Leiden University Medical Center

Cochlear Implants in the future: What can we expect?

A kaleidoscopic overview

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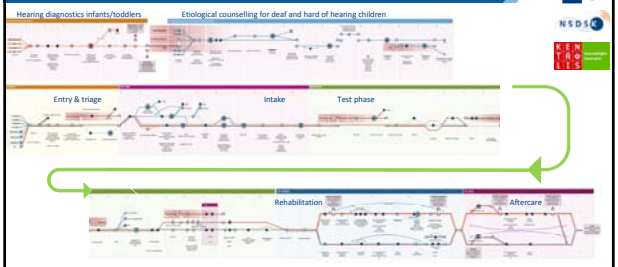
LEIDEN UNIVERSITY MEDICAL CENTER

Leiden, small town in the Netherlands

The oldest Dutch university (1575)

CI & ABI is care pathway in Expert Centre for Rare Ear Diseases

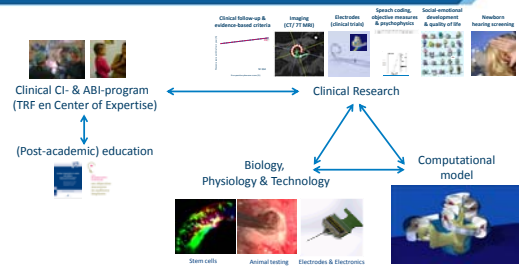
Formal accreditation 2021 – Transmural collaboration with NSDSK & Kentalis



https://www.orpha.net/consor/cgi-bin/OC_Exp.php?lng=GB&Expert=625941

Mission & overview of inner ear research in LUMC

Goal: Improving hearing and vestibular function



Translational inner ear & CI research in LUMC

PhD-theses – partly in Medical Delta

Theses to be defended soon:
- Dick Biesheuvel
- Randy Kalkman

We use all 4 major CI brands

80 implantations annually

Advanced Bionics
(HiRes90K/Ultra3D)
(USA/Switzerland)

Cochlear
(Nucleus Freedom/Nucleus Profile)
(Australia)

Med-El
(Synchrony Pin)
(Austria)

Oticon Medical (Neuro ZTi)
(Danmark/France)

Despite their success, current CIs have several limitations

- **Variability in outcomes**
  - Current multiple-regression models explain <20% of the variance
- **Limited speech understanding in background noise**
  - Puts a limit on social functioning in school and at work
- **Poor directional hearing**
  - With bilateral CIs
  - In bimodal conditions (CI and contralateral hearing aid (HA))
- **Poor music perception**

What will be the future of CI?

Looking in the crystall ball…

- Expanding indications
- New/better technology
- Surgical advancements
- Biological therapies

What will be the future of CI?

Looking in the crystall ball… - But just a kaleidoscopic view…..

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Looking in the crystall ball…

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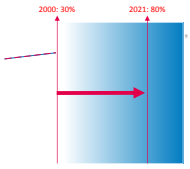
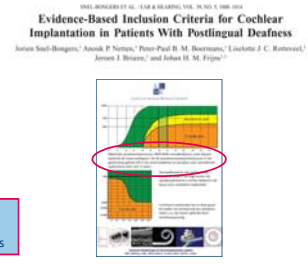
Almost every candidate benefited from CI

Reason to alleviate the inclusion criteria



Awareness to start CI-trajectory timely,
e.g., avoid people losing their jobs
Important aspect: Management of expectations



Evidence-Based Inclusion Criteria for Cochlear Implantation in Patients With Postlingual Deafness

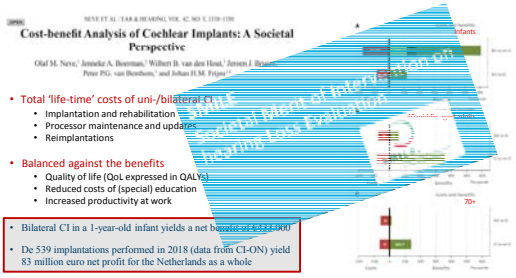
Expanding indications for CI

A continuing trend

Criteria vary between countries, but are continuously updated, driven by the ever improving (predictability of the) results

- In recent years more relaxed criteria for adults, e.g., in the Netherlands, the UK and Flanders
  - Better preservation of residual hearing → EAS option available in all brands
  - Increasing numbers of bimodal users
    - Special hearing aids to be used contralateral to CI
- Bilateral CI in children reimbursed in most countries
- Bilateral CI in adults reimbursed in many countries (but not in the Netherlands)
- Increasing attention for CI in unilateral deafness and asymmetric hearing loss
  - Also in children? → Prof. Astrid van Wieringen's lecture this afternoon

