Intra- and Post-Operative Electrocochleography in Cochlear Implants

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- [Host] At this time it is my pleasure to introduce our presenter, who will discuss intra and post-operative electrocochleography in cochlear implants. Dr. Aniket Saoji is the director of the CIA program at the Mayo clinic in Rochester, Minnesota. He is a clinical audiologist with a PhD in psychophysics from the State University of New York at Buffalo. Prior to his position at Mayo, Dr. Saoji was a principal research scientist at advanced Bionics where he was involved in the development of new signal processing and speech coding strategies. He has coauthored several patents and publications on the technologies developed at advanced Bionics that has led to significant improvement for a cochlear implant patients. Thank you, Dr. Saoji and at this time I'll hand the mic over to you.

- [Aniket] Hello everybody, my name is Aniket Saoji and I would like to say hello from nice and cold Rochester, Minnesota. I don't know, the weather outside is saying, I think 20 degrees Fahrenheit or something like that. So good morning or good afternoon. Wherever you are on the East or the West coast or in the Midwest. Today I'll be talking about intra and post-operative electrocochleography in cochlear implants. Before we go through the rest of my presentation, I would like to thank audiology online for giving me an opportunity to present on this platform. And thank you again and thank you to all the attendees who are listening in to this presentation for attending this talk. Before we go in deep into the presentation. Here is a quick disclosure. I at some point in my career, have spent 13 years in the research development and technology department of Sonova, out of which 11 years were at Advanced Bionics in sunny California, and two years were at Phonak in Warrenville, Illinois. As I'm still a consultant for AB AMA and I am an advisory board member and consultant for Envoy medical. I do receive research support from Advanced Bionics as well as cochlear corporation for everything that I do with cochlear implants. Quickly go through the learning outcome for today's course, we will describe electrical potentials that are measured using electrocochleography. We will look at intra-operative application of electrocochleography and during cochlear implant surgery. And the third learning outcome is describe, we will look into the post-operative application of

electrocochleography, cochlear implant patients with reserve residual hearing that is in patients who have a residual hearing post-operatively. So cochlear implants, doesn't need much introduction these days, even though it is a class three medical device that is used to restore hearing sensation and speech perception in patients who have varying degrees of hearing impairment. There are three approved cochlear implant manufacturers approved by the United States FDA whose devices are gonna be implanted in patients. starting with, Advanced Bionics, Cochlear and Med-EL. So cochlear implants, you know, each implant manufacturer has some type of a processor that goes behind the ear, or maybe all-in-one piece processor. It uses a microphone to. It uses a microphone to capture the sound from the listening environment. Then that sound is dubbed, goes through some signal processing chain and then using this cable and the coil, or the headpiece here is communicated to the implant that is placed under the skin. The implant electronics then takes that signal and sends it to the auditory nerve using this electrode array and the electrode array is placed inside the cochlea.

So 10, 15 years ago it was easy to ask a question who qualifies for a cochlear implant and the answer would be simple. Well, patients with severe to profound hearing loss get a cochlear implant. In the last few years, the criteria has, oh, sorry. The criteria has significantly changed and more and more patients with significant, residual hearing, not only in the low frequencies but also in the high frequencies have started receiving cochlear implants. And from our experience over the past 10 years or so. What we have learned is that these patients who have partial hearing loss and receive a cochlear implant receive significant benefit in terms of speech understanding and music perception, using their cochlear implantation. And what has been also shown by our Rene Gifford and others is that, if we are able to preserve the residual hearing in this patient and amplify that ear along with the cochlear implant, then the combined acoustic and electric hearing provides the best cochlear implant outcome in terms of sound localizations, speech perception and music appreciation. But the small problem, or a big problem here, is that some of the patients who receive a cochlear implant

show a decrease or complete loss of residual hearing after cochlear implant surgery. That means these patients have some amount of hearing before the surgery and after the surgery, whether it is immediately after the surgery or sometime afterwards, they end up losing their residual hearing. Now, from our experience in the last 10, 15 years, what we have learned is that there are several intra-operative factors the intra-operative factor could be cochlear trauma while placing the electrode that is, when the electrode is being placed in the cochlear it may lead to some sort of a cochlear trauma and that can lead to loss of residual hearing, or there might be other post-surgical factors where recovery from the surgery, or the inflammation after the surgery can lead to some loss of residual hearing. So there are many intra-operative, as well as post-surgical factors that contribute to the loss of residual hearing after cochlear implantation.

