Improving Electrical Impedance Tomography Imaging of the Brain

Background

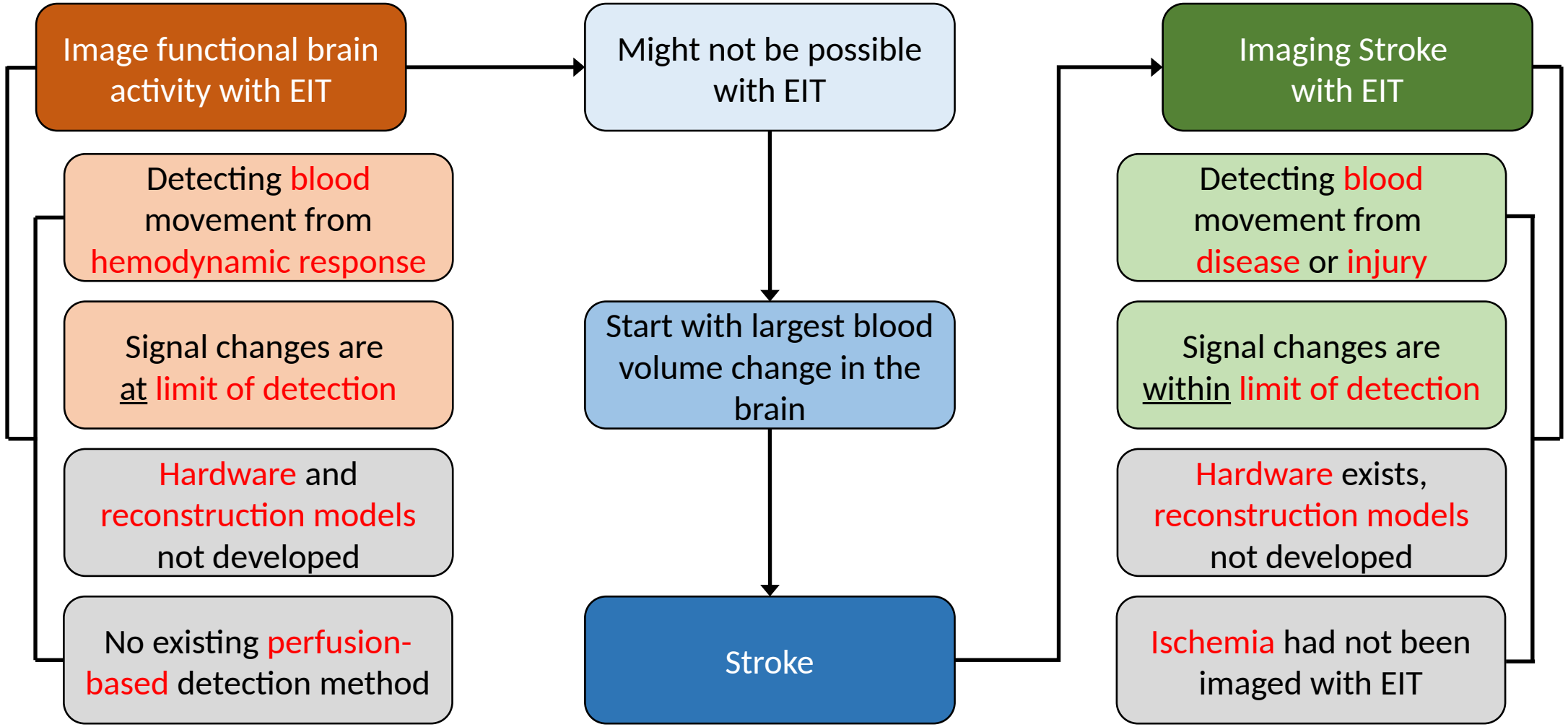


Image functional brain activity with EIT
Might not be possible with EIT
Imaging Stroke with EIT
Detecting blood movement from hemodynamic response
Signal changes are at limit of detection
Hardware and reconstruction models not developed
No existing perfusion-based detection method
Start with largest blood volume change in the brain
Stroke
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

