ABSTRACT BOOK

fNIRS & IMAGING

Functional near-infrared spectroscopy: A prognostic tool to predict cochlear implant outcomes

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Whilst many cochlear implant (CI) recipients achieve good speech understanding, some people receive less benefit from their implant than others, and large variability still exists in how well individuals can understand speech through their CI. While some influential factors have been identified, including age at onset of hearing loss and the duration of deafness, currently there is no accurate predictor of how well an individual will perform with a CI. However, a better understanding of the mechanisms underlying the variability in CI may inform clinicians in counselling patients prior to implantation about their likely prognosis and help shape the rehabilitation that they receive post-implantation, to ensure that limited healthcare resources are directed effectively.

Evidence suggests that 'cross-modal' reorganisation of auditory brain regions could be an important factor in understanding and predicting how much benefit an individual will receive from their CI. Following deafness, cortical areas that would usually process auditory information can reorganise and become more sensitive to the intact senses, such as vision. Indeed, it has been shown that individuals with a CI rely on a heightened synergy between audition and vision. Such findings highlight the importance of exploring and understanding how the brain responds to auditory and visual speech information before and after cochlear implantation. However, the time course and nature of these changes in cortical responsiveness, and their relationship with an individual CI user's ability to make use of auditory and visual speech information has, until recently, been challenging to study.

Specifically, the established methods for non-invasive brain imaging in humans are generally not well suited to research involving CI users due to the electric and magnetic artefacts generated by the operation of the CI. In this talk I will review our work using functional near-infrared spectroscopy (fNIRS), a flexible and non-invasive imaging technique which, owing to its optical nature, is fully compatible with CIs and is essentially silent. Our work indicates that fNIRS provides a powerful tool to explore cortical reorganisation during deafness and following cochlear implantation. By developing fNIRS as a tool to study how the brain responds to multisensory stimulation before and after cochlear implantation, we can provide valuable insights into the reasons for variable CI outcomes.

Localization of cortical response to audiovisual, visual, and auditory speech stimuli using functional near-infrared spectroscopy: an exploratory study in normal-hearing adults

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Background: Functional near-infrared spectroscopy (fNIRS) is an increasingly popular technique used to investigate cortical function, including auditory- and visual- functions. fNIRS provides a silent and non-invasive functional imaging technique that is compatible with hearing devices. However, fNIRS is only recently adopted in auditory research (Harrison et al., 2021) and considerable variability exists in the experimental designs and analysis techniques used by different researchers (Luke et al., 2020). Hence, the current study aimed to set up and test an fNIRS protocol to evaluate cortical activation to audiovisual, visual, and auditory speech in normal-hearing adults. Based on the results of this exploratory study, the current test protocol will be evaluated for future research with CI users and hearing aid users.

Methods: A group of 31 normal-hearing adults (mean age 58.76 years, standard deviation 14.49) was included. A pseudorandom block design was used, whereby bi-syllabic Dutch words were used as stimuli, randomly alternating between auditory (i.e. only sound), visual (i.e. only video-recording), and audio-visual (i.e. sound and video combined) presentation. Besides, a silent control condition was included. Optodes were placed bilaterally on the auditory and visual cortices. Data were recorded using a NIRSport 2 system and analyzed using MNE-Python. Localization of cortical activation was determined per condition.

Results: Results showed cortical activity in the left temporal cortex during auditory speech stimulation. However, this activation was not significantly different from baseline. During visual speech stimulation, significant activation was found in the occipital cortex, more especially in the primary visual cortex (V1), and visual association cortices (V2 and V3). This region also showed significant activation during audiovisual speech stimulation, in addition to non-significant activity in the left temporal cortex.

Discussion and conclusions: Possible explanations for the non-significant results in the auditory condition could be the high mean age of the participants in the current study or the used stimuli. In conclusion, the current study provides evidence that fNIRS can be a useful neuroimaging technique for the localization of cortical responses to auditory, visual, and audiovisual speech stimuli. Future work will compare the current results obtained in normal-hearing individuals to CI users and hearing aid users.

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Individualized CI surgery by new innovations in radiological image processing

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Background & Objectives: The goal was to develop a new research imaging tool to support the surgeon individualize CI surgery based on the individual analysis of CI subject's pre and post-operative CT by reconstruction of inner ear and electrode in a fast and convenient way. With structure preservation being an important factor during CI surgery, the goal was to include an accurate estimation of the location of basilar membrane and osseous spiral lamina within the reconstructed inner ear.

Methods: The research software has been developed using active shape model and AI technology to determine the shape and size of individual cochlea and an accurate location of basilar membrane and osseous spiral lamina. The active shape model is derived from 35 high resolution and contrast microCT images. The software includes novel analysis measurements to plan structure preservation surgery.

Internal studies have been performed to determine the accuracy of the cochlea and electrode model.

Results: The research imaging software is able to assess shape of the cochlea and location of the basilar membrane. Validation of the model showed mean estimation error of 62µm

In order to assess the CI electrode array scalar location a 3 scale trauma rating was used (T0, T1, T2). T0 being the electrode located in Scala Tympany, T1 electrode interacting with basilar membrane or osseous spiral lamina and T2 indicating translocation into scala vestibuli.

Conclusion: A novel imaging research software has been developed that detects the individual shape of the cochlea and position of the electrode based on CT images.

Due to the high accuracy of the predicted cochlea and electrode models, the software could be used to individualize of CI surgery, by means of individualizing pre-operative planning and post-operative assessment of CI surgery by assessment of electrode location.

Towards autonomous cochlear implant surgery by objective measures

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Background & Objectives: The first aim is to describe the actual HEARO procedure. Secondly we report on our clinical cases implanted with the HEARO system that performs image guided surgery with highest autonomy.

Methods: The Hearo system consists of a robotic arm executing the drilling, a reference system to link the scan of the ear to the patient using the registration procedure and a dedicated facial nerve monitoring system to allow a save passage of the facial nerve. The associated equipment is a high precision (0.1mm) intra-operative mobile conebeam CT scan and dedicated software to analyze the scan and to define the drilling pathway. The HEARO system aims for full cochlear coverage and soft surgery. Therefor it allows for flexible (0.8mm) lateral wall electrodes (Flex electrodes; MED-EL).

The current HEARO procedure for RACI comprises several steps of: 1) titanium fiducial screw placement 2) perop CBCT imaging, 3) pre-operative trajectory planning, 4) patient-image registration, 5) middle ear access robotic drilling till 3mm lateral from the facial nerve 6) CBCT with reference rod in the drilled trajectory to control for deviations from the planned trajectory, 7) stepwise drilling passing the facial nerve plane with electric facial nerve monitoring till access of the facial recess and 8) inner ear access robotic drilling with drilling pressure control at the round window bony overhang (cannonostomy).

Results: The Hearo procedure was then performed as a feasibility study in three patients and subsequently as an efficacy study ongoing for 25 patients with severe to profound sensorineural hearing loss and in which the temporal bone anatomy allowed enough space between the facial nerve and the chorda tympani for save passage of the drill.

The variability of defining and accessing the different predefined targets resulted in SEM of 0.05-0.07mm. These results allowed for the human feasibility experimental surgical CI using RACI. The results in terms of accuracy and precision and the experiences of the first patients will be presented and discussed. No adverse events were noticed and the full procedure could be performed.

Conclusion: Robotic assisted cochlear implantation is feasible in clinical setting. The procedure proves to realize the requested accuracy and precision to safely perform the procedure and form a sound platform for improving CI surgery.

Electrode array placement in a case of cochlear facial dehiscence with help of intra-op fluoroscopy and measuring the level of facial nerve stimulation

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Background & Objectives: This case illustrates the difficulties of a patient with cochlear facial dehiscence (CFD) and cochlear implant electrode array placement. During pre-op CT scan examination, a CFD was located at 15 mm distance from the round window.

Methods: The surgery was scheduled at Oslo University Hospital Intervention Centre, which has the facilities to perform intra-op fluoroscopy during electrode array placement. A slim modiolar electrode was chosen to keep the distance to the lateral wall of the cochlea and the CFD. After insertion, implant evoked electrical auditory brainstem responses (EABR) were measured for electrode contacts that were in the region of the cochlear facial dehiscence. This was done in order to may measure the response of the stimulation and assess the threshold of a facial nerve stimulation.

Results: Intra-op fluoroscopy demonstrated difficulties during electrode array insertion at the position of the CFD, after different manoeuvres of the array placement, such as pull back and rotation, the array passed by the CFD. Post insertion EABR did show clear eV responses in the region of the CFD. At higher stimulation levels (such as 250CL) the response revealed an additional response which might be a facial nerve stimulation due to the electrical stimulation.

Conclusions: CFD may cause difficulties during electrode insertion, as this case illustrates. The bone opening may cause a “leakage” of the electrical field and cause a facial nerve stimulation. Intra op fluoroscopy has been shown to be a valuable tool to achieve desired electrode array placement. EABR measurements may indicate the threshold of facial nerve stimulation.

Study of the cochlear insertion area and its relevance for cochlear implantation

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Background and objectives: With softer electrode arrays, Ecoch G monitoring and minimal traumatic surgery, more often residual hearing can be preserved in case of cochlear implantation (CI). Many subjects, however, loose the residual hearing after a period of two years after CI. A thorough understanding of the cochlear microstructures at the level of the insertion area, inside of the cochlea, is crucial. This could help improving the insertion process and avoid microtraumata that induce late onset fibrosis higher up in the cochlear duct. A commonly available, however, non-destructive method for reliable insertion trauma evaluation remains a challenge.

Micro-focus Computed Tomography allows for non-destructive 3D visualisation. In combination with a hafnium-substituted Wells-Dawson polyoxometalate (Hf-POM) it can differentiate between intracochlear fluid and soft tissues.

In this study we investigated the relevant intracochlear microstructures of fresh-frozen human cochleae. Furthermore, there is a need for scalable models to enable controlled, repeatable insertion experiments.

Methods: Contrast-enhanced microCT imaging (CE-µCT) for the evaluation of in total seven fresh-frozen human cadaveric cochleae was performed. The CE-µCT results were validated by comparison to histological images. In four of these cochleae, trauma was induced after the first imaging, followed by imaging. µCT images of two cochleae were used to produce 3D printed models of the scala tympani. Their anatomical accuracy was quantified as the geometric deviation of the printed 3D model from the original cochlea, expressed as the Root Mean Square Error (RMSE). Insertion forces were registered.

Results: CE-µCT allowed visualizing not only the mineralized, but also the soft tissues within the cochlea. The anatomical accuracy of 3D printed scala tympani models was within the limits of cochlear anatomical variability with RMSE ≤ 0.11mm. The maximum insertion forces were comparable for full electrode insertion in 3D models (median; IQR = 86.84mN; 38.36mN) and in fresh-frozen cochleae (median; IQR = 106.08mN; 71.72mN).

Conclusions: Our study reports on CE-µCT imaging as a novel non-invasive imaging method for the evaluation of fresh human cochleae. It enables detailed, quantitative 3D assessment of electrode insertion trauma. Additionally, CE-µCT images are a reliable base for development of anatomically and mechanically accurate, scalable cochlear models.

Improving the sensitivity of cochlear implant integrity testing: Recording electrode voltages with surface electrodes to diagnose partial short circuits in Advanced Bionics Ultra V1 devices

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Background: Advanced Bionics (AB) Ultra V1 devices are vulnerable to partial short circuits, resulting from moisture ingress. The manufacturer provides clinicians with a diagnostic test to identify this fault, "Electric Field Imaging" (EFI), using trans-impedance measurements. AB estimate the sensitivity of the algorithm incorporated in the test to be between 70 and 90%. We Recorded Electrode Voltages (REVs) using surface electrodes and compared these with the EFI test.

