Interfacing of Cochlear Implants With the Human Body & Complications

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Motivation

- Inner hair cells (IHCs) are responsible for transforming vibrations into electrical signals, which we can then perceive [1].
- IHCs can suffer extensive damage due to excessively loud sounds of high dB (Figures 1-2). Over time, this will impact an individual's ability to hear.
- For patients with damaged/missing IHCs, an alternative is desired. A biocompatible device is needed replace the electrical signals generated by the cochlea.

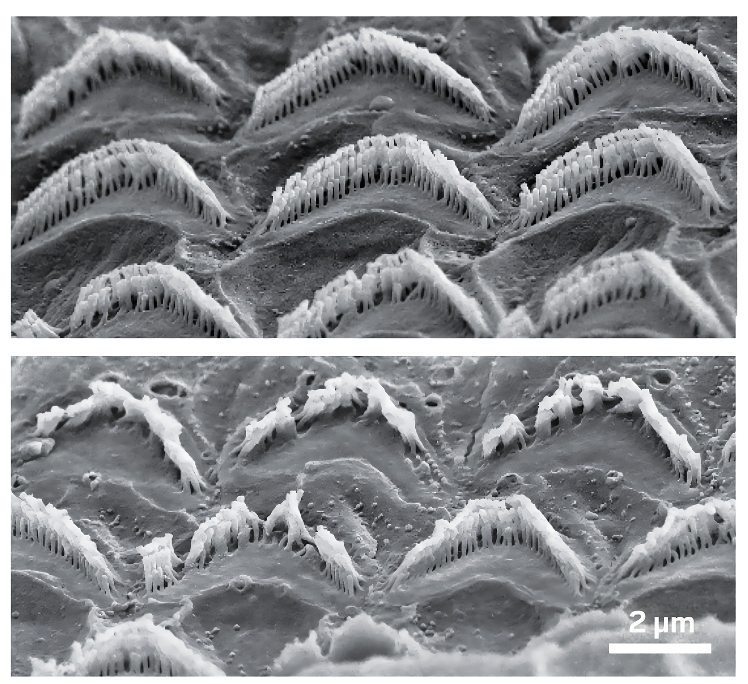

Figure 1: Healthy (top) vs. damaged (bottom) IHCs. [2].

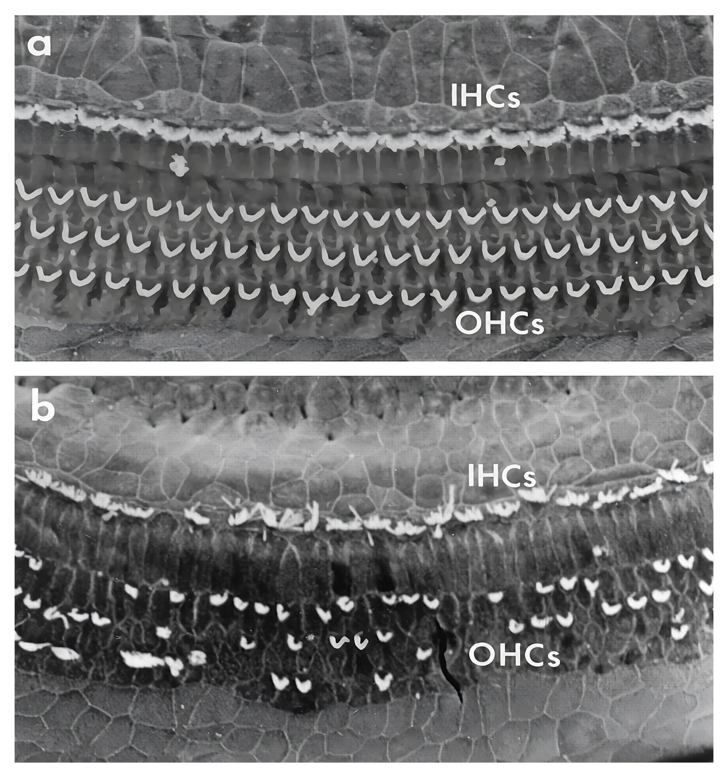

Figure 2: Undamaged (top) vs. damaged (bottom) outer and inner hair cells. Further in distance compared to Figure 1 [3].