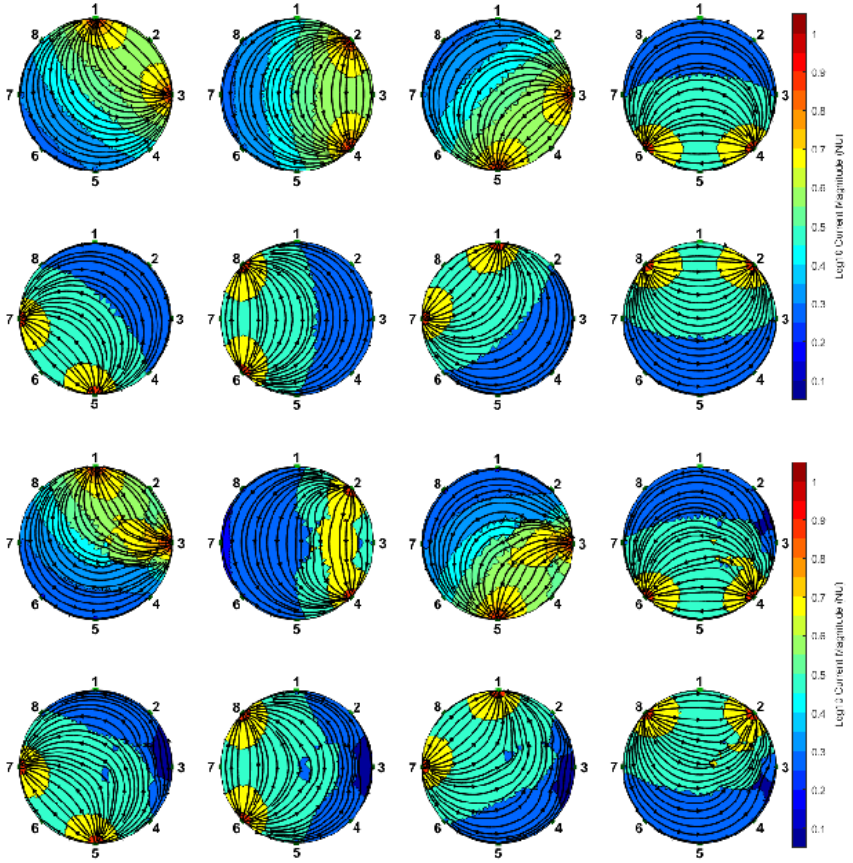
Contributions

- 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

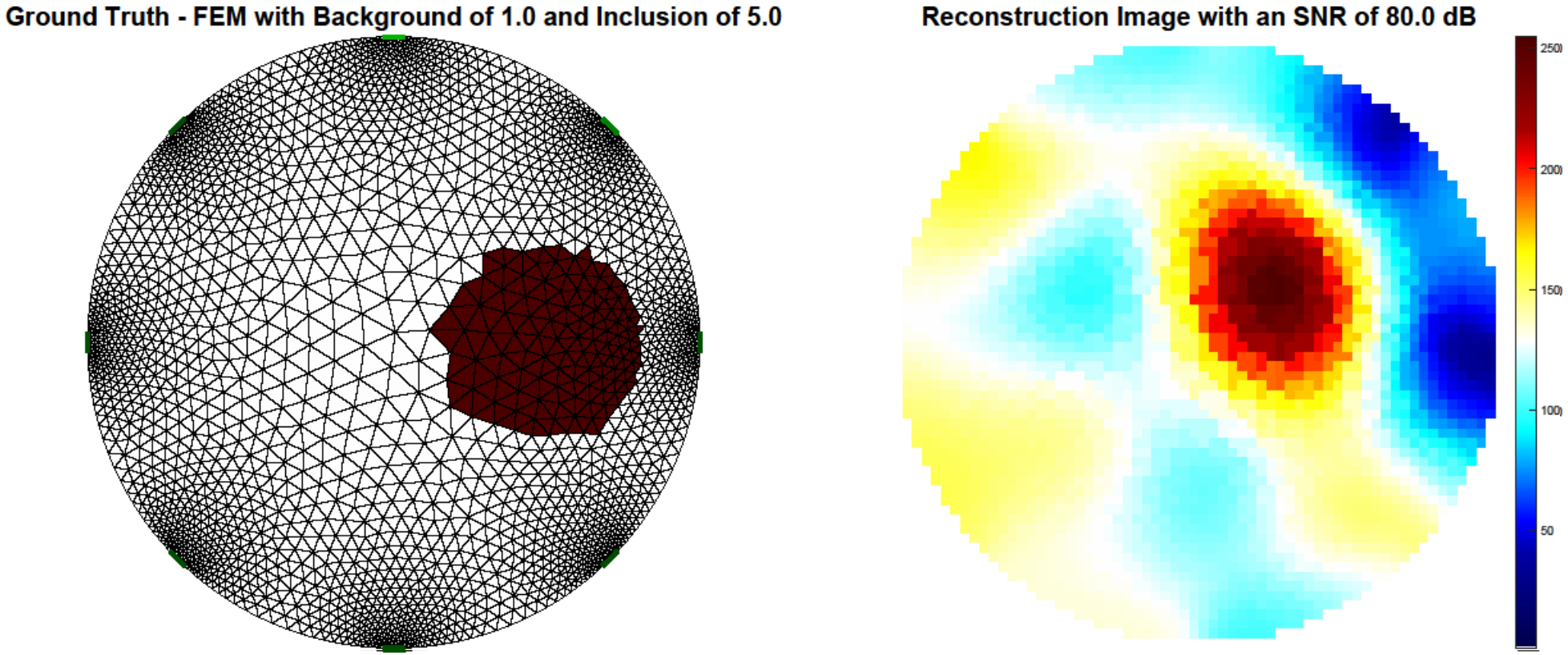
EIT

- 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)



EIT


Ground Truth - FEM with Background of 1.0 and Inclusion of 5.0
Reconstruction Image with an SNR of 80.0 dB
250
200
150
100
50

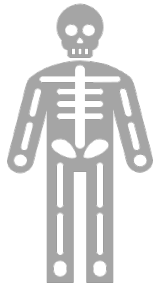
EIT-Stroke

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.



