Improving Electrical Impedance Tomography Imaging of the Brain
Background

Image functional brain activity with EIT

- Detecting blood movement from hemodynamic response
- Signal changes are at limit of detection
- Hardware and reconstruction models not developed
- No existing perfusion-based detection method

Might not be possible with EIT

Start with largest blood volume change in the brain

Imaging Stroke with EIT

- Detecting blood movement from disease or injury
- Signal changes are within limit of detection
- Hardware exists, reconstruction models not developed
- Ischemia had not been imaged with EIT
Purpose

• **Brain imaging**
  • Develop non-invasive stroke detection methods for:
    • Perioperative ischemic stroke
    • Cerebral edema
    • Hemorrhagic transformation
  • Image functional brain activity in humans for:
    • Long-duration functional imaging studies
    • Monitoring brain perfusion during cardiopulmonary bypass
    • Brain tumor detection (relatively high metabolism)
    • Monitoring state of consciousness during surgery

• **Lung imaging**
  • Study respiratory consequences of weighted restraint

• **Pre-processing**
  • Develop tools to automate EIT data cleaning
Contributions

• **EIT Stroke**
  • Designed and analyzed 2 methods for detecting cerebral ischemia with EIT, 1 successful

• **EIT Brain Imaging**
  • Electrode design and testing for brain EIT in humans
  • Realistic human reconstruction model from CT and MRI images
  • GUI for delivering N-back working memory task
    • Coordinates data collection and organization
    • Records time of stimuli and responses for *post-hoc* analysis

• **Weighted Restraint**
  • Discovered reserve volume collapse despite apparent normal recovery from exertion

• **Automated electrode quality assessment and data rejection tool (EQADR)**
  • Novel method for detecting faulty EIT electrodes and measurements
  • Improves accessibility, speed, and reliability of EIT analysis
EIT

• Produces real-time images of internal conductivity distribution
• Measurements are taken from surface electrodes
• Harmless, insensible currents passed between unique pairs of electrodes
• Resulting voltages are measured from other pairs of electrodes.
• Highly sensitive to noise
• Blood has higher conductivity value than brain tissue
• Hypo-perfused regions have low relative conductivity (ischemia)
Ground Truth - FEM with Background of 1.0 and Inclusion of 5.0

Reconstruction Image with an SNR of 80.0 dB
EIT-Stroke

What is a stroke?
The pathological state of reduced blood supply to the brain. Strokes are the second largest cause of death worldwide. Can otherwise lead to a wide range of disabilities or loss of function.

How does it occur?
Ischemia - blockage of an artery (80% of cases)
Hemorrhage - blood vessel rupture causing internal bleeding (20% of cases).
EIT-Stroke Study

• Data collected by group at UKE Hamburg
• 5 anesthetized pigs
EIT-Stroke Reconstruction Models

CT images → Model creation → Isolating brain in EIT images
EIT-Stroke Methods

• Bolus injection
  • EIT images from 1-20 seconds after saline injection
• Ensemble using arterial pressure signal
EIT-Stroke Results: Saline

- Images from saline injection did not reflect DWI images
- Investigate reflection of PWI images in future studies
EIT-Stroke Results: Ensemble

- Consistent conductivity patterns observed in baseline (A)
- Ensemble images reflected DWI images in 4/5 pigs
EIT-Brain Imaging

• Many imaging modalities detect functional activity by exploiting hemodynamic response

• EEG contamination?
  • Magnitude of EEG signal: $1 \times 10^{-6} - 1 \times 10^{-4}$ V
  • Magnitude of EIT signal: $1 \times 10^{-3}$ V
  • EIT signal on average 10-100 x larger than EEG signal
EIT-Brain Imaging - Mesh

CT images → Tissue segmentation → Mesh generation
EIT-Brain Imaging - Electrodes

- Electrical components
- Electrode housing and mounting plate
- Mk II design
EIT-Brain Imaging – Protocol Software

• Presents working memory task
  • Creates new randomly generated set of stimuli from 3 customizable test parameters

• Records:
  • Data collection timing
  • Stimulus presentation timing
  • User response timing
  • Answer correctness
EIT-Brain Imaging – Simulations

• Simulated conductivity perturbations in human reconstruction model to assess sensitivity
  • 8 radial positions, for each of 3 foci sizes, for each of 3 foci distances
  • Perturbations (correct change in correct location observed)
    • 10% decrease (49/72 [68%])
    • 1% decrease (38/72 [53%])
    • 1% increase (44/72 [61%])
    • 10% increase (49/72 [68%])
EQADR

• Save time
• Increase accessibility of EIT
• Produce highest quality images in the presence of noise
• Reliable images from data of unknown and inconsistent quality.
EQADR – How it Works

• Assign each electrode and measurement a score
• Remove electrodes or measurements above threshold after score resolution
EQADR – How it Works

- Blue - clean
- Red - rejected measurements
- Magenta - from rejected electrode

Faulty electrode identified  →  All noisy meas accounted for  →  EQADR retains data lost by Z thresholds
EIT-Restraint

A: Human figure
B: EIT (Electrical Impedance Tomography)
C: Reconstructed Data

D: Graphs showing changes over time (Global, ΔZ)
E: ΔZ graphs for different phases (U, R, W, X, P)
F: Images showing different views (U, R, W, X, P)

Right side: Graphs showing experimental phase (U to P) with data points for different groups (control, restraint 1, restraint 2)