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Hear Restore RTD 2013

FNSNF

Development of a Mathematical Model of the Electrical Properties of Bone

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Scope and Purpose

Direct Cochlear Access (DCA) aims to replace mastoidectomy

- Precise robot blindly drills a tunnel to reach the cochlea
- No visual access to OP field
- Narrow drilling trajectory sets delicate vital structures at risk
- Electromyography (EMG) has been proposed to assess drill to nerve distance
- Current development lacks sensitivity and specificity
- Bone electric properties required to improve the predictions

Materials & Methods

Determination of the electrical properties of bone tissue

- Development of tools to machine accurate bone samples.
- Development of protocol to keep bone samples as fresh as possible (no freezing, short storage time)
- Measurement of the trabecular and cortical bovine bone
- Determine and minimize adverse influences on measurement system.

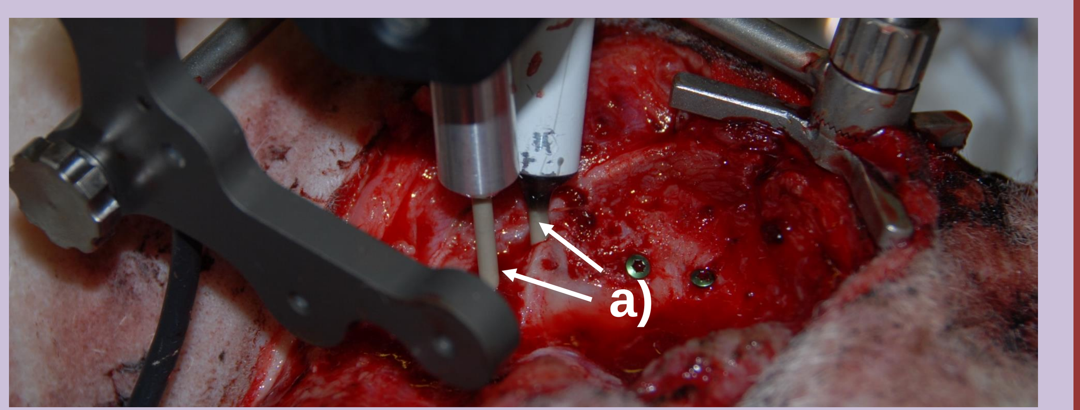
***in-vivo* study to measure electrical properties of bone tissue**

- Development of measurement setup to in-vivo measure bone impedance in a sheep model
- Apply electro impedance spectroscopy (EIS) sinusoidal waveforms with frequencies 15Hz, 110Hz and 1070Hz and current magnitudes of 125µA, 250µA and 500µA.
- Results to verify the accuracy of mathematical bone models.

⇒ Further knowledge about the electrical properties of the mastoid bone is essential.
⇒ A mathematical model of the electrical properties of bone tissue will help understanding electrical mechanisms.

Comparison of different bone impedance measurement protocols at a frequency of ~1100Hz

In-vivo impedance measurement (1070Hz)



Sheep study: inserted multi-electrode probes

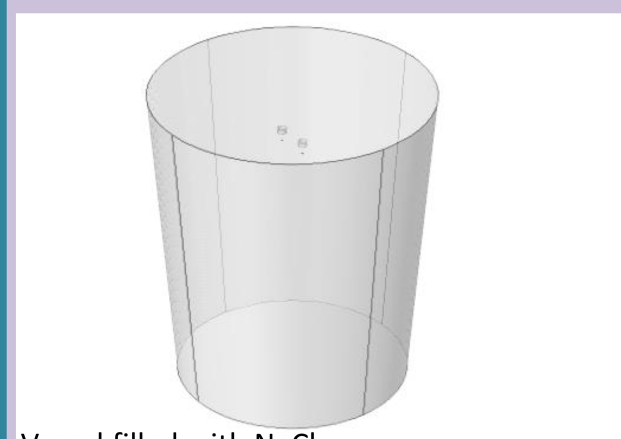
Trajectory distances from 5.69 mm to 9.98 mm.