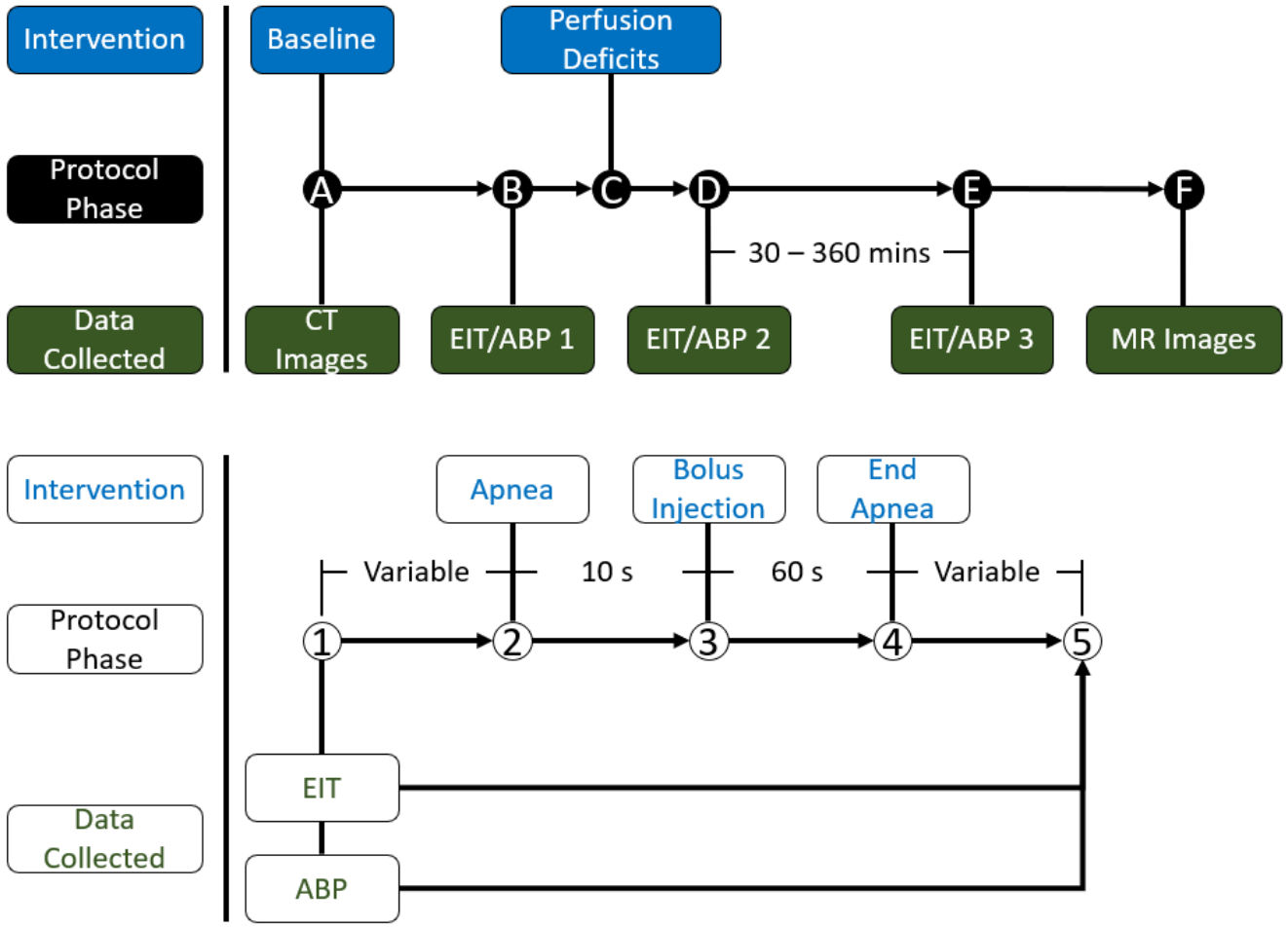
How does it occur?

Ischemia - blockage of an artery (80% of cases)

Hemorrhage - blood vessel rupture causing internal bleeding (20% of cases).

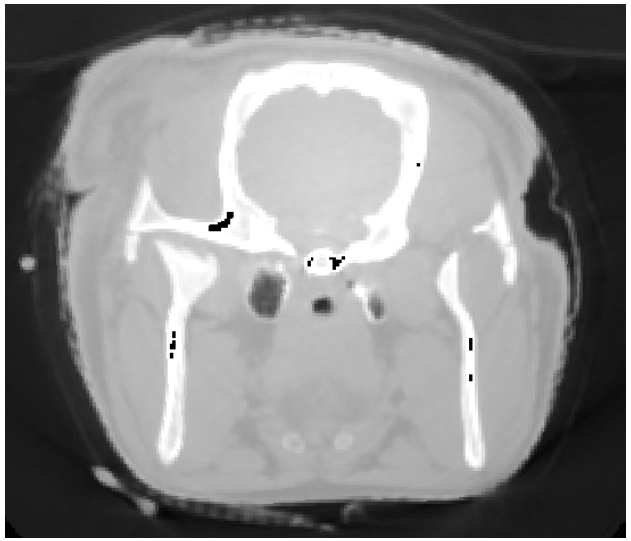
EIT-Stroke Study

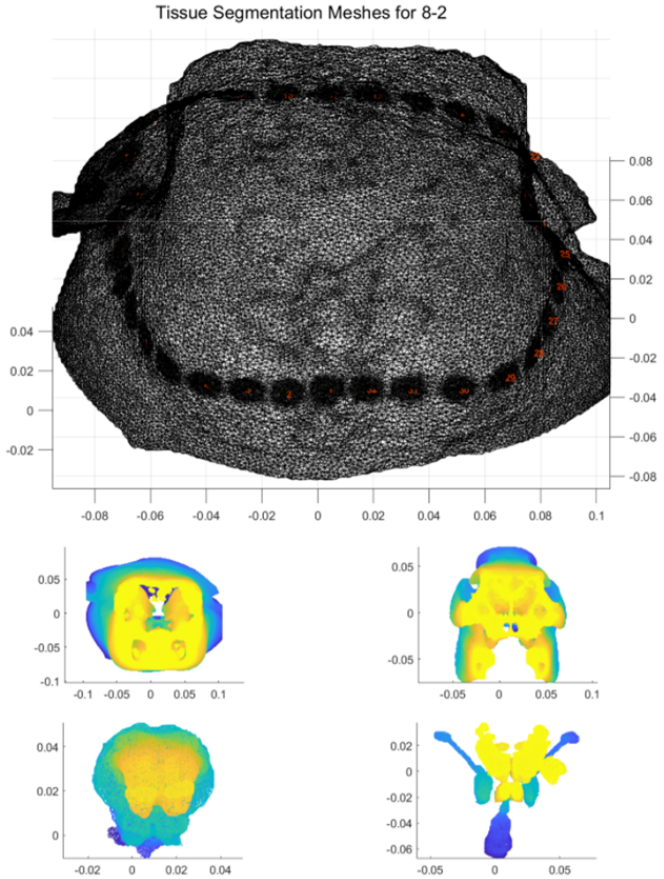
- Data collected by group at UKE Hamburg
- 5 anesthetized pigs