Method: 65 AB Ultra V1 devices supported by the University of Southampton Auditory Implant Service were assessed by REVs and EFI during routine clinic appointments. 32 devices had been tested at least twice, 16 in children and 16 in adults by March 2023.

REVs was performed with surface electrodes placed on the earlobes and forehead, whilst the implant was stimulated in live mode, taking approximately five minutes per ear.

Results: 10 of the 32 devices which had been tested at least twice presented as normal at the earlier test, based on the EFI test and two criteria previously suggested in the published literature for REVs. Relative Electrode Voltages (EVs) across the electrode array were calculated for measurements made with the recording electrodes on the ipsilateral and contralateral earlobes. These were fitted to a polynomial (cubic) function, showing excellent agreement, mean R-squared=0.97 (range 0.89-0.997). For individual electrodes, the mean absolute difference between the predicted and measured values was 1.1%, st dev 1.3%. All REVs differed by <6% from the predicted value, except one of 10%.

Devices which presented as abnormal on the EFI test gave a poorer fit to a cubic function, mean R-squared=0.79 (range 0.40-0.96), based on the later tests (N=33). The mean absolute difference between the predicted and measured EVs was 8.2%, st dev 9.3%. All devices had at least one electrode with an EV ≥9% different from the predicted value. 32 devices were returned as normal on the later EFI tests. Of these, 15 devices had REVs <3% from predicted values for all electrodes, whilst 17 devices had at least one electrode with a REV ≥9% different from the predicted value.

Conclusions: REVs was found to be highly sensitive to partial short circuits caused by moisture ingress in AB Ultra V1 devices. EVs were well fitted to a cubic function in normal devices. Results suggest that 77% of devices tested were affected by the fault at the later test.

IMPEDANCE 1

Predicting cochlear implant electrode placement using monopolar, three-point and four Point impedance measurements

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Background & Objectives: Positioning of cochlear implant (CI) electrode arrays close to the spiral ganglion cell bodies within the modiolus may improve hearing outcomes. Measurements of electrical impedance recorded at the CI's electrode contacts could potentially be used to assess electrode positioning in real-time during electrode array insertion. In this study, we introduce a protocol for "three-point impedances" in which we record bipolar impedances in response to monopolar stimulation at a neighboring electrode. We aimed to assess the usability of three-point impedances and two existing CI impedance measurement methods (monopolar and four-point impedances) for predicting electrode positioning during CI insertion.

Methods: Impedances are recorded during step-wise CI insertions into human cadaveric temporal bones placed in a 0.9% saline bath. The distance between the electrodes and the modiolus is assessed at each step using cone beam computed tomography. Linear mixed regression is used to assess the relationship between the impedances and electrode-modiolar distances. The experimental results are compared with an existing lumped-element model of an implanted CI and with clinical impedance data.

Results: Three-point and four-point impedances strongly correlated with electrode-modiolar distance, while monopolar impedances were only minimally affected by changes in electrode positioning with respect to the modiolus. An overall model specificity of 62% was achieved when incorporating all impedance parameters. This specificity could be increased beyond 73% when prior expectations of electrode array positioning are incorporated in the model. Model simulations confirmed that three-point and four-point impedances, but not monopolar impedance, are sensitive and specific to local changes in electrode-modiolar distance. The average experimental impedance was within one standard deviation of the mean clinical impedance for all electrodes.

Conclusion: Three-point and four-point impedances are promising measures to predict electrode-modiolar distance in real-time during CI electrode array insertion.

Monitoring of daily impedance fluctuations in experienced CI users

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Previous studies suggest that changes of electrode impedances in cochlear implant users can be used as a biomarker for changes in cochlear health and clinical events such as the loss of residual acoustic hearing. In current clinical routine, impedance information is obtained only during clinical visits. As such, knowledge is lacking about the normal or abnormal daily variability of impedances. The aim of this study was to collect and describe daily impedance fluctuations at the electrode contacts of experienced adult CI-recipients and to collect information on the health of the user via self-assessments.

The study was conducted in two phases. In phase 1, 20 experienced Nucleus CI users measured their electrode impedances on all available electrodes 5 times per day for a period of 14 days. Data collection was performed using a wireless measurement system on a mobile device in the recipient's home environment. In addition, device usage, use of medication, medical and hearing conditions of the subjects, and events occurring during the observation period were collected. Five out of these 20 participants were recruited for phase 2, in which an improved measurement system was used to collect the data. This new research tool enabled the separation of the impedance into its subcomponents: access resistance and polarization impedance.

Data analysis of phase 1 showed that in 16 subjects the median impedance range within a day (excluding the first measurement) stayed below 500 Ohm. The remaining 4 subjects had a daily impedance range up to 2500 Ohm. Three of these subjects showed additional deviations of their daily average impedance value compared to their overall average impedance value of more than 500 Ohm. There was no correlation observed of these variations with the patients' self-assessments or clinical reports. Furthermore, impedance fluctuations per subject were similar in phase 2. A separation into impedance components revealed that slow variations over subsequent days were mainly influenced by the access resistance. The polarization impedance on the other hand showed daily peaks in the morning measurement, as there was no electrical stimulation overnight.

This study showed that increased fluctuations of electrode impedances do not necessarily relate to clinical events and that impedance patterns are patient dependent. To further characterize impedance patterns, a follow-up study is planned on a larger study population monitored over a longer period.

Investigation of the reduction of facial nerve stimulation in cochlear implant users using precision triphasic pulses

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Facial nerve stimulation (FNS) in cochlear implant (CI) users can be significantly reduced by using triphasic stimulation pulses with cathodic first phase. However, the reduction in FNS by triphasic stimulation may not be sufficient.

Therefore, it is investigated whether the so-called precision triphasic pulse has a greater potential in reducing FNS. This pulse is already implemented in CIs from the manufacturer MED-EL (Innsbruck, Austria) and consists of three phases of the same duration. On the other hand the amplitude relation of each phase, can be adjusted. For example, a precision triphasic pulse with a phase amplitude relation (PAR) of 0.7 consists of a first phase, with an amplitude that is 70% of the second phase amplitude. Consequently, for charge balancing, the amplitude of the third phase has to be 30% of the amplitude of the second phase.

A model of the implanted cochlea with an adjacent facial nerve was simulated. The simulation showed an even more effective FNS reduction at PAR of 30%, 40% and 50% compared to the standard triphasic pulse shape. A PAR of 40% showed the highest effectiveness.

The simulation results are currently compared to intraoperative electromyographic measurements (EMG) in CI patients. For this purpose, the CI is electrically stimulated after the implantation and while the patient is still under anesthesia. The strength of the electromyographic response of the muscles orbicularis oculi and orbicularis oris is recorded using subcutaneous needle electrodes. The stimulation pulse shapes are biphasic, triphasic and precision triphasic. The resulting amplitude growth functions are compared.

The preliminary results of the EMG measurements confirm those of the simulation. It can be assumed that the precision triphasic pulse could lower the FNS in CI users more effectively than a triphasic pulse.

Pneumolabyrinth following cochlear implantation resolved after shunt adjustment

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Case report

Background: A male with a previous history of cerebellar astrocytoma. He underwent initial surgery of the tumour at the age of 3 and lost his hearing in the left ear. A ventriculoperitoneal (VP) shunt was inserted at the age of 13 to manage hydrocephalus. At the age of 46 he lost his hearing in the right ear.

Methods/results: He was implanted with a CI via the round window. The surgery was performed with no complications and impedances were normal. At activation impedance values showed atypical high values and worsened over time. One month post activation the impedances were so high they prevented the patient from hearing via the implant. A CT scan suggested air in the cochlea.

The patient experienced that the hearing was better in the morning and worsened over the day. The hearing via the implant seemed to be affected by the intracranial pressure.

Three months post activation the shunt was adjusted from 80mm H2O to 100mm H2O to gain a higher intracranial pressure. Impedances started to show normal values. One year post activation the patient scores 68% on monosyllabic words via the CI.

Conclusion/summary: We present a case with atypical high cochlear implant (CI) impedances at activation. One month later the patient had no benefit from the implant and a CT suggested air in the cochlea (pneumolabyrinth). The shunt was adjusted to prevent air entering the cochlea.

All you see is an electrode: probing CI electrode properties for optimizing Stimulationparameters of cochlear implants

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Background: Cochlear implants (CIs) have achieved remarkable success as neural prostheses, globally employed to restore sensorineural hearing loss via direct electrical stimulation of the auditory nerve. However, the current clinical application of CIs employs a standard stimulation protocol, which unfortunately leads to reduced spectral resolution in auditory nerve stimulation. Notably, commercially available CI electrodes exhibit variations in contact size, wire shape, no.of contacts, total length, and configuration, all dependent on the manufacturer. How these differences affect cochlear implant current spread and function is not well known.

Methods: CI electrodes from four different manufacturers (Advance Bionics, Cochlear, MED-EL, Oticon) were received and each CI electrode was inserted into a linear cochlear model filled with artificial perilymph along its length. The investigation encompassed electrochemical impedance spectroscopy (EIS), covering a wide frequency spectrum of 5 Hz to 13 MHz, performed among all conceivable electrode pairs. From the resultant impedance responses, an impedance matrix was obtained for all electrode pairs. The response is being fitted using an equivalent electrical circuit model. An analytical model is being developed to extract the resistive and capacitive subcomponents of a CI electrode.

Results: Impedance spectroscopic responses demonstrated broad similarities in amplitude and phase across the implants. The impedance matrices showed dependence on the distance between the two measured electrodes. Based on this, we proposed equivalent circuit model, an extension of the general impedance model for biomedical electrodes, and currently it is being fitted with the recorded impedance data. From the model, the sub-components of impedance will be extracted and differences across the implants will be analysed.

Conclusion: Unlike conventional clinical impedance measurement, our approach is analysing the subcomponents of impedance for a better description of a CI electrode. In future, our simulation model should be able to predict the stimulation pulse parameters preoperatively to ensure that each electrode is providing appropriate levels of stimulation to the auditory nerve in the patients.

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Electrocochleographic patterns reflecting residual hearing changes in cochlear implant users

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Introduction: Electrocochleography (ECochG) responses recorded through the intracochlear electrodes of a cochlear implant (CI) can provide valuable information regarding the hair cell and neural health at different regions in the cochlea. In response to low-frequency acoustic stimulation, the largest ECochG responses are expected at the most apical electrodes. However, patterns with maximal amplitudes in the more basal regions of the cochlea have been reported. A possible explanation could be changes of the inner ear mechanics due to contact between the electrode array and the basilar membrane (BM), leading to acoustic energy focusing close to the fixation. We hypothesize that the contact between the BM and the electrode array could induce an inflammatory process within the cochlea and affect the cochlear health. This study aimed to investigate how different ECochG patterns correlate with residual hearing changes in the initial year following CI surgery.

Methods: Adult subjects with residual acoustic hearing undergoing CI surgery at the University Hospital of Zurich were included in this study. ECochG responses to 500 Hz tone bursts were recorded at different electrodes of the electrode array at three different time points: intraoperatively after full CI electrode array insertion, between four and twelve weeks postoperatively, and after one year of CI activation. Pure Tone Audiometry was performed preoperatively, approximately six weeks post-surgery, and after one year of CI activation.

Results: Preliminary results showed that intraoperative atypical ECochG peak patterns, with a maximum in the more basal region, remained stable at six weeks and one year following implantation. Hearing thresholds were reduced six weeks after implantation, but no further reduction was measured after one year in patients with a more basal peak pattern.

