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# Episode 64: Medical Bionics: Cochlear Implants and Beyond

## Medical Bionics: Cochlear Implants and Beyond

VOICEOVER
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SHANE HUNTINGTON
Hello, and welcome to Up Close, coming to you from Melbourne University, Australia. I?m Dr Shane Huntington. On a given day, the majority of us wake up and take for granted the senses that we rely on so heavily for survival. We see, hear, smell, taste and feel our way through our environment. For some people in our community, one or more of the senses is limited, and they have to adapt accordingly. These limitations can be a result of many factors, some originating from birth, and others incurred as a result of injury or disease. In recent years, the concept that we could replace parts of the body with bionic implants has become a reality. In the case of the human ear, science has provided us with the opportunity to repair hearing problems, changing the lives of many in our community.
Today in Up Close, we are joined by two of Australia?s leaders in bionic research: Professor Robert Shepherd, Director of the Bionic Ear Institute and Professor of Medical Bionics at the University of Melbourne, Australia; and Professor Tony Burkitt, Chair of Biosignals and Biosystems in the Department of Electrical and Electronic Engineering at the University of Melbourne, Australia. Welcome to Up Close, Rob and Tony.

ROBERT SHEPHERD
Thank you.

TONY BURKITT
Thank you.

SHANE HUNTINGTON
Gentlemen, I?m eager to talk about some of the advances you?ve had in the

cochlear implants area, but before we do that I think it?s important to give our listeners an idea of the anatomy of human ear itself. Rob, if you could maybe start off on this and give us an idea of what the components of the ear are, and what their job is.

ROBERT SHEPHERD
Sure, Shane. The ear is charged with converting the mechanical vibrations of sound into nerve impulses. So it interfaces the physical world of acoustic signals with the nerve world of neural pulses. So the external ear consists of three major compartments: the external ear canal; the middle ear, which is separated by the tympanic membrane or ear drum and has three small bones, the ossicular chain - they?re the smallest bones in the human body ? that connect to the inner ear. The inner ear is a snail shell type of structure, so it?s a spiral structure, that?s about 25mm long in the human, and it?s a site that converts the mechanical vibrations of sound into nerve impulses.
In the inner ear there?s about 12,000 hair cells that are charged with converting this mechanical vibration into nerve impulses. The ear does basically a frequency analysis of the incoming sound, and different locations within the inner ear vibrate and stimulate the hair cells, and with the stimulation of the hair cells we get nerve impulses in what we call a tonotopic manner. So that the high frequencies stimulate nerves in the base of the inner ear, or cochlea, and low frequencies stimulate nerves and hair cells in the apex of a cochlea.

SHANE HUNTINGTON
Just to be clear: the sound comes in the ear and ?

ROBERT SHEPHERD
The sound comes in the ear ?

SHANE HUNTINGTON
? it has to end up as an electrical impulse ?

ROBERT SHEPHERD
Right.

SHANE HUNTINGTON
? so it obviously goes from sound, vibrations in the air, to mechanical vibrations, and then to electrical vibrations ?

ROBERT SHEPHERD
Right.

SHANE HUNTINGTON
? or electrical signals.

ROBERT SHEPHERD
Electrical signals. So the sound hits the ear drum, or tympanic membrane. The

external ear is designed to protect the tympanic membrane and to sort of focus the sound into the tympanic membrane.  Then the tympanic membrane will vibrate these three little ossicles.  They?re really important because they amplify the sound so that the sound can then travel into the fluid-filled cochlea.  If we didn?t have this amplification in the middle ear, most of the sound energy would be reflected back out the cochlea.  It?s just like someone speaking to you when you?re under water.  It?s very difficult to hear.  Most of the sound energy is reflected back.  So this is what we call an impedance matching technique, and it is very effective at transferring the energy into the inner ear.
Then there?s a standing fluid wave that progresses along the inner ear exciting [a] particular region of the hair cells.  The hair cells are exquisite.  We talk about nanotechnology.  These hair cells are excited by nanometre displacements.  They?re extremely sensitive, and being so sensitive they?re also extremely sensitive to pathologies, so deafness is a very common outcome.

SHANE HUNTINGTON
How do we actually perceive sound?  So the ear creates this electrical impulse.  What happens at that point?