So coming to the placement of the electrode, the cochlear, we know has three compartments. The bottom compartment is called as the scala tympani as shown here. The top compartment is called the scala vestibuli and the compartment in the middle, which houses the organ of Corti here, which we can see the hair cells, the tectorial membrane, and the basilar membrane, is known as the scala media. Now, ideally, the entire array should be placed into the scala tympani, that is in this bottom compartment. Now, here is a picture of a cross section of a cochlea where an electrode was placed. So here is the electrode. Here is the scala tympani. Here is the scala media here. And then the scala vestibuli on the top. So in the first term, the electrode is all in the scala tympani. Also in the second term, both of the electrodes are still in the scala tympani. But what you can see here is that this electrode is very close to the basilar membrane. Now, imagine trying to place a tin wire in a snail-like structure, we have no idea of where the electrode is going. And we have very little control over how the electrode is being placed into the cochlea. So during the placement of the electrode, if there is any kind of an insertion trauma, to the basilar membrane, whether the electrode kind of forks into the basilar membrane or the electrode, pierces through the basilar membrane and translocates from the scala

tympani into the scala of vestibuli, both these types of trauma can lead to loss of residual hearing. So Laura Holden from Washington University has a great article that was published in 2013 that shows that there are several patients who can have electrode, some of their electrodes, placed into the scala of vestibuli. That is some electrodes transferred from scala tympani into the scala vestibuli, and these patients who have more and more electrodes into the scala vestibuli perform significantly poorer in terms of their speech understanding as compared to patients who have their entire array placed into the scala tympani. So I think there is very compelling evidence to say that ideally, the whole entire electrode array should be placed into the scala tympani and without any cochlear trauma. Now, with the current technology, we are unable to visualize the electrode location during the placement of the array.

And this is where I think the role of an audiologist becomes important. We have all learned in our school days what is electrocochleography, and some of us are still using, electrocochleography or ECOG in patients who are suspected to have Meniere's. So, what is ECOG? Well, ECOG is a technique which is used to measure electrical potentials from the cochlea and auditory nerve. And it is this technique that we can possibly use to monitor cochlear trauma and guide electrode placement during cochlear implant surgery. So in today's talk, we will look at, we will go into depth about what is electrocochleography, what are the potentials we can measure using electrocochleography? How are these potentials measured during surgery? And how are they used to monitor implant electrode placement? Post-operatively we'll also look into how these potentials can be used to rehabilitate patients with cochlear implants. So, when we say we are going to use electrocochleography to measure electrical potentials, well, we first need to generate the potential, and then we need to record the potential. So the electrical potential from the cochlear or the auditory nerve, can be generated using a brief direction acoustic stimulus such as tone burst or clicks or an electrical stimulus like we routinely use during NRT, NRI or ART measurement in cochlear implants. These are measurements we perform immediately after the electrode placement and also post-operatively to make sure that the electrical signal is

reaching the auditory nerve. Now, once we generate these potentials, whether we generate it acoustically or electrically, we need to record these potentials and these potentials can be recorded using electrodes that are placed on the surface of the scalp, or using the tip-trodes. The other type of electrodes that can be used to perform these measurements are transtympanic or sometimes referred to as extracochlear electrodes. By sometimes we place an electrode on the promontory and the promontory can pick up these signals as well. Now, with the advancement in the cochlear implant technology, lately, we have been able to measure these potentials using the cochlear implant electrodes. That is, we do not need any scalp electrodes, or any extracochlear electrodes to perform these measurements.

So coming to ECOG. So when we present a stimulus during electrocochleography depending on the type of stimulus we can, and the filtering mechanism employed, we can measure the following four evoked potentials. One of them is called cochlear microphonics or CM. The other one is called auditory neurophonics, auditory nerve neurophonics or ANN and then the other two potentials, which we generally measure for patients with Meniere's is summating potentials, SP or action potential, or sometimes known as compound action potential or CAP or AP. The cochlear microphonics were first measured by Wever and Bray in 1930. And were thought to be coming from the outer hair cells. So here is a quick summary of the generators side of these different potentials. Cochlear microphonics are assumed to be generated from the outer hair cells or mostly the hair cells and the supporting cells. Auditory nerve neurophonics, as the name indicates, comes from the auditory nerve. The summating potentials, again come from the hair cells and the compound action potential is again coming from the auditory nerve. But one thing to remember is that the cochlear microphonic ANN, SP is an ongoing response for the application in cochlear implant. That is when we present the stimulus at the same time we acquire the electrical potentials, that is the stimulus and the potential are presented and recorded at the same time. So let's dive in deep for what we do during ECOG measurement as it relates to cochlear implants. During the ECOG measurement, we use an acoustic tone