- Measured with a) steel multi-electrode.
- Sheep Model

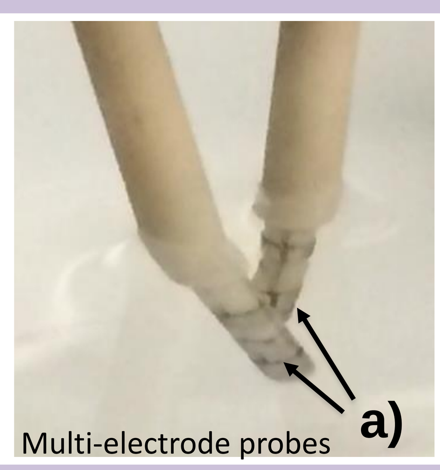
	Ring	Tip
Impedance MEAN	1.7 kΩ	11.9 kΩ
Impedance SD	600 Ω	9.26 kΩ
Phase MEAN	-45.99	-42.74
Phase SD	9.49	6.19

Impedance magnitude correlates with trajectory distance (Pearson: r = 0.766).

Measurement of NaCl with sheep setup (1070Hz)



Vessel filled with NaCl



Multi-electrode probes

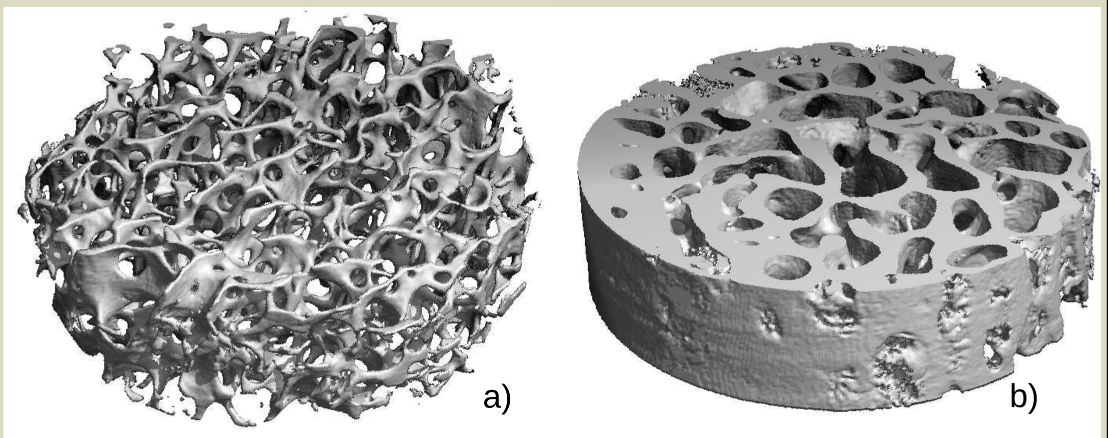
Electrode distance 6.5 mm

- Measured with a) steel multi-electrode.
- Use of sheep measurement system.

	Ring	Tip
Impedance MEAN	423 Ω	1.090 kΩ
Impedance SD	22 Ω	156 Ω
Phase MEAN	-71.42	-54.44
Phase SD	2.06	0.77

Impedance lower than in sheep study where current flow was restricted to conductive cavities within the tissue

Ex-vivo impedance measurement (1099Hz)



microCT 40 (resolution 16µm)

Bovine trabecular bone sample ∅8mm h:2mm

- Measured with gold contacts.

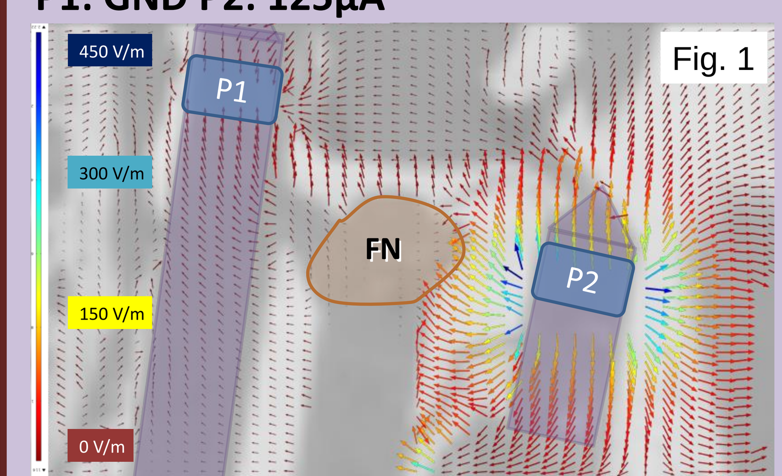
	a)	b)
BV/TV	0.099	0.453
Impedance	727Ω	3.24 kΩ
Phase	-31.2	-34.7
Resistivity	18.25 Ωm	81.32 Ωm
Resy. NRM BV/TV	18.25 Ωm	17.77 Ωm