Conclusion: More basal ECochG peak patterns can indicate a possible fixation of the BM and can lead to a reduction in residual hearing within the initial weeks following cochlear implantation. However, this does not necessarily lead to changes of cochlear health or further deterioration of acoustic hearing thresholds after one year of CI use.

Hearing perception and tinnitus reduction during extracochlear electrical stimulation

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Introduction: Previous studies have shown that auditory nerve stimulation via a cochlear implant can reduce tinnitus. However, for people suffering from tinnitus without severe hearing loss, cochlear implantation is too invasive to be considered as a treatment. In this study, we aimed to investigate the feasibility of extracochlear stimulation as a potential treatment for tinnitus. Additionally, we examined whether extracochlear electrical stimulation can induce a hearing sensation, thereby enabling hearing impaired individuals to benefit from combined electric and acoustic hearing.

Methods: Six patients who underwent standard ear surgery were temporarily implanted with extracochlear electrodes at various locations in the middle ear. Electrophysiological recordings and subjective feedback were collected to assess hearing perceptions induced by extracochlear stimulation. The influence of extracochlear stimulation on tinnitus was evaluated through standardized tinnitus questionnaires before and after stimulation with the extracochlear electrodes.

Results: Subjective feedback on hearing impressions during extracochlear stimulation was collected in four out of six patients. Extracochlear stimulation successfully induced a hearing perception in all four patients, although these impressions were not loud enough to be detected as electrically evoked auditory brainstem responses. Additionally, two out of six patients reported experiencing tinnitus, and their perceived tinnitus decreased during extracochlear stimulation.

Conclusion: These preliminary results suggest that extracochlear stimulation has potential as a treatment option for hearing loss and tinnitus. The results also provide a foundation for further investigation of stimulation parameters best suited for extracochlear stimulation.

New developed sensor technology for intracochlear sound pressure measurements in *ex-* and *in-vivo* experiments

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Background: Quantification of intracochlear sound pressure (ICSP) is an objective measure for the evaluation of the biomechanical hearing process from the outer to the inner ear. Existing methods to measure ICSP remain difficult mainly because of the laborious sensor preparation, the sensor's prone to sensitivity changes with mechanical perturbation, the complexity of setup, and limitations of the sensor's performance.

The goal of the project was to develop a family of simple and robust intracochlear acoustic receivers (ICAR) that can record the liquid-borne sound inside the cochlea, and thus, suit for experiments in temporal bones and chronic experiments in large animals.

Methods: Our ICAR concept is based on a commercial MEMS condenser microphone customized with a protective diaphragm that provides a seal and an optimized geometry for accessing the liquid filled inner ear. Two design configurations of the ICAR were developed and fabricated: (1) a sensor for laboratory use on cadaver samples with sophisticated positioning capabilities and adaptive sensor head geometry and (2) an implantable version of the ICAR that can be simply plugged into the cochlear duct during in-vivo experiments in sheep which provides a representative model for the human ear.

Results: The two types of the ICAR have been successfully fabricated and tested. The ICSP measurements in a human cadaver temporal bone and in sheep yielded data in agreement with the literature. The surgeons reported high levels of ease of use and satisfaction with the system design.

Conclusions: Our results confirm that the presented MEMS CMIC-based ICAR is a promising technology for measuring ICSP in human temporal bones and acute large animal experiments. The concept has potential as an acoustic receiver in totally implantable cochlear implants.

Using an app-based data collection tool to measure impedances remotely in everyday life

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CI fittings are optimized based on performance and subjective evaluations of recipients as well as measures of device function such as electrode impedance. Impedances are typically measured during in-person clinic visits which can be separated by months to years. Programming actions undertaken based on these

impedance measurements are assumed to be relevant for everyday listening in-between clinic visits. However, impedances fluctuate day-to-day, for example due to illness, fluctuations of hormones, inflammatory responses, etc. (Sainz et al., 2003). If there is a considerable increase in electrode impedances, the implant may no longer be able to provide high enough voltage to deliver required stimulation levels. This could impact sound perception including overall loudness, speech perception, and sound quality.

At the time of abstract preparation we had recruited 22 participants (14 had completed the study). Participants were asked to measure impedances through AB's research app at least once a day for three months. App notifications were enabled to allow daily reminders at the time selected for each participant. Study compliance was monitored on a weekly basis and participants who missed measurements were sent a reminder to make the daily measurements. Preliminary results show that the majority of participants were able to complete the impedance measurements in a timely manner without much involvement from the researchers. Nine of the 14 participants who had completed the study missed fewer than 10% of measurements over the course of the study. Preliminary analyses show that while large impedance fluctuations are rare, impedances do fluctuate from day-to-day. 88% of impedances fluctuated less than +/- 0.5 kOhm around the mean.

This study shows that an app-based data collection tool can be used to make objective measurements such as electrode impedances outside the clinic environment without direct clinician or researcher oversight. From a research perspective, remote data collection can ultimately afford enrollment of large participant populations for any given study. From a clinical perspective, the ability to monitor impedances remotely opens the door to uncover optimization opportunities to CI program parameters between clinic visits.

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A novel anomaly pattern of trans-impedance matrix in cochlear implant

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Introduction: Trans-impedance matrix (TIM) meaurement is described in the literature as a methodology for assessing both geometrical integrity and placement of the electrode in cochlear implant (CI) surgery. TIM was also used in routine post-surgical: to confirm the positioning of the CI electrode; to descriminate different type of etiologies in patients with CI. For these reasons it's important a visual inspection of the TIM during the follow-up. In our clinical practice after analyzing several post-operative TIMs we identified a novel pattern that we call 'Scatter'. The aim of this study was to analyze the group of the 'Scatter' TIM pattern in order to explore the correlation with different patients and device characteristics.

Methods: TIMs were collected in 697 CI. We excluded CI in inner ear malformations so, the sample observed was 679 TIMs. The Scatter pattern was found in 66 devices (9,7%). This pattern was classifies as Severe (25 devices) and Middle (Mid) Scatter (41 devices) according to visual extension of the anomaly. We compared Severe and Mid TIMs Scatter among them and with a group of Normal (Good) TIM (21 devices). We considered: visual extension of the pattern; time of CI use; type of the CI internal part; auditory performance (speech audiometry in quiet at 65dB and in noise - Matrix Test); impedance and NRT. We also analyzed thee parameters; Shannon Entropy, Exponental Decay and Spatial Correlation.

Results: A difference was found in some parameters between Severe Scatter, Mid Scatter an Good TIM groups. The Shannon Entropy and Exponential Decay parameters have higher value in Severe Scatter compared to Mid Scatter or Good TIM. We do not found significant correlations between TIM pattern and auditory performance or etiology. However, a large variability in speech in noise (SNR at Matrix Test) respect 'normal' TIM population was observed although no differences in mean were apparent. Finally, Scattered Tim was

significantly associated in patients with an avarage time of CI use of 135 months and with Slim Modiolar (CI24RE) and Contour Advance (CI512) array.

Conclusions: Scatter pattern is a novel previously underscribed anomaly of TIM (with different grade). A numerical base to validate the inspection approach is here described. The anoamly it seems associated with long device-life and type of internal part. More data and longer follow-up are necessary to full understand the phenomenon and implication in terms of hearing performances over time.

Application of extra- and intracochlear electrocochleography for diagnosing retrocochlear disorder in an infant (case report)

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Background: Cochlear implantation (CI) is a possible therapy to help patients with sensorineural hearing loss (SNHL). One of the causes of SNHL is an auditory neuropathy spectrum disorder (ANSD), e.g., retro-cochlear disorder, where the outer hair cells in the cochlear are intact while the inner hair cells, the synaptic transmission, or the spiral ganglion neurons are not responsive. This constellation results from an abnormal electrophysiological response that can be identified in audiological testing, such as electrocochleography (ECochG) and auditory brainstem response (ABR) recording: the presence of cochlear microphonic (CM) and/or otoacoustic emission (OAE) and the presence of an unusual ABR.

Objectives: This study has three goals: reporting the feasibility of CI in an infant with ANSD; reporting the use of transtympanic and intracochlear ECochG recordings intraoperatively to evaluate the presence or absence of auditory neuropathy; and presenting the cochlear response during CI insertion.

Case Report: An 11-month-old male infant was diagnosed with bilateral ANSD. OAE and/or CM are present, but the early auditory evoked potentials (EAEP) are either dysmorphic or completely absent. The response audiometry to Mainzer children's songs and aided audiogram test showed reaction at 60 and 70 dB nHL, respectively. Furthermore, ABRs and auditory steady-state response (ASSR) showed potential at 100 dB nHL.

Methods: CI implantation was decided for the right ear with a FLEXsoft electrode array (MED-EL, Innsbruck, Austria) inserted via the round window. Objective measurements were done in three sections: preoperative, intraoperative, and postoperative, which consist of extracochlear ECochG presurgery, intracochlear ECochG & electrical compound action potential (ECAP), and electrical auditory brain response (E-ABR), respectively. Extracochlear ECochGs were recorded using a transtympanic needle electrode fixed at the promontory. 1 kHz alternated tone bursts at 80, 90, and 100 dB nHL served as acoustic stimuli. Intracochlear ECochGs were recorded using the most apical CI electrode with 500 Hz tone bursts at 115 dB nHL acoustic stimuli during electrode insertion. For E-ABR measurements, electrical biphasic pulses ranging from 600 to 1200 qu were delivered to apical, medial, and basal electrodes.

Results: Transtympanic ECochG captured derivable CM; however, there was no clear CAP detectable even at 100 dB nHL. Intracochlear ECochG recordings revealed observable CM amplitudes with amplitudes up to 60 µV. Here, changes in latency and phase change were observed. CI was fully inserted into the cochlea without any complication. Impedance telemetry resulted in the normal range. ECAP thresholds were detected on all electrodes except the most apical and basal electrodes, where no thresholds were found. E-ABR wave V was captured with an amplitude of approximately 150 nV at all stimulating electrodes.

Clinical Outcomes: Hearing thresholds by ECAP measurement were significantly reduced during the first and second months of clinical control. Six months after CI implantation, the child responds very well to sounds, dances to children's songs, and parents are planning for the 2nd CI implantation in the opposite ear.

Conclusions: CI implantation is a feasible therapy for children with inner hair cell/synaptopathy disorders. ECochG is an essential diagnostic test to confirm the diagnosis of ANSD. ECAP measurement is a crucial tool for assessing the neural response of auditory nerves. The recording of E-ABR ensures robust auditory conduction from the cochlea to the brainstem. However, in the presented case, the specific location of the disorder remains unknown. Finally, the use of intracochlear ECochG is likely to improve clinical surgical routine in the future.

WEDNESDAY 27 SEPTEMBER

ESRT SESSION

Development of a sensitive stapedius reflex measurement based on electromyographic signal –A sheep model

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Introduction: Cochlear Implant (CI) fitting success strictly depends on the accurate definition of the dynamic area between the minimal current amount (T level) inducing an auditory sensation and the maximal allowing the patient to hear without discomfort (C level). Behavioral method-based fitting requires active feedback, being otherwise (e.g., intraoperatively) ineffective.

Objectives: The need to develop effective objective measures for a more precise CI fitting independent from subjective patient's feedback has focused the attention of the experts in the field on the electrically evoked stapedius reflex threshold (ESRT).

Material/Patients & Methods: We developed an adult sheep model, in which the stapedius belly was minimally exposed via a retrofacial approach designed to avoid middle ear and/or facial nerve damages. A pair of custom-made electromyography (EMG) electrodes were implanted in the stapedius belly. The EMG signal corresponding to the stapedius reflex (SR) elicited by a tympanometer was recorded.