burst, even though we are dealing with cochlear implants, we use an acoustic tone burst, and this is primarily done in patients who have some level of residential hearing in the ear that is going to be implanted, okay. So here we are showing a brief duration acoustic stimulus, acoustic tone burst, something like 10 to 25 to 30 or 40 milliseconds. And here is a representation of the wave form of a 500 hertz stimulation with a condensation polarity. There it starts with a zero and this is a condensation polarity stimulus shown here. And this is a cochlear microphonic signal. So we are presenting this sinusoidal stimulus, and at the same time we are recording this potential called a cochlear microphonic, or a signal from the cochlear and we are, oh sorry, we are recording a evoked potential from the cochlea. In this case, the cochlear microphonic looks exactly the same as that of the stimulus and is shown here in green. In the next presentation, in the next stimulus presentation, instead of the condensation polarity, we use the rarefraction polarity. And that is opposite in polarity as compared to the condensation phase and the stimulus, and the cochlear microphonic recorded from, during this presentation also looks just like the stimulus, okay.

So, we use an alternating polarity stimulus that is, we go back and forth between condensation and rarefraction polarity, and we keep doing this and keep acquiring the stimulus. While we are doing that, if we decide to add these two stimuli that is, we decide to add the evoked potential measured from during the condensation phase, the rarefaction phase, this is what will happen, right. So here is our cochlear microphonic waveform for the condensation phase, and then we add the rarefaction phase to it. They basically cancel and we do not, and we get a flat line, that is, we do not get any response. However if you take the two and now subtract one from the other. Okay, so this is how it's done. So here is our cochlear microphonic wave file. And then here is our negative phase, but this time, instead of adding, we are gonna subtract it. So, when we subtract it, we kind of switched the phase of the response and when we add it, we get a nice cochlear microphonic signal. So, a cochlear microphonic is derived by subtracting the response for one phase from the other. If we add the response of one phase to the other, we end up losing the cochlear microphonic signal. Now, coming to

the, coming to auditory nerve neurophonic, okay. The auditory nerve neurophonic is also a response that is phase locked, remember, there is phase locking in the auditory nerve, so the nerve responds in a phase locked manner to one particular phase for this condensation phase. When we present the rarefaction polarity we get a similar response that is locked to another phase here. Now when we add these two, we get what is called as auditory nerve neurophonic, okay. Now, if we subtract the response, if we subtract these two responses, we end up getting a flat line. Remember we are gonna shift this phase and then add it to this response here. And that's gonna give us a flat line.

So let's quickly summarize what we are doing. We are presenting a condensation phase and to that phase we are gonna acquire the responses for cochlear microphonic and auditiry nerve neurophonic, okay. Even though they are separated in this figure here, they're not gonna be separated in the acquisition stage. That is we don't know what is cochlear microphonic, we don't know what is auditory nerve neurophonic. We are gonna do the same thing for the rarefaction phase and we are gnna acquire the responses to these two. If we subtract the responses of the one phase from the other, we get cochlear microphonic. If we add these two responses, we get auditory nerve neurophonic. So by definition, cochlear microphonic and auditory nerve neurophonic is nothing but the way we add and subtract the responses acquired using this electrocochleography technique, and that helps us differentiate within the cochlear microphonic or the outer hair cells and the auditory nerve neurophonic of the auditory nerve. Now, one important difference between these two responses is that the cochlear microphonic frequency, like it's shown here in the FFT, is exactly the same as the stimulus frequency. So we are denoting it we are representing it by F, whereas the auditory nerve neurophonic, the frequency of dotted in nerve neurophonic is two times the frequency of the stimulus. And so this is the stimulus frequency, and then you can see the auditory nerve neurophonic frequency. So for example, if this is a 500 hertz stimulus, the cochlear microphonic will also have a frequency of 500 Hertz, whereas auditory nerve neurophonics is gonna have a frequency of 1000 Hertz. I hope this is

clear. If any questions, please go ahead and type in your question and I'll try to do my best to answer them. So coming to cochlear implants, okay. In a patient who has significant residual, low-frequency, residual hearing for example, what can we do? We can present a 500 Hertz stimulus like the one that is shown here at a somewhat loud level. And that stimulus is gonna go and stimulate the apical region of 500 Hertz inside the cochlea, okay. That stimulus is going to generate cochlear microphonics, cochlear microphonics is generated from the outer hair cells, and so we measure the signal using the cochlear implant electrodes. So how do we do that? So you see this array of electrodes here, we use the most apical electrode as the recording electrode, and then this case here is used as the ground electrode. So we record the responses between the active electrode and the ground electrode, just like like it's shown here. Similarly, we record the responses within the active electrode here on this array and the case electrode shown here.