CI increases Quality of Life (QoL) of the recipients and benefits society as a whole


Cost-benefit Analysis of Cochlear Implants: A Societal Perspective

- Total 'life-time' costs of uni-/bilateral CI
  - Implantation and rehabilitation
  - Processor maintenance and updates
  - Reimplantations
- Balanced against the benefits
  - Quality of life (QoL expressed in QALYs)
  - Reduced costs of (special) education
  - Increased productivity at work

- Bilateral CI in a 1-year-old infant yields a net benefit of € 332.000
- De 539 implantations performed in 2018 (data from CI-ON) yield 83 million euro net profit for the Netherlands as a whole

What will be the future of CI?

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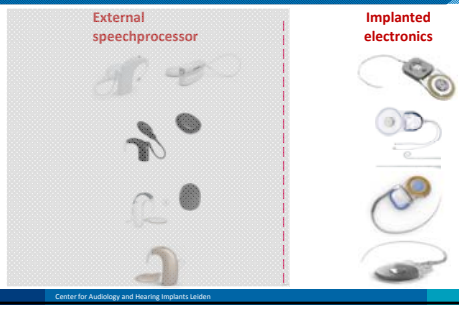
Information pathway of CI signal

Performance is determined by combination of steps

External speechprocessor

Implanted electronics



Currently 3 rotating magnet systems on the market

Increased MRI-compatibility

MedEl Synchrony

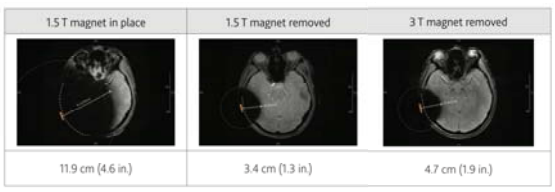
AB HiRes Ultra3D

Cochlear Profile Plus

The magnet blanks part of the MRI image

Also rotating magnets!

gradient echo pulse sequence

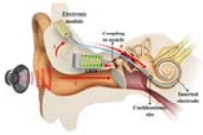


- Effects depends on CI type, exact position and MRI sequence

The totally implantable cochlear implant (TICI)

The idea has been around for more than 2 decades

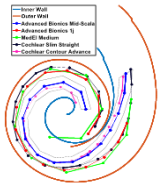
- No external speech processor required: Invisible solution!
  - **Internal rechargeable battery**
    - Charging during sleep via coil in pillow?
    - Emergency charging via external speech processor?
    - Limited life-time: How to deal with battery replacements (after how many years?)?
  - **Internal speech processor**
    - Must be externally programmable/upgradeable
  - **Internal microphone**
    - Under de skin (like in Otologic MET)?
      - Attenuation, esp. of higher frequencies
      - Internal body noise (chewing, blood vessels)
    - Connected to the middle ear structures?



- Currently ongoing trials by MedEl and Cochlear

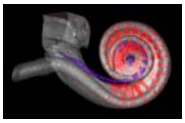
Electrode developments

- Reducing insertion trauma: Structure and hearing preservation
  - Tendency to become thinner (but how to handle reimplantations?)
  - Straight (=outer wall) or precurved/perimodiolar – what is better?
  - Actively curling (and sensing?) electrodes
    - Shape memory alloy (e.g., Nitinol)
    - Thermosensitive polymers
    - Piezo-electric elements
- Reducing tissue reactions (and delayed loss of residual hearing)
  - Peri-operative corticosteroids
  - Drug releasing electrodes (corticosteroids and other)
  - Special coatings (zwitterionic, nanocoating and other)
- Including electronics in the electrode array
  - More flexible stimulation, less wires, so more flexible
  - Requires new materials instead of silastic and platinum (biocompatibility and other safety issues)



Optical instead of electrical stimulation

- An important limitation of current CIs is electrical current spread
  - Limited number of independent channels (typically 8-10) despite larger number of contacts in the array



- Several attempts to use intracochlear optical stimulation
  - Very selective stimulation is possible using micro-LEDs and/or fibre optics
  - Direct laser stimulation – requires a lot of energy (thermal risk)
  - Optogenetics
    - Using channelrhodopsins to make the auditory nerve more sensitive to light
    - Requires genetic modification – not yet useable in humans

