Fundamental Concepts for Wideband Acoustic Immittance Measurements

Presenter: Joseph Kei, PhD

- [Christy] It is my pleasure to welcome Dr. Joseph Kei, a professor out of the University of Queensland. And I am so delighted to welcome Dr. Kei as part of our Seminars in Hearing series. The series is put on every year by AudiologyOnline. We wanna thank Dr. Catherine Palmer for allowing us to host series as well as Dr. Almakadma for coordinating the series. At this time, I'll hand the mic over to you, Dr. Kei.

- Thank you, Christy, for the introduction. I hope that, say, might say, audience would hear me well, and good evening to you all. My topic today is actually focused on wideband acoustic immittance measurements. And these are my disclosures. And then my learning outcomes. There's basically three learning outcomes. And at the end of the presentation, I would introduce, say, two of three adult clients' sort of case studies, and there might be a surprise as well, so. So background, well, why do we have to actually do this webinar? So basically, we are looking at a new technology. And over the last two decades, there has been a lot of, say, research into that sort of wideband acoustic immittance. And then the device to actually, say, do this testing is becoming available.

And throughout this time, we have been actually trying to do research to find out if it is useful to diagnose the conductive conditions. And despite extensive research going to that area, we're still finding that this technology is still not translated into daily practice. And there are many reasons for it. Some people will say, "Oh, well, "so it's actually too complicated, "and this, too new, this technology." And so we think, well, what is the main reason for doing this webinar? But perhaps, we'll actually arouse, say, greater awareness and education among the hearing practitioners, maybe. And if this is the case, then we have this webinar today. So, why consider middle ear function in wideband? So as you know, the middle ear amplifies sound, and it is actually trying to compensate for the difference in impedance between the outer ear and the inner ear.

Now, without this middle ear, the sound would actually bounce off from the inner ear, and then not much sound can get into the inner ear then. So, what about the middle ear amplifications? Well, it amplifies sound, but it depends on, say, the impedance of the middle ear itself. And because of that, the middle ear amplifies sound with different extent depending on the frequencies. And we know that single-frequency tympanometry, such as 226 hertz or 1,000 hertz, they are actually evaluating middle ear function at only one frequency, and it does not provide the full picture of the function of the middle ear across the frequencies. And further, there is a major limitation in the single-frequency tympanometry, in that, so if you want to measure admittance at a frequency higher than 2,000 hertz, there might be a problem because you're not able to get accurate results due to probably the possibility of the standing waves in the middle ear when you are testing at the high frequencies.

So four kilohertz, eight kilohertz, of course, they'll be creating these standing waves. However, with the advancement of the technology, WAI, say, can measure admittance, absorbance, and other measures, which I will introduce later. And we introduce these measures right across the frequencies from 220 to 8,000 hertz. Now, let's look at this mass-spring-resistance system. I think it's a very familiar sort of situation, so like an experiment even in high schools, when you have, say, on the right side, in the diagram, you see a mass standing on, say, with the wheels there, and it's attached to the spring, and the spring is attached to the wall at the other end. Now, imagine that if we actually, say, move the mass to the right side, away from that equilibrium position, and if it is actually moved by, say, a certain amount, and then, after that, we release the mass, and, of course, because of the spring action, it is actually bringing this system into sort of vibration, basically.

So when we actually pull the mass to one side, now, in that case, the spring is actually extended, and it is actually storing the energy. We call that the potential energy. But when we release the mass, well, the mass will actually move back to this equilibrium position, and when it is moving, it's actually releasing the kinetic energy, which is the energy due to motion. When everything is actually in motion, it is actually giving the kinetic energy. So in that case, the initial potential energy is transferred into kinetic energy, and so on, and this sort of vibration continues with this continual exchange of potential and kinetic energy, and that is actually setting up the system into vibration.

And during the vibration, of course, you know, so even with wheels, there is some friction, say, at least, you know, with the ground, in that case, so this friction is going to slow down the vibration, and eventually it would actually come to a standstill after some time. So this sort of frequency of the vibration, when it's vibrating, so how many times per second is it vibrating? So we call this a frequency. And the frequency of vibration is given by a formula, which seems to be a little bit daunting, anyway. It is, say, one over two pi times the square root of the k, which is the stiffness, over the mass. And you can already see in here that, say, the frequency of vibration is really dependent on the stiffness and the mass.