So in cochlear implants, we do not use surface electrodes to perform electrocochleography because we want to do this during surgery as well. So we use the implant electronics so that we can use one of these electrodes as the recording electrodes and the other electrode as the ground electrode. So how exactly does it work? So here is a schematic illustration, okay. Here is the cochlea, or more specifically the basilar membrane. Remember, we want the electrode array to be placed entirely into the scala tympani here. We don't want the electrode to go through the basilar membrane and cause any trauma to the surviving hair cells in the cochlea. So during the surgery, we place a, we present a 500 hertz stimulus, like it's shown here that generates cochlear microphonics, okay. The 500 hertz stimulus is going to stimulate the hair cells enduring in the 500 Hertz region in the cochlea, and generate cochlear microphonic. And then when the electrode is introduced from the round window, and we use this most apical electrode here as the recording electrode, and we measure cochlear microphonic. As this electrode starts approaching the 500 Hertz location in the cochlea, we should start seeing a gradual increase in the cochlear microphonic amplitude that is shown here. I'm sorry I was using my cursor, but what I

wanted to show was, and I don't think you can see my cursor. So I finally got my cursor up here on the screen. So we are using this most apical electrode as the recording. Let me go back. So we had using this most apical electrode here as the recording electrode, and as this electrode travels near the 500 Hertz location, which is where the cochlear microphonics is generated, we get to see a bigger and bigger cochlear microphonic amplitude. The idea is that if this electrode pierces the basilar membrane and causes destruction of the hair cells, then we are gonna see a immediate drop in this cochlear microphonic amplitude. So this amplitude is gonna be used as a guidance during the placement of cochlear implant array. So how do we actually do this? I don't want to go into the details of the whole setup, but I just thought I'll give you a flowchart of how it's done.

We have a tone generator. If you want to present a 500 hertz stimulus, we need a tone generator that is going to generate a acoustic tone burts such as 500 hertz, and that is gonna be presented through a tube or an insert earphone, into the ear canal, okay. This tone generator is synchronized with a software that is gonna measure ECOG and do all that addition, subtraction, and all of it, and display the cochlear microphonic amplitude. This electrocochleography software is connected to the POD or the CPI-3 to the processor and then to the cable and the headpiece and coil, and that then talks to the implant and captures the responses from the electrode array. I know this is a lot to take in and we will go through this one more time, when I show you some of the OR pictures as to how this is exactly done, okay. So let's start with the preparation of how we are gonna set this up in the OR. So here is our nice old, plain old, yellow form plan that we use, that we put in the ear canal and here is the tube of the insert earphone that we use to present the 500 Hertz stimulus, okay? Now see the difference between this black stem here and the black stem that we have got in this, in this picture here, this black stem, when we fold this all over, we fold this tube can be kinked. and that will prevent the 500 Hertz stimulus from being delivered in the ear canal. So I think it is important to make sure that there is no kinking, there is no kink here in the stem of this foam plug. when we are actually doing the measurement. Now, once we take this

yellow foam plug and put it in the patient's ear canal, we cover this ear canal or this part of the concha with something known as bone wax, okay. We take this bone wax and we cover it because at some point they are going to wash this whole region with betadine and we don't want any liquid or betadine entering in the ear canal because if there is fluid in the ear canal our stimulus of 500 Hertz will simply not make it to the tympanic membrane and then we may not get any responses. So it's important to make sure that we take good care of, so that any fluid does not reach. It does not reach the ear canal. Here's a question. Does shortening the black stem of the insert earphone affect the insertion depth of the ear phone, thereby affecting the stimulus intensity? I think it's a great question. I don't think it will affect the insertion depth because you can push, there is a long, there is a long tube here so you can push the tube just to the same point where you would want to place the foam tab. And I don't think that the length of this, this black stem is long enough to significantly affect the stimulus intensity. it might bring up the level up, by maybe .5 DB or something like that. Although I have not done the measurements, but it's a very short, very short stem. So great question.

