normal, have absorbance measurements below this line. And the top line means that 90% of everybody that's normal has measurements below this, okay? So the majority of normal hearing, will be within this shaded area, okay? So one way to use this shaded area, is if you have a measurement that has low absorbance, like for example if the peak was reduced below the gray line, you know that the sound conduction is not normal.

There's a lot of loss of vibrations there. Something is making the ear not vibrate, okay? Could be vernix, could be residual tissue in the tympanic cavity. This is one way to apply it. It may get a little bit complicated, when some parts of the absorbance, are within the shaded area, and some parts are outside the shaded area. And so this might require us to take a closer look. But lot of times when we're doing newborn screening,

we want either the equipment, to automatically figure this out, or we want an operator, who's not very trained in acoustics and audiology, to be able to quickly make a decision. So the other way to analyze this, is called Absorbance Area Index.

Essentially what Absorbance Area Index is, it's basically an average, over a select range of frequency, typically in this region. 'cause that's where we get the best diagnostics. So we average between 1,000 and 4,000 Hz, and researchers, actually Dr. Lisa Hunter from Cincinnati, created norms for this average. So they took absorbance from 1,000 to 4,000, and in this sort of green box right here, they established a normal 10th to 90th percentile. And they also had ranges established for abnormal ears, ears that failed the screening, because of conductive issues. And they show the sort of 90th percentile, 10th percentile of that, as well. And so if you take the average of absorbance here, where I'm moving my cursor, and you just average this number, you're going to get this triangle here.

This is your Absorbance Area Index, between one and four kilohertz. And if it falls in this green box, it means your measurement is normal. But if it falls in the red box, it means your measurement is abnormal, all right? So let's look at some examples. Okay, here we are again, this is the normal measurement, here's the Absorbance Area Index for it, and here's an example from another baby, that is abnormal, okay? You see there's a little bit of your canal wall resonance here, so that's good. And then well there's this big change here, right? This is a very obviously abnormal measurement. You can see the principle component, the principle resonant component, where most of the vibrations happen in the ear are gone, they're very much diminished, reduced, and they are below the gray-shaded area.

So this is an example that anyone that can look at, and say, "Yeah, that's abnormal, okay?" But if we use the Absorbance Area Index, we can see that it's also abnormal, right? So if we average between the purple no, the violet trace here between 1,000 and

4,000, we're gonna get this purple triangle in this area, and it's clearly within the red box, so it's abnormal, all right? These are simple examples. Let's look at slightly more complicated cases, okay? So we remove this one, just so we don't have too many traces, and I'm gonna show you two more traces that have a little bit of more subtle abnormalities in them, okay? We have two traces, one in the green, and one in sort of the light blue color here.

Okay, so let's start with the light blue color. Let's see if we can interpret what this means. Okay, well the ear canal wall resonance is there. Okay, that's good. And then we have this big decrease in absorbance in low frequencies and it appears that this peak, which was a mid frequency peak, has shifted now to mid-high frequencies. What could this mean based on what we learned so far? When you reduce absorbance in low frequencies, that basically indicates that impedance is higher in the lows. So what causes impedance to be high in the low frequencies? It's stiffness reactance, right? This is a stiffened system. Maybe there's vernix that's actually dried up, on top of the tympanic membrane, and it's causing it not to vibrate.

It's literally just making it stiff, so that increased stiffness impedes low frequencies, and shifts the resonance to a slightly higher point, okay? So anytime you see that the peak shifts to a higher frequency, that's a higher frequency resonance. It indicates that there is increased stiffness, and typically it's accompanied, by reduced absorbance in the lows, okay? Conversely, if we look at the green trace, the opposite happens. We have a slight shift towards the low frequency, and a reduction in absorbance. Again, looking at the green here, reduction in absorbance in the mid-high frequencies, okay? So that indicates that because of increased impedance in the highs, and that's typically related to mass, we can infer there is increased mass loading in the system.