And these two are actually operating against each other in some way. And if you can see from this formula that if the stiffness increases, say, the k increases, then you'll see that the frequency of the vibration increases. On the other hand, if, say, the mass increase, in that case, because it is in the denominator, say, when the mass is large, it means it will have sort of a small ratio in there, and so the frequency of vibration would be reduced, would be smaller, right? So the greater the mass, the lower the frequency. And we can compare this sort of system with the middle ear, considering the middle ear as such a system, which is having mass, spring, and resistance as well.

And you can see on this diagram on the left that you have, say, this eardrum, and it's got all these elements, like resistance elements, spring elements, stiffness elements, and also the mass, and it's actually connected to the inner ear, and so on. So I would say this would actually be a good analogy between these two systems, and they are operating probably in a very similar manner. In the middle ear, we have the mass elements, which includes the pars flaccida of the tympanic membrane, ossicles, perilymph, et cetera, and then we also have the spring elements, like the stiffness elements, like the ligaments, the tendons, tympanic membrane, and also the air enclosed in the ear canal, as well as the middle ear space.

You know, with the ear canal volume, we would expect, of course, that the smaller the volume, the greater the stiffness, and vice versa, and vice versa. So this is actually something that we know that it will affect our results because of that sort of stiffness and also the stiffness of the middle ear space. And there are other resistance elements in the system. Every moving part is actually contributing to the resistance. And this resistance is actually quite important that it will die down the vibration. Now, without any of the resistance, we'll get into trouble. Suppose if you hear a pure tone, and then, if there are no resistance elements, and you will hear the pure tone forever, and it will drive you mad then.

It will drive you mad, I'm sure. So we like to have resistance. Impedance is actually the resistance to motion, basically. This is what it really means. It can be represented mathematically in terms of its components, and we're going to introduce these components due to mass, due to stiffness, and also due to the resistance, R. So the mass acoustic reactance, which is what it is called, represents the impedance to motion due to the mass element of the middle ear. So it means the greater the mass, the greater the impedance to motion. And so the stiffness acoustic reactance, and we call it XS, and it represents impedance to motion due to the spring elements of the middle ear.

So in other words, the greater the stiffness element, the greater the impedance to motion, like when you have a very strong spring, and you have very high stiffness. Acoustic resistance, R, is the resistance within the system due to friction, due to friction, and it's actually, due to the friction, it's losing the energy, and then the vibration will die down. So when we actually look at how we are going to represent this impedance mathematically, and we can see that on the right side, you see a diagram showing you those elements, like, say, the real elements on the horizontal axis is the resistance. This is actually the resistance, horizontal axis. Whereas, on the vertical axis, you have the XM and the XS, so due to mass, due to stiffness.

And these two elements are just like the brothers fighting against each other, you know, like this is sort of big fight. And then, so, when they are of equal strength, they cancel out each other. But when they are not of equal strength, so one will actually win over the other. And so we can have sort of a net effect after that sort of cancellation, to some extent. So if we are left with this sort of, say, impedance sort of vector-like. And then, so together with the actual resistance, it's like a vector quantity, right? It has got magnitude and direction, and it also has got magnitude and direction, and so the sum of these two components together will get the impedance.

And the impedance, Z, actually have got, say, the magnitude and direction. And the direction is actually given by the angle, phi. And phi can be any number depending on this, components of the R and the XM minus XS. Now, these are just sort of the idea, but on the actual equation, we want to represent that using the vector quantities. So Z is actually equal to R plus the, say, the vertical axis, so we call it, say, the imaginary axis, which is the j. j is just representing the vertical axis, which is the imaginary sort of components when there is a lot of exchange in, say, energy between the potential energy and the kinetic energy. And if you look at this, so you actually have to say, "What are we measuring then?