So once, so it is important that we are in the OR, that the audiologist is in the OR and making sure that we take care of the foam plug. We put the insert earphone in the ear canal, block this off with bone wax because afterwards, the surgeon is going to take the pinna, take this pinna and kind of fold over the pinna and then prepare for surgery. So the next picture is going to have some more graphic there from the OR okay. So here is the final prep. Just before we are ready to get, to measure, to place the electrode and measure cochlear microphonic suiting surgery. So let's go through this. This is, I think, pretty important. So here you can see the tube. Of the insert earphone and you don't see the form plug because it's in the ear canal and covered, this pinna is folded over and kind of fold over. And this transparent section here is called the Ioban, okay. Now we got to first put this insert earphone tube and put that bone wax. Then the surgeon folds the pinna over, and then the first thing they do is put these drapes and you can see these drapes. This is the drapes. You can see these drapes that are

put on the patient. It is important to let them know that you want these drapes to be placed further back and behind here because if these drapes are here, if these drapes are covering the implant side, then we might have some difficulty placing the coil on the magnet. And we'll come to that in a second. So it's important to kind of put these drapes further behind and back, okay. And as you can see, the implant is already placed in the pocket. So the surgeon has done the facial recess. He has made a pocket, he has placed the implant inside the pocket. Here is the electrode array that is about to be placed in the cochlea. And just before that happens, we take this coil, you know, we have the coil, the headpiece, and the wire, and we put this into a sterilized ultrasound sleeve that is shown here. And then this coil is placed over the magnet. So now we have started talking. Our software has started talking with the implant so that when this electrode here, the most apically electrode is being placed, we can start measuring cochlear microphonic. So again, you present the stimulus, blip, blip, blip, blip, blip, sound going into the ear all the time while the electrode is being placed. And the most apical electrode is used as the recording electrode.

So let's go ahead and bring up the first video. I would like you, to take you into the OR where we are now measuring cochlear microphonic while the electrode is being placed in the cochlea. Here, you can see the surgical screen, or this monitor that we see that is synchronized in time with cochlear microphonic measurements. Here is the amplitude of the cochlear microphonic that is measured ,here is the actual signal that is measured from the cochlear, the actual cochlear microphonic that is measured from the cochlea. And here you can see the frequency. This is frequency in kilohertz on the X-axis. So 500 hertz is here, and then this is the amplitude. So let's go in and see what's going on. So this is the electrode that is almost placed into the cochlea. And when you hear a drop, as soon as you pull back it recover. So really go slow insertion for the last two electrodes. Okay, can you just slow down Dr Carlson. No, pull back. So let me, let me pause here for a second. You'll see that the cochlear microphonic, signal amplitude was nice and good. As soon as Dr. Carlson, who is one of our neurotologists, tried to place the last two electrodes the last two electrodes that are

still outside of the cochlea in this situation. When he tried to push the electrode just a little bit in, we saw a big drop in the cochlear microphonic amplitude indicating that the cochlea is either touching the basilar membrane or is doing something that is not desirable. So we said, fine. I mean, your signal, our amplitude has just dropped. You need to pull the electrode back. Okay, so let's continue with the video here. Just a millimeter. So I said, just pull back just a millimeter. Easier said than done. Yep. And you can see as soon as he just barely pulled the electrode back, we had a complete recovery in the signal here. So let's keep playing. No, you're good. Now you're good. So from here on where you have to go very slow, maybe just turn the electrode just a little bit. Now that's easier said than done. But see, you can see the power of this tool, right? I mean, you can guide, really guide, electrode placement using electrocochleography during surgery. Now let's go ahead and put up the second video. Okay well, let me pause it here. You know, this is, again, this is using the new AIM system, the commercial AIM system that was launched by Advanced Bionics recently. And so we have only shown the electrocochleography amplitude, or the cochlear microphonic amplitude here. And in this, what we are trying to do is to make, to kind of focus the microscope in such a way that we can actually see each and every electrode. So you should be able to see. I couldn't get my cursor, but I want to see each and every electrode as it is entering the round window here, okay. So just, just take a look at the video. The last two electrodes are going in and see as the electrode is going in, the most apical electrode is reaching 500 hertz stimulus. And you can see a rising amplitude in cochlear microphonic. That's exactly how we want it to look like, okay. And we just have to be careful monitoring it and making sure that we communicate quickly to the surgeon if we see anything, any changes in the cochlear microphonic amplitude. Let's go ahead and put up a third video, now. This video was--

- [Amy] Double the amplitude it was when you first started.