Resistivity in literature 12.2 Ωm

Modeling bone impedance

Simulation of in-vivo situation

A: Electric Field @1000Hz [V/m] (sheep mastoid)
P1: GND P2: 125µA



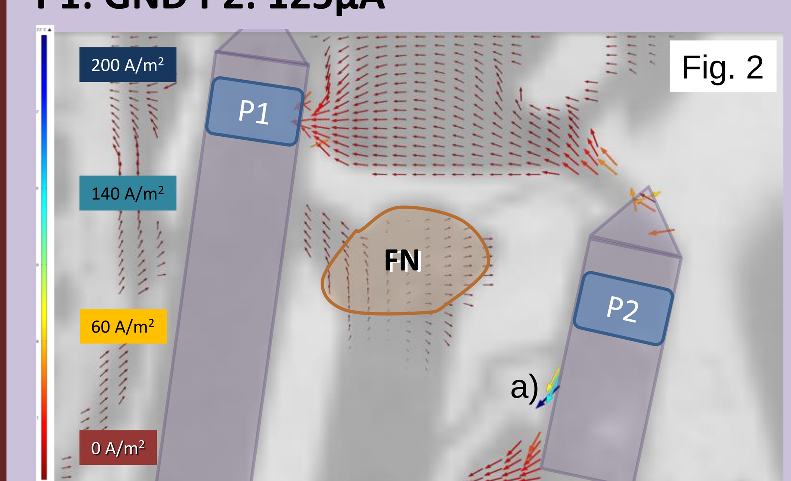
Blood @1000Hz:
Cond: 700e-3 S/m
Perm: 5260

Bone @1000Hz:
Cond: Frq. response
Perm: Frq. Response

P1: & P2: Anodes
FN: Facial Nerve

- Field in non conducting bone
- Due to high distance P2-FN, nerve should not trigger

B: Current Density @1000Hz [A/m²] (Sheep mastoid)
P1: GND P2: 125µA



Blood @1000Hz:
Cond: 700e-3 S/m
Perm: 5260

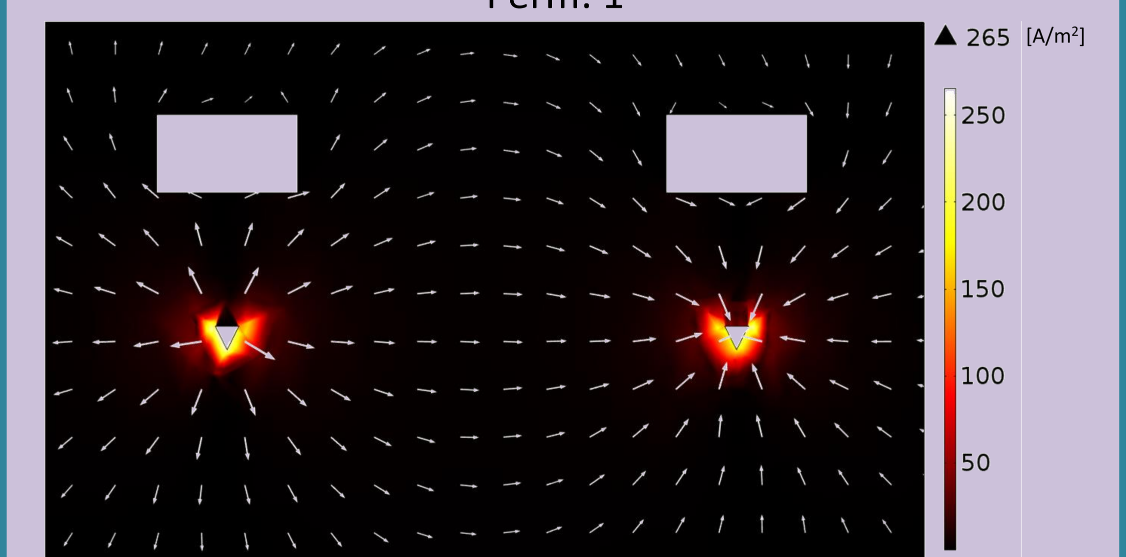
Bone @1000Hz:
Cond: Frq. response
Perm: Frq. Response