Results: The study included 9 sheep of which only 6/9 had SR under anaesthesia. In those sheep, it was possible to measure the reflex via EMG between 1- and 6-months post-implantation. In one case, the reflex was first detected after 3-months post-implantation suggesting that it was related to post-surgical recovery.

Conclusion: Our first results showed that EMG electrodes could be used for long-term SR recording in sheep. Transposing these results in human would help to improve CI fitting, particularly in the first year, when the correct selection of the dynamic area is crucial for long-term success.

Preliminary results of a new stapedius-reflex-fitting-method for cochlear implant users

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Introduction: Electrically evoked stapedius reflex threshold (ESRT) has all the traits to become an optimal objective measurement for the fitting of CI patients, particularly in case of children and/or of patients unable to effectively communicate with the audiologist.

Objectives: A novel setting for the ESRT assessment not requiring pre-ear-pressurization and not limited to a probe frequency of 226 Hz is being developed. Such a setting is currently tested in a study enrolling adult and pediatric patients in subsequent age-blocks, running in Vienna (Austria) and Tubingen (Germany).

Materials/Patients & Methods: Patients implanted for at least 6 months with a MED-EL CI are recruited. After successful tympanometry, ESRT is assessed with a commercially available device for each active CI channel.

The same test is performed with our setting, too. The test order is randomized. Results with either setting are then compared with pre-existent maps generated on behavioral fitting results.

Results: Until now 28 adult patients have been enrolled. The novel method was successful in all patients with detectable ESRTs. The threshold obtained with the ESRT measurement were significantly lower than those obtained via behavioral fitting, suggesting that behavioral methods tend to yield maps with rather high stimulation levels.

Conclusion: Considering the promising results, the development of an ESRT setting not requiring pre-pressurization of the ear would mean reduced time exposure and better acceptability of the procedure.

Intra-operative measurements of the stapedius reflex via EMG - A feasibility clinical study

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Introduction: Accurate, reliable recording of electromyographic (EMG) signals corresponding to the stapedius reflex (SR) is crucial for the development of implantable sensors within smart closed-loop cochlear implants (CI). A critical factor is a safe and reliable EMG electrode placement.

Objectives: To assess retrofacial approach combining pre-operative use of 3D imaging for surgical planning with intraoperative real-time EMG-signal acquisition system.

Material/Patients & Methods: A clinical trial was set up at study sites in Jena and Tübingen, Germany, to assess SR-related EMG response. An EMG electrode is placed on the stapedius muscle (SM) belly after CI implantation. The CI is then used to deliver electrical stimulation and via the stapedius reflex elicit the SM contraction to determine whether SR is detectable visually and/or via EMG recording. Electrodes are placed in the SM preferentially using the retrofacial approach, or from the pyramidal eminence, anterior to the facial nerve, according to the individual anatomy.

Results: 17 patients were recruited. 4/17 were withdrawn from the study because of non-compliance with the selection criteria upon screening. SR EMG was successfully recorded in8/13. Offline signal processing was used to remove artefacts. Data analysis showed a correlation between the SR EMG signal and the visual detection of the SR at the level of the stapedius tendon of 0.93. The EMG signal manifested even before the visual observation in 41% of the assessed cases.

Conclusion: Our results confirmed that it is possible to reliably record SR-related EMGs intraoperatively. The use of the retrofacial approach for the SM exposure and subsequent electrode placements was found safe and effective.

Relationship between electrically evoked stapedius reflex threshold and stimuli burst Duration in a group of children using cochlear implants – preliminary data

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Background: Objective measures mostly used to fit cochlear implants are the electrically evoked action potentials in the first place, followed by the electrically evoked stapedial reflex thresholds (ESRT).

Several studies have shown that the general correlation between ESRT and subjectively measured comfort levels (MCL) is high (Hughes, 2012; Alvarez et al, 2007; Gordon, Papsin and Harrison, 2004; Lorens et al., 2004).

But till now the effect of the stimulus length to obtain reflexes has not been studied in the pediatric population.

Material and Methods: 30 children at the age less than 5 years, Med-El CI users, with all 12 active electrodes, with no cochlear malformation. All of them have been implanted with Standard or FLEX 28 electrodes and wore a SONNET audioprocessor.

A standard middle ear analyzer, Titan from Interacoustics (Assens, Denmark), was used for tympanometry and to record the stapedius reflexes electrically elicitated.

Stimulation parameters were as follow: burst duration: 100, 200, 300, 500 ms, stimulating electrodes: 2, 6, 9, 11. Additionaly behavioral MCLs for different fitting intervals were compared with achieved ESR thresholds.

Results: For 11 children we managed to complete the procedure and to record ESR threshold for all mentioned durations. Stimulation burst length had a significant effect on the eSRTs (p-value = 0.002), whereas the electrode number had a less significance on the threshold (p-value = 0.02); no effect was found for the interaction electrode-stimulation burst length. All the profiles show a tendency of increased stimulation level needed to elicit a reflex, towards basal electrodes which was also more pronounced with the decrease of the burst duration length.

Conclusions: ESRT threshold values depend on such parameter as burst duration. Objective measures as eSRT can be used safely for CI fitting in young children. Understanding the relationship between the different parameters can improve the fitting procedure.

Human stapedius muscle 3D-modelling: A systematic segmentation improves the effectiveness of the method for surgical planning

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Introduction: Dyna-computed tomography (Dyna-CT) provides high quality imaging of the temporal bone (TB) with low radiation. Its effectiveness in pre-planning difficult otosurgeries involving small structures of human middle and inner ear such as the stapedius muscle (SM) depends on the capability to reliably segment them using consistent landmarks.

Objectives: We used Dyna-CT-based 3D-reconstructions of the human TB to plan in advance the optimal surgical protocol for intraoperatively electrically evoked stapedius reflex threshold (eSRT) measurement via retrofacial approach. Segmentation was completed based on a standardized protocol.

Material/Patients & Methods: SM was manually segmented with 3D-Slicer for 30 human TB Dyna-CT datasets. Landmarks considered for segmentation were the mastoidal segment of the facial nerve (mastoid-mFN) (sagittal view); stapes (neck and head), stapedial tendon, pyramidal eminence and mFN (axial view). Surrounding structures such as FN, sigmoid sinus, semicircular canals were also segmented. 3D renderings were inspected by 4 otoneurological surgeons instructed to qualitatively evaluate the feasibility of the retrofacial approach. In 5 cases the 3D-modelling was used to access the SM during cochlear implant surgery.

Results: SM was identified in 30/30 dataset and manually reconstructed together with the surrounding structures. Complete SM exposure with respect to FN was observed in 58.3% of cases, partial exposure in 28.3%. The intraoperative exploration of the SM confirmed the preoperative prediction.

Conclusion: The use of our segmentation protocol for 3D reconstructions of tiny middle- and inner-ear structures is a valuable tool for surgical planning, in case novel/difficult approaches, to improve their safety profile of the surgery.

Accessing the stapedius muscle via a novel retrofacial approach: Pre-clinical testing and initial results in a clinical study

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Introduction: Electromyographic (EMG) signals, corresponding to the stapedius reflex (SR), is a reliable objective measurement for cochlear implant (CI) intra-/post-operative fitting. Still, the stapedius muscle (SM) size and position are extremely challenging for a safe and effective electrode placement in clinical routine.

Objectives: Our team developed a protocol to access the SM via retrofacial approach in order to stably place EMG electrodes in the SM in a safe way; and a surgical planning tool, based on Dyna-CT-based 3D image processing to pre-operatively assess the feasibility and safety of such approach.

Material/Patients & Methods: 18 human temporal bones (TBs) were assessed. Manual middle/inner ear structure 3D-segmentation was performed in 12/18; mastoidectomy and posterior tympanotomy in 18/18 TBs. Upon facial nerve (FN) mastoidal segment identification, retrofacial access was performed. It was also assessed during real-life MED-EL CI implantations. Intraoperative SR-related EMG signal was recorded.

Results: TB assessment suggested 72.2% successful SM retrofacial access rate, with a posterior access to the FN; 4±0.78 mm from the stapes head. The drilling depth was 2±0.30 mm. The exposure took 5-8 min. Preliminary intraoperative results were in line with the results obtained in TBs.

Conclusion: SM retrofacial approach following the results of the surgical planning tool helped to distinguish cases where such approach could be successfully and safely implemented from those where it could be risky. The surgical planning tool can be effectively used for safe and effective planning of otosurgeries, for which pre-surgery assessment of tiny ear structures accessibility is required.

ECochG

Can simultaneous intra- and extracochlear electrocochleography enhance the interpretation of cochlear function during cochlear implantation?

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Background: The objective to preserve residual hearing during cochlear implantation (CI) has recently led to the use of electrocochleography (ECochG) as an intra-operative monitoring tool. As the recording electrode moves during insertion with respect to the different signal generators in the cochlea, response changes can result solely from a changing contribution of the underlying generators in the absence of cochlear trauma. We hypothesized that intracochlear ECochG recordings show signal changes not reflected in simultaneous extracochlear ECochG recordings.

Methods: Eleven subjects with residual hearing were enrolled in this study. The CI electrode array was inserted in a stepwise manner. At each step intracochlear ECochG responses (through the most apical electrode of the CI using back-telemetry) and extraECochG responses (needle electrode placed close to the round window) were simultaneously recorded. The acoustic stimulus was a 500 Hz tone burst at 110 to 120 dB SPL with alternating starting phases.

Results: Abrupt or slowly progressing phase changes in intracochlear recordings were observed in the difference curves of all subjects, without corresponding phase changes in extracochlear recordings. Abrupt phase shifts of approximately 180 degrees occurred in five cases. Our results show that an amplitude decrease with associated near 180-degree phase shift and harmonic distortions in the intracochlear difference curve during the first half of insertion was not accompanied by a decrease in the extracochlear difference curve's amplitude. Late amplitude decreases in intracochlear difference curves (near full insertion) did correspond to extracochlear amplitude decreases.

Conclusions: Phase shifts and amplitude decreases in intracochlear ECochG recordings can be observed without associated changes in extracochlear recordings, likely caused by movement of the recording electrode with respect to the different signal generators. Our findings suggest that comparison of intracochlear ECochG recordings with simultaneous extracochlear recordings could enhance the interpretation of ECochG changes and potentially allow for differentiation between traumatic and atraumatic changes in intracochlear recordings.

Predicting hearing preservation in cochlear implant patients using dual-frequency electrocochleography

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Goals: The implications of signal changes in intracochlear electrocochleographic (ECochG) recordings during cochlear implantation remain controversial. The aim of this study was to investigate whether dual-frequency ECochG recordings enhance the interpretation of ECochG amplitude drops. We hypothesized that simultaneous ECochG amplitude drops in both frequencies reflect cochlear trauma, relevant for postoperative hearing loss.

Material and Methods: During insertion of the CI array, ECochG responses to two tone bursts with a frequency of 500 and 750 Hz were recorded continuously with the CI's most apical electrode. ECochG amplitude drops were classified as either simultaneous drops in both frequencies or non-simultaneous drops. A significant drop was defined as a reduction of ≥ 30% from a previous peak. Postoperative hearing preservation was assessed four weeks after surgery.

Results: ECochG responses could be recorded in nine out of twelve patients. In 56% of the participants, simultaneous drops were observed, while 44% showed non-simultaneous drops. CI recipients with simultaneous drops in ECochG recordings had a similar postoperative hearing loss compared to CI recipients with non-simultaneous drops ($t = 0.838$, $p = 0.43$).