So it could be that there's some residual tissues, still sitting on those ossicular bones, for example, just making the load a little bit more difficult to vibrate but more mass,

right? And that peak is up here. All right, so the reason I call these subtle, is that we still have a lot of good vibrations, but they are shifted in frequency and they're certainly going to cause a little bit of change in our screening outcomes. If we use Absorbance Area Index, for subtle changes like this, we may fall in this overlap region, right? So you see the triangles, for the light blue and the green. They fall in this area that overlaps, between the green and the red, and that's an inconclusive area.

So it is not something we can do automatically. We have to look at this and say, "Well this may be normal, may not result in a fail, may not result in a fail, in a screening test." So let's look back more carefully, and make the type of interpretations, that I just walked you through a little bit ago. Okay, so what if there was a different way that just focuses on the peak, since I spent a lot of time talking about peaks, right? So this next method is actually a method, that I have developed, and we're calling it the Absorbance Peak Template. And I know we all love the little square in the tympanogram and if the tympanometric peak falls in it, we know it's normal.

If it's not or bigger or smaller, we can call it ASAD. I'm trying to make something similar, just to simplify, like the way we approach wideband measurements. So we created this box here, and this box basically is based on an analysis, of a large number of measurements from newborn ears. And we analyze both absorbance peak, we analyze the principle absorbance peaks, in the mid-frequencies here, for their peak absorbance and for their peak frequency, so two variables, and on both of those variables we created a normative range. So the fifth percentile for peak absorbance. If your peak absorbance is greater than 0.67, it means you're within the normal range. And if it's close to one or below that, it's also within normal range, right?

Fifth to 95th percentile. For peak frequency, we also created norms. If your peak falls within this range, between almost 1,100 Hz and 2,200 Hz, you are sort of within normal resonance frequency, okay? So based on this square, let's look at the purple trace

again. Okay, here's what I just said. We can ask ourselves very simple questions, for our interpretation. Is the peak absorbance slow, and is the peak frequency shifted to a higher or lower frequency? Okay, if we're looking at the purple trace, well clearly the peak is low, there is no peak within the box, it's low. That's an obviously abnormal measurement, it's a very likely ear that will fail the test, because sound conduction is not normal.

And if we look at the green, sorry, if we look at the light blue here, you'll see that the peak of absorbance is not low, it's still high enough, but it's shifted outside the box, to the right of the box. And that is an example of increased stiffness, and for the green, it's sort of borderline within normal. So, but it has increased mass, and it's shifted to a lower frequency. Okay, these are kind of like three different ways, that we can look at wideband absorbance analysis, for newborns specifically. All right, so now that we looked at all this, let's think about how this is useful. Let's circle back to newborn screening, okay? How do we use wideband absorbance, and newborn screening outcomes together, to make recommendations?

All right, there are different referral recommendations, that we can have based on wideband absorbance findings. So let's look at the table here. This is a comprehensive table. It's showing us the screening outcomes on the first column. So could be AABR, could be OAE, but if they fail or they pass. The second column, shows wideband acoustic immittance outcomes. So whether we have normal or abnormal wideband absorbance, and what recommendation would go. So that's kind of the recommendation matrix, that we're hoping to be able to implement, whenever wideband absorbance, becomes part of your screening test battery. it's kind of like my research mission, to make that happen. Okay, so let's talk about referral. Okay, we have two examples here, AABR or OAE failing, we could have AABR OAE failing, with normal wideband absorbance, okay?

Kind of like the the dark blue color trace, that we showed earlier. So what does that mean? It means the baby failed the screening for OAE/AABR and their sound conduction was normal. This is our very rare one in 1,000 babies, that has permanent congenital hearing loss. This is the reason why we have universal newborn screening in the first place. This is a baby we do not wanna lose. We don't want to pointlessly rescreen them over and over. We wanna prioritize 'em for diagnostics, okay? From day one or day two in the hospital, we can schedule this baby, for AABR diagnostic test right away, okay? On the other hand, if the baby fails the screening and WBA, wideband absorbance is abnormal, we can wait a few days and screen the baby, okay?