Background

- **1800:** Alessandro Volta stimulated his internal ear by using electrical current [4].
- **1957:** André Djourno and Charles Eyriès tried to restore the facial nerve function of a patient whom was also deaf, by using a wire with electrical current. The patient experienced auditory sensations [4].
- **1961:** William House and John Doyle developed an electrode. These reported auditory percepts, also noticing the change of loudness when the level of stimulation varied and the change of the pitch with the variation in the rate of stimulation [4].
- Some auditory stimulation occured in all these contexts, but the science was simply not there yet to achieve a working implant for use in day-to-day situations.

Figure 3: Alessandro Volta, inventor of the battery, stimulated his ear using electrical current [A1].

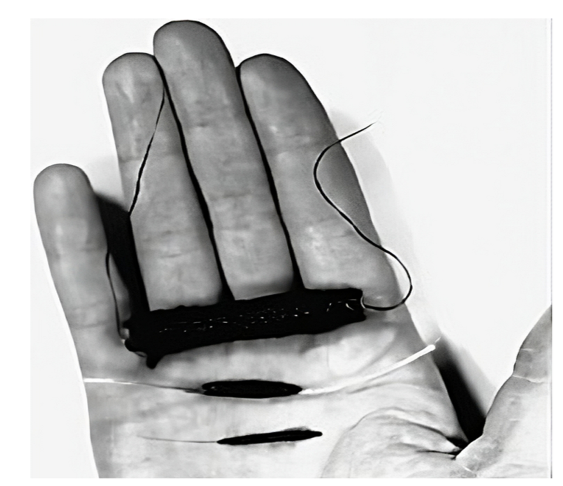

Figure 4: Inductor coil used for stimulation by Djourno [A2].

Material & Methods

- The primary material that makes up the electrodes consist of platinum-iridium alloy, which was chosen due to its biocompatibility and effective conductivity. [5]
- Silicone rubber is used as the insulation. [5]
- Titanium is used for the hermetic sealing of the cochlear implant's internal components. [5]
- Method of installation involves a mastoidectomy followed by a posterior tympanotomy to install the electrode array.

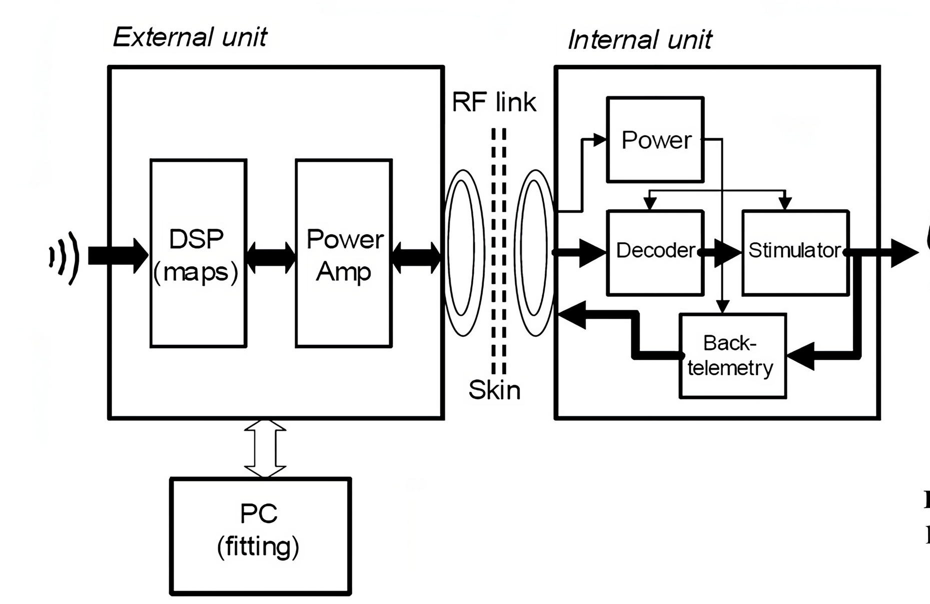

Figure 5: Architecture and functional block diagram [5].