- [Aniket] Okay, this video is showing the electrode placement for a nucleus, 622 device here. Which is from Cochlear Corporation, and this is their, this is their software

that is now used to measure cochlear microphonic. So here is the cochlear microphonic amplitude. Here's a cochlear microphonic signal, and here is the spectrum or the FFT showing the nice cochlear microphonic that we are recording. The neurotologist is Dr. Carlson and one of our audiologists, Amy Olin is monitoring the cochlear microphonic and providing feedback to the surgeon. So let's take a listen.

- [Amy] And it's still growing a little bit more here. Now it's about three times the amplitude it was when you first started. So we're still growing. Right, looks like you're gonna peak here in terms of amplitude, it's still growing. Got a really nice response to 500 Hertz, and you're starting to drop an amplitude right now. Do you want to just hold it there for a sec? How far are you in? Okay we had two other cases.

- [Aniket] Well, so ii like you can see here, you know, we saw a drop, we immediately alerted the surgeon saying, you're seeing a drop. You need to really slow down hold it there, maneuver the electrode to see if we can maintain the signal here or prevent any further decrease in cochlear microphonic amplitude. We can also try to recover the signal if you deem it to be absolutely necessary. So like, you can see here, we are, we can. use cochlear microphonic amplitude to guide, electrode placement during cochlear implant surgery. Let's go back to the presentation now. Okay, well there are lots of ways of describing these patterns and cochlear microphonic amplitude increase, decrease. What is significant? What is not significant. I don't think I'll be able to cover all of those things in today's presentation, but I thought I can point you to a nice couple of, nice articles that kind of tells you how electrocochleography during placement of the electrode is predictive of final scalar location. scalar as in we want it to be in scala tympani, not scala vestibuli, and then kind of different patterns and what do those patterns of amplitude tracings mean when we are monitoring cochlear microphonic during cochlear implantation, both of them are very nice articles and kind of give us an in depth understanding of, you know, how this can be used during surgery. So let's come to post-operative monitoring, during post-operative monitoring, we can measure something called as an ECOG audiogram. I think the real word is

cochlear microphonic audiogram that is you systematically decrease the 500 hertz stimulus presentation level and find the lowest level at which we can measure a response and call it a cochlear microphonic audiogram, okay. So here are some patients. So here are I think 24 or 26 patients from one of our papers with my colleagues, Kanth Koka and Leo Litvak. So here is an audiogram. The black symbol shows the audiogram, at different frequencies. The frequency on the X-axis, the amp, the DBHL on the Y-axis, and the response in red is the cochlear microphonic audiogram, or the cochlear microphonic audiogram measured. And then this is the auditory nerve neurophonic audiogram, which we can ignore for this presentation. So the cochlear microphonic audiogram very nicely follows the pure tone thresholds. And these are pure tone thresholds measured in the implanted ear that is, the ear had significant residual hearing before surgery, that ear was implanted and after implantation we were able to preserve residual hearing.

So we can now measure cochlear microphonic audiogram and see how well the cochlear microphonic thresholds predicts the pure tone thresholds or the warble tone thresholds in the implanted ear. And here is the same data in a plot correlation plot. And you can see a very high correlation here between the audiometric thresholds and the difference thresholds. Remember the difference between the two stimuli and the responses measured for the two phases is cochlear microphonic so it's, this is the cochlear microphonic threshold here and audiometric threshold. And you can see that there is a very high correlation between these, in between these measurements here. So once we know that we can, you know, measure a audiogram. I just wanted to show you how right after the electrode placement, we can measure an audiogram and how quickly and how fast we can do that. So here is a patient that was recently implanted at St Mary's, at the Mayo clinic, St Mary's hospital. And let's put up the fourth video that shows the audiogram measurement. After we are, we are done with the electrode placement. So here it is. We are measuring, we are now starting to measure the audiogram, it says 125 the threshold is 60 DB. 250 the threshold is, 250 the threshold is. I can't get my cursor here, but 60 DB at 500 Hertz. It is 55 DB or so. So 1000 Hertz

is 60 DB and can anyone hear the loud stimulus in the background there, and it's 80 DB so you can hear it. At this point, it's almost there. You can hear me say that it's almost complete preservation at this point. So right after the electrode is placed, you can quickly measure an audiogram, and because we know that audiogram kind of predicts kind of closely follows, the warble tone thresholds, we can then say, well, right after surgery, what happened? And then maybe one month after surgery, what happened? So let's go back to the presentation. Now that we know that we can quickly measure an audiogram after surgery, and then post-operatively Or right during surgery and post-operatively, and then here is the intra-operative cochlear microphonic threshold. And then the red one shows the pre-operative thresholds. And that is why you hear me say, well, it looks like near complete preservation. At that point, that is the point where we have just placed the electrode. And we said, well, everything looks good. Electrode placement looks good and we go in here. But here is the thing, right? There are lots of post-surgical factors and there might be some other intra-operative factors that can lead to loss of residual hearing.

