Did Someone Say Implants?

Cochlear Implants

Kirsten Zernask-Cebek
Doralice Ferreira
What you will expect to \textit{Hear}...

- Sound
- Anatomy of the Ear
- Anatomy of the Cochlea
- Process of Hearing
- Hearing Loss
- Cochlear Implants
  - How it works
  - Biomaterials and Biocompatibility
  - Ethics and Future Research
Sound

Humans can generally hear sounds with frequencies between 20 Hz and 20 kHz
Sound is a disturbance of mechanical energy that propagates through matter as a wave.

Hearing is mainly concerned with two parameters of sound:

- frequency (wave/sec = Hertz) → pitch
- pressure level (dB) → intensity.
Anatomy of the Ear
External Auditory Canal

Semicircular Canals

Cochlea

Eardrum

Malleus

Incus

Stapes

Eustachian Tube
The external ear serves to protect the tympanic membrane (eardrum).

Collects and directs sound waves through the ear canal to the eardrum.
The middle ear is an air-filled cavity carved out of the temporal bone. It connects to the throat via the Eustachian tube.
Adjoining the eardrum are three linked, movable bones called ossicles, which convert the sound waves striking the eardrum into mechanical vibrations.

The hammer (malleus) joins the inside of the eardrum.

The anvil (incus), connects to the hammer and to the stirrup.

The base of the stirrup (stapes), fills the oval window.
The inner ear consists of a maze of fluid-filled tubes, running through the temporal bone of the skull.
The bony tubes (bony labyrinth) are filled with a fluid called perilymph. Within this bony labyrinth is a second series of delicate cellular tubes, called the membranous labyrinth, also filled with a fluid (endolymph).

This membranous labyrinth contains the actual hearing cells, the hair cells of the organ of Corti.
Cochlea
The cochlea is the organ that converts sound waves into neural signals.

Inside the cochlea, is the organ of Corti (containing the cells responsible for hearing).

These cells, which are attached to the basilar membrane, have hairs that stick out, which are in contact with the tectorial membrane (extracellular gel).
When the sound waves enter the cochlea, it causes the basilar membrane to vibrate up and down. This motion creates a shearing force between the two membranes, and causes the hair cells to bend back and forth.

This causes internal changes within the hair cells which creates the electrical signals.

Auditory nerve fibres rest below the hair cells and pass these signals onto the brain.
How Do We Hear?
Air-borne sound waves funnel down through the ear canal and strike the eardrum.

Eardrum vibrates

Vibrations are passed to ossicles:

Malleus → Incus → Stapes

Oval Window

Vibrations become fluid-borne.
Vibrations are transmitted to the hair cells of the organ of Corti.

Vibrations converted into *nerve impulses*.

Travel over the cochlear nerve

Auditory cortex of the brain

Interprets the impulses as sound
If Something Goes Wrong...
Hearing loss occurs when there is loss of sound sensitivity produced by an abnormality anywhere in the auditory system.

There are two types of common hearing loss:

- **Conductive Hearing Loss**

- **Sensorineural Hearing Loss**
  - Occurs when there is damage to the cochlea or to the nerve pathways from the inner ear to the brain.
  - Hair cells are often fewer in number and damaged
  - Hair cell loss may be caused by a genetic mutation, illness, loud noises
Cochlear Implants
Cochlear Implants

More than 45,000 patients worldwide have undergone implantation
A surgically implanted electronic device, often referred to as a ‘bionic ear’

It is designed to provide or restore a sense of sound to someone profoundly deaf or severely hard of hearing

It does not amplify sound like a hearing aid; rather, it directly stimulates functioning auditory nerves in the cochlea with electrical signals, essentially sending the sound signal directly to the brain
What is a Cochlear Implant?

- Hearing through a cochlear implant is different from normal hearing; it takes time to learn or relearn how to process the sound.

- However, it can allow many people to recognize warning signals, understand other sounds in the environment, and even enjoy a conversation in person or on the phone.
How does a cochlear implant work?

- Cochlear implants bypass damaged portions of the ear and directly stimulate the auditory nerve.

- Signals generated by the implant are sent by way of the auditory nerve to the brain, which recognizes the signals as sound.
Parts of the Cochlear Implant

*External:*

- **microphone**
  - picks up sound from the environment

- **speech processor**
  - filters sound to clarify audible speech
  - sends the electrical sound signal to the transmitter through a thin cable

- **transmitter**
  - a magnetic pad placed behind the external ear
  - uses electromagnetic induction to transmit sound signals to the internal device
Parts of the Cochlear Implant

*Internal:*

- **receiver and stimulator**
  - secured in bone beneath the skin
  - Picks up signals from the transmitter, converts them into electric impulses and sends them through an internal cable to electrodes