Conclusion: These preliminary results suggest that the isolated analysis of ECochG amplitude drops in dual-frequency ECochG does not enhance the interpretation of signal changes. The inclusion of phase changes and different signal components in the analysis may improve hearing outcome prediction.

Improving the interpretation of intra- and post-operative electrocochleography recording

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Background & Objectives: It is now possible to record electrocochleography (ECochG) via a cochlear implant, making such recordings more likely to be made. Intra-operative ECochG, is recorded to give real-time feedback to the surgeon, with the intention of reducing cochlear trauma. However, interpreting these data needs some thought, in relation to cochlear trauma, the assisting of programming and prediction of outcome.

Method: For 12 ears implanted with HiRes90k cochlear implants, cochlear microphonic (CM) recordings were made intra-operatively and around 12 months after surgery. Intra-op recording was made from electrode contact 1 at 115 dB SPL. Post-op recordings were made from all 16 electrode contacts in turn, used stimulation levels decreasing from 115 dB SPL in 10 dB steps until noise floor and were repeated for 250, 500, 1,000 and 2,000 Hz acoustic stimulation frequencies. An unaided audiogram was also measured on the same day. The CM recordings were analysed to determine if, 1) data were monotonically organized with respect to the stimulus level, 2) there were CM amplitude peaks of 6 dB or more recorded for contacts other than contact 1, 3) the CM growth rate for 10 dB increases in stimulus level, 4) how well CM amplitude varied across the cochlea with stimulus frequency and 5) how these data help interpret the intra-operative recordings and predict outcome.

Results: For 27 attempted recordings 18 (67%) were successful. At the 2,000 Hz stimulus, 3 recordings failed to provide data above noise floor. A further 4 ears did not provide valid data for two or more stimulus levels, meaning that 8 of the 12 ears (67%) provided data sets that could be analysed. The maximum CM level across participants was 40 µV (range 1.2 to 352 µV). In 14 of the 18 recordings (78%), there was a peak amplitude of 6 dB or higher on a contact other than contact 1. The mean growth for a 10 dB increase in stimulus level was 2.6 (range 1.4 to 4.9), or 8.3 dB. Analysis with respect to the unaided free-field hearing levels and outcomes is ongoing.

Conclusions: Two-thirds of ears returned extended data sets 12 months after surgery, confirming that residual hearing can be preserved for some time. Analysing the CM amplitude from only the most apical contact is not enough to characterize the cochlea. Multi-level recording allows individualized growth rates to predict hearing levels. Insights into cochlear health can be used with other measures when programming CI recipients.

Multi-frequency ECochG monitoring through the AIM system

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Background: Today's Cochlear Implant (CI) candidates often have significant residual hearing. With the electro-cochleography (ECochG) measurements it is possible to monitor the insertion process of the electrode array in real time and adapt the insertion speed, depth and angle with the aim to minimize the insertion trauma. Currently it is investigated how to differentiate drops of the response caused by damage/trauma (as shown in Koka et al. 2018) and ones caused by changes of recording position.

Methods: A research version of the AIM (Active Insertion Monitoring) system has been developed to monitor cochlear microphonics (CM) during the insertion for several frequencies simultaneously. This has been used by Saoji et al. (2023) during 10 cochlear implantations in subjects with residual hearing. Post-insertion electrode scans were also analysed for phase changes. Buechner et al. (2022) used a single frequency (usually 500Hz) for monitoring the insertion in 47 patients and analysed the recordings for amplitude and phase changes.

Results: Results from Saoji et al. do show frequency-specific responses for all subjects. In some cases post-insertion electrode scans do show different peak locations for different frequencies. There was no correlation between CM amplitude drop and post-operative drop in pure tone thresholds. Buechner et al. also looked at residual hearing preservation and the course of intra-operative CM monitoring. There was no correlation when looking only at the amplitude, but there was a significant finding when additionally also considering the phase.

Conclusion: The current findings suggest that measuring multiple frequencies or considering also the response phase might add valuable information for differentiating amplitude drops caused by damaging cochlear structures or by passing the generator site.

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AIM provides real-time feedback to the cochlear implant surgeon for atraumatic electrode insertion

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Background & Objectives: AIM is a medical grade Windows tablet designed for intra- and post-operative use and offers a variety of objective measures via Advanced Bionics cochlear implants (CI). One of those measures is Electrocochleography (ECochG), an evoked potential which allows live monitoring of the cochlea during the insertion of the electrode array via acoustic stimulation. Published literature suggests ECochG is a useful marker for cochlear integrity. AIM essentially provides real-time information to the surgeon on cochlear health and alerts them of impending trauma so that a corrective action can be deployed. This is of particular interest to paediatric recipients with residual hearing, as structure preservation has been evidenced to lead to better postoperative outcomes, offers the possibility to stimulate electro-acoustically, and safeguards against future revision surgeries and treatment options.

Methods: Across several clinical studies, ECochG was recorded using various stimulation frequencies, although usually 500 Hz, during insertion of the electrode array. Amplitude drops (both absolute and percentual) and phase changes of the cochlear microphonics signal were analysed and correlated with changes in hearing thresholds following surgery. Additionally, changes in the ECochG trace were compared against electrode array scalar positions identified using post-operative CT scans.

Results: Larger ECochG amplitude drops during electrode insertion were associated with significantly poorer hearing preservation. For 85% of cases hearing preservation was within 30 dB HL of their pre-operative audiogram, and 50% within 15 dB HL. Interaction between amplitude and phase information needed to be considered to differentiate between trauma and insertions beyond the cochlear microphonic's generator site. Finally, the presence of the ECochG signal during insertion and preserved hearing post-operatively were associated with better post-operative outcomes.

Conclusion: The data collected to monitor for feasibility of detecting impending trauma and alerting the surgeon on time are encouraging. Using Advanced Bionics' AIM system to monitor the ECochG signal during surgery provides the surgeon with real-time objective metrics to aid the electrode insertion process and maximise the CI candidate's chances of a more optimal and atraumatic electrode array insertion, and hence post-operative outcome.

COGNITIVE MEASURES

Cortical detection of binaural cues in children with cochlear implants

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Objective: To assess cortical access to binaural cues in children using bilateral cochlear implants

Background and rationale: Multi-channel electroencephalography has shown evidence of cortical processing of interaural level differences (ILDs) and interaural timing differences (ITDs) in children with normal hearing. Findings that activity evoked by ILDs or ITDs lateralize to the contralateral auditory cortex were consistent with animal data. By contrast, this evidence of binaural processing in the brain was absent in a cohort of children using bilateral cochlear implants (BCI). Nonetheless, children with bilateral cochlear implants demonstrate behavioral sensitivity to changes in ILDs. We thus suggest that children with BCI are capitalizing on unilateral changes that are presented with ILD changes. If so, the cortex should retain the ability to detect ILD changes in this unique way but this could be compromised by access to level cues in each of the two CI processors. This study tested the hypotheses that the sensitivity of cortical ILD detection of ILDs: 1) relates to behavioral ILD sensitivity and 2) can be reduced by asymmetric programming between the two CI processors.

Methods: Twenty-two children with bilateral cochlear implants (mean(SD) age at CI-1: 5.1(4.5) years and CI-2: 5.7(4.6) years) and 7 typically developing peers (mean(SD) age: 14.2(2.7) years) were recruited. Cortical responses were evoked by stimuli presented bilaterally using the child's CI processor settings through the NIC4 research system. A 1 kHz pure tone with 40 Hz amplitude modulation was presented for 2s; bilateral stimuli at ITD=0 and ILD=0 were presented for 1 s and the ILD was switched (6 ILD conditions: +/-4, +/-10, +/-20 dB) for another 1s. Surface response amplitude areas to onset, ILD change, and offset were calculated. Behavioral sensitivity to the same stimuli was measured in a lateralization procedure as reported previously.

Results: Cortical responses to changing ILDs were well-defined in both groups and amplitudes increased with increasing ILD regardless of the ear to which the cue was weighted. Cortical responses to onset and offset of bilateral CI input were also present but did not consistently change in amplitude with ILD change condition, thus providing control data. The slope of amplitude with ILD change in the change response provided a measure of cortical ILD detection sensitivity. There was no effect of weighted ear but this measure of cortical ILD detection sensitivity was positively correlated with behavioral ILD sensitivity and negatively correlated with asymmetric dynamic range between the 2 CI processors.

Conclusions: Cortical processing of binaural cues is impaired in children using bilateral CIs, suggesting poor integration of bilateral CI input. On the other hand, the brain is adept at detecting changes in sound including changes in ILDs which translates to behavioral sensitivity to ILDs. This sensitivity can be diminished by asymmetric CI programming.

Behavioral and cortical effects of cochlear implantation in children with early and late onset single sided deafness

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The objective of the present study was to investigate the association between the cortical effects of cochlear implantation and speech perception outcomes in children with early versus late onset single-sided deafness (SSD). Cochlear implants (CI) have been provided to help mitigate developmental challenges but binaural hearing remains a challenge in this population. Recent work has shown that the implant's protective effect against aural preference might be more effective in those with early-onset SSD as compared with older children who experience late- onset SSD despite chronic consistent CI use. However, it is unclear whether the persistence of cortical asymmetry reflects hearing abilities including perception of speech. We hypothesize that increased cortical asymmetry (as observed in children with late-onset SSD) predicts more asymmetric speech perception and a smaller bilateral benefit compared to those with early- onset SSD.

To test this hypothesis, 48 children who received a CI following limited durations of SSD [mean (SD) = 2.2 (1.5) years] were included in this study. Among these, 34 children had early onset deafness and 14 had acquired SSD post-lingually. Cortical responses were measured using multi-channel electroencephalography during the initial period of CI use (0-1 month, n = 17, 11 of which early onset) and after chronic CI use (≥3 months, n = 21, 15 of which early onset). Responses were evoked by acoustic clicks (100μs) delivered at 250Hz in trains of 36ms via an insert earphone in the normal hearing ear and by electric biphasic pulses (57μs pulse-width) delivered at 250 pulses/s from an apical electrode (#20) in the CI ear. Localization of cortical sources of activity underlying peak amplitudes was performed using the time-restricted artifact and coherent source suppression (TRACS) beamformer. Cortical lateralization and aural preference were calculated from peak dipole moments in the temporal (auditory) cortices. Speech perception was measured using age-appropriate word recognition tests (n = 40) in 3 ear conditions (normal hearing ear alone, CI ear alone and bilateral hearing) and 2 noise conditions (quiet or with co-located speech weighted noise at SNR=+10 dBHL). Additionally, spatial release of masking (n = 25) was measured with speech awareness or recognition thresholds with noise at 3 positions (co-located with speech in front or moved to 90 degrees to the left or right) to assess benefits of spatial separation. Comparisons between cortical and speech perception data are ongoing using linear mixed model regressions.

By exploring the link between cortical asymmetry and asymmetric speech perception, this study will shed further light on the aural preference syndrome in children with SSD as well as on potential effects of CI to reduce developmental challenges of SSD.

No retinotopic organization of central field of view in auditory cortex after early deafness, a 7T fMRI study

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Objective: The Acoustic change complex (ACC) is an auditory cortex potential evoked in response to change within an ongoing sound. The ACC has shown valuable correlations to speech perception in cochlear implant (CI) users and is therefore promising as an objective measure of auditory performance. Since processing of auditory changes is indispensable for speech perception, the ACC might be more predictive of speech perception than auditory potentials evoked in response to an onset stimulus. The aim of this study is to compare the ACC to onset potentials of the auditory cortex and brainstem, as objective measures of auditory performance in CI.

