Hear Restore RTD 2013

Electrical Impedance Measurement in the Mastoid Bone

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Introduction

Hearing impairment is among the most common reasons for disability (Shield 2012; WHO 2013). Therefore the ARTORG Center and the Institute for Surgical Technology and Biomechanics (ISTB) of the University of Bern developed a robotic system to enable minimal-invasive microsurgical implantation of the cochlear implant. The goal of this technology driven approach is to reduce the invasiveness of the procedure, to decrease the OR time and to increase the reproducibility of the outcome. Nevertheless it is critical to ensure a high level of safety to the procedure. Drilling through the facial recess to the cochlea sets the facial nerve at risk. Neuro-monitoring has been proposed as a solution to provide functional guidance during surgery (Ansó, 2013; Ansó et al., 2012). It is a widely used technique to locate and assess nerve function. For motor nerves, an electrical stimulus is injected into the tissue surrounding the nerve. FN stimulation is then detected by electromyography (EMG), with needle contacts at the eyelid orbital rim or at the oral commissure. The action potential elicited muscle responses are identified. Most preferably the stimulation signal should be injected directly by the drill. But (Ansó, 2013) showed that FN monitoring, when using the whole drill as an electrode, lacks of sensitivity and specificity. He concludes that developing a specific electrode/drill might improve the whole procedure. So it would be helpful to have an electrical model of the mastoid, to get a basis of understanding the way electrical signals propagate in the temporal bone. A finite element model (FEM) of its electrical properties would help to develop new stimulating probes or drills. The model could in addition also be used to provide improved estimate of the distance between the drill bit and the nerve during surgery.

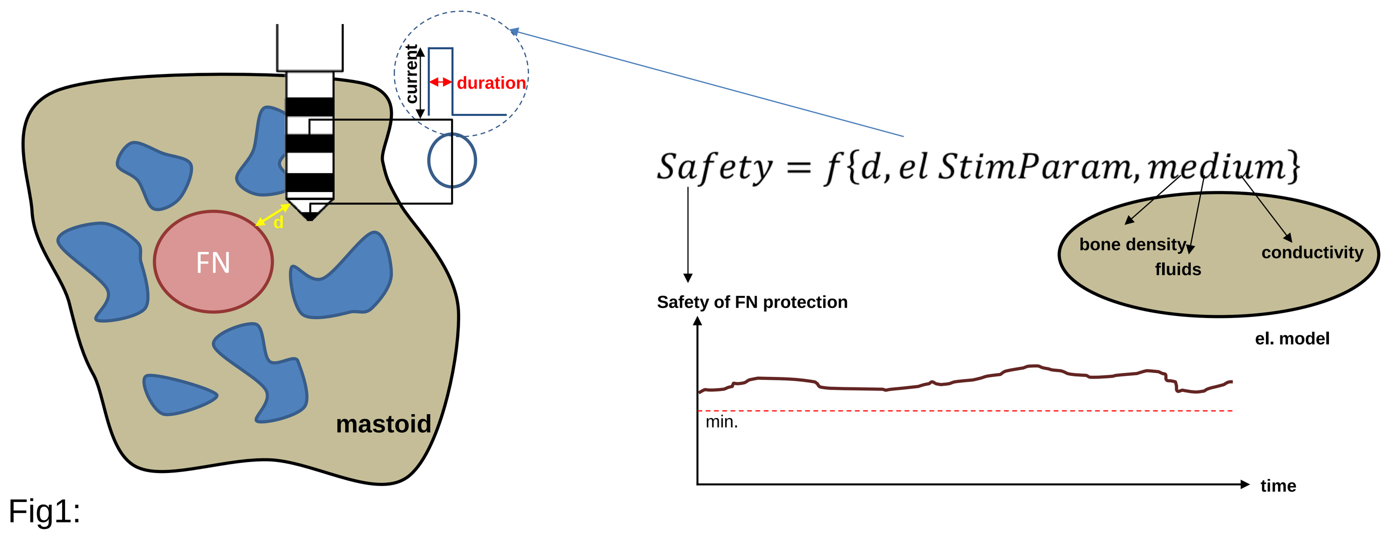


Fig1:

Task Definition

- FN stimulation directly through the bone.
- ***Safety*** is function of (Fig1):
  - distance ***d*** drill to facial nerve (FN).
  - ***electrical stimulation parameters.***
  - bone as the conducting ***medium.***
- Understand electrochemical processes, when injecting currents into bone.
- No 3D model of electrical properties of bone available.