Information pathway of CI signal

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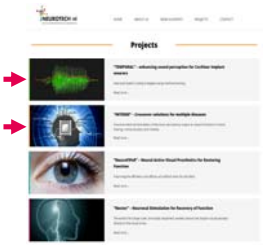
External speechprocessor

Implanted electronics

Progress at the level of the speech processor

- **Smaller speech processors (better batteries, smaller electronics, more efficient speech coding strategies)**
- **Option of off the ear processors (body-worn vs. head-worn)**
- **Integrated acoustic stimulator for use with EAS**
- **Incorporation of signal processing technology, which was originally developed for hearing aids**
  - Directional microphones (both in the speech processor and externally connected)
  - Noise reduction algorithms
  - CROS-devices for unilateral CI-recipients without useful contralateral hearing
  - Direct (acoustic) coupling to a contralateral hearing aid
- **Improved connectivity**
  - E.g., bluetooth with smartphones, PCs etc.
  - Options with special protocols and devices for meetings (e.g., Roger)
  - Apps for remote testing and remote fitting
- **Auditory scene selection**
  - The speech processor selects features based upon listening environment (e.g., quiet, noise, music)

NeuroTech-NL: Dutch Neurotechnology Consortium

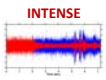


NEUROTECH nl
INTENSE
Health Holland
TEMPORAL

Information pathway of CI signal

Performance is determined by combination of steps

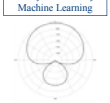
INTENSE

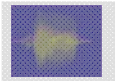


Pre-processing

Noise reduction
Microphones
AGC

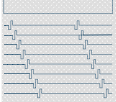
Auditory Scene Analysis
Machine Learning



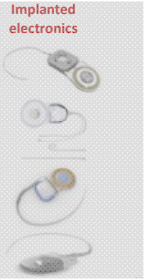


Coding strategies

Temporal envelope
Fine structure
Pulse shape
Pulse tables



Implanted electronics



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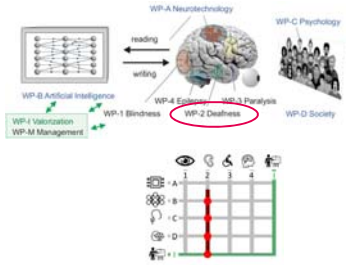
NWO Crossover-grant – Consortium from Neurotech-NL



INTENSE

www.intenseproject.eu

Center for Audiology and Hearing Implants Leiden

Leiden University Medical Center

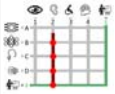
INTENSE

Workpackage 2: Deafness

Personalized and context-aware noise suppression

WP-leader: Prof.dr.ir. Johan H.M. Frijns, ENT-surgeon
WP-co-leader: Dr.ir. Jeroen J. Briaire, clinical physicist-audiologist
Center for Audiology and Hearing Implants Leiden (CAHIL)
Department of Otorhinolaryngology and Head & Neck Surgery
LEIDEN

INTENSE – WP2: Deafness
NWO Crossover-grant – Consortium from NeurotechNL



- **Task 2.1**: Preprocessing, directionality, voice tracking, scene analysis
  (LUMC + Donders institute, **prof. Marcel van Gerven**)
  <-> WP-B (and WP-1)

- **Task 2.2**: Classroom interaction
  (LUMC + FSS-UL, Developmental psychology, **prof. Carolien Rieffe**)
  <-> WP-C

- **Task 2.3**: Reducing listening effort with CI
  (LUMC + Amsterdam UMC (VUMC), **prof. Sophia E. Kramer**)
  <-> WP-D

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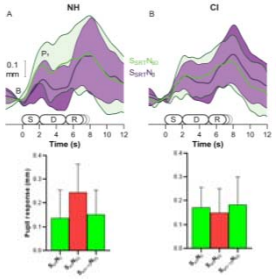
Task 2.1 Artificial Intelligence (AI) in pre-processing for CIs

Example: Selective amplification of speakers

Center for Audiology and Hearing Implants Leiden 31-Oct-22

Measuring listening effort with an eye tracker
Pupillometry: Pupil dilates with increasing effort



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LIACS Health~Holland

Machine learning To Enhance teMPoral cOding foR cochleAr implants:
Bridging the gap between computational models and the clinic

PPP-TKI grant

Johan HM Frijns & Jeroen J Briaire
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Department of Otorhinolaryngology and Head & Neck Surgery