" So when we are actually trying to find out the function, say, of the middle ear, we're trying to actually measure Z. Z is the impedance. And then this, the magnitude of this impedance, which defined by the length of this vector here, we will be able to see that it is actually simply calculated by the square root of the R square plus these components square. This is actually just a straightforward formula. And the direction of Z is actually represented by the phase angle. What happens if the system is at resonance? So at resonance, what does that mean? So the middle ear is in a state of resonance when the impedance attains a minimum value, and the vibration itself is in phase with the incoming sound.

In that case, the phase is equal to zero. Well, I still don't know what you're talking about then. Okay, so, now we can actually look at the equation again. So the impedance Z of the vibrating object can reach a minimum value. And how's that going to actually have a minimum value? So if you look at this equation here, so Z equal to R, R has to be non-zero anyway, something in there, plus the j XM minus XS. Now, what happens if XM is equal to an opposite to XS. It means the two brothers are fighting against each other, and then they cancel each other completely. And in that case, it gives us a zero there.

So in that case, the minimum value of Z is actually equal to R. Now, when that happens, the system is in resonance, and the phase angle will become zero. And what about the frequency at which these resonance occurs? It is actually given by the formula which I introduced a bit earlier on. We can look at this sort of frequency of resonance and looking at guitar strings. If you have, say, experience playing a guitar, then you will realize probably that, say, each string has its own function. Each string has its own frequency of resonance, f0. So if you just look at, say, the strings, there is actually the tension in the string, we call it the stiffness, in this case, and also the density, it means how thick the string is, and we call it the mass, right?

And of course, each string is tuned to vibrate at the resonance frequency of the string, and it's given by this formula. Imagine now that, so tensing up a string, it means you are increasing the k there, and it would make it actually vibrate at the higher frequency.

It means the resonance frequency is actually higher and vice versa. Look at the thicker strings compared to the thinner ones. If you can see that the thicker strings are having greater mass. In that case, it's actually vibrating at a lower frequency. And when that happens, you can actually see that this sort of frequency changes with the mass of the string, basically. And the thinner string will vibrate at higher frequencies.

So we are looking at this sort of resonant frequency. In that manner, hope that you'll be able to understand this sort of acoustic resonance in the guitar. Now, that would actually, say, change to another topic about this amplification of the middle ear. As I mentioned earlier that the middle ear amplifies sound of different frequencies to different extents. And we know that, say, when that happens, if we're going to look at the middle ear transfer function, which is defined as, say, the gain, and it is given by the output minus the input, some pressure levels. And if you can actually find out the gain for each frequency, then we'll be able to plot a graph, like this on the right side.

And then these are the results actually obtained, say, based on the idea of the, say, situation when we measure this middle ear transfer function in the cadavers. And so, because of this, we'll be able to know, say, what's happening in there. So you see that there'll be a very high gain, say, at some frequencies and some lower gain at other frequencies. And maximum gain, of course, is actually happening here when Z, when the impedance is actually at a minimum. And in that case, resonance is actually occurring at this frequency, basically, more or less like that. And then, so, eventually, if you plot the graph, say, at the bottom there, you'll see that, say, the phase changes from positive to the negative, and it's actually passing through the point with the zero degree phase when the resonance occurred.

What about the gain at the frequencies on the lower end? So for the frequencies, for the sound of frequencies in the lower end, you have got greater impedance. And this greater impedance is due to the natural stiffness of the middle ear. And on the other side of the scale, like in the high frequencies, so it got greater impedance. And this impedance is actually due to the natural mass of the middle ear system. So you can see that if the mass of the middle ear system changes, this will affect the impedance of this side. And overall, what does this sort of middle ear transfer function tell us? It is actually similar to the spectrum of sound going into the middle ear.

Now, let's look at the wideband acoustic immittance test. So when we are doing this, we need to actually, of course, you know, check if there is anything wrong. When we do the otoscopic examination and is all clear for testing, then we'll actually put the probe, say, and with the appropriate sized rubber probe tip, and then place that at the entrance of the ear canal. And so this is actually, it's just like doing otoacoustic emissions, you know. And the probe stimulus is a transient wideband stimulus. It's usually a click or a chirp. And the research has found that, say, the results from a click or a chirp is actually very similar. And how loud, how large is the stimulus?