ROBERT SHEPHERD
So what we?re doing is driving the nerves through activity in the hair cells so that we?re getting a small population of nerves, depending on which frequency we?re hearing, that are excited and send action potentials through a fairly complex central auditory pathway.  There?s a whole relay centre between the auditory nerve and the auditory cortex, where we believe we?re perceiving sound.  But most importantly is all along this pathway is this frequency map that we?ve learnt during development that?s present up to the level of the auditory cortex, so when we excite a high frequency region small neural population in the inner ear, we exclusively excite neurones in a small high frequency region of the auditory cortex, and we perceive that as a high frequency pitch.

SHANE HUNTINGTON
It?s an incredibly complex scenario.  How is this compromised in a scenario where someone has limited or completely diminished hearing?

ROBERT SHEPHERD
Well, there?s two forms of hearing loss.  One is a conductive hearing loss, typically associated with the middle ear, so the little ossicular chain is not working properly, or there is a damage to the ear drum, or even wax in the external canal, can impede the mechanical passage of the acoustic wave.  That?s conductive hearing loss, and with a conductive hearing loss audiologists would fit a hearing aid which amplifies the sound.  The important thing is that the patient still has the presence of hair cells which have that ability to convert the mechanical vibration into nerve impulse.  So the first type of pathology is what we call a conductive hearing loss.
The second and most common is a sensory neural hearing loss, and that?s mainly where patients have lost their sensory hair cells.  So they don?t get benefit from a conventional hearing aid.  We can amplify the sound significantly with a hearing aid

but in these patients, if they have a widespread hearing loss, there are no sensory cells to convert that mechanical vibration into a nerve impulse.  So they don?t get any benefit from a hearing aid if they have what we call a severe to profound sensory neural hearing loss.

SHANE HUNTINGTON
So that?s a scenario where essentially one of the connecting elements in the ear is essentially not there so it doesn?t matter what the input is, it will never get to the ?

ROBERT SHEPHERD
Exactly.  The chain has been broken.

SHANE HUNTINGTON
Now, you talked about these various ways in which the hearing can be affected. What are some of the causes?  I assume a lot of this is at birth but also there?s damage and so forth that can occur during our lifespan.

ROBERT SHEPHERD
Absolutely.  There are many causes.  There are genetic issues associated with the incorrect development of the ears, particularly the inner ear, and they?re quite a common form of pathology.  But most of us obviously have normal hearing, but these hair cells are very, very sensitive.  They?re very sensitive to what we call ototoxic drugs.  Some of the antibiotics, some therapeutic drugs that we receive can damage hair cells, and they can damage them permanently.  In addition to that, the hair cells are very sensitive to loud noises, so when we go to rock concerts we need to use hearing protection.  The loss and the damage does not occur at the rock concert. Tragically it occurs weeks, months and years later.  So it?s important to protect our hearing now for the future.
Viral and bacterial infections that enter the inner ear can completely wipe out the hair cells.  And finally, just getting older, we?re gradually losing hair cells, and many of us in the 40s and 50s would see that when we go to parties and start to have difficulty understanding one on one communication in a noisy environment.  That?s evidence that we?re starting to lose some of our hair cells, and that will progress over time and it will be accelerated if we?ve been exposed to loud noise during our younger life.

SHANE HUNTINGTON
You?re listening to Melbourne University Up Close.  I?m Dr Shane Huntington and we?re speaking with Professor Robert Shepherd and Professor Tony Burkitt about medical bionics.
Tony, I want to turn attention to you now as our electrical engineering expert in the room.  There are many types of hearing aids that are already on the market.  What do they do?

TONY BURKITT
As Rob alluded to, the conventional hearing aids basically amplify the sound, so the clinician will actually work out what particular type of hearing loss the patient will have and what particular frequencies are affected with their hearing loss, and then

provide them, these days it?s usually with a digital hearing aid so that they can actually program it to adjust, as it were, to be able to amplify those frequencies that the patient is having trouble with.  But as Rob mentioned, the majority of people who have hearing loss actually have a sensory neural hearing loss, so they won?t get any benefit from the hearing aid, and for those people that?s where a cochlear implant is really the only form of device that will give them some benefit.

SHANE HUNTINGTON
With the cochlea implant, what job does it do in the ear that makes it so special and so distinct from existing systems on the market?

TONY BURKITT
Conventionally what happens with somebody who has a sensory neural hearing loss is that the transduction of the mechanical vibration into nerve impulses is broken down, and this is usually at the level of the hair cell, so typically either the hair cells have died or else some component along the way has died and is just no longer functioning.  So basically what the cochlear implant does is that it actually sends out electrical pulses that are picked up directly by the nerve.  So it, as it were, sort of bypasses the biological way in which that transduction takes place and provides an alternative electrical route to directly stimulate the nerve.
Now, of course, the trick there is to provide the nerve with the sort of excitation that it will expect to get in the normal hearing situation, and that?s where a lot of our research is devoted to.