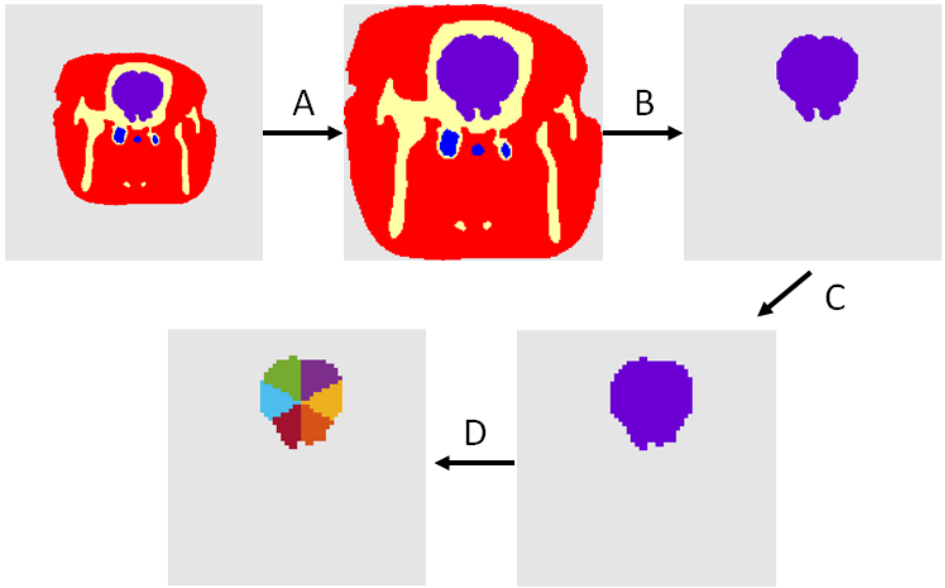


EIT-Stroke Reconstruction Models

CT images → Model creation → Isolating brain in EIT images

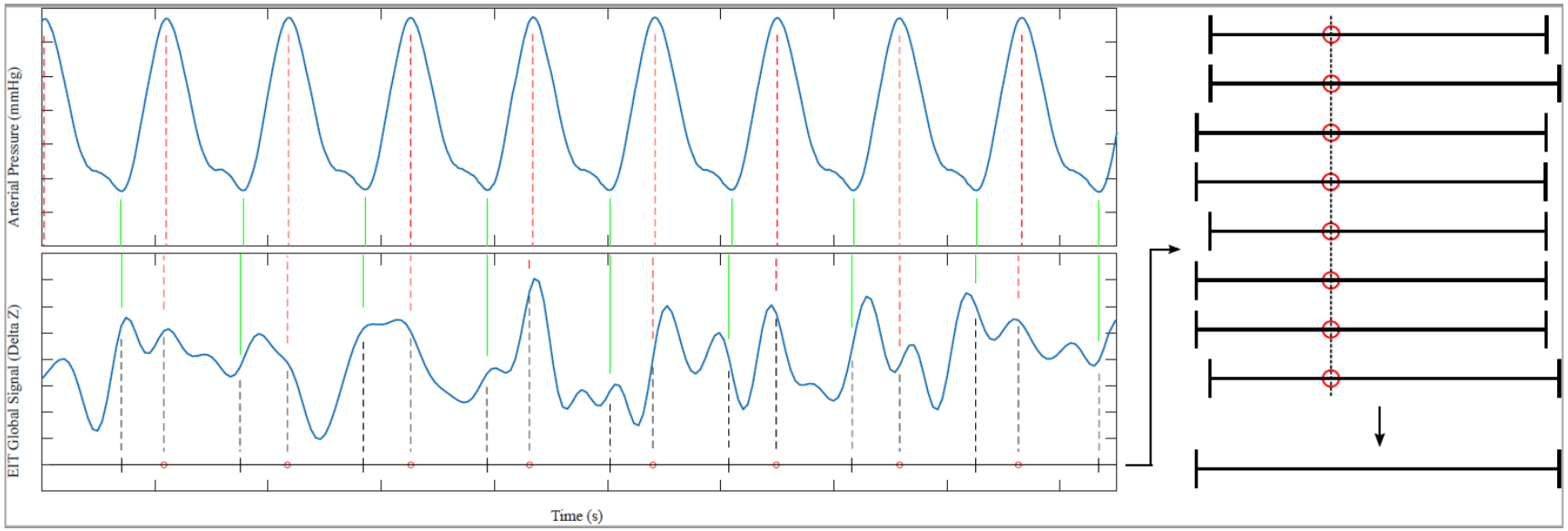




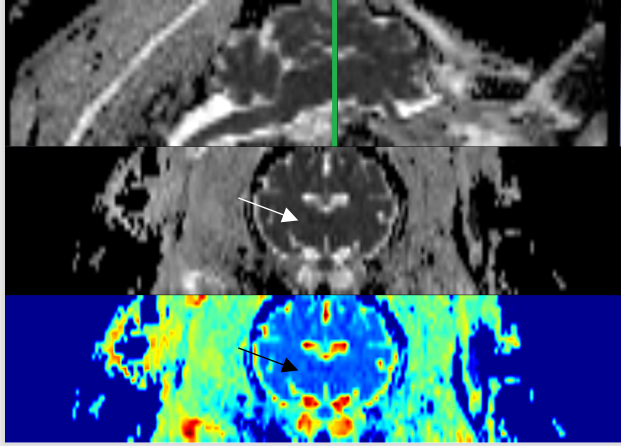


EIT-Stroke Methods

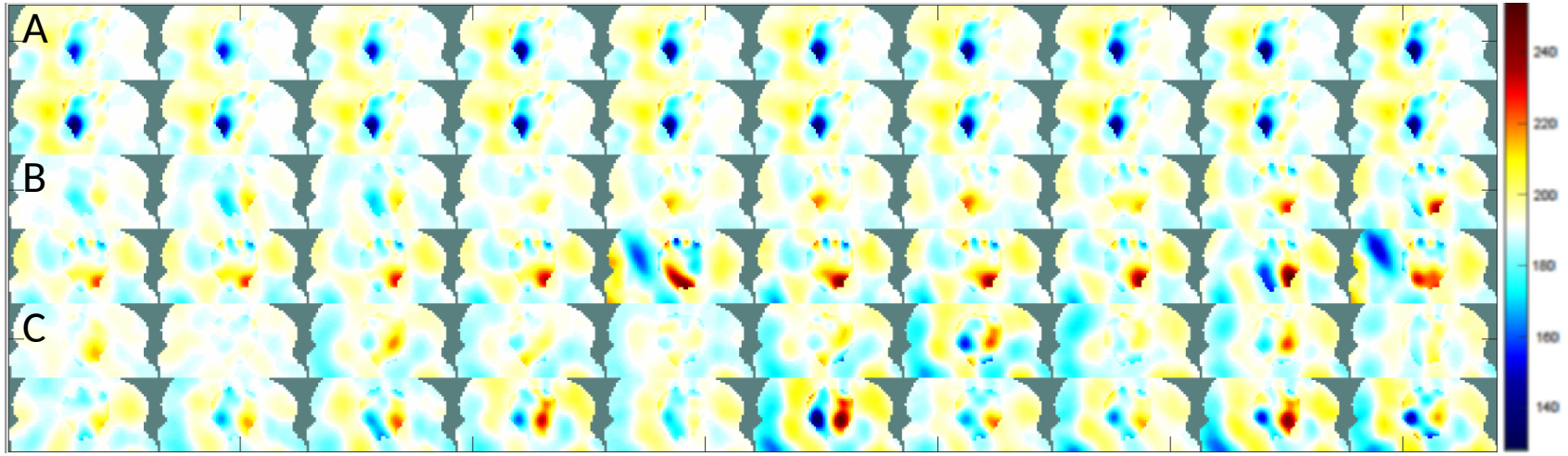
- Bolus injection
  - EIT images from 1-20 seconds after saline injection
- Ensemble using arterial pressure signal