Thomas HW Bäck & Anna Kononova
Leiden Institute for Advanced Computer Science (LIACS)
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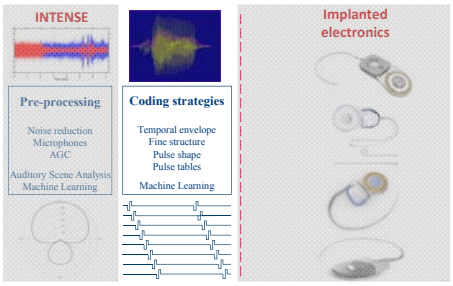
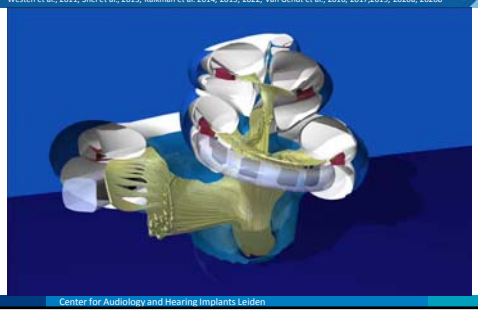
Machine learning To Enhance teMPoral cOding foR cochleAr impLants



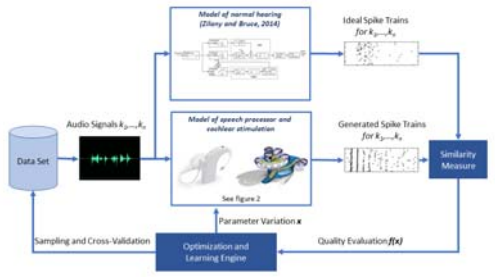
Computer model of the implanted cochlea

Frijns et al., 1995, 1996, 2001, 2009, 2011 ; Briaire et al., 2000, 2005, 2006; Westen et al., 2011; Snel et al., 2013; Kalkman et al. 2014, 2015; 2022; Van Gendt et al., 2016, 2017,2019, 2020a, 2020b



TEMPORAL overview

Using computational models to define optimal stimulation patterns



What will be the future of CI?

Looking in the crystall ball…

- Expanding indications
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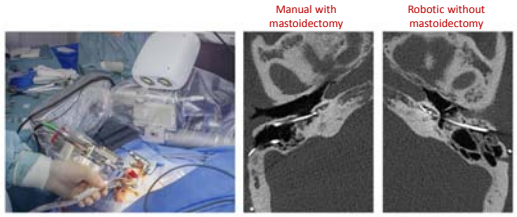
- Surgical advancements
- Biological therapies

Surgical advancements

- Soft surgery to preserve cochlear structure and function is common now
  - Less traumatic electrodes
  - Slower insertions, avoiding suction, use of anti-infammatory drugs
  - Discussion: (extended) round window or cochleostomy?
- Electrocochleography (ECochG) via the implant to monitor residual hearing
  - Electrical signals from the outer hair cells with acoustic stimulation
  - Feedback to the surgeon
- Robotic surgery
  - Image guided/stereotactic surgery, even without mastoidectomy
    - What about the facial nerve?
  - Robotic drilling
  - Robotic electrode positioning
  - Robotic insertion
    - Avoiding surgical tremor
    - No tactile feedback …

Robotic surgery without mastoid drilling



Caversaccio et al., 2019

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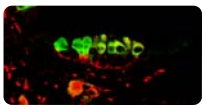
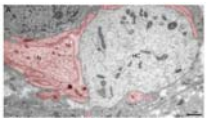
Biological therapies for hearing loss

Currently in laboratory/animal research

- Additive to cochlear implantation: Optimizing the electrode-to-neural interface
  - Neural preservation: Neurotrophins (e.g., BDNF, NT-3)
  - Neural regeneration: Neurotrophins, stem cells



- Restoring natural hearing
  - Hair cell regeneration
  - Inner ear organoids from stem cells
  - Gene therapy (Atoh-1 first success story)
    - In the future also possible at the embryonic level?



Take home messages

- Cochlear implants are currently the most advanced neuroprotheses
  - Large benefit for both adults and children
  - Beneficial for society as a whole
  - The indications are becoming more and more relaxed
- Despite their success there is ample room for improvement in several domains
  - A wide range of promising research projects is going on now and starting in the near future
- Research needs an ever continuing close collaboration between
  - Academic researchers: fundamental, translational and clinical
  - Industry: CI and hearing aid manufacturers
  - Caregivers and schools for the deaf and hard of hearing
  - Patient organisations and individual CI recipients

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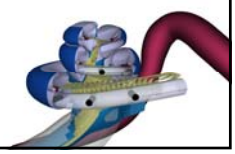
Thank you for your attention!



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