SHANE HUNTINGTON
You make it sound extremely simple but I know it?s not.  What are the some of the challenges in doing them ? in fact, it might be best if you first describe what this looks like.  Part of it sits, I understand, outside the body, and part of it sits inside the body.

TONY BURKITT
That?s right, yes.  There are two components.  The present generation of cochlear implants really look like a very large hearing aid.  The only difference that you really discern is that attached to the bit that?s sitting on the back of the ear, it actually sits directly over the skin held on by a magnet, and is sending radio frequency signals through to the implant which is completely under the skin.  So, in fact, if you were to remove the external component of the cochlear implant, the person would be completely deaf.  They would no longer be receiving the input, so they wouldn?t hear anything.
The implant itself lies underneath the skin behind the ear, and it has a receiving coil, because it?s actually receiving the power externally, from external batteries, so there are no internal batteries at all in the implant;  and it?s also receiving the signal, and that signal is telling which electrodes to send out the impulses on, and what time to do that.  And so, the electrode ray actually goes from the implant behind the ear down through and is coiled around inside the inner ear, inside the cochlea, and that?s where the electrical impulse is actually sent out from to connect up with the nerves.

SHANE HUNTINGTON
What are the some of the major challenges that have had to be overcome in terms of the development of the cochlear implant over the last five or ten years?

ROBERT SHEPHERD
It?s very interesting to realise that the development of the cochlear implant was based here at Melbourne, in Melbourne University, and Tony and I are very fortunate to have worked with Graeme Clark and been part of that cochlear implant team. In the seventies, there was great concern about even doing surgery in a deaf ear. Nobody had done it. There were all sorts of concerns about would that increase issues around infection, issues about what sort of damage one could do to the inner ear. Our group had to solve those. So there were a lot of surgical issues to make sure that we could implant a deaf ear safely with these electrodes, that a long term stimulation using these fine electric pulses would not cause any damage to the nerve cells we?re trying to stimulate. In addition to that, is to develop a technology that would prevent fluid from the body entering into the electronic components that drive this device, and damaging the device.
So we now have patients that were implanted with the first cochlear devices in 1983, and they?re still using these devices. It?s a testament to how excellent the bio engineering was in developing the device. The other challenges, of course, were around developing smaller devices for children. Children now as young as six months of age are receiving these devices. Head growth became an important issue. So there are many multi-disciplinary types of problems to solve from surgery, biology, and bio-medical engineering.

SHANE HUNTINGTON
I?m curious. When we talk about hearing, do we know that you and I and Tony ? we all hear in the same way? How much work does the brain do after the signals leave the ear? Do we know what?s happening there?

ROBERT SHEPHERD
The brain does an enormous amount of processing, and there?s about five neural processing relay centres from the auditory nerve to the auditory cortex. It?s very, very complex. We also know that what?s really important is having sound experience during those very early years of development, because that helps to lay down the foundation for a normal structured auditory cortex. For an example, in the early years when we implanted people that were profoundly deaf from birth, and they were implanted as 18, 19, 20 year olds, those patients had great difficulty with the concept of loudness, with the concept of pitch, and we believe that?s because they didn?t have that basic rudimentary function of the auditory cortex laid down with auditory experience.
We now know through our research that we can achieve that with a cochlear implant, but it must be provided at a very early age. Clinical audiologists have shown that the earlier the child is implanted, the better the outcome. If they?re born deaf, there?s a window of opportunity within the first five to seven years, and then that opportunity diminishes. So earlier the better and, as I said, now we?ve got techniques to confirm that a young child is profoundly deaf at six months, so they can be implanted at a

very young age.  The children that are implanted at six months of age with a cochlear implant, so their only auditory experience is through a cochlear implant, have language development that is at the same rate as a normal hearing child, and that?s a testament to brain plasticity.  But all is not lost in an adult.  Adult brains are still plastic, and that?s good news for you and it?s good news for me.  But the extent of the plasticity is not the same as during that critical period during the development.

SHANE HUNTINGTON
I can imagine, you know, we often talk about how it?s more difficult to learn a new language when you?re an adult, and a lot of that is attributed to that neural plasticity and something as complex as hearing should be seen as almost like a super language in terms of learning something new, and presumably where the challenge comes from.