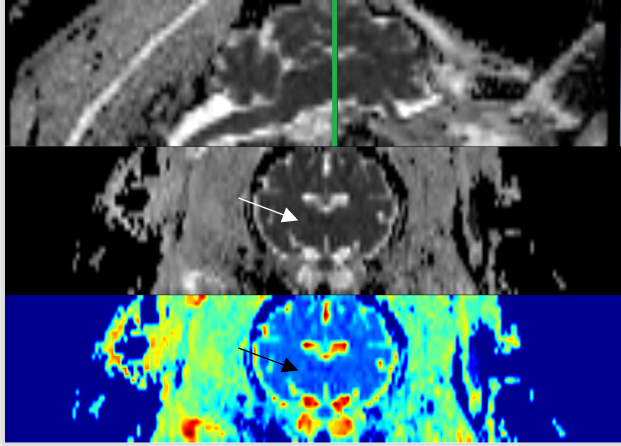
EIT-Stroke Results: Saline



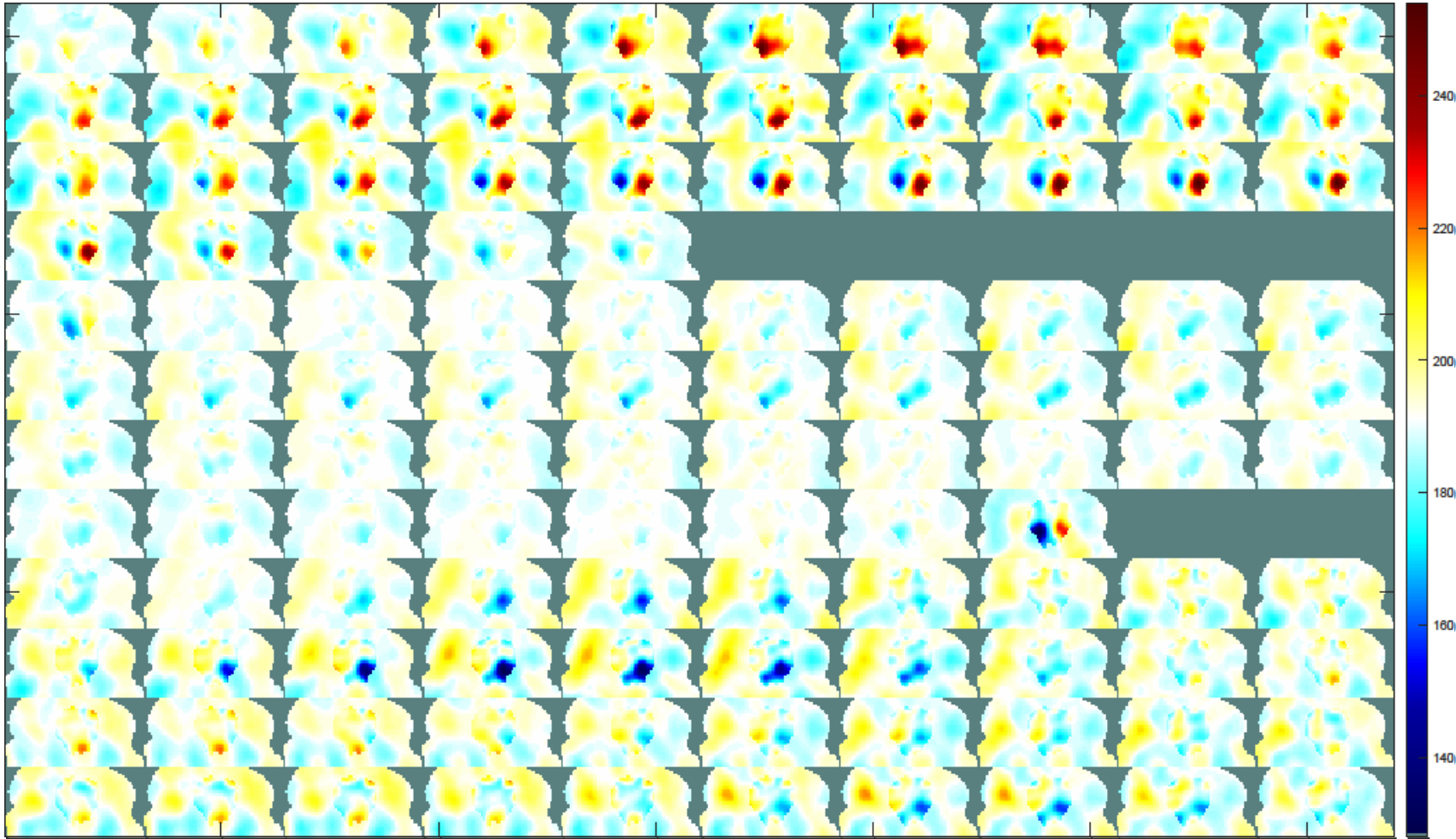
- Images from saline injection did not reflect DWI images
- Investigate reflection of PWI images in future studies