Objectives

- Determine the properties to build a 3D FEM of bone, by the use of specialized tools.
- Verify the theoretical electrochemical model with the experimental data (ex- and in-vivo).
- Use the combination of FEM and high resolution CT data to specify the stimulation parameters for patient specific FN monitoring.

Modeling Strategy

Fig2: 3D mesh generated from 40µm µCT of sheep mastoid.

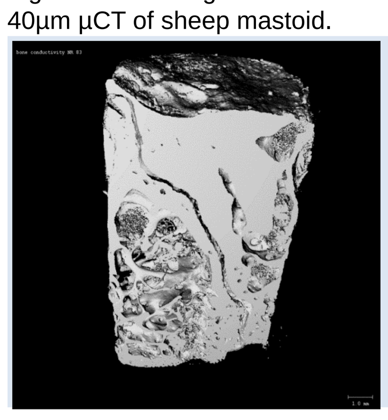
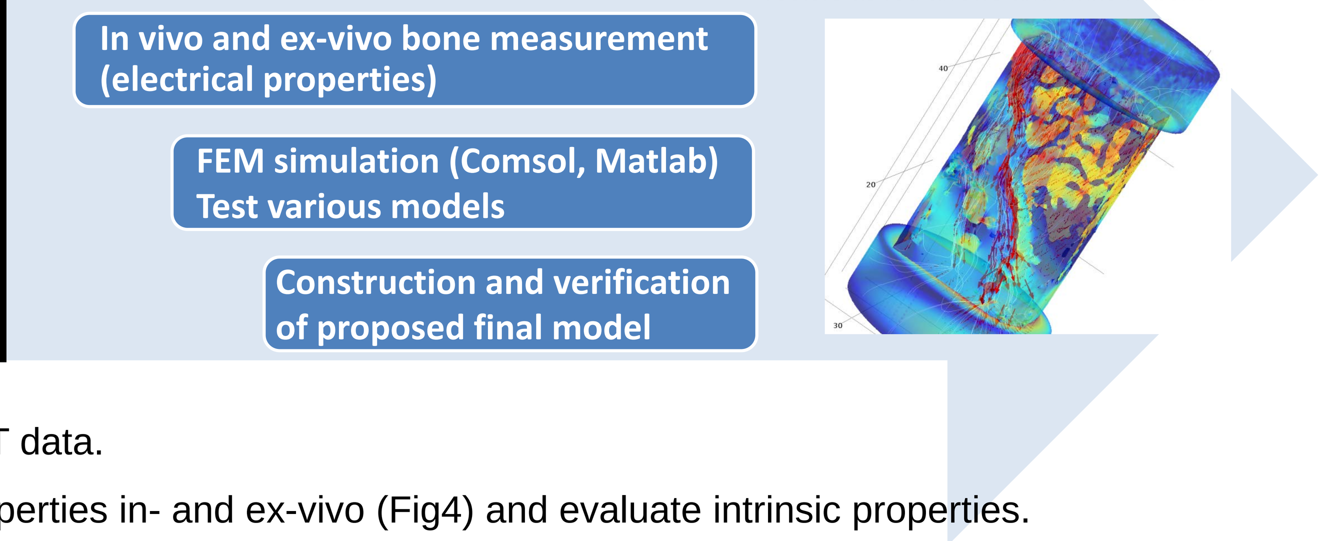


Fig3: 3D mesh generated from same µCT images as Fig2. Bone segmented with simple threshold to separate from soft tissue. Resulting mesh "virtually" contacted with two steel electrodes to inject current. current density as colors. current density vectors as red arrows and white ribbons.