P1: & P2: Anodes
FN: Facial Nerve

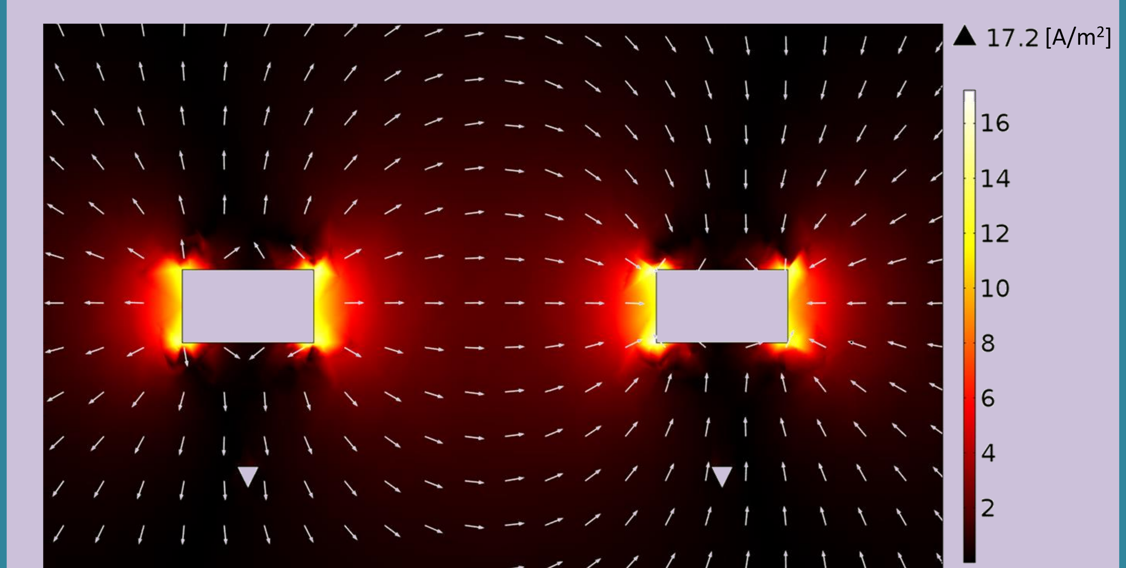
- No current flow in the FN
- Fig. 2 a): High current density caused by small cavity touching P2 behind the electrode.

Simulation of NaCl vessel

Nacl@1000Hz @125µA: Cond: 1.6 S/m
Perm: 1



Color = current densitiy, simulation of tip-tip configuration



Color = current densitiy, simulation of ring-ring configuration

- Current density 10 times higher in tip configuration.
- Tip-tip Impedance 640 Ω
- Ring-Ring Impedance 110 Ω

Main Findings:

- In-vivo impedance magnitude correlates with trajectory distance (Pearson: r = 0.766).
- Stainless steel electrodes cause phase shift in body fluid electrolyte.

- NaCl impedance measurement 423/1090 Ω
- NaCl impedance simulation 110/640Ω
- Electrochemical effects at the interface; stainless steel contact affects measurements
- Lower contact surface leads to higher impedance for both measured and simulated impedance.

- The resistivity of the ∅ 8mm bovine sample at 1kHz is in the same range as in the literature.
- Impedance seems to be linearly correlated to BoneVolume to TotalVolume ratio (BV/TV).
- Resistivity might be normalized to BV/TV.
- Tentative evaluation shows inconsistencies in impedance at lower frequencies.
- Measurement setup not yet suitable to measure impedance with voltages above 1V (complex electrochemical processes)