Methods: Thirteen bilaterally deaf and six single-sided deaf CI user were included in this study, all with unilateral CI experience for at least one year. ACCs were evoked in response to frequency increases within pure tones. ACCs were compared to cortical auditory evoked potentials (CAEP) in response to onsets of pure tones, and to auditory brainstem responses (ABR) in response to biphasic pulses.

Results: Both ACC amplitudes (r=0.51-0.53, p=0.019-0.026) and latencies (r =0.51-0.68, 0.003-0.035) had strong correlations to speech perception in quiet and in noise. Only onset CAEP amplitudes (r =0.51- 0.66, p = 0.002-0.024) correlated to speech perception in quiet and in noise. ABR amplitudes and latencies were not consistently correlated to speech perception.

Conclusion: The ACC has a stronger relation to speech perception compared to onset CAEP and ABR. This can be contributed to the fact that the ACC reflects cortical processing of frequency changes, compared to meaningless processing of onset stimuli by the onset CAEP. The consistent correlations found between speech perception tests and ACC latencies and amplitudes reveals the promising value of this test as an objective measurement in CI users.

MOSAICS SESSION

Individualized phoneme training for adult CI users

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Background & Objectives: Current literature on phoneme training for adult cochlear implant (CI) users often focuses on adapting training difficulty rather than customizing training materials to address individual needs. This study introduces a novel approach aimed at improving phoneme confusion errors among adult CI users through individualized phoneme training via a mobile app. By targeting specific phoneme confusion errors based on diagnostic testing, our objective is to enhance overall phoneme perception and ultimately facilitate improved word perception.

Methods: We recruited twenty-five post-lingually deaf, experienced adult CI users to participate in a four-week phoneme training program using a mobile app. Participants were instructed to train for 20 minutes daily, in five-minute intervals, five days a week. The training materials were tailored to each participant's unique phoneme confusion errors, as determined by the outcomes of a phoneme test in a quiet environment.

Results: To date, twelve out of the twenty-five participants successfully completed the required four weeks of training. Preliminary analysis reveals diverse outcomes regarding improved phonemes, both within individual participants and across the group. The final results from these twelve participants will be presented at the conference, shedding light on the effectiveness of the individualized bottom-up phoneme training approach.

Conclusion: Our innovative approach to individualized bottom-up phoneme training shows promise in enhancing foundational speech perception at the phoneme level among adult CI users. By addressing specific phoneme confusion errors through personalized training materials, we anticipate that these improvements will extend to enhanced word perception. This research has the potential to make significant contributions to the field of auditory rehabilitation for CI users, paving the way for improved speech understanding and communication outcomes.

Exploring reaction times as objective measures of the auditory periphery

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Cochlear implants offer hearing restoration to individuals with severe to profound sensorineural hearing loss by directly stimulating the auditory nerve with electric pulses. Despite their success, multichannel implants still have compromised spectral resolution due to temporo-spatial interactions between pulses. Typical assessments of temporal interactions have used subjective and/or discrimination paradigms which can be challenging and inefficient in capturing responses.

To address this, we present an objective and continuous measurement using reaction times. We collected responses from 14 cochlear implant recipients in response to pairs of biphasic pulses with varying intervals (59 – 350 μs). Two pulse configurations were tested, differing in the order of anodic and cathodic phases. Testing spanned sub- to supra-threshold stimulus amplitudes. Our findings reveal that decreasing the pulse

interval resulted in faster responses, indicating increased pulse integration at intervals below 150 µs. Moreover, pulses with consecutive anodic phases elicited faster responses, implying stronger interaction compared to their cathodic counterparts.

Our study demonstrates that reaction times can effectively capture peripheral temporal interactions in electric hearing. Additionally, we propose a model based on leaky integration of stimuli by the auditory nerve, along with a decision-time model, accurately describing the observed reaction times. Ongoing research investigates the predictive capabilities of individual time integration constants in relation to speech outcomes and spectro-temporal sensitivity for cochlear implant recipients with diverse performance levels. The study aims to determine how cochlear conditions contribute to outcome variability among cochlear implant users.

AuDiET: Auditory Diagnostics and Error-based Treatment - Towards performance-based fitting

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Unexpected poor outcomes are a well-known problem in the field of Cochlear Implants (CIs). It is hard to predict how well a potential CI user will recognize speech after their implantation, and it is also difficult to address poor performance after the implantation. Each user's poor outcomes need to be addressed post-implantation, by either fitting the sound processor or by auditory training. However, current clinical practices for post-implantation follow-up are not configured to address each user's individual issues: instead, fitting usually focuses on delivering uniform levels of stimulation across the full range of frequencies covered by a CI and training is left to the discretion of audiologists and speech-language therapists.

The AuDiET (Auditory Diagnostics and Error-based Treatment) clinical trial has been designed to investigate whether a different paradigm would be possible: specifically, one in which the treatment is evidence-based, performance-driven and patient-centered. The main assumption driving the study is that intervention, whether focused on fitting or training, should be targeted at those areas of phonemics where each subject is experiencing the greatest difficulties. This means, for instance, that subjects who have issues especially at recognizing or discriminating high-frequency phonemes will receive a fitting intervention aimed at making high-frequency sounds clearer and more distinct; subsequently, they will train on recognizing and discriminating those same phonemes.

A sample of 25 postlingually deafened, experienced CI users whose native language is Dutch makes up the study population for AuDiET. A battery of tests assessing both phoneme and word recognition has been developed in order to assess each recipient's error pattern. After undergoing these tests, each subject is given personalized fitting and training interventions based on their individual error patterns. The results of tests after each intervention are then compared to the baseline and previous interventions. Early results already show that fitting interventions can have a noticeable effect, both positive and negative, on the recognition of vowels and consonants. More complete and detailed early data will be shown and explained at the conference.

Assessing top-down auditory processing using objective measures based on electroencephalographic (EEG) recordings and behaviour

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Introduction: Cochlear implants (CI) provide substantial hearing benefits to severely hearing-impaired adults. Nevertheless, speech perception remains challenging and performance outcomes differ across CI users. In challenging listening situations, top-down neurocognitive factors have been shown to be relevant for understanding speech in typical hearing listeners. This might also hold for CI listeners and potentially vary depending on bottom-up auditory processing skills. Therefore, we investigated both bottom-up and top-down auditory processing using objective measures based on electroencephalographic (EEG) recordings and behaviour.

Methods: Measuring EEG during an auditory-digit working-memory task in which memory load and intelligibility were manipulated revealed an effect in the alpha frequency band (Obleser et. al., 2012, J Neurosci; Petersen et. al., 2015, F. Psych.). We aimed to replicate these results in 26 CI listeners showing a range of speech recognition outcomes. Participants memorised a sequence of digits (2, 4 or 6 digits) presented with three levels of SNR (0, +5, +10 dB) and used a button press to report whether a later presented probe stimulus was included in the preceding sequence. Since alpha-band activity has been associated with working-memory load and attentional processes, it was expected that better-performing CI listeners would display higher alpha in centroparietal electrodes as memory load increased and SNR decreased. In poorer-performing CI listeners, this effect was expected to disappear in the most challenging conditions.

Results: Behavioural results across all participants, showed that both memory load and SNR had a main effect on accuracy ($p=0.003$, $p=0.003$). Furthermore, an interaction effect was found between memory load and SNR on promptness (1/RT) for correct trials ($p=0.005$), with an increase in memory load leading to a significant decrease in promptness. A decrease in SNR enhanced this effect for memory loads of 2 and 4 digits. We observed a general increase in alpha power throughout the digit sequence and onset of retention phase. The alpha power had a complex relation to CI performance, where the poor performers indeed showed less alpha power, and the relation of CI proficiency and alpha power was not linear.

Conclusive remarks: The results show that response time in CI listeners is affected by both memory load and SNR, as well as alpha power. However, the relation of alpha power to CI performance was more complex. Further analysis will provide insight into interindividual variability related to CI outcomes, which might help gain understanding of performance variability in CI listeners.

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PREDICTORS OF PERFORMANCE

Predicting speech perception with the acoustic change complex and onset auditory Evoked potentials in patients with sensorineural hearing loss and cochlear implants

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A. *Background&Objectives:* Over the past two decades the acoustic change complex (ACC), a cortical potential evoked by a change in an ongoing sound, has been widely studied in experimental settings. Several studies revealed interesting correlations between ACC responses and psychophysical outcomes, but this has not resulted in clinical implementation yet. In three cohort studies, we have investigated the clinical value of recording ACCs to frequency changes in normal-hearing, hearing-impaired subjects and cochlear implant (CI) users and determined to which extent ACC measures can predict speech perception in noise performance.

Methods: ACCs were recorded in 13 adult subjects with sensorineural hearing loss (SNHL), 24 age-matched normal-hearing (NH) subjects and 19 CI users. The stimuli consisted of a 3 s base tone, an upward frequency sweep of 3 ms towards a 300 ms target tone varying from 0.1 to 12% above the base. Base frequencies were 0.5, 1, 2 and 4 kHz. ACC tresholds and peak amplitudes and latencies were compared to psychophysically assessed frequency discrimination thresholds (FDTs) and speech reception thresholds (SRTs).

Results: ACC thresholds had a moderate to strong correlation to psychophysical FDTs ($r=0.67$, $p<0.001$). ACC thresholds increased with hearing loss and higher ACC thresholds were associated with poorer speech perception in noise ($r=0.55$, $p=0.005$). Correlations between SRT and ACC latencies and amplitudes were even stronger ($r=0.65$-0.67, $p<0.001$).
Using multiple regression analysis we found that when averaging the ACC latencies over 1, 2 and 4 kHz and average hearing loss, SRT could be explained for 87% by ACC latency (35%) and HL (52%). Considering only the ACC measures over those three frequencies, SRT could be explained for 74% by latency (60%) and amplitude (14%). In the CI users, a similar association was found between SRT and ACC N1 latency ($r=0.77$, $p<0.001$) and N1-P2 amplitude ($r=0.71$, $p<0.001$).

Conclusion: The ACC to fast and large frequency changes (a few semi-tones) can be used to predict speech perception in noise. The predictive value using the latency is better than the ACC threshold, which is also more time consuming. In 2023 a large scale external validation study will start to confirm the clinical value of this ACC prediction model (ACCEPT study).

B. *Objective:* The Acoustic change complex (ACC) is an auditory cortex potential evoked in response to change within an ongoing sound. The ACC has shown valuable correlations to speech perception in cochlear implant (CI) users and is therefore promising as an objective measure of auditory performance. Since processing of auditory changes is indispensable for speech perception, the ACC might be more predictive of speech perception than auditory potentials evoked in response to an onset stimulus. The aim of this study is to compare the ACC to onset potentials of the auditory cortex and brainstem, as objective measures of auditory performance in CI.

Methods: Thirteen bilaterally deaf and six single-sided deaf CI user were included in this study, all with unilateral CI experience for at least one year. ACCs were evoked in response to frequency increases within pure tones. ACCs were compared to cortical auditory evoked potentials (CAEP) in response to onsets of pure tones, and to auditory brainstem responses (ABR) in response to biphasic pulses.

Results: Both ACC amplitudes (r=0.51-0.53, p=0.019-0.026) and latencies (r =0.51-0.68, 0.003-0.035) had strong correlations to speech perception in quiet and in noise. Only onset CAEP amplitudes (r =0.51- 0.66, p = 0.002-0.024) correlated to speech perception in quiet and in noise. ABR amplitudes and latencies were not consistently correlated to speech perception.

Conclusion: The ACC has a stronger relation to speech perception compared to onset CAEP and ABR. This can be contributed to the fact that the ACC reflects cortical processing of frequency changes, compared to meaningless processing of onset stimuli by the onset CAEP. The consistent correlations found between speech perception tests and ACC latencies and amplitudes reveals the promising value of this test as an objective measurement in CI users.

