Evaluation of EIT images using Esophageal electrodes

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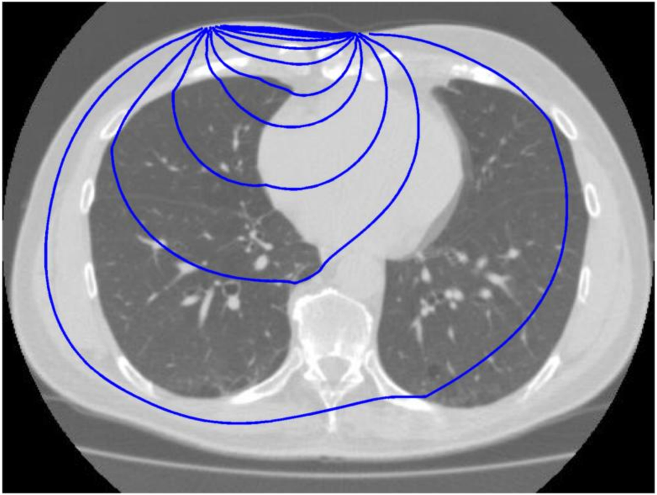
Problem: EIT internal sensitivity is low



Current streamlines (blue) for 16 electrode adjacent stimulation

Idea: internal electrodes

Internal electrodes (i.e. in boreholes) are often uses in geophysical ERT surveys

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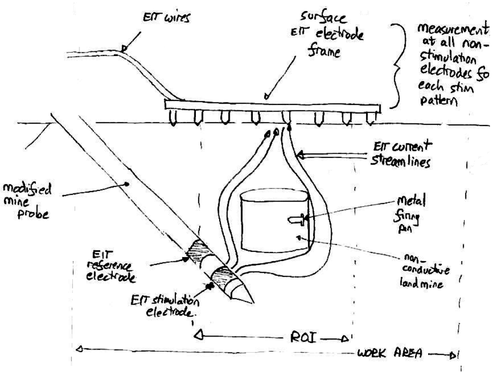
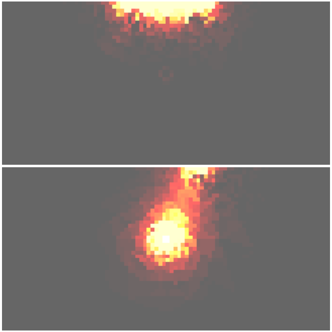
Example: landmine probe concept

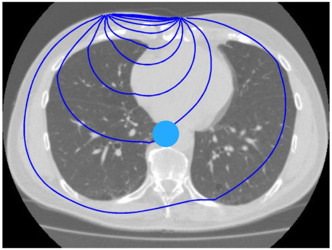


Sensitivity without (above) and with (below) probe



Esophageal electrodes

- Esophagus touches anterior wall of heart
- Using a balloon catheter, good electrical contact is possible



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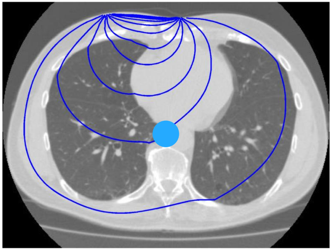


Some previous work in EIT community, largely simulation

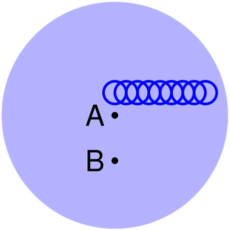
- Schuessler *et al* 1995 “Utility of an esophageal reference electrode . . . ”
- Tehrani *et al* 2012 “Modelling of an Oesophageal Electrode for Cardiac . . . ”

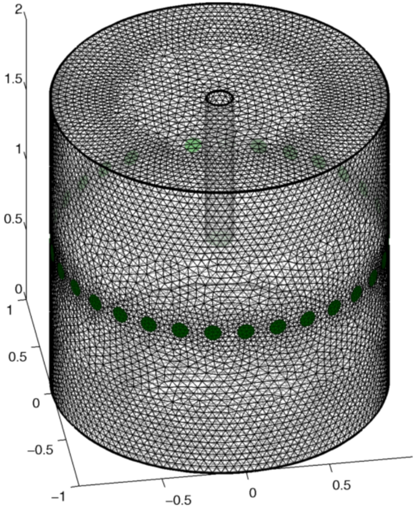
Esophageal Impedance Topography (*also EIT!*) uses single impedance electrode