- Build mesh on µCT data.
- Measure bone properties in- and ex-vivo (Fig4) and evaluate intrinsic properties.
- Simplify model with the help of a specifically developed homogenization technique.
- Finally evaluation of result with cone beam CT of clinical quality.

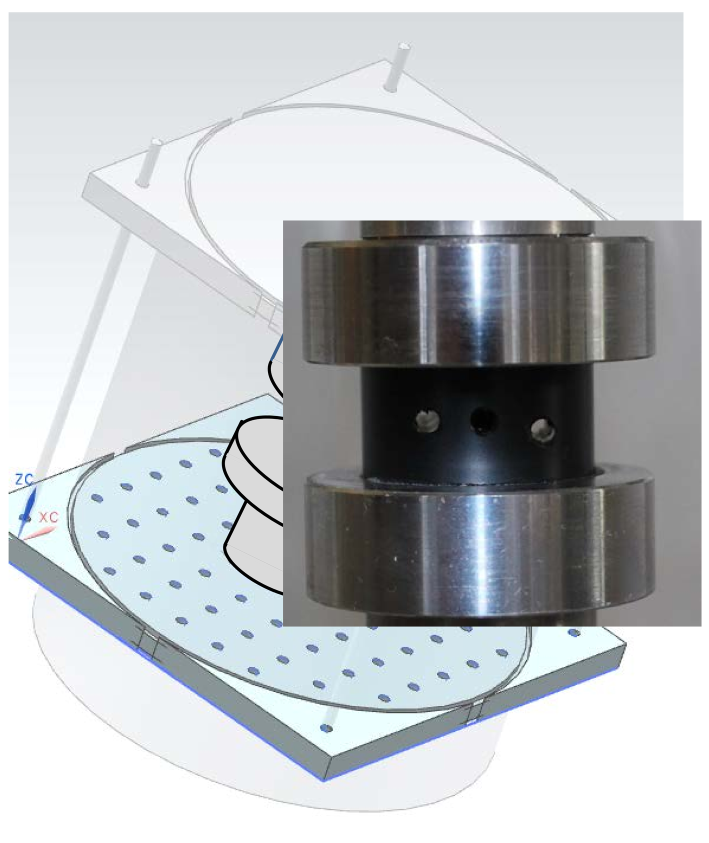


Fig4: CAD of cell and stainless steel electrodes plus reference sample(black).

Ex-vivo Measurement Setup

- Closed measuring cell made of PMMA to keep the humidity in the cell high, so the bone does not dry out.
- Stainless Steel electrodes with 30mm diameter
- Perforated ground plate to place the cell over NaCl solution.
- Measuring device: Fluke PM6306 RCL-meter
  - Uses resistor and capacitor in parallel as model (Fig 5).

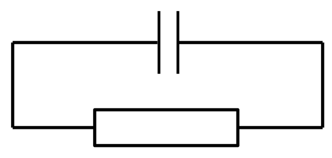


Fig 5

- Measuring parameters
  - Frequency change log scale 100Hz to 100kHz.
  - Excitation voltage change 50mV, 100mV, 200mV, 400mV, 1V, 2V.

Results

Bone dries out fast in standard atmosphere (Sierpowska et al. 2003). The experiment intended to show the effect on cortical bovine bone when measured in standard atmosphere. The frozen bone samples were thawed and measured with the setup in Fig4. In fact drying out could be observed optically. The surface color changed quite fast from glossy light brown to dull oatmeal. The three picture couples below show impedance, phase and nyquist plot at time zero when the bone was just thawed (left picture of couple) and the same property after one hour (right picture of couple).