Cognitive and peripheral factors influence speech recognition in noise by CI users

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Background & Objectives: Cochlear implant (CI) outcomes are known to be variable and difficult to predict. According to results from vocoder-based CI simulations with normal listeners, 10 to 20 channels allow >90% sentence recognition in quiet with only tens of minutes of exposure. Some CI recipients can also achieve this between one day and one month after activation (James et al., Ear Hear 2019) and go on to have high scores even at low signal-to-noise ratios. We hypothesized that CI subjects with no 'bottom-up' or 'top-down' limiting factors would achieve >90% sentence understanding at one month after activation. We also wanted to understand the progression of sentence understanding in noise over time, and how this is influenced by limiting factors.

Methods: Longitudinal sentence recognition scores were collected for 32 adult Nucleus CI recipients. Top-down tests were the Montreal Cognitive Assessment (MoCA), the Stroop test for interference, and two subtests from the French ECLA-16+ reading battery to evaluate phonological awareness. Bottom-up tests were amplitude growth functions (AGF) for anodic- and cathodic-leading biphasic pulses, spread of excitation (SOE) and recovery functions. Sound processor usage was also collected.

Results: CI subjects ranged in age from 26-87 years (median 70). Subjects generally used their processor more than 10 hours per day. A third (13/32) of subjects scored >90% sentence recognition at one month. Apical SOE curves were more often wide (i.e., >5 electrodes) than for basal SOE curves. AGFs varied widely (1-20 µV/CU) and most subjects showed stimulus polarity effects (slope ratio).

Thirteen subjects had one or more abnormal top-down test results. In both apical and basal locations, one subject had abnormal ECAP recovery and three wide, asymmetric SOEs. Subjects with no limiting factors were significantly more likely to achieve >90% score in quiet at one month (Fisher test, odds ratio 8.6, $p<0.05$). Those with identified limiting top-down or bottom-up factors generally scored lower in noise over several months to a year compared with those without.

Conclusions: These results suggest that cognitive factors strongly influence speech recognition performance in quiet and in noise with CIs. There were few (4) examples in our sample of identified bottom-up limiting factors related to neural health or the electrode-neural interface. The focus of the presentation will the characteristics and improvement of the ECAP-based peripheral tests.

Objective measures of neural health and their relationship to cochlear implant users' speech intelligibility

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Cochlear implant (CI) users' speech perception is very individual. Various factors underly this inter-individual variability such as etiology, cognitive/linguistic performance and the number and status of the functionality of spiral ganglion neurons (SGNs), i.e., the neural health. Neural health affects the success of information transfer to higher stages of the auditory system and there is increasing evidence of its importance in understanding the variation in subjects' performance. Initial attempts to estimate neural health in humans had a post-mortem nature which prevented their clinical applicability. Recently, indices based on electrophysiological measures have played an important role in estimation of neural health. Some of these measures exploit the characteristics of the stimulating pulse, e.g., a change in the interphase gap or the leading polarity of a biphasic pulse, a clinically relevant pulse shape. The goal of this study was to investigate one such measure of neural health, the effect of polarity on its diagnostic potential, its relationship to age as a proxy for neural degeneration, and its potential to partially explain the variation in CI users' speech perception.

The measure investigated the change in the linear slope of an eCAP AGF as a response to an increase in the interphase gap (IPG) of a biphasic pulse, i.e., IPG effect on slope (IPGEslope) which was measured on all 12 contacts of the MED-EL electrode array. A forward masking paradigm, together with further offline processing, was used to reduce the artifact. The forward masking approach was implemented in two different conditions: 1) stimulation with an anodic-leading pulse (FMA) and 2) with cathodic-leading pulse (FMC), which enabled the investigation of the effect of polarity. The speech information in different frequency bands (transmitted via different electrodes) is not of equal importance for effective speech intelligibility. Consequently, the neural degeneration along the cochlea is of varying detriment. To take this relationship into account, a weighting function was applied to the IPGEslope of each electrode. Lastly, the across-site mean of the IPGEslope was reported as the index determining the neural health for each ear.

The results showed a significant correlation between the IPGEslope and age ($R2 = 0.54$, p-value < 0.001) only for FMC condition. A mild but significant correlation was observed for both polarities between the IPGEslope and speech recognition in quiet (Freiburg monosyllable test, FMT) and in noise (Oldenburg sentence test, OLSA). In both cases, the correlation was improved after applying the speech-related weighting function (For FMC; OLSA: $R2 = 0.33$, p-value < 0.01, FMT: $R2 = 0.25$, p-value < 0.05).

The outcome of this study highlighted the potential of IPGEslope as a clinically relevant objective measure for estimation of neural health. The measure has potential for improving the prediction of CI outcomes and for fitting of CIs, and consequently for the speech intelligibility of CI users.

Using objective measurements to guide electrode placement and fitting in paediatric ABI recipients: the Antwerp University Hospital (UZA) experience

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Background: Auditory brainstem implantation (ABI) is indicated for children with bilateral profound sensorineural hearing loss who are ineligible for traditional cochlear implantation. While adult ABI recipients can usually be fitted via subjective feedback, paediatric ABI recipients are unable to provide (sufficient) subjective responses to guide optimal fitting. There is, therefore, a greater need for additional information retrieved from objective measures to support the fitting procedure in the paediatric population.

Aim: To give an overview of the intra- and postoperative objective measurements used used to optimally place the electrode and to fit 9 pediatric ABI recipients performed at the Antwerp University Hospital (UZA).

Methods: To guide optimal electrode placement and fitting, evoked auditory brainstem responses (eABR) were recorded intraoperatively and at activation. For recordings, a Medelec Synergy or Biologic- Navigator Pro were used. For stimulations, the clinical software MAESTRO was used. In the two most recent cases, electrically evoked compound action potentials (ECAP) were measured at activation. The ABI electrode placed on the cochlear nucleus was used for stimulation and recordings.

Results: In 7/9 (78%) of the cases the placement electrode was used prior to electrode insertion to estimate optimal electrode placement. This was dependent on the operating neurosurgeon. In 6/7 (86%) of the cases the ABI electrode was repositioned after first eABR results. An eABR was observed in 82% of the measured electrodes intraoperatively and 74% of the measured electrodes at activation. In the long-term fitting maps, 73% of the electrodes were activated. In the two cases in which we aimed to perform LEP measurements, we were able to record LEP in one case, in which it corresponded to some degree with present eABRs at activation and activated electrodes in the final fitting map.

Conclusion: The use of a placement electrode as well as intraoperative eABR measurements could guide electrode placement during ABI surgery. The intraoperative eABRs differed from those measured at the day of activation. Given these observed electrophysionlogical changes over time, it is recommended to rely on the eABR performed at the day of activation when fitting of the ABI. The electrodes with an eABR present at activation were all activated in the long-term fitting maps.

THURSDAY 28 SEPTEMBER

EVOKED POTENTIALS

Electrically evoked auditory potentials: from auditory periphery to cortical responses

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Background: The objective measures at the different stages of cochlear implantation are of the primary importance especially in pediatric population. The neural response telemetry (NRT) which is informative for monitoring of cochlear implant and auditory nerve fibres functioning at the surgery stage and during the rehabilitation process does not provide enough information about functional integrity of the auditory pathway at higher levels.

Material and methods: 120 patients with cochlear implants were included in the analysis (73 with Cochlear and 47 – with AB). The age of patients varied from 1.6 to 37 years. NRT/NRI was performed in all patients, the eABR registration – in 37 and registration of cortical responses - in 43 patients.

Patients underwent the eCAP testing, free field audiometry, age- and development-appropriate speech recognition tests. eABR were recorded via Eclipse EP25 (Interacoustics) with eABR External Trigger protocol during the sleep.. The electrically evoked cortical response registration to speech stimuli was performed with HEARLab device and the software module for Aided Cortical Assessment.

Results: In recovery function investigation the correlation between the auditory nerve refractoriness parameters and patients individual stimulation frequency preferences was obtained. Spread of excitation was significantly narrower in case of perimodiolar electrode placement which could suggest better differentiation with this location. The significant decrease of stimulation level was also obtained. The combination of eCAP and eABR measures resulted in an overall estimate of electrode-to-nerve interface quality and the ability of each contact to deliver focused stimulation. Relevance of these measures as a tool for objective prediction of CI programming parameters was then evaluated by comparison to speech intelligibility scores (in adults) and speech therapist's reports (in children). Special attention was drawn to the dynamics of amplitude/latency parameters of cortical responses after the switch-on of the speech processor and 3 and 6 months after first fitting. The significant increase of the amplitude and decrease in the latency of P1 peak was obtained.

Conclusion: Introduction of different classes of electrically evoked responses from auditory periphery to auditory cortex will provide an objective control of the functional integrity of the auditory pathway and the rehabilitation effectiveness in children after cochlear implantation.

Objective measurement of cortical potentials with the cochlear implant electrode

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Background: As auditory nerve responses only reflect the peripheral part of the auditory pathway, measuring more central responses (Cortical auditory evoked potentials, CAEP) could add more value and insides as they should better reflect the conscious perception. They also provide information about brain plasticity, which could help track auditory brain development.

Methods: The back telemetry of AB implants has been modified to allow for real-time streaming of measurement signals. Different experiments have been conducted to test the feasibility of measuring cortical potentials in response to acoustic stimulation, while experiments with contra-lateral and ipsi-lateral electric stimulation are ongoing. Different recording configurations have been tested and were optimised. For control, full EEG-cap recordings were also measured.

In addition to evoked potentials, Aldag et al. presented acoustically a mixture of two speakers and tried to decode the auditory attention based on the EEG.

Results: In Attias et al. (2022) Acoustically evoked responses could be measured in most study subjects within a moderate time of around 3 minutes (100 averages), and the morphology matched to that recorded using single-channel scalp EEG. The accuracy of the auditory attention decoding in Aldag et al. (2022) was much poorer compared to the full EEG cap recordings, but was still above chance level in 3 out of 5 subjects. Ipsi-lateral electric stimulation followed by immediate recording presents levels of stimulation related artifact, and need to be further optimized.

Conclusion: The feasibility of recording CAEP over the cochlear implant electrode without additional equipment has been shown, but there is still a long way to go to improve the recording quality, especially the artefact suppression for ongoing electrical stimulation. After improving the technical challenges, this could be used for tracking brain development as effectiveness of CI, automated fitting (setting levels, closed-loop fitting, just-noticeable differences in electrode, level, timing) or auditory attention decoding.

References:
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Short- and long-latency components of the eCAP reveal different refractory properties

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Background and objectives: The refractory recovery function (RRF) of the electrically evoked compound action potential (eCAP) is commonly used to assess the refractory properties of the electrically stimulated auditory nerve (AN). Recent studies have identified two distinct components within the eCAP: a short-latency component (S-eCAP) and a long-latency component (L-eCAP), believed to originate from different populations of auditory nerve fibers. This study aimed to compare the refractory characteristics of S-eCAP, L-eCAP, and the raw eCAP (R-eCAP). Additionally, differences in refractory properties between children and adults and their relationship with cochlear implant (CI) outcomes were examined.

Methods: Retrospective analysis of 121 Hi-Focus Mid-Scala or 1J cochlear implant recipients. The R-eCAP was separated into S-eCAP and L-eCAP using deconvolution. Three refractory parameters were assessed: absolute refractory period (T), saturation level (A), and recovery speed (τ). Comparisons were made between R-eCAP, S-eCAP, and L-eCAP, and differences between children and adults were explored. Associations with speech perception in adult CI recipients were analyzed using linear mixed modeling.