- Lin *et al* 2014 “High-Resolution Esophageal Impedance Topography . . . ”

Simulation study: Models

- 32 electrode EIT system, with one central electrode
- One electrode from boundary placed in centre
- Skip-4 stimulation
- Cases: (A) centre, (B) 40%, (C) None

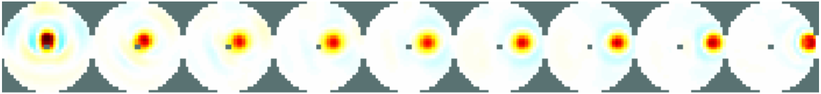




Simulation results

Internal Electrode: (A) centre, (B) 40%, (C) None

A



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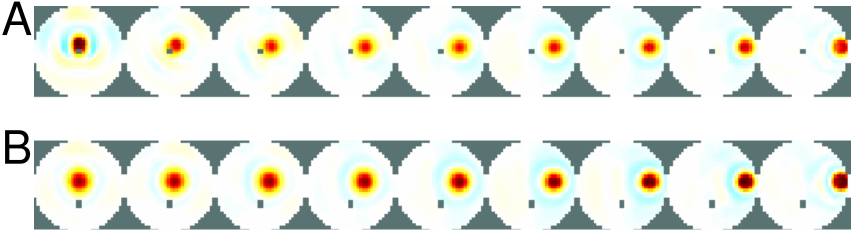

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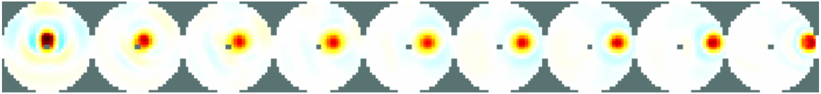
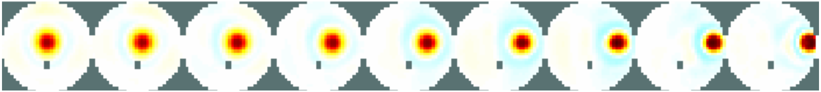
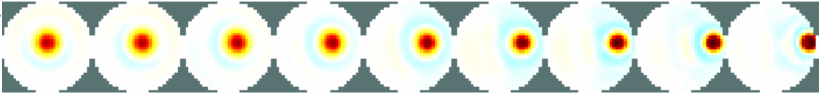
A