We're presenting that at about 100 dB peak SPL, which is roughly 65 dB nHL. And we're presenting that at a click rate of 21.5 per second. And we need to have, say, the average of the 32 stimuli giving the 32 responses. So after averaging these responses, we're able to see a final sort of output, which is actually showing us all these different measures, and we need this averaging to reduce the noise effect. And for each click stimulus, the WAI test, it means the wideband acoustic immittance test, measures many, many parameters. It measures the Z, which is the impedance. It measures the Y, because Y is just one over Z, all right. And it measures the phase angle at each of the frequencies and actually measures the power reflectance, the power reflectance, which I'll actually talk about in the next slide, and also it's given us the power absorbance.

The power absorbance is the opposite of reflectance. And so we are measuring all these quantities across the frequencies from 220 to 8,000 hertz. So there are many, many frequencies we are testing. The responses. So now, let's look at how we are going to actually get this sort of power reflectance in the angle reflectance. So basically, say, the WAI test is actually not a new test in itself. It is a modification of the traditional test, but we actually need to have some modification, for example. So we get the responses to undergo a calibration process in order to find out the exact impedance. In so doing, we are actually required to actually measure the pressure reflectance. Now, you know sound is a wave, and it's got the incident wave going into the ear, and then we've got the reflected wave coming back from that middle ear.

And in that case, we're trying to find out, say, the ratio of the amplitude of the reflected wave over the incident wave. Now, this is the first thing that we have to actually measure. And after we've got this pressure reflectance, we can actually look at the, say, the square of this pressure reflectance and transform this square of this pressure reflectance into another measure, which is called the power reflectance. So the the power is actually the energy divided by time. So it's basically sometimes people have got many other names to call this, but the proper name is actually power reflectance. And in that case, so we can measure this reflectance, and it gives us an idea of how much sound is reflected.

And it is actually from a theoretical perspective that the measurement of the power reflectance does not depend on the position of the measurement. Theoretically, it should have the same value when you measure at the entrance of the ear canal, or anywhere around the ear canal, or even at the tympanic membrane. Theoretically, they are the same, if you are assuming that so the ear canal is like a uniform cylinder, symmetrical cylinder. And however, our shape of the ear canal changes because the cross-sectional area changes from one point to the other, slightly. And because of that, so there are some minor variations in the results when we measure power reflectance. And this is all contained in the article by Susan Voss, 2008.

Now, this is actually the shape of the results of the power reflectance. So basically, if you look at the graph here, the horizontal axis is actually the frequency. It's in the log scale. And say, the vertical axis represents the power reflectance. And the reflectance is high, because it's from zero to one, the reflectance is high in the low and the high frequencies. And the reflectance is low in the region between one k and four k, four kilohertz. So it is actually characteristic of what, say, the middle ear is functioning. And because of this lower reflection between one and four k, we are able to hear the sounds within this frequency better than at other frequencies. And we can hear speech better because we are able to have better hearing in one to four kilohertz, because of the lower reflectance in there.

In a certain way, we can say that the middle ear acts as a filter to allow sound of one to four kilohertz to pass with the lowest reflectance. And that is why we actually hear better here. And now, let's look at, say, another term, which we called power absorbance. Power absorbance is actually the opposite of power reflectance. And as I've mentioned, there are many, many sort of names given to this sort of absorbance. So many people just call it, say, power absorbance, wideband absorbance. So this is what I'm trying to use, you know, say, in my publications as well. Say, the wideband absorbance is the opposite of wideband reflectance, you know, wideband reflectance. Again, another name for the reflectance.

You've got it WBR. So in fact, so WBA, the absorbance, is equal to one minus the reflectance. Now, why do we actually use the absorbance more than in the earlier days? In the earlier days, we talk about reflectance all the time, and the research papers are all talking about the reflectance. But then one thing that I realized is that the audiologists doesn't really like, say, the valleys, or, you know, doesn't like these sort of troughs. They like mountains. They like mountains. And that's why, say, the wideband absorbance when it's converted, say, from this reflectance, we can see the mountain there. Looks like type A or, you know, so like a mountain. And we like mountains, easier to interpret, and that's why.