Results: Significant differences in refractory characteristics were found among the eCAP components. RT was longer than ST and LT, and ST was significantly longer than LT, indicating variations in refractory recovery time. RA was larger than SA and LA, while SA was significantly larger than LA, suggesting differences in response saturation. Sτ was longer compared to Rτ and Lτ, implying variations in the rate of refractory

recovery. Children had larger SA and LA and a shorter RT compared to adults. A shorter Sτ was associated with better speech perception in adult CI recipients.

Conclusion: The study reveals distinct refractory properties of the eCAP components, differing from the R-eCAP. The refractory characteristics of S-eCAP and L-eCAP provide additional clinical insights, including differences between children and adults and their impact on speech performance following cochlear implantation. Future assessments of auditory refractory properties should consider both eCAP components to enhance the clinical evaluation of auditory function.

Automatic detection of eCAP thresholds - Precision and accuracy of different methods

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Objective: This study aimed to compare different automatic electrically evoked compound action potential (eCAP) threshold detection methods in combination with various averaging and artifact reduction techniques. The precision and accuracy of these methods were evaluated.

Methods: Five automatic eCAP threshold detection methods (sigmoid amplitude growth function [AGF], linear AGF, signal-to-noise ratio [SNR], cross-covariance between adjacent levels, and cross-covariance with maximum level) were examined. Two averaging methods (standard averaging [SA] and FineGrain averaging [FG]) and two artifact reduction methods (alternating polarity [AP] and forward masking [FM]) were considered. A total of 20 combinations were tested. Success rates, threshold confidence intervals (TCIs), and correlations between eCAP thresholds and T-levels were analyzed.

Results: The FG and FM combination yielded the highest success rates among the different threshold detection methods, with SNR demonstrating the overall highest success rates. Two-way ANOVA results revealed significant effects of both the artifact reduction/averaging method and the threshold detection method on TCIs. The FG and FM combination showed the best results in terms of TCIs, while the sigmoid AGF threshold detection method had the lowest mean TCI. Similar results were observed for the correlation between eCAP thresholds and T-levels, indicating significant effects of the artifact reduction/averaging method and the threshold detection method on the correlation coefficients. The FG and FM combination consistently performed the best, and the sigmoid AGF threshold detection method resulted in the highest correlation coefficients.

Conclusion: The combination of FG and FM for averaging and artifact reduction proved to be the most effective approach in this study. Among the automatic threshold detection methods, the sigmoid AGF method exhibited the highest precision and accuracy in determining eCAP thresholds. Future research should focus on expanding the dataset, refining the automatic eCAP threshold detection methods, and exploring the clinical implications of the determined eCAP thresholds in cochlear implant fitting.

The first experience in electrically evoked compound action potentials measurements with SmartNav System

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Background & Objectives: The new Nucleus SmartNav is a wireless system (an iPAD app and a surgical processor) from “Cochlear”, Australia. It provides the diagnostic measurements to confirm the device

integrity, auditory system response and support post-operating fittings. For surgeons it gives the additional information that the electrode array is properly placed (angular insertion depth measurement, speed of insertion and placement check functions).

The goal of our study was to prove that a new system can replace the standard clinical computer set-up for cochlear implant intraoperative Electrically evoked Compound Action Potentials (ECAP) measurements and equivalent in measuring electrodes impedances and ECAP.

Methods: A prospective between subject comparison study was conducted with 44 test subjects (24 males and 20 females aged from 8 m-38 y.o.) whom cochlear implantation was performed at Erebouni Medical Center, Yerevan, Armenia in 2021-2023. 28 patients were implanted with Nucleus CI532, 13 patients with CI632 and with CI612, CI622 and CI522 – one patient, respectively. The ECAP threshold measurements (via AutoNRT algorithm) were performed intra-operatively using both the Nucleus SmartNav system and the standard clinical system (CS EP) and compared.

Results: In all cases ECAP thresholds were measured successfully intraoperatively with both tested systems. The Wilcoxon Signed Ranking Test was used to confirm that ECAP threshold measurements obtained with SmartNav were found to be equivalent to the Custom Sound system within a clinically acceptable range. ECAP thresholds were measured and found to correlate closely between the two measurement systems (r is tending towards +/- 1).

During the electrode impendences measurements comparison obtained by both system the visible difference in electrodes impedances measured at the basal electrodes (E1-8) was found but the difference was statistically not significant ($p>0.05$).

Conclusions: The new Nucleus SmartNav system provides equivalent electrode impedances and ECAP threshold registration results, including success of making measurements, compared to the standard clinical set-up. Taking into the account provided additional information (angular insertion depth measurement, speed of insertion and placement check functions) provided by SmartNav system it will give more opportunities for increases the efficiency of the CI implantation and clinical process.

Electrically-evoked ABR in children with auditory neuropathy spectrum disorder

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Background and Objectives: The aim of the study was to estimate applicability of electrically evoked ABR for the estimation of neural integrity in children with auditory neuropathy spectrum disorder (ANSD) and compare eABR data with other objective measures and hearing performance.

Material and Methods: 7 children with ANSD diagnosed with ABR, CM and OAE registration with profound hearing loss according to the age-appropriate behavioral tests and implanted with Nucleus CI512 (Cochlear) were enrolled in the study. In all cases ANSD had congenital/early onset, without risk factors for hearing loss and comorbid issues. In some patients OAE was present along with the non-implanted ear in implanted ear. Patients underwent the eCAP testing, free field audiometry, age- and development-appropriate speech recognition tests. eABR were recorded via Eclipse EP25 (Interacoustics) with eABR External Trigger protocol during the sleep. Electrical bipolar stimulation was provided through Custom Sound EP software. At least 3 electrodes were tested in each patient. eABR thresholds were tested with stimulus pulse width (PW) of 25 and 37 usec for the majority of patients, and at PW up to 100 usec - for patient with poor CI outcomes.

Results: eCAPs in 6 patients were within the normal range. In patient with poor CI outcomes eCAPs were not stable from session to session, recordable at 14 electrodes as maximum. eABR wave eV with the latency

about 4 msec was registered in the majority of patients at all tested electrodes. eABR thresholds corresponded to patient's last MAP C-levels. Testing of patient with poor CI outcome with different stimulus parameters (PW from 25 to 100 usec, decreasing stimulation rate from 26 to11 stimuli per sec, changing mode of stimulation) did not reveal the wave eV.

Conclusions: eABR measurements in 7 children with ANSD demonstrated restoration of neuronal conduction and synchronous firing in auditory pathway up to brainstem after cochlear implantation in 6 patients. eABR results match hearing performance and eCAP measurements in these patients. They most probably have auditory synaptopathy while patient with poor CI outcomes had "true" auditory neuropathy. eABR along with other objective tests might be useful tool for hearing rehabilitation outcomes prediction in patients with ANSD after cochlear implantation. At the same time the experience in eABR application for clinical practice should be expanded.

Spread of excitation as a measure of sensitivity to interaural mismatches

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Background and Objectives: Interaural mismatches decrease sensitivity to binaural cues such as interaural time differences (ITD) for bilateral cochlear implant (CI) users. Poor sensitivity to ITDs can lead to a degradation of localization and lateralization abilities, as well as increased difficulty understanding speech in noisy environments. However, the effects of interaural mismatch may be mitigated by broad current spread.

Current spread can be estimated using spread of excitation (SOE) functions. These measure the extent to which electrodes stimulate overlapping neural populations. This is done by measuring electrically evoked compound action potentials (ECAPs) in response to stimulating different electrodes. We hypothesized that a broader SOE would correspond to a decreased effect of interaural mismatches. The goal of this study is to determine if the SOE functions can predict the effect of interaural mismatches on CI users' ITD thresholds.

Methods: SOE functions were measured for multiple probe electrodes across the array using a forward-masking subtraction method implemented with Cochlear's Custom Sound EP software. Participants also completed an ITD detection task that measured the ITD thresholds for different interaural electrode pairs.

Results: SOE functions and ITD threshold functions differed across participants. Additionally, the preliminary results suggest that SOE may be related to the effects of interaural mismatches on ITD sensitivity.

Conclusions: The preliminary results suggest that SOE functions may be a possible way of predicting which CI users will be affected by interaural mismatches. Future studies will investigate the relationship between SOE and other binaural cues, such as interaural level differences.

BONE CONDUCTION MEASURES

Intracochlear pressure and skull vibration for stimulation at the skull bone and intracranial fluid

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Background: The frequency dependent contributions of the various bone conduction (BC) pathways are poorly understood, especially the fluid pathway. The aim of this work is to measure and investigate sound pressure propagation from the cerebrospinal fluid (CSF) to the cochlear fluid in order to estimate stimulation location dependent performance of BC stimulators.

Methods: Stimulation was provided sequentially to the bone (BC) or directly to the intracranial contents (hydrodynamic conduction, or HC) in four cadaver heads. Each ear was tested individually, for a total of 8 samples. Intracranial pressure was generated and monitored via commercial hydrophones, while the intracochlear sound pressure levels (ISPL) were monitored via custom-made intracochlear acoustic receivers (ICAR). In parallel, measurements of the 3D motion of the cochlear promontory and stapes were made via 3D Laser Doppler Vibrometer (3D LDV).

Results: Regardless of the significant differences in absolute stapes and promontory motion, the ratios between the otic capsule velocity, the stapes volume velocity (relative to the cochlea), and the intracochlear pressure were very similar under BC and HC stimulus. Under HC, the cochlear fluid appears be activated by an osseous pathway, rather than a direct non-osseous pathway from the CSF. However, the osseous pathway itself is activated by the CSF pressure.

Conclusions: The findings indicate that the skull bone plays a role in the interaction between the CSF and cochlea for BC and HC stimulation at high frequencies. At low frequencies, inertia is the dominant for activation of the cochlea.

Experimental quantification of the relationship between temporal bone 3D motion and intracochlear pressure

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Background: The temporal bone, including the otic capsule, undergoes a complex 3D motion pattern that depends on the frequency of the BC stimulation. The correlation between the 3D motion of the surrounding bone and the intracochlear pressure difference across the cochlear partition is not yet known and is to be investigated.

Methods: Preliminary measurements were conducted in a single fresh frozen cadaver head, where the both medial and lateral bone surfaces of the temporal bone have been exposed. The skull bone was mechanically excited in the frequency range of 0.1- 20 kHz via the actuator of a bone conduction hearing aid (BCHA). Stimulation was applied to the ipsilateral mastoid and the typical bone-anchored hearing aid (BAHA) position sequentially, each via a conventional transcutaneous (5-N steel headband) and percutaneous coupling. Three-dimensional motions were monitored across the lateral and medial (intracranial) sides of the skull at the ipsilateral temporal bone, via a 3D laser Doppler vibrometer (LDV) moved by a customized robotic positioner. A total of 70-100 measurement points (~5-7 mm pitch) were distributed across each side of the bony surface of the temporal bone. The motion of the ipsilateral promontory and stapes were also recorded.

Additionally, intracochlear pressure in the scala tympani and scala vestibuli was measured via a custom-made intracochlear acoustic receiver (ICAR).

Results: The temporal bone surface, surrounding the otic capsule, remains rigid-like up to 5 kHz, in contrast to the parietal plate, which deforms above 1 kHz, with an onset of deformation near the stimulation already at 0.5 kHz. The magnitude of the complex ratio of the differential intracochlear pressure and the promontory motion increases with frequency, up until 10 kHz, beyond which it has a trend to decrease with frequency.

Conclusions: The area around the otic capsule appears rigid up to significantly higher frequencies than the rest of the skull surface, resulting in primarily inertial loading on the cochlear fluid.