So for example, what do we show here? Is pre-operative audiometric thresholds, and then intra-operative cochlear microphonic threshold. And we see that the cochlear microphonic thresholds are slightly elevated than the pre-operative audiometric thresholds, but they are still preserved in most of the patients, so it doesn't look like patients wherever we were able to monitor the electrode placement and you know, monitor all of it, doesn't look like the electrode caused any damage to the cochlear and caused complete loss of residual hearing like we would expect. Now, of course, our middle ear is open. There is sometimes a little bit of fluid in the middle ear that can affect our ECOG measurements. But we still are able to get good cochlear microphonic thresholds that are kind of very similar or close to the pre-operative audiometric thresholds. However, when we measure the post-operative audiogram much later, maybe one month or three months after surgery, now remember, once a patient has cochlear implant surgery, they have lots of fluid in the middle ear for, you know, anywhere between two weeks to six or eight weeks sometimes. And so if they have

fluid, we obviously cannot measure a good audiogram. Then we got to sometimes rely on bone conduction thresholds. And then there are some vibrotactile responses and so on. So you have to measure like two or three months after surgery to get a good post-operative audiogram or post-operative audiometric threshold shown here on the Y-axis. And you can see that at that time, a lot, many more patients had lost the hearing completely in the implanted ear. So certainly we were able to preserve these thresholds during surgery, which possibly suggests that we did not cause much cochlear trauma, or did not cause any cochlear trauma. Although it's, it's all an indirect measure. There is no way to visualize and kind of confirm that. But post-operatively, maybe during the recovery phase, something goes wrong. Maybe the inflammation may be apoptosis or some kind of a process that is going on that kind of, adversely affects hearing preservation.

So this is the application, you know, post-operative audiogram measurement. And then once we can measure this for children, Sarah Coldhurst at Oakland Children's Hospital has done some amazing work where she's able to measure the audiogram quickly, the cochlear microphonic audioogram quickly in pediatric patients, and then maybe use those for EAS fitting, that is the acoustic fitting of the, acoustic component in the implanted ear. So coming to other emerging applications of these post-operative ECOG measurements. Well, one we covered was the pure tone threshold in the cochlear implant. Patients can be predicted using cochlear microphonic threshold measurement. Sometimes we see these patients who have developed the new air-bone gap or what we'd call us conductive hearing loss after surgery. These patients did not have conductive hearing loss before surgery. When they develop conductive hearing loss after surgery, a lot of times we question whether the bone conduction responses are true or whether they are vibrotactile. Well, guess what we can measure, post-operatively, we can measure cochlear microphonic or ECOG responses for air conduction stimuli as well as bone conduction stimuli. Although sometimes I'm getting, we do get a big artifact. So we have a publication here, in 2017 where we measured air-bone gap. In patients reliably using cochlear microphonic measurements. Because

when we are measuring cochlear microphonic, the only way we can get a response is if the stimulus that we are presenting actually reaches the basilar membrane and stimulates the hair cell. If there is a vibrotactile response, then we will not be able to measure any cochlear microphonic thresholds. The one big thing that we are trying to evaluate these days is when we preserve residual hearing, and we preserve residual hearing. I always forget to use this cursor, which I don't have control over. When we preserve residual hearing, we are now stimulating electrically as well as acoustical in the same ear. It is quite possible that we are going to have some interaction between the electric and acoustic stimulus that is presented simultaneously in that ear. Which is undesired, can lead to distortion, and could potentially harm the ear.