And the results in here is actually showing that in horizontal axis, it is the frequency, and the vertical axis goes from 0% to 100%, and this is zero to one, yeah. And the result that we've got here is actually the result from my right ear, and it's showing the graph looking like, say, that sort of a mountain. Now, let's look at the proper definition now, proper definition of wideband absorbance, immittance absorbance. So it is actually the energy absorbed by the middle ear divided by the energy of the incident wave, basically. So with this sort of ratio, we will actually see that the absorbance varies from zero to one, from zero to one. And if no energy is absorbed by the middle ear, whereas in here, it's very close to zero, say, in here, maybe it's about 10%, so in that case, WBA is equal to 0.

1. And when it's absolutely zero, it's zero. When it's 40% of the energy is absorbed by the middle ear, WBA equals 0.4, so here, at this point here. So we can see that the absorbance equals to 0.4, and so on, if we can actually see when it reached 100%, of course, in that case, it will be equal one. However, my result is actually showing the best sort of absorbance is actually 86 or something. But anyway, it is following this sort of shape. The shaded area here is actually representing the normative data, say, of the absorbance values from 5% to 95%. Now, we have to look at, therefore, the relationship between absorbance and impedance. And if you look at the diagram on the right side here, diagram, say, figure A here, so this is actually a graph of the absorbance against the frequencies.

Now, you see that the absorbance reached the highest point here, for example. This is the highest point, and it's actually in a stage of resonance, for example. So in that case, say, you see that on the sort of lower frequency, lower to mid frequency area there, so the impedance is high. It's actually caused by the stiffness of the outer and middle ear system. It's sort of a natural sort of stiffness of the middle ear system and is actually suppressing the absorbance in this area due to the natural stiffness of the outer and middle ear system. Whereas, on the other side, on the high frequency side, higher than the resonance frequency, we see that the impedance is also high.

And this is actually related to having the mass elements of the middle ear, and it's the impedance due to the natural mass of the outer and middle ear, and thereby suppressing the absorbance in this region. Impedance obtains minimum, as I've said just before that, say, there is a very small impedance here. It means we've got maximum absorbance in here. And this is the frequency of resonance when you see that in the diagram there that the impedance reached the lowest point, it's the lowest point, and then go back up again. Now, at this point, when we have the lowest impedance, we do have, say, the resonance occurring. And with the phase angle that's actually changing from, say, this negative until the positive but reaching the phase equal to zero at this point of the resonance.

Yeah, this is how it looks like in general. Now, if you look at, say, the absorbance even in healthy adult ears, and you can see that, so despite this sort of slight variations, we can still see that between one and four kilohertz, there is a broad absorbance peak. There's a broad peak there. And outside this range, so the absorbance becomes smaller. And we always expect to have this primary peak in a normal adult ears. And in particular, I would actually suggest, therefore, that, so the peak here at around one kilohertz is actually due to the resonance of the middle ear, which is occurring at about 1,000 hertz for adults. And you can see that even in normative data, there is a little sort of a peak there.

And this pattern is very nice pattern. Whereas, the highest peak over there may be related to the resonance of the ear canal. The resonance of the ear canal is usually happening at around 3,500 hertz, around that sort of value. And that's why you can see roughly, say, two peaks within the broad peak. And there are always, say, what is normal? You know, normal absorbance actually varies depending on the person, on the individual, because the anatomy of the outer and the middle ear of the individual is actually given rise through their own characteristic, say, absorbance spectrum, absorbance curve, we call it as well. So in summary, the wideband absorbance results do not only reveal the acoustic mechanics of the middle ear, but they also show the resonance effects of the outer and middle ear, for example, the ear canal and the middle ear cavity, which I mentioned before.

So, what happens? So you can see there's some variation. In some set of these adult ears, you can see that, say, some of them have got, say, a value of the absorbance below the fifth percentile of the normative data. Now, so usually, we say when it is outside the range, we consider that as, say, not so normal, in a way. However, so these variations is actually clear. If you compare, say, these sort of results, the red curve is actually showing a lower sort of absorbance results compared to the others. So in that case, I can see that the stiffness of the middle ear of this person, given by the red curve, is actually having greater stiffness than the other ears.