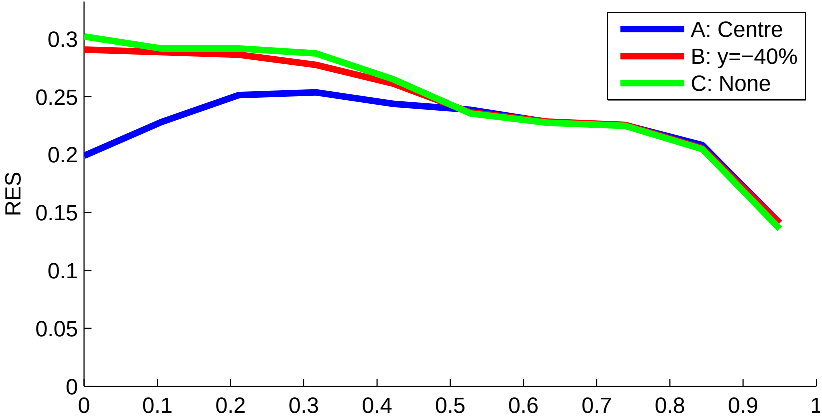
B



C

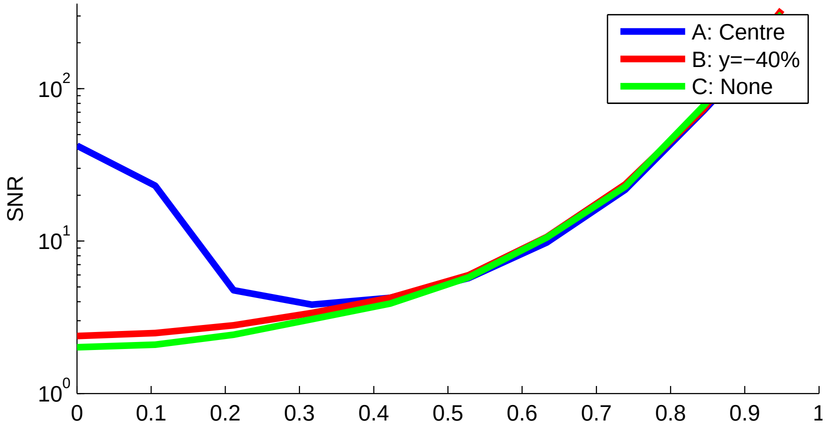


Resolution


A: Centre
B: y=−40%
C: None
RES
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

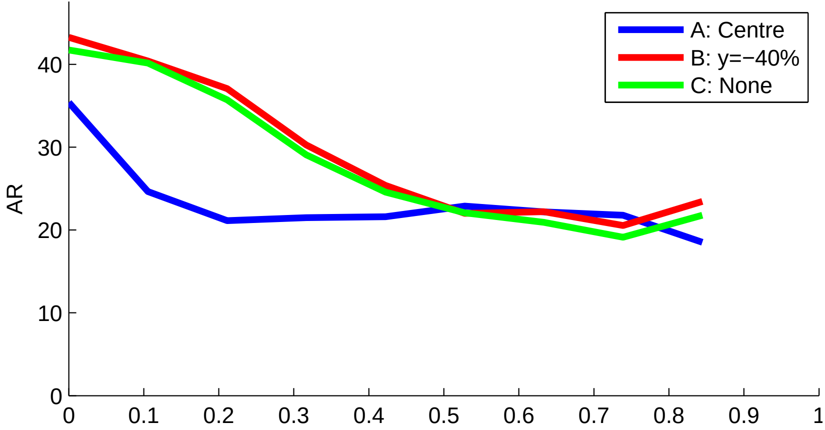
Performance: Figures of merit

Signal to Noise Ratio

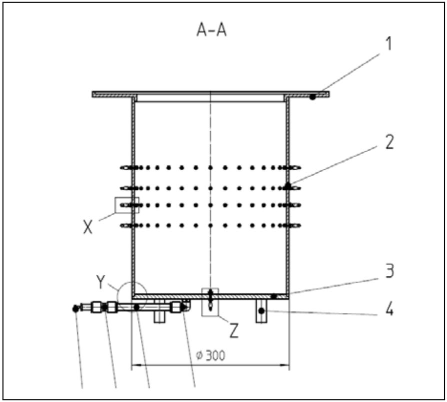


Performance: Figures of merit

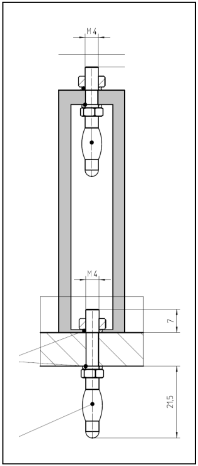
Amplitude Response



Tank Evaluation

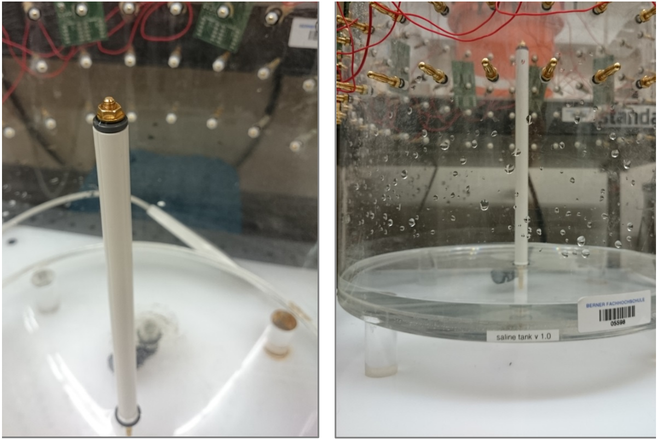


Phantom Tank in crosssectional view



Central electrode fixation system

Tank Evaluation



Pictures of the implemented central electrode in the phantom tank

Tank Evaluation: Challenges

- Currently, we can't get our tank data to reconstruct well
- Our best guess it is that it is a modelling issue
- Need an accurate (3D!) model of the current propagation near the electrode