So if we can measure cochlear microphonic using acoustic stimulus and then measure the same cochlear microphonic again while we are presenting the electric stimulus, we can figure out electric and acoustic interaction. Again, this is a newly emerging tool, a new application of inner, electrocochleography in cochlear implants. I think there are now a couple of publications on that have tried to measure electric and acoustic interaction in the implanted ear and we can read, go to these references and find out more information. And one thing that we have just started to begin exploring is to determine the location of the cochlear implant electrode along the cochlear space. What do I mean by that? We place so many electrodes in the cochlea, one electrode, one might be closer to the 500 Hertz place. Electrode five may be closer to the 1000 Hertz place, electrodes 10 may be closer to the 2000 hertz place and so on. But there is no way for us to find out which electrode is located at which frequency region inside the cochlea. So if we can measure cochlear microphonic for different frequencies 250 hertz tone, 500 hertz tone, 1000 hertz tone, 2000 hertz pure tone stimulus and so on, and measure and change the recording electrode and vary the recording electrode inside the cochlea. We should be able to predict which electrode is located at which frequency region inside the cochlea. And that should help us then determine the frequency allocation tabled in cochlear implants. This is the work that we have just started collecting data on, and I think there are one or two publications out of Australia

where they have shown that this is possible and can be used for better rehabilitation of patients with cochlear implantation. Thank you. And these are the references if somebody wants to, find out more information about use of ECOG intra-operatively and post-operatively in cochlear implant patients.

- [Host] We're going to go ahead and open up the floor for questions for Dr. Saoji or comments.

- [Aniket] I don't see any questions. I assume that either the presentation, well there is, there is one question. So let me read the question. Have there been any studies correlating brain cancer shortly after CIS surgery? I am not aware of such a study, but maybe there is and I just don't know the answer to your question, sorry. So a question from Aurora, clarify an acoustic stimulus is used to elicit the cochlear microphonic during surgery? That's correct. So in patients who have residual hearing, when we present a low, generally, most patients have low-frequency residual hearing in those patients, we present an acoustic stimulus that stimulates the hair cells and generates cochlear microphonic, that cochlear microphonic is being picked up by the cochlear implant electrode and is used, and the amplitude of that recording is used to guide cochlear implant electrode placement. So you're absolutely right, yes. There is an acoustic stimulus that is used to generate the cochlear microphonic. The implant in this situation is simply used to record the cochlear microphonic.

- [Host] Thank you, Aurora for your question. We have another question here from Nancy. Nancy asks, Dr Saoji, do you only use a 500 Hertz stimulus?

- [Aniket] Very good question. Well, generally we recommend using a low frequency stimulus such as 500 Hertz, because that goes and stimulates the apical end or the apical region of the cochlea. And remember, the electrode is being placed through the round window. So the round window is in the basal end of the cochlear and the electrode is going in. So that kind of gives us an opportunity to monitor the placement

of the array throughout the cochlea, if you use a high frequent system, such as 2000 Hertz, number one, the patient may not have any residual hearing, and if the patient doesn't have any residual hearing, then most likely all the hair cells are dead in that region and we may not be able to generate any cochlear microphonic. Number two, if the electrode region pass, if the most epical recording electrode passes that 2000 Hertz region in the cochlea, then we will see a decrease in cochlear microphonic amplitude that can be then confused with trauma. So it is advisable to always use a low frequency stimulus. Now our latest work at Mayo clinic, we are using a four stimulus, a four pure tone stimulus complex. That is for example, we are using 250 hertz, 500 Hertz, 1000 Hertz and 2000 Hertz in patient who have significant residual hearing. So with a multi-frequency stimulus, we are able to better monitor cochlear implant electrode placement. That's work in progress and it's pretty complex. I decided to keep that out of out of today's presentation, but we recently have a paper that was published, in actually a case report that was published in Otology, Neurotology that talking about multi-frequency cochlear microphonic measurements.

- [Host] Thank you, Dr. Saoji. we'll leave the floor open just for another moment or two for any last questions or comments. We did have one comment from a member saying that this, this was her first time with a presentation like this and that Dr. Saoji is an excellent teacher. Thank you for keeping it simple. I will agree, for an advanced level course, this was very, relatable and able to understand for an audiologist point of view. So thank you, Dr. Saoji to speaking to us in our terms.

- [Aniket] No thank you, I mean, that feedback helps me. I was really worried because this is heavily technical, I mean very technical and I think the challenge is to kind of simplify things even for my own sake, because I sometimes get lost in this, and then I'm like, what am I exactly doing? And then, okay, eventually it all comes back. So thank you for the feedback and I hope I was able to explain it. And if you have any questions now or later, please feel free to reach me.

- [Host] Thank you everyone and have a great day. This will be the conclusion of our course.