If we are in a situation where we have like the peaks shifted, for example, you might anticipate that this baby, will likely pass like tomorrow. But if it's an example where absorbance is really reduced, kind of like that example we looked at, with the purple trace, then this is probably a baby that's not gonna pass in a day. It might take a little bit of time for that to recover. And then if the babies pass, obviously we are not gonna do any rescreening on them, but having those wideband absorbance measurements, can also give us some insight. So let's look at those more closely, okay. Here are some examples of newborn screening, and TEOAE-based screening. You see it here in this sort of second column of these two panels.

Here we have TEOAEs, the different bands, the gray bars represent the noise floor, and the red bars on top of them represent the level. And obviously if we have a lot of red on top of the gray, it means we have a large SNR ratio. And the check marks here indicate that those bands passed. So both of these examples I have for you are TEOAE-Pass. If we look at the first one, this one has a wideband absorbance trace that falls within the gray-shaded area. So it's normal across all frequencies. And you can see the TEOAE measurements, are just very robust, right? If you look at the second row here, absorbance is not quite quite normal, right?

It looks like it's reduced in the mid-frequency range, and the major peak has shifted slightly to the right. So when that happens, we infer that there is increased stiffness, right? Stiffness impedes low frequencies, it shifts the resonance higher, again, like tensing the string of a guitar, , that's where that resonance is now at a higher pitch, and impedance is more in the low frequencies, right? So absorbance has this shape now. So we may anticipate is that some frequency bands in the low frequencies may fail for this baby, and though in this example, we do not have that manifest, you can see that actually, the TEOAE levels are much lower, okay? They're still big enough to pass the TOAE screening because the SNR still favorable.

But we went from like 20 Db SPL, 30 Db SPL, all the way down to 5 Db SPL, right? So in some babies this may cause some bands to fail. My guess would be the low frequency bands will fail, in others it may not, depending on what their baseline TEOAE level is, if it's large or no. Okay, so that's interesting, but let's go to the ones that are more important, okay? Here are examples of babies that fail the screening, okay? The all you can see here is basically noise, and the different TEOAE bands, with some maybe the 2,000, 3,000 Hz have a little bit of TEOAE levels above that, but they're all below normal. SNRs are abnormal, okay? So these two examples, are babies that failed the TEOAE screening.

Okay, let's look at what WBA tells us, wideband absorbance. First one looks pretty normal to me, okay? Very robust mid-frequency peak, mostly within the normal range. So this is a baby that has normal sound conduction but abnormal OAEs, right? This is our baby that has potentially permanent, sensorineural hearing loss. This is the baby we refer directly to diagnostics, okay? We don't wanna lose this baby to the system. Well we don't wanna rescreen them pointlessly, and we don't wanna risk having to refer them, over and over and over for screening, and at some point they may not

show, or they may be lost to the system, right? This is a baby that we absolutely wanna retain, and we want to diagnose and intervene for early.

The second example is a clearly abnormal absorbance, okay? The peak is completely diminished. Majority of the trace in the mid-frequency range are below normal. And unsurprisingly, this baby failed the TEOAE screening, OAEs are actually more affected, by abnormal sound conduction than AABR is. If you think about it, for OAEs, we need the stimulus, to make it through the conductive sound pathway. So we get a little bit of loss of stimulus level going in and then once the OAE response is generated, it also has to travel back, through that same conductive pathway, getting reduced once more. But for AABR it has to pass only one way, and the response we get through the nerves, not through the ear, right?