Impedance

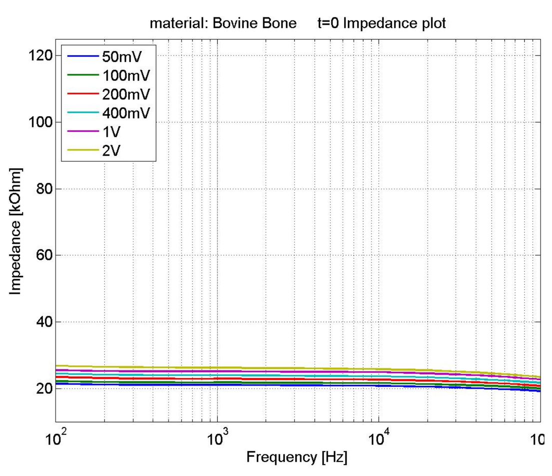


Fig6: Impedance, measured shortly after bone is put into cell.

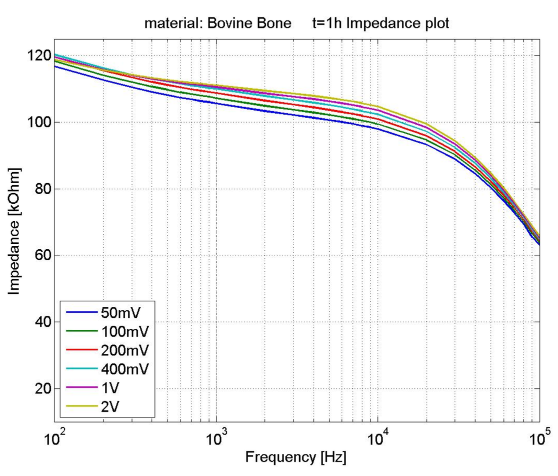


Fig7: Impedance after one hour distinct frequency dependence is visible.

- Impedance increases from 20kΩ(Fig6) to 130kΩ (Fig7). in one hour
- Frequency dependence of Impedance changes too (Fig6 & Fig7).
- Only a few hundred Ohm impedance drop over frequency at t=0 (Fig6).
- Prominent impedance drop from 120kΩ to 70kΩ after one hour (Fig7).

Phase

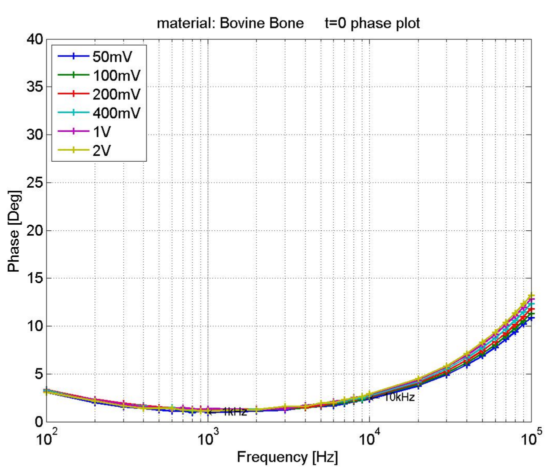


Fig8: Phase measured shortly after bone is put into cell.

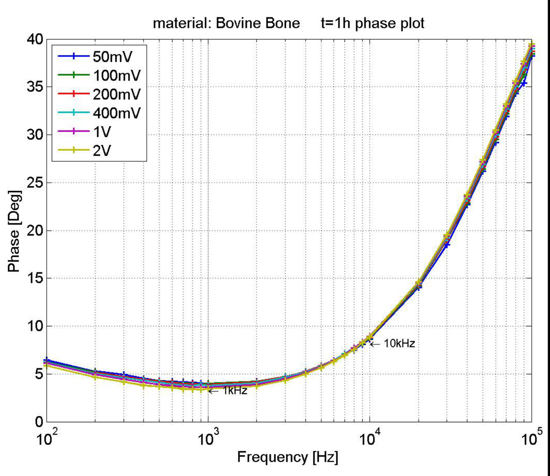


Fig9: Phase graph after one hour, bending still similar.

- Phase increases from 12° (Fig8) to 40 °(Fig9) at 100kHz in one hour.
- Similar bending of graph.
- Variance caused by different stimulation amplitude is small.