- **electrode array**
  - wrapped inside the cochlea
  - composed of approx. 20 electrodes that take the signal from the stimulator, and send an impulse directly to the brain
The *Earhook* sits on top of the ear to hold the sound processor securely in place.
The Processing Unit houses the main "computer" for the sound processing system. Contains microphones that help pick up sound.
BTE Controller has buttons which allow you to adjust volume, programs and sensitivity.
Coil/Cable unit helps to transmit the electric impulses that enable you to hear.
The *Magnet* connects with a magnet on the inside of the skin. This connection helps conduct sound to the hearing nerve.
The **Receiver/Stimulator** delivers the correct amount of electrical stimulation to the electrodes on the array to represent the sound signal that was detected.
The **Electrode Array** is the main piece of the implant that stimulates the auditory nerve fibers in the cochlea, which carry the signal to the brain, where it is interpreted.
Bioengineering Considerations

- the cochlear implant differs from something like an optical implant because it is not replacing the tissue – more like a pacemaker
- select materials for optimal electrical performance
- develop a biocompatible casing
Biocompatibility

- Electronics need to be reliable over many years of use
- Implanted components must not lead to long term effects – non-toxic
- Signal transmission should not cause tissue damage
- All electronics must be sealed such that corrosive bodily fluids can not damage circuitry
- Sealing points where wires enter or leave implanted package require special care
- Needs to withstand surgery and subsequent flexing
- Most importantly: the body has to accept the implant
Electrode Array

- Requirement:
  - Ability to insert a pre-curved electrode array that’s designed to fit inside the inner wall of the cochlea, with sufficient memory to return to its curved shape

- Solution:
  - silicone rubber casing (Silastic) around metal array, that is molded into the desired shape
Bio-Polymers

- Silastic is a trade name for silicones

- It is suitable for long-term medical applications for several reasons:
  - stable in heat or harsh conditions
  - retains flexibility and elasticity (even at low temps)
  - an excellent ion barrier and electrical insulator
  - will not allow water through unless in gas phase
Bio-Polymers

Other polymers that can be used:

• Teflon: chemically inert, and thus resistant to attack
  - in cochlear implants, it is used to insulate electrode leads; can separate from leads because it does not bond to wire

• Dacron (polyester): generally a weave of continuous fibers
  - prevents electrode balls from sinking into Silastic
  - allows adhesion of antenna coil to skull with bone cement
  - matted felt allows soft connective tissue to grow, as a barrier to invading bacteria
Electrode Array

- Metal chosen for electrode must be able to pass large amounts of currents, without electrolytic dissolution or gas formation

- This can cause extreme shifts in the local pH

- Platinum has a gassing limit around ten times that of stainless steel

- The gassing limit for iridium is another order of magnitude higher than that of platinum
Electrode Array

- Requirement:
  - needs to be flexible enough to move around the cochlea without causing trauma

- Solution:
  - a composite of platinum and iridium is used (90:10)
  - pure iridium cannot be formed easily into electrode contacts or leads
Stimulator

- The stimulator components are resistors, capacitors, coils and diodes

- Requirement:
  - electrical components must be kept separate from bodily fluids to maintain functionality

- Solution:
  - they are placed in a hermetically sealed compartment, made of biocompatible material
  - titanium is used in many cases
Stimulator

- Titanium is highly biocompatible:
  - will not corrode in a reduced oxygen/increased chloride environment
  - rarely corrodes due to pitting or crevices
  - non-toxic
  - drawback: more difficult to machine and hermetically seal than cobalt/chromium alloys or stainless steel

- Ceramics:
  - high strength, wear resistant, highly resistive, can offer complete hermeticity
  - transparent to radio frequencies
  - can be almost any size, with various compositions and properties
  - generally aluminum oxide
  - problems with sealing case
Ethical Issues

Are you thinking what I’m thinking Pinky?

I think so Brain...but what if the people don’t want a cochlear implant?
Who is eligible?

- Implantation into the cochlea has a low success rate with people that suffer from deafness medial to the cochlea (Acoustic Neuroma).

Better or Worse Ear?

- Since studies have shown that there are no long-term advantages to implanting the patient’s better ear, many surgeons opt to implant the worse ear.
  - The patient would continue to wear an aid in the best hearing ear.
  - Decided by the physician and patient because there is a risk of losing all residual hearing in the implanted ear.
What can go wrong?

- Patients with a cochlear implant are unable to undergo an MRI because of the magnet component of the implant.
  - To resolve this issue, a removable magnet device was developed.
  - However, it can become displaced due to head trauma, which is a minor, but not uncommon issue.

- In patients who have a history of meningitis leading to hearing loss, labyrinthitis ossificans may have caused obliteration of the scala tympani. In this case, the array can be placed into the scala vestibuli.
What can go wrong?

- Infection/allergic reactions
- Failures due to injury/repeated stresses
- Failures in insulation of electrical components
- Component failure – diode failure
- Reports have shown that recipients with cochlear implants may be at higher risk for meningitis
Looking to the Future

- Research is now being directed towards using neurotrophins (nerve growth factors) in the implant to actually stimulate nerve growth within the ear.

- Research is also being conducted on potentially using a shortened electrode array, for individuals whose hearing loss is limited only to higher frequencies.
Looking to the Future

- Researchers are also exploring ways to make the cochlear implant convey the sounds of speech more clearly.

- Bilateral implantation (both ears) is another expanding area – issues to be considered include synchronizing the sound processing.
Looking to the Future

The same thing we do every night Pinky...try to take over the world...of impaired hearing!

So what are we going to do tomorrow night Brain?
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