Okay, so this is kind of what we wanna do, okay? I hope everybody at this point, has an appreciation for like this technology. All right, I have a couple more slides here, that I want to go over. Not to go over time. Some practical considerations. How easy is it to measure WBA? Very easy. Actually a little bit easier than OAE measurement. You just put the probe in the ear, it takes 16 seconds, it collects all the information you need. It's less prone to environmental noise. The stimulus level usually around 60 to 70 Db SPL. So even if there's a little bit of noise in the environment, it's not gonna be as affected as OAES. The measurements are reliable. Interclass correlation coefficient was actually very high.

And the test-retest differences are characterized and quantified. They're about 0.05 to 0.1, okay? So remember absorbance goes from zero to one. So zero to 100 and the test-retest is anywhere between 5% and 10%. A couple of things to consider, because the wideband absorbance does not pressurize the ear. You know with tympanometry, if you have a leaky insertion, it's just not gonna pressurize, and you will know. For wideband absorbance, you have to learn about that some other way, okay? So what

ends up happening is we have a leaky measurement. Absorbance will be inflated in the low frequency, okay? So let's look at this example at the top here. I'm just gonna blow this up here. Okay, this is absorbance on the Y-axis.

Frequency on the X-axis. And the sort of brownish colors, orangeish colors here, are normal absorbance, without any suspicion of acoustic leaks. But if a prop tip is loose, what you're going to have, is this sort of abnormally inflated absorbance. And this is not inflation, due to enhanced vibrations of the middle ear, or enhanced sound conduction in the middle ear. It's simply sound that got lost, didn't come back to the probe, it left the ear. So it's counted as being absorbed, but it's actually just lost, right? And it looks like it's inflated like that. And we developed, actually this is my work, developed a criteria to identify, if you have absorbance leak related artifact like that.

So based on both absorbance and impedance phase. Some equipment will show you this, some won't. Hopefully this criteria, will be adopted and automated for you. And so if absorbance is lower than 0.58, or if impedance phase, is lower than negative .11 cycles. This indicates that you have a good fit. But visually, if you have inflated absorbance like this, you might wanna just refit your probe and test again. Okay, one more consideration here. If you have a spontaneously collapsed ear canal, okay? You might have heard spontaneously collapsed canals. You might have seen those in geriatric patients, where the ear canals are collapsed. This actually also happens in babies, the very first hours of life. And we were able to characterize this during our research.

So remember the cartilage in the baby's ear canals, are completely flexible. And if in the uterus they were doing this the whole time, it's gonna take them several hours, for that ear to reopen, okay? So look at absorbance here, you see this orange trace, this is spontaneously collapsed, we did nothing to it, this is how it was. And for this baby, I actually stretched their pinna to the back a little bit, and I was able to measure the blue

trace here. Okay, so how did I know that this orange, is not due to calibration error, or maybe it wasn't facing the wall. How do I know that this is due to collapsed canal? Well we had this cool experiment that we did, where we actually introduced pressure in the ear canal, kind of like tympanometry, but for the purpose of testing collapsed canals.

If you see the blue line here, the blue line is what it was, before we collapsed the ear and then we inserted a probe and we pressurized the ear, negative pressure, and we got the orange trace, all right? So then we removed the probe, and give it a little bit of time and remeasured, we got the black, so it restored back, okay? So this is kind of a cool way, of learning about the physiology of the ear canal walls in newborns. But just letting you know, if you get a measurement like this, anytime you get a measurement with negative values, you know there's something wrong. 'cause absorbance should not be negative. But this kind of pattern, is very much indicative of collapsed ear canals.

And this will cause the babies to fail the screening, if they have collapsed canals. This is actually one of the reasons we don't screen babies, in the first six hours, 10 hours of life. We wait a little bit of time. Okay, I know I went a little bit over time here. So let me summarize very quickly. So what did we learn today? Well, wideband absorbance measured at birth, can improve referral paradigms, and hopefully the timelines of intervention for congenital hearing loss. Testing is very simple, reliable, and time efficient. Recent efforts have improved our ability to assess and interpret. Hopefully some of those examples I showed you, show you that it's actually not very difficult to interpret wideband measures.