ROBERT SHEPHERD
Absolutely, and the child is programmed to learn language at the same time as they?re receiving this auditory input, so there?s a double drive, and I?m like you, I have great difficulties learning a language at 55 years of age.

SHANE HUNTINGTON
Tony, obviously this is a very complex system.  How much is each implant tailored to a particular patient, based on the particular problem that they have with their hearing.

TONY BURKITT
It?s very important to actually tailor the settings of the implant to each patient.  So in fact what happens is that when the implant is turned on, one of the very first things that they do is what they call map the implant.  That?s to go through and actually check every electrode, and essentially what they want to do is to work out basically what level of stimulation do the patients hear.  So what?s their threshold of stimulation, and then when you take it up further, what?s their maximum comfortable level?  So you do that for every electrode in the implant, and you?ve actually got to also check that you really have got the right match between the frequencies that you?re giving that particular electrode and how the patients are actually perceiving that.
So there?s a huge amount of this, what we call psychophysical testing, where you really have to just ask the patient exactly what it is that they?re hearing, and be able to interpret that.

SHANE HUNTINGTON
On average, how long does it take for a patient to learn how to hear?

TONY BURKITT
Well, as the patients get more experienced with a cochlear implant, their performance improves, and part of this is due to this brain plasticity.  In fact, anecdotally, if you ask patients what the implant sounds like immediately when it?s turned on, they find it very difficult to understand.  It sounds very much like a badly tuned radio, a little bit like Donald Duck.  But then you can ask patients years later,

and even though they?re receiving almost exactly the same input, they?ll say that speech sounds almost entirely natural.  It?s because they actually have learnt to interpret it that way.  There might have been minor improvements in terms of the technology, but most of it has to do with brain plasticity.

SHANE HUNTINGTON
Gentlemen, I was trialling some speech recognition software the other day, and I thought it was a good bit of homework to do before we did this interview, and I noticed that if I had music on in the background it didn?t work very well.  It said the level of noise was unacceptable.  But in hearing we often have this complexity.  How does the cochlear implant deal with all of that complexity at once?

TONY BURKITT
You?ve actually your finger on one of the key problems with cochlear implants:  this problem of background noise.  So what we have to do is try and figure out ways in which to extract from that signal that?s coming in what actually is the speech and what is the noise, and quite often that?s not immediately apparent.  There are various techniques that people have been developing to do that.  One of the use of microphones that are directional, so that you?re actually able to focus upon the person who is standing directly in front of you, and to be able to eliminate all the signals coming from other directions.  That helps improve what we call the signal to noise ratio.  This idea of the cocktail party effect.  I mean, how do you actually hear in a noisy environment is one of the great challenges for cochlear implants and one that we?re ? we?re seeking to really understand how it is that the human auditory system does that normally, and then to try and replicate that in the processing that we?re doing in a cochlear implant.

SHANE HUNTINGTON
I can imagine one of the other areas that you have had to tackle is the one of ethical issues surrounding the need to repair hearing.  There is an entire culture based around deafness.  What sort of barriers have you come up against there, and how do you address those issues of parents who are deaf wanting their children to also remain deaf when they are born so?

ROBERT SHEPHERD
Well, we have to respect those cultures.  The deaf culture groups sees signing as another language and as a culture in its own right.  Just as we send children on weekends to language schools, they want to maintain their culture and they, I believe, feel threatened by reduction in the number of children that, through cochlear implantation, that would be taking an active role in the deaf culture.  Having said that, parents play an enormous role in making sure that their children use cochlear implants properly.  So we know that the home environment and a rich oral environment is very, very important for a young child with a cochlear implant.
So there?s good reason to believe that children with a cochlear implant that were brought up in a deaf house would not perform as well because they?re not getting that drive, that acoustic drive, that we know is needed for the plastic development of the brain and to improve the use of cochlear implants.

SHANE HUNTINGTON
You?re listening to Melbourne University Up Close. I?m Dr Shane Huntington, and we?re speaking with Professor Robert Shepherd and Professor Tony Burkitt about medical bionics.
Gentlemen, the bionic ear is just the start, I can imagine. There are many parts of the body that we?d like to be able to replace with bionic components. What?s next on the agenda, Tony?

TONY BURKITT
The most exciting one that?s immediately here is the retinal implant. This is an implant that goes into the eye for those people who are blind, but where the visual nerve is still functioning. So it is actually still capable of sending a signal back to the brain, but where that transduction from the light coming in into the electrical signals has broken down, and that typically happens through the degeneration of the photoreceptors, so this is a much much more complex problem than the cochlear implant. Obviously the eye is a very sort of small, but it?s also a rapidly moving object, and so the challenges there to actually get the electronics small enough to be able to work, and reliably enough, are enormous.