Practial issue: Electrical Safety

Macroshock	"…current between two different areas of skin" Electrical Safety Standards: IEC 60601-1 "patient auxiliary current" $\longrightarrow$ 10 mA

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Electrical Safety Standards: IEC 60601-1
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Microshock "risk …with intracardiac electrical conductors"
theorised …10 μA directly to heart $\longrightarrow$ VF

- An esophageal electrode is a Macroshock risk.
- Currents (including leakage) must be μA
- Can't use for current stimulation
- Can't use currently available EIT systems

Discussion

- Internal electrodes seem to be a good idea, similar to geophysical ERT
- Esophagus is close to heart, and should help improve cardiac EIT.
- Esophageal electrode would be fairly non-invasive
- Stimulations show advantages, especially SNR and resolution
- Practical problems ...
- Major EIT system redesign required
- What stimulation and measurement patterns should be used?

Evaluation of EIT images using Esophageal electrodes

Authors: Stephanie Eng, Martin Grambone, Andy Adler

Introduction: EIT investigates a medium using electric current from surface electrodes. Due to the diffusive nature of current propagation, EIT is most sensitive, and has its highest resolution, near the electrodes. Placing an internal electrode should improve EIT performance in the image center. The least invasive location for this internal electrode is the esophagus. Two simulation studies of the use of an esophageal electrode have been performed [1] and [2], and showed the predicted improvements. These studies were limited by considering only simulations and a single stimulation and measurement pattern.

Objective: To evaluate the benefit of an internal electrode, as a function of its position, stimulation and measurement pattern, using simulation and tank measurements.

Methods: We investigated using a single esophageal electrode using a finite element simulation and a tank phantom. In both cases, the geometry was that of a cylindrical tank with a single transverse plane of electrodes. Images were compared to a reference configuration of 32 electrodes on the medium surface in a single plane. The experimental configuration was to place one of the electrodes from the tank surface into the tank medium. The simulation FEM was created using netgen. The tank phantom used a acrylic cylinder with a custom jig to hold the internal electrode in place. A non-conductive ball was displaced from the edge to the medium center while EIT data acquired using several different ”skip” values for the stimulation and measurement pattern. Two different electrode positions were evaluated: 1) in the medium center, and 2) 50% of the radius toward the edge.

Results: Images were reconstructed of each target position with respect to an empty medium, using a GREIT and a GN algorithm. The noise figure was set to 1.0 for all algorithms. The figures show images reconstructed for simulated targets as a function of the radial position of the target (top row: internal electrode in the centre, middle: internal electrode at 50%, bottom row: no internal electrode). Measures of resolution, noise performance and image amplitude were made. Results show an overall improved performance near the center electrode on all measures. Results for tank data (not shown) show similar trends, although image artefacts need to be carefully managed in the reconstruction.

Discussion: As predicted, internal electrodes can improve the quality of EIT images. Our results match the previous simulation work [1,2] as well as simlar approaches using boreholes that are used in geophysical EIT. Interestingly, in [3] a similar approach is proposed, but called ”Esophageal” Impedance Tomography. For invivo use, however, several issues need to be considered. First, electrical safety is of key concern, since the electrode is close to the heart. We recommend the esophageal electrode be only used for measurement and not current stimulation. Next, image reconstruction is very sensitive to the electrode location. In practice the esophageal electrode can move, and the imaging algorithm must compensate for this effect.

References:

1. JN Tehrani, C Jin, AL McEwan Modelling of an Oesophageal Electrode for Cardiac Function Tomography Comput Math Methods Med. 2012:585786.

2. TF Schuessler, JHT Bates. Utility of an esophageal reference electrode for thoracic electrical impedance tomography. Proc IEEE EMBS,559-560, September 1995.

3. Z Lin et al High-Resolution Esophageal Impedance Topography (EIT) Parameters for Quantifying Bolus Retention Gastroenterology 146:S342–S343, 2014