The same with the black curve there, the bold black curve, also having a slightly greater stiffness as well. So, how are we going to assess the ears with a conductive condition? Now, the assessment of this requires the accurate measures of the impedance, absorbance, middle ear gain, and the resonance. So in ears with a conductive condition, their natural mass stiffness and resistance elements can be changed depending on, say, their sort of condition, on the conductive condition, and this will result in different impedance, absorbance, gain, and resonance. And this is affecting the shape of the graph, of the absorbance spectrum graph. So diagnosis of the middle ear disorders can be looking at assessing the absorbance values across a wide range of frequencies, so how high or how low the absorbance values are across the frequencies.

At the same time, we should be looking at the shape of the absorbance spectrum, the configuration, we call it, and this will tell us, say, more about how the stiffness and the mass elements interact in the middle ear system. Back to this graph that we have seen before that. So if this is actually sort of a normal absorbance result for a normal person. So now, as we mentioned before that, so in the lower to mid frequencies, you've got greater impedance due to the natural stiffness of the system of the middle ear. And, say, on the other side, we have got the greater impedance due to the natural mass of the middle ear system. And right at the top there, perhaps, this will be the minimum of the Z.

And you are having this highest absorbance. If we look at the condition when you have greater stiffness of the middle ear, this could be due to negative pressure, high negative pressure, because of the eustachian tube dysfunction, or it could be due to some stiffness, greater stiffness, due to otosclerosis or something along that sort of, say, pathology, then you'll see that there'll be greater impedance. There will be greater impedance. And because of the increased stiffness, this greater impedance is actually, say, acting on the graph to make it lower at this end. At the same time, if you look at the frequency of the, say, resonance frequency, it's actually shifted slightly to the higher end as well. Now, in this case, you will see that the configuration has changed.

In the other scenario, when you have decreased stiffness, for example, those with a floppy eardrum. A floppy eardrum does not necessarily give rise to hearing loss in adults. But this sort of measure is very sensitive to, say, the stiffness, especially when it is decreased stiffness. And you can see that with decreased stiffness, say, the curve here is actually showing greater absorbance because we have got decreased impedance because of the decreased stiffness. So it seems that the curve is actually shifted to the left side, to the low frequency side, in so doing, affecting, say, the configuration here. So when you see that on the lower end or lower frequency end to the middle frequency, when it's actually increased, that's actually meaning decreased stiffness.

It could be due to any condition, but WAI measures would not actually, say, diagnose what type of problem the ear might have. But it just shows the graph. What happened with increased mass situation of the middle ear system, like, for instance, those with maybe, say, some condition which actually have increased the mass? Now, like, for example, cholesteatoma, so that sort of situation, and you see that the greater impedance is acting on it, so they suppress that peak and actually shift the configuration to the left side as well. Now, so when you see this, now, can you observe that this sort of configuration is very similar to the one with reduced stiffness? Yeah, they're very similar. They're very similar.

But sometimes you can't tell which one is which. That's why you cannot interpret, say, wideband absorbance results alone. It should be interpreted together with other measures, like the audiogram, otoacoustic emissions, et cetera, to make the correct diagnosis. What happens if you've got very high stiffness and mass together, say, like those children with glue ear, otitis media with effusion? There's a lot of thick effusion filling up the whole middle ear cavity. You're able to see a graph which is suppressed all the way down. Now, let's talk about, say, another measure sort of, say, still wideband absorbance testing, but now we apply it at a pressure to the ear canal as if we are doing tympanometry. In that case, say, this is actually going to give you not just the absorbance against frequency, if you look at from that side, but it also gives you another dimension of measure, like the pressure variations.

Like you can see in the pressure variation, even in here, you can see there is a peak there, and then go down there. So it looks like the, say, 226 hertz tympanogram, right? But now, these three-dimensional sort of results is actually a bit difficult to interpret, and it's a bit daunting when you first learn about how to interpret these results. In fact, these results is actually giving you, say, a lot of information, not just this sort of dimension, it also calculates for you the resonance frequency of your middle ear. And so it has got some sort of additional information to help you to diagnose the condition. And when I was actually traveling, at one time, maybe about 10 years ago, and then my airplanes came across, say, California.