SHANE HUNTINGTON
Give us a bit more of an idea of what the bionic eye as such would actually have to do. I mean, this hearing is complex but vision, I am assuming, is even more complex, because of the volume of data that you?re acquiring with the eye at any given time.

TONY BURKITT
That?s right. You can think of hearing as being like a one dimensional problem. You basically have the frequency components. With they eye, you have the two dimensional image that comes in on the retina as well as, of course, all of the additional components, the intensity, the colour and so forth. In the initial implant, what we?ll be seeking to do is to be able to give people basic recognition of objects, so we won?t necessarily be addressing questions of colour and so forth, but it will be to be able to enable people, in the first instance, to be able to be mobile themselves, to be able to move around independently. So that involves being able to see where objects are, where doors are, windows are, that sort of thing; a very basic level of visual function.
The next level up, what we would call a medium or high density electrode array, is to give people the perception of large scale print, and that gives them more independence. It enables people to function more normally. But we imagine that that?s going to be probably in a timeframe of about ten years, eight to twelve years, something like that, before we can get to that sort of level.

SHANE HUNTINGTON
Finally, I?d just like to canvass what other areas of the body we?re thinking about replacing.

ROBERT SHEPHERD

First of all, the cochlear implant is no doubt the most successful neural prosthesis to date.  Cochlea have implanted 120,000 people around the world.  It?s a great story. But there are also some other great neural prostheses or medical bionic devices commercially out there at the moment.  The two other major devices are deep brain stimulation for control of movement in Parkinson?s disease, and that?s been very successful over the last 10 years.  The second device is a device that electrically stimulates the spinal cord for patients that have severe pain.

Those three devices, including the cochlear implant, are commercially viable.  What we?re trying to do now is build on this technology, build on the journey that Tony and myself and our research colleagues have done over the last 25 years with cochlear implants, and work with other experts to develop new medical bionic devices using safe electrical stimulation techniques.

So besides a bionic eye, work is being done, not in our lab but overseas, on developing a vestibular prosthesis for people with balance disorders.  We know a lot about artificial limbs.  Particularly that work is being done in the States, with a lot of military funding, interfacing artificial limbs and the control of artificial limbs with mind machine interfaces, using recording electrodes in the brain.  Spinal cord stimulation for gait is another important area of research.  So people with significant spinal cord damage, stimulating certain regions of the spinal cord to help control and co-ordinate the muscles required for walking.  That work is really progressing very, very well. Again, as with the development of a cochlear implant, it must be done in a multi-disciplinary environment, using skills from medical research, biomedical engineering, nanotechnology, ICT, biological sciences and the physical sciences, to bring this type of new development together.

SHANE HUNTINGTON
Professor Robert Shepherd and Professor Tony Burkitt, thank you for being our guests on Up Close today.  This is some truly extraordinary work.

TONY BURKITT
Thank you.

ROBERT SHEPHERD
Thank you.

SHANE HUNTINGTON
Before we finish today, we?d like to give you a few examples of the types of sounds that someone with a cochlear implant would experience.  Upon the first listen, you will find these sounds somewhat disturbing and unclear.  If you listen to them a second time, you will realise that relative to a person not being able to hear at all, there?s an extraordinary level of clarity and an ability for people to communicate through sound via the cochlear implant.  Keep in mind the alternative to this is profound deafness.

SOUND PLAYED
Little Miss Muffet sat on her tuffet eating her curds and whey.  There came a great spider that sat down beside her and frightened Miss Muffet away.

Humpty Dumpty sat on a wall.  Humpty Dumpty had a great fall.  All the king?s horses and all the king?s men couldn?t put Humpty together again.

SHANE HUNTINGTON
Relevant links, a full transcript and more info on this episode can be found on our website at upclose.unimelb.edu.au.  We also invite you to leave your comments or feed back on this or any episode of Up Close.  Simply click on the ?Add New Comment? link at the bottom of the episode page.  Melbourne University Up Close is brought to you by the Marketing and Communications Division in association with Asia Institute of the University of Melbourne, Australia.  Our producers for this episode were Kelvin Param and Eric van Bemmell.  Audio recording by Russell Evans.  Theme music performed by [Sergio Ecole].  Melbourne University Up Close is created by Eric van Bemmell and Kelvin Param.  I?m Dr Shane Huntington.  Until next time, goodbye.

VOICEOVER
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