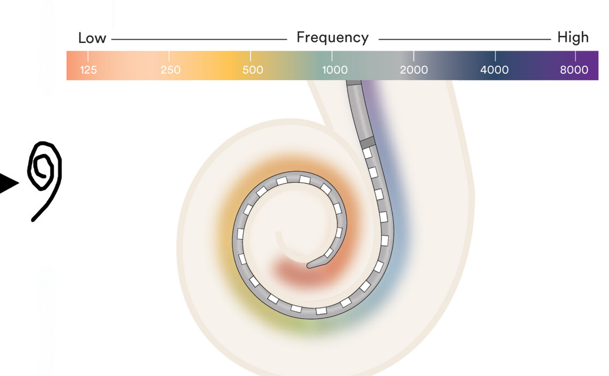

Figure 6: Representation of the cochlear electrode location, as well as the frequency corresponding to location in cochlea [A3].

Usage

- An estimated 1,000,000 cochlear implants have been implemented worldwide as of July 2022 [6].
- The market for implants is dominated three main manufacturers: Cochlear Limited, Med El, and Advanced Bionics.
- Australian-based Cochlear Limited has reportedly sold 650,000 cochlear implants, while the other two primary manufacturers have not shared sales reports [6].

- Microphone recieves external sound waves, which is then converted to a digital signal by the processor.
- The transmitter obtains these signals, and is also interfaced with the reciever.
- Reciever turns the signals into electrical pulses, where the implant electrodes stimulate the cochlear nerve.
- Stimulated nerves send the signals to the brain.

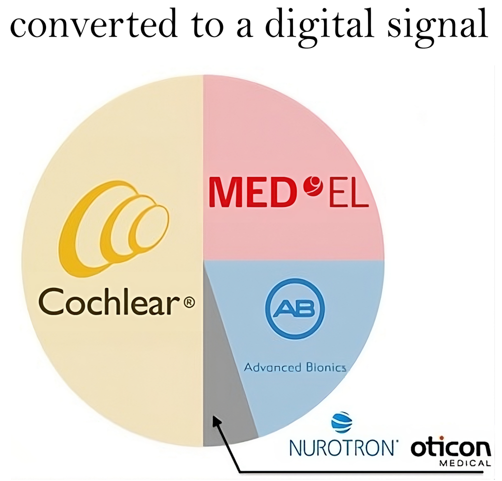

Figure 7: Market share for cochlear implants [6].