And on top of it, and when I looked down, wow, that looks like wideband tympanometry results. It's got some sort of landscape. So, how am I going to diagnose the conductive condition just by looking at these mountains? Wow, it's so stunning. So that's why, you know, I say, "Wow, yeah, "I have to learn how to actually interpret the results." So now, we know that, say, the wideband absorbance results across the frequencies and pressure is actually, say, something that we can measure in wideband tympanometry. So because we are measuring at different pressures as well, different frequencies as well, so we're going to get sort of a picture, a two-dimensional picture of the absorbance results at zero daPa, zero daPa.

So it's the same as the atmospheric pressure. We actually obtain a result. And if we also obtain a result at the tympanometric peak pressure, which is TPP, we call it. So you know that at this TPP, the middle ear or the eardrum is free to vibrate without a lot of impedance, you know. It is actually, say, showing you that is the best result when there is no other obstructions. Because the negative pressure has been compensated for, and at this pressure, so the eardrum is free to vibrate. And wideband tympanometry also provides you with, say, the admittance against pressure at all these frequencies that you can measure. It provides this phase angle too. So there's a lot of information contained in this wideband tympanometry.

And it also provides you with a wideband tympanogram. There's a wideband tympanogram. I haven't heard about it before. Now, there is actually some sort of, say, result similar to that of a tympanogram, but this tympanogram is average across the many frequencies from 375 to 2,000 hertz. Now, in that case, on the right side, you can see here this is the ear canal pressure, and that is actually the absorbance. And as I've mentioned to you before that when you are doing wideband tympanometry, you can also obtain the resonance frequency in children and adults, but not for neonates and infants. They've got a different sort of, say, middle ear system. You know, they've got a mass-dominated middle ear system.

So except for this, when we're doing that testing on children and adults, we're able to measure the middle ear frequency, resonance frequency. Well, let me show you a few case examples. These are real case examples that we can see, that in this case, it is just the hypermobile eardrum. That means sort of a, the eardrum that has got, when you measure using the 226 hertz tympanometry, now, you get a very high peak. So the admittance is 1.75 minimal is a very high peak, say, and the TPP is actually pretty normal. There is no abnormal sort of negative middle ear pressure. Now, even with that, we just look at the eardrum being so floppy, and then this is actually the result we would get.

And so it's just having the absorbance sort of increased in the low to mid frequencies. In another case, we have the ossicular fixation. Now, this would also include, say, otosclerosis or whatever. Now, in this case, we actually have a 34-year-old male who's diagnosed from very young. Say, at four years of age, he was already tested and found to have a mild, very mild, conductive hearing loss in his left ear, in the left ear. And, say, the 226 hertz tympanometry results show a TPP of minus 35 daPa, and the admittance, the Y, is equal to 0.25 minimal. Now, this means that so is giving you sort of a high stiffness, you know, when you see that the Y is so low.

And also, with the ipsilateral acoustic reflex testing, there are no reflexes detected from 0.5 to 4 kilohertz. Now, this actually meaning the stiffness of the middle ear, but not due to negative middle ear pressure, but due to the stiffness itself, and it gives you a sort of absorbance diagram showing you that, so this is actually, say, still within normal limits, but then, now, this characteristic sort of drop in here, the trough in here is actually indicating, say, that there is high stiffness in the system, and then the whole sort of broad peak is shifted, is shifted to the right side. And you can see that this is meaning that very high stiffness in the middle ear. What about, say, the other case?

This is a complicated case. I might have to explain that things a bit of detail. A 64-year-old male is diagnosed with a mild to moderate sensorineural mixed hearing loss in his left ear. Mixed meaning both conductive and sensorineural components in there, or sensory, basically, so. And he has got a results, as shown on the left side. Now, how are we going to interpret the results in this case? I don't know. I just look at the 226 hertz tympanometry results first. The TPP is minus 136 daPa, negative pressure. That's actually indicating some additional stiffness in the middle ear just due to the negative middle ear pressure. And the admittance is pretty normal, so it has got some, say, good mobility of the middle ear.

