MSc Research assignments; Cochlear Implants at Leiden University Medical Center

Cochlear implants (CIs) are electrical prostheses for patients with severe hearing impairment. A cochlear implant is an electrode inserted in the inner ear (cochlea), where it electrically excites the auditory nerve. An image of the cochlea and auditory nerve is shown in figure 1.

Currently approximately half a million people worldwide have received a CI. Cochlear implantation is a major topic within the research department of the LUMC ENT (ear-nose-throat) clinic. The Leiden cochlear implant programme is widely recognized as leading in the field of computational modelling, imaging and translational evaluation of new and evolving stimulation patterns. The research is closely intertwined in the clinic clinical practice making it easy to verify theoretical work with patient data and providing the unique opportunity for students to get an introduction in the clinical practice. The research group is a multidisciplinary team including engineers, doctors, physicists and biomedical scientists. There is a close cooperation with Delft University of Technology.

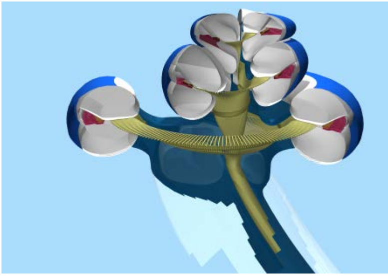

Figure 1: 3D model of the cochlea and auditory nerve

Improving stimulus and speech strategies are major topics in current CI research. To gain insight in the exact process of electrical stimulation of the inner ear a computer model has been made. This consists of a geometrical part to describe the conduction of electrical current through the cochlea and an active nerve fiber model to study neural excitation [1], [2]. Electrical behavior of the nerve membrane can be modeled with an electrical circuit network, partly shown in figure 2. Such a model can predict nerve responses to different stimulus shapes, and the effect of electrode design and position.

Assignment 1: Improving the cable model of the auditory nerve

Description: The active nerve fiber model is a deterministic model that calculates nerve fiber potentials based on the flow of Potassium (K) and Sodium (Na) ions, and a leak current. The model can be improved by including slow potassium channels and stochastic behaviour of the ion channels. The effect of such modifications can be investigated by comparing the outcomes with previous model outcomes and animal experimental data as known from literature.

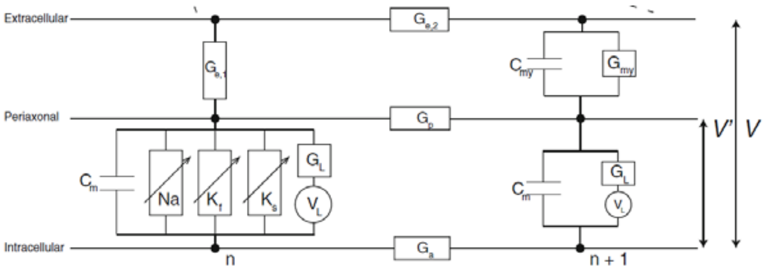

Figure 2: equivalent electrical circuit network of node in a nerve fiber

Practical information: duration at least 45 ECTS. Location is LUMC.

Profile and background: MSc student in the field of applied physics, electrical engineering or informatics who has affinity with medical research, or biomedical engineering or technical medicine who has affinity with modelling and programming. Experience with programming is a prerequisite, preferably including object oriented programming.

Assignment 2: Modified activation function to fast predict nerve responses to pulse trains

Description:

In the literature some computationally efficient methods to predict nerve responses to external electrical stimulation have been proposed. Well-known efficient models use the activation function, which is the second spatial derivative of the external potential field ($\Delta^2 V_e$) [3]. Some modifications to this activation function have been proposed, in order to incorporate the behaviour of the complete membrane [4], [5]. Warman uses the total equivalent driving function, which includes the activation function, as well as a passive redistribution of internal currents. Peterson et al followed a somewhat similar method, where they modify the activation function with a weighted sum of the spatial derivatives along the axon; as shown in equation 1.

$$MDF_2 = \sum_j W_{|n-j|}(PW, d) \cdot \Delta^2 V_{e_j}$$

Equation 1: modified driving function

These kind of methods provide a computationally efficient way to predict nerve thresholds. They are currently only applicable to homogeneous fibers, although auditory nerves have inhomogeneous morphologies. Up to this date no generalized model of the modified activation function that incorporates auditory nerve morphology has been published. The goal of this project is to develop a model that uses a generalized, modified, activation function. Alongside this project another fast predictive model is developed at the LUMC. The model should be tested in comparison to this other fast model, to the active nerve fiber model, and data known from animal experiments.

Practical information: duration at least 45 ECTS. Location is LUMC.

Profile and background: MSc student in the field of applied mathematics or applied physics who has affinity with medical research, or biomedical engineering who has affinity with modelling and programming. The program should preferably be written in Matlab.

General information; CI research at LUMC

https://www.lumc.nl/research/programmes/80304013111221/80115053217221/

https://www.lumc.nl/org/kno/research/scientificprojects/CochlearImplantation/112820/

References

[1] R. K. Kalkman, J. J. Briaire, D. M. T. Dekker, and J. H. M. Frijns, “Place pitch versus electrode location in a realistic computational model of the implanted human cochlea.,” *Hear. Res.*, vol. 315, pp. 10–24, Jun. 2014.

[2] D. M. T. Dekker, J. J. Briaire, and J. H. M. Frijns, “The impact of internodal segmentation in biophysical nerve fiber models.,” *J. Comput. Neurosci.*, no. 1995, May 2014.

[3] F. Rattay, “Analysis of Models for External Stimulation of Axons,” *IEEE Trans. Biomed. Eng.*, vol. 33, no. 10, pp. 974–977, 1986.

[4] E. N. Warman, W. M. Grill, and D. Durand, “Modeling the effects of electric fields on nerve fibers: determination of excitation thresholds.,” *IEEE Trans. Biomed. Eng.*, vol. 39, no. 12, pp. 1244–54, Dec. 1992.

[5] E. J. Peterson, O. Izad, and D. J. Tyler, “Predicting myelinated axon activation using spatial characteristics of the extracellular field.,” *J. Neural Eng.*, vol. 8, no. 4, p. 046030, Aug. 2011.