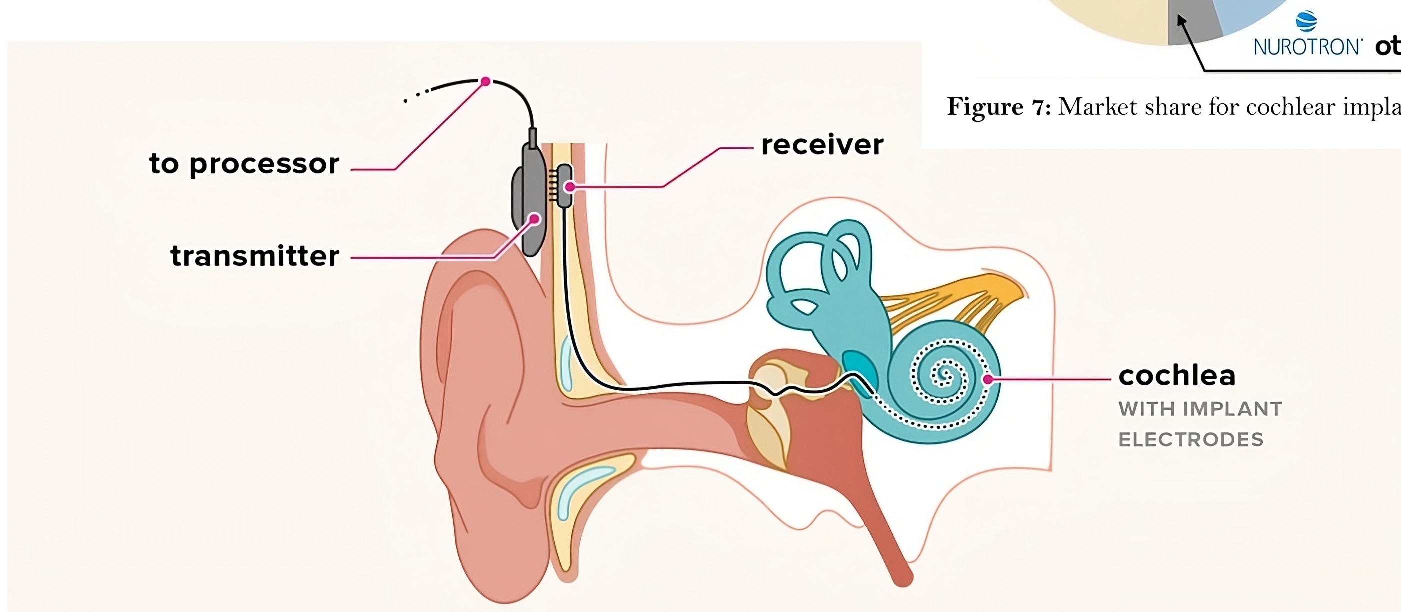

Figure 8: Visual explanation on how a generic cochlear implant may be modeled and implemented for a user [A4].

Complications

- A global complication rate of 19.9% with major complications occurring in 5% of cases and minor complications in 14.9% of cases [7].
- Adults experienced a higher rate of minor complications. While children primarily faced more major infectious complications [7].
- Infectious complications were the most common cause of issues. Surgical revisions were occasionally necessary due to serious conditions like meningitis or device failure [7].

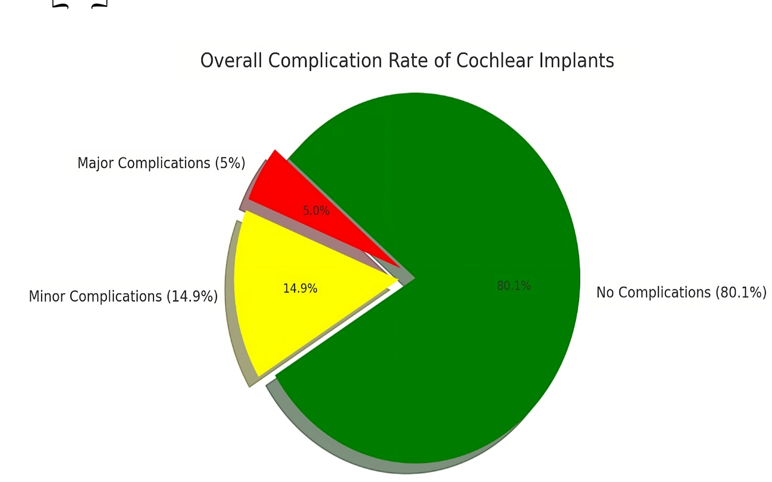

Figure 9: Overall complication rate of cochlear implants according to peer-reviewed paper [7].

Figure 10: Example of infection found after cochlear implant [A5].

Future Developments

- Preservation of spiral ganglion neurons (SGNs) remain an important future topic, as they are the target of stimulation [8].
- Neurotrophin-3 and BDNF are both important for the survival of SGNs, which improve transmission and performance of biological systems [8].
- Successful inner hair cell regeneration could bypass the need for cochlear implants altogether in some cases.

Figure 11: OTOPLAN, planning software to select the right electrode for each cochlea. Personal customization is key [A6].

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Additional Resources

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