And there's also been improved ways, to ensure that the quality of the measurements are accurate, such as identifying when acoustic leaks are present, or when ear canals are collapsed. This QR code here, if you scan it, it will take you to the Seminars and

Hearing website, and on there you will see the special issue. We worked on a special issue, myself and 10 other colleagues. There are six articles there, that are meant specifically for clinicians, that will walk you sort of through, how to interpret wideband acoustic immittance, applications in adults, otologic cases, newborns, infants, children, wideband middle ear acoustic reflexes. We can use that instead of tympanometry to measure reflexes. Some really cool topics there. I wish you would check it out.

Also in this series on August 23rd and August 30th, Dr. Joseph Key from Queensland University, Australia, will be presenting more on the adult aspect, and more of the basics, of wideband acoustic imittance. So some of the theoretical aspects that I discussed today will be discussed at more length, with more case studies. And Dr. Navid Shahnaz will discuss applications in children, otitis media and common applications in children. With that, this concludes my presentation, so hopefully we have some time to answer some questions. Thank you so much for your attention.

- Thank you so much, Dr. AlMakadma. We're gonna go ahead and open up the floor, for any questions or comments that you might have. We do have one question here from Janine. Do you recommend WBA for babies only? And what about adults?

- Thank you for that question. No, actually, wideband acoustic immittance, is very, very useful in adults. We have potentially an ability to perform pre-surgical diagnosis, of actual etiologies before the surgeons go in. So wideband acoustic immittance, because they may produce very unique responses to different pathologies. We may be able to tell, for example, in otosclerosis apart from a certain disarticulation from cholesteatoma, before we go into surgery. So definitely for adults. There are more cool applications in adults, where we can now introduce pressure, not for technical reasons, but to add another dimension of measurements, that's called wideband tympanometry, or 3D tympanometry. Tune into Dr. Keys' webinar for that. There's gonna be more on that later. Also, one of the Seminars and Hearing articles, that we have by first author

Dr. Chris Sanford, is specifically about adult pathologic and audiologic correlates, so make sure to check that out.

- Thank you for your question, Janine. We have a comment here from Christine. Christine just mentioned Dr. AlMakadma. This was a superb teaching and explanation. Thank you again for your presentation.

- Thank you so much, Christine.

- We have one more question here from Patricia. Can you estimate, how many hospitals are using wideband immittance, as part of their newborn screening?

- That's a very good question. I do not know the answer to that, and I don't anticipate that many of them do. We do in my hospital, just because I happen to be sort of one of the people, that are sort of leading this discovery, so to speak. We are performing this, in addition to our university hospital screening program. Our major birthing center, is where we do all of our research experimental data. I do not know how many hospitals are using this as standard of care basis, but I'm hoping that that will be something that will happen in the next five or 10 years.

- Thank you for your question, Patricia.

- May I follow up, just one more follow up? . There are more people probably using this for outpatient screening. So when your baby is referred from the hospital, and they come back two weeks later, actually the most recent GSIH recommendation recommends wideband measurements for this population. So I see that Monica also asked the question about reimbursement. This is just a good segue to answer this question too. Because this is in recommendation now. GCIH has recommended it for infant newborn screening, or follow-up screening. You may actually be able to get

reimbursed for it. So you can get reimbursed for OAE, AABR, and imittance testing at the follow-up test, if you have an outpatient screening clinic, and though there is not a dedicated billing code, for wideband immittance, a lot of the resources I looked at, like Pediatrics for example, Online, they say you can use an extended service code for that. So 22 I think is the extended service code. Hope that answered your question.

- Thank you, Monica, for your question. Well, Dr. AlMakadma, I don't see any other questions in the queue, so I'd like to thank you for your time and your expertise, and also for putting together this wonderful annual series that we have with Seminars. And this concludes today's course. Thanks so much everyone for joining us.

- Thank you very much.