EIT-Stroke Results: Ensemble



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

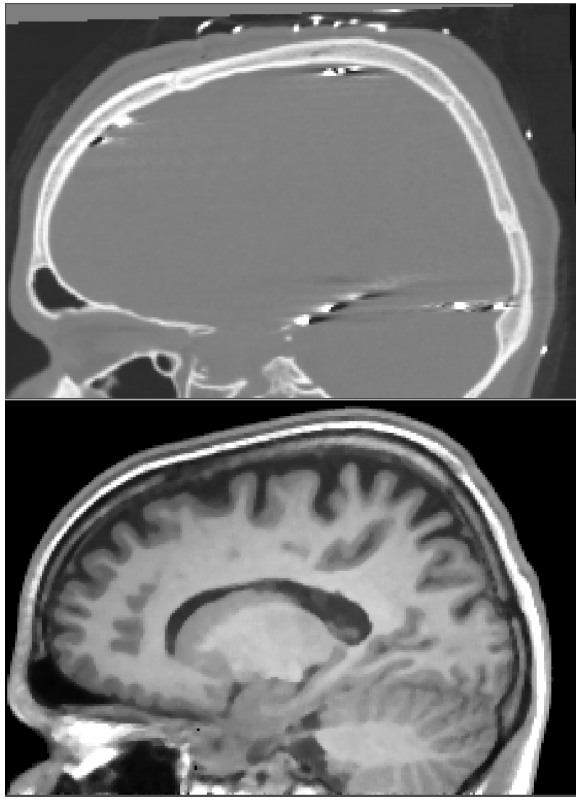


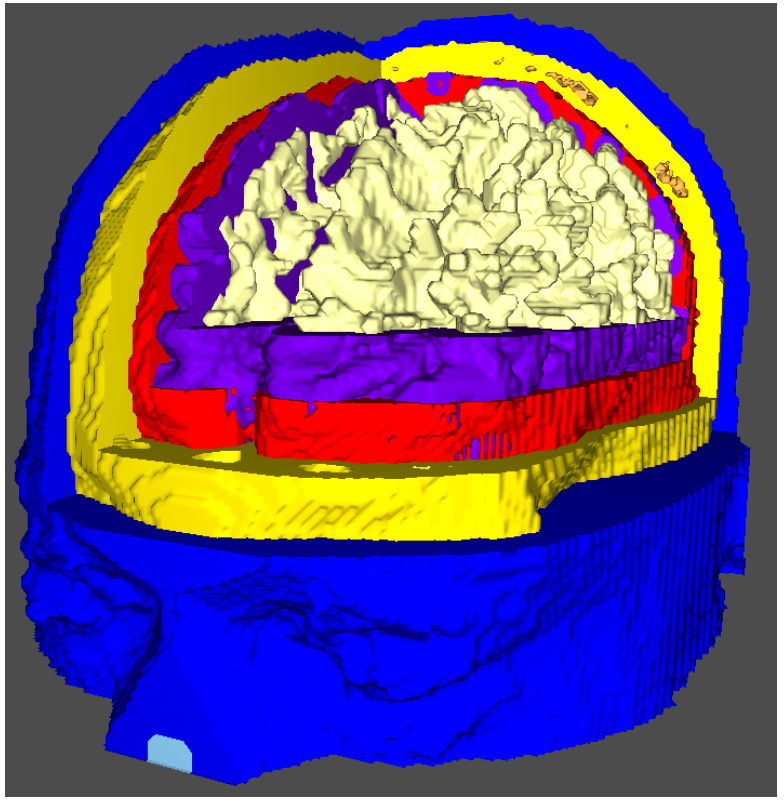
EIT-Brain Imaging

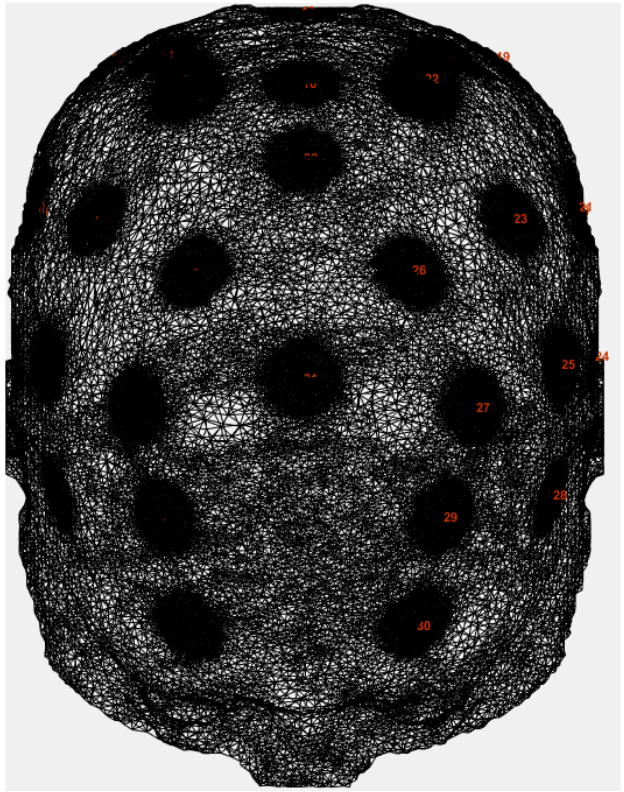
- Many imaging modalities detect functional activity by exploiting hemodynamic response
- EEG contamination?
  - Magnitude of EEG signal: $1 \times 10^{-6} – 1 \times 10^{-4}$ V
  - Magnitude of EIT signal: 1×10^{-3} V
  - EIT signal on average 10-100 x larger than EEG signal