What is actually interesting in this is that the ipsilateral acoustic reflex results, they are all absent. From 0.5 to 2 kilohertz, they're absent. Now, normally, if it were just having a negative pressure of this sort of amount, if you do acoustic reflex testing, which is actually testing at TPP, you should be able to get reflexes, but now you don't have it. What does that mean? And the wideband tympanometry revealed this sort of diagram, which looks a little bit complicated to interpret, but let's actually tease out what's important in this sort of graph here. And so, in here, it shows so many, so many sort of, say, parameters to look at. But along this sort of bold line here, this is actually the results at TPP, which is minus 136 daPa.

Now, if you look at this, let's analyze it using a two-dimensional diagram here, that on this diagram, we have got the wideband absorbance at zero daPa, which is same as atmospheric pressure. And because we're testing so many different pressures, we can obtain these sort of results. We also have results at TPP. Let me just add that TPP when the eardrum should be, say, free to vibrate without the influence of the negative middle ear pressure that is present, okay? So we've got these two sort of graphs showing. Now, the WBA TPP sort of graph here is actually showing you that it is not so normal. It's not so normal. Although, it still have good mobility, say, good absorbance in those sort of frequencies, we observe that this part of the sort of curve is actually, say, quite low, and there is a characteristic sort of drop in here, a trough in here, that's actually indicating still there's stiffness in the middle ear.

And if you look at the one without compensation for the negative middle ear pressure, so this WBA at zero daPa here, this curve actually show that the negative middle ear pressure creates even greater stiffness on top of the underlying cause of the stiffness. In this case, it is actually showing you very clearly that so in the testing at, say, this sort of zero daPa, this is actually what you see in the absorbance result, which is showing even lower sort of results, and also having, say, the broad peak shifted to the right side, to the high frequency side. Now, what does this mean? So it means that by using, say, comparing these two graphs, these two sort of absorbance pattern, we'll see that there is an underlying sort of disease, underlying sort of problem in this ear.

This ear is not just having, say, the negative middle ear pressure due to the eustachian tube dysfunction. It has got another sort of problem which is also giving you that sort of result. That underlying problem is probably due to the middle ear dysfunction. In this case, it's actually otosclerosis. Now, this is a bonus. I'm supposed to give you three adult sort of results. Now, I'm going to give you another one which is from my sort of, say, research. And in my research, I've been testing a lot of, say, childrens in the school. And I actually applied this sort of tympanometry and also the wideband absorbance measure. And I found that in this six-year-old girl, and we found in the audiogram that there is an average hearing threshold of 30 dB HL, which is sort of a mild sort of conductive hearing loss.

And so the 226 hertz tympanometry is showing no peak at all, and the ear canal volume is actually 0.67 mL, and the ipsilateral acoustic reflexes also absent because it is actually no peak. And this sort of absence of the acoustic reflexes is actually expected because of the middle ear issue. And this child has got glue ear. And with the glue ear, you can see that this graph is actually coming down very low, and you can be almost certain that there is fluid, thick fluid in the middle ear. Oh, I think that I've gone over time a little bit, but thank you for your attention. I hope that would give you a clearer view of, say, this wideband acoustics measure.

- Thank you so much, Dr. Kei.

- We've got some references. So that's all from me. Thank you.

- [Christy] Thank you so much, Dr. Kei. I'll leave the classroom open here just for another minute or two. We don't have any questions in the queue currently, but this does conclude the content portion of this presentation. So if you do need to log off, feel free to. And for those of you who have any questions or comments for Dr Kei, please send them through, and we can queue those up for him. Dr. Kei, it doesn't look like there's any questions that's come through, so I'd like to take this time and thank you for your time. I know it's early morning where you are, so we really appreciate you coming on and sharing your passion on this topic as well as your expertise.

It's not very often that we have someone who can come on and speak to tympanometry in general or immittance and specifically wideband acoustic immittance. So thank you so much for your time. And this concludes today's course.

- So yeah, it's my pleasure, really. Thank you.