Nyquist Plot

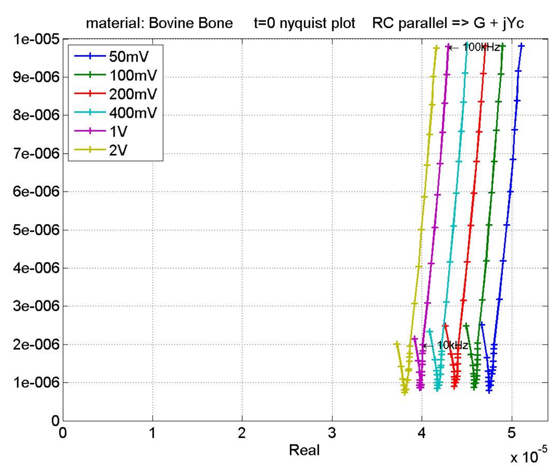


Fig10: Nyquist plot of data shortly after bone is put into cell.

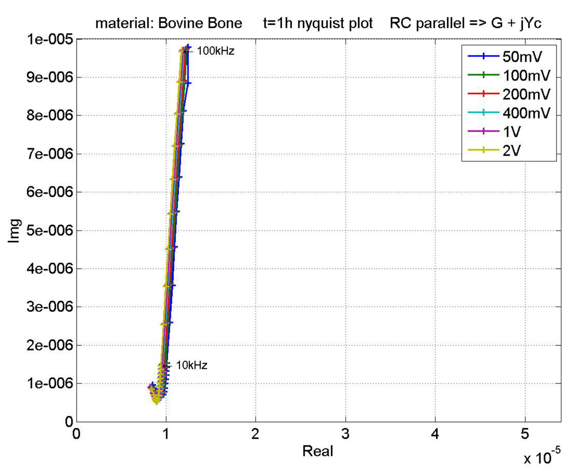


Fig11: Nyquist plot after one hour.

- nyquist plots related to stimulation amplitude have the same shape but with different real parts for the different amplitudes.
- Nyquist plot confirms trend of impedance and phase.
- Variance caused by different stimulation amplitudes mostly affects resistance (real) and disappears with time.
- Slope in all nyquist graphs is similar.

Discussion

1. The variation in impedance and its phase is probably due to decreasing humidity of the bone.
2. The bone liquid contains NaCl which makes it an electrolyte so it cannot be excluded, that the bone impedance electrochemical processes also affect.
3. The phase increase is the result of increasing resistance (real part of nyquist plot Fig10 & Fig11) .
4. The electrical bone properties depend on the bone fluid.
5. The atmosphere for further measurements has to be humid.

Bibliography

- Ansó, J. (2013). Master of Science Thesis Integrated facial nerve monitoring for functional control of robotic assisted drilling in the mastoid.
- Ansó, J., Stahl, C., Gerber, N., Williamson, T. M., Gavaghan, K., Caversaccio, M., … Bell, B. (2012). Feasibility of Using EMG for Early Detection of the Facial Nerve During Robotic Direct Cochlear Access.
- Gesellschaft, D. C. I. (n.d.). Deutsche Cochlear Implant Gesellschaft e.V.
- Shield, B. (2012). Evaluation of the social and economic costs of hearing impairment.
- Sierpowska, J., Hakulinen, M. a, Töyräs, J., Day, J. S., Weinans, H., Jurvelin, J. S., & Lappalainen, R. (2005). Prediction of mechanical properties of human trabecular bone by electrical measurements.
- Sierpowska, J., Hakulinen, M. A., Töyräs, J., Day, J. S., Weinans, H., Kiviranta, I., … Lappalainen, R. (2006). Interrelationships between electrical properties and microstructure of human trabecular bone.
- Sierpowska, J., T yr s, J., Hakulinen, M. A., Saarakkala, S., Jurvelin, J. S., Lappalainen, R., & Töyräs, J. (2003). Electrical and dielectric properties of bovine trabecular bone--relationships with mechanical properties and mineral density.
- WHO. (2013). WHO | Deafness and hearing loss. World Health Organization.