EIT-Brain Imaging - Mesh

CT images → Tissue segmentation → Mesh generation

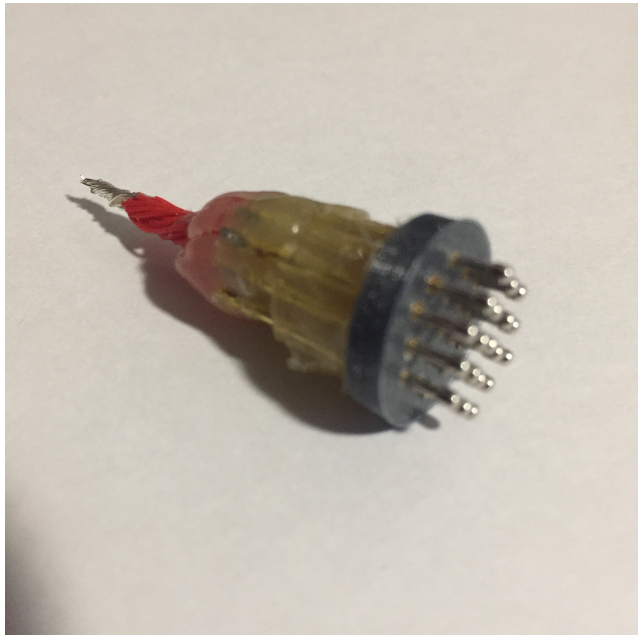






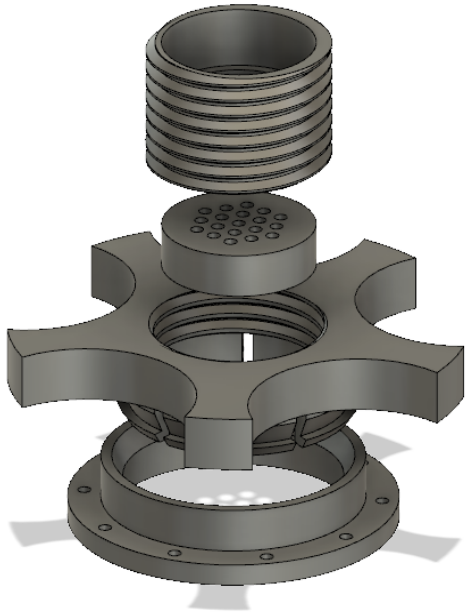
EIT-Brain Imaging - Electrodes

Electrical components



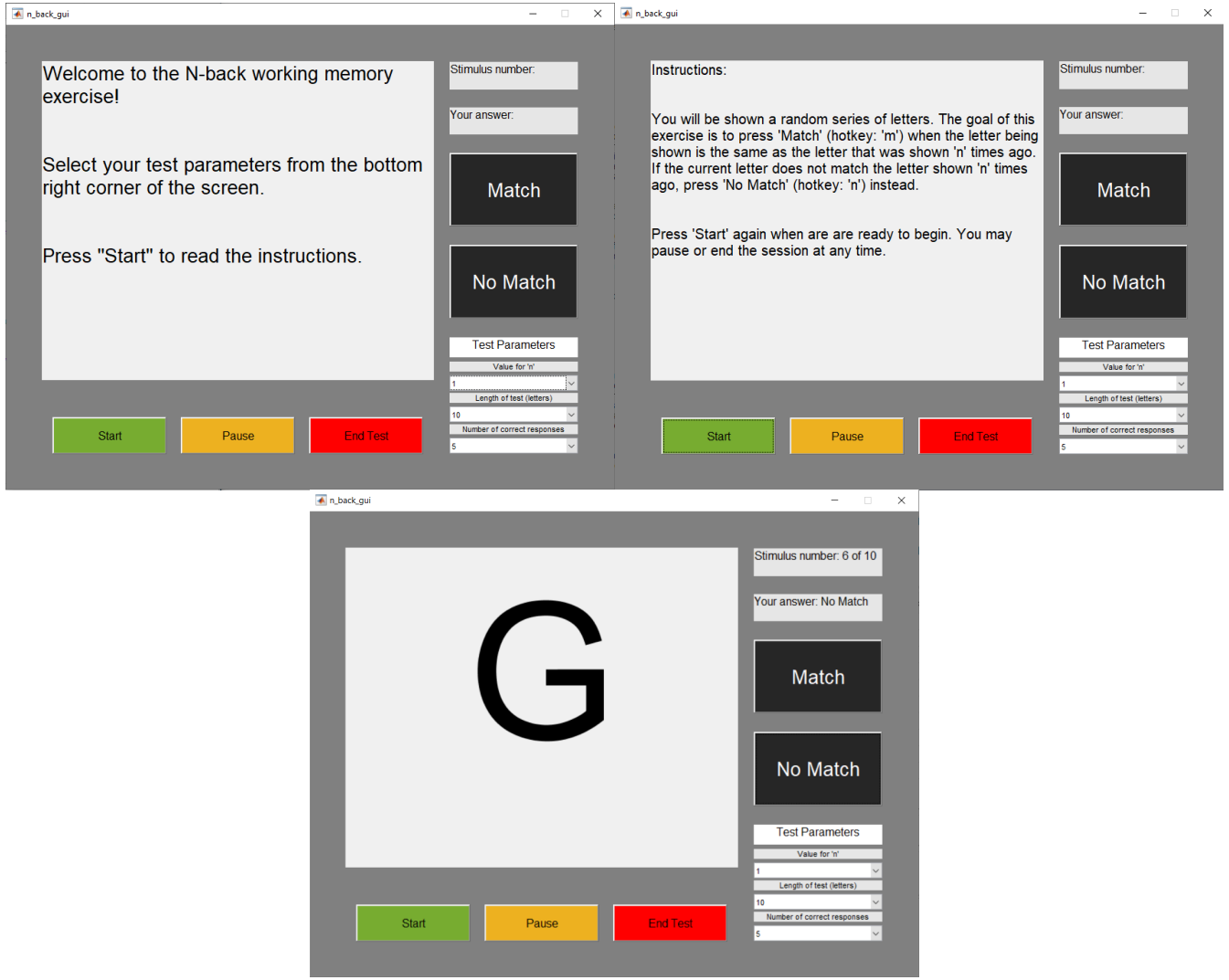
Electrode housing and mounting plate

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

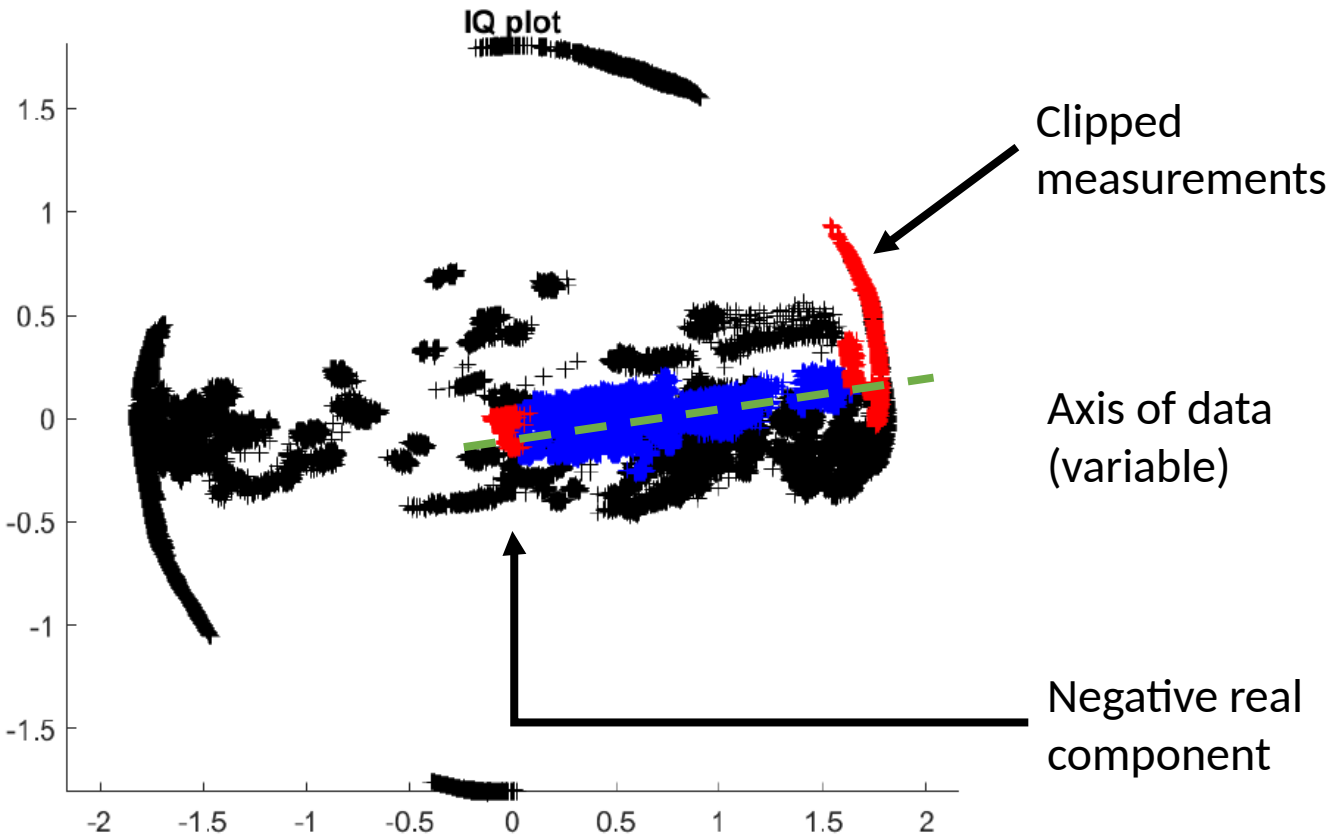


EIT-Brain Imaging – Simulations

- 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%])

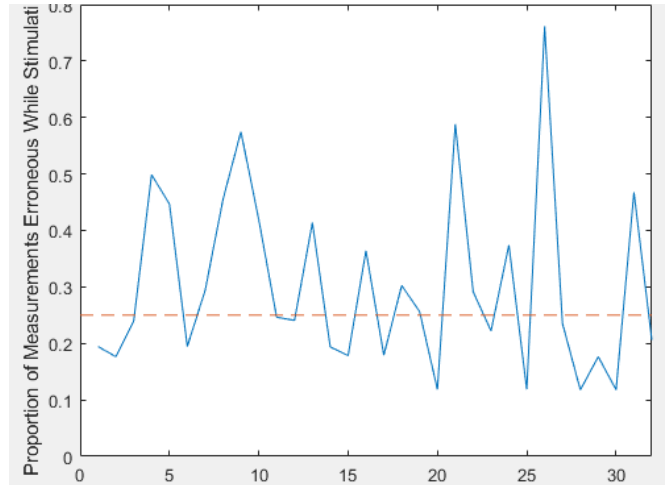
EQADR

- Save time
- Increase accessibility of EIT
- Produce highest quality images in the presence of noise
- Reliable images from data of unknown and inconsistent quality.



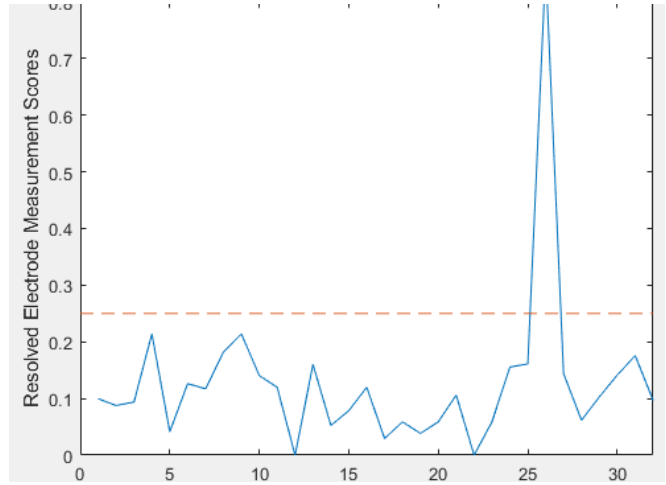
EQADR – How it Works

- Assign each electrode and measurement a score
- Remove electrodes or measurements above threshold after score resolution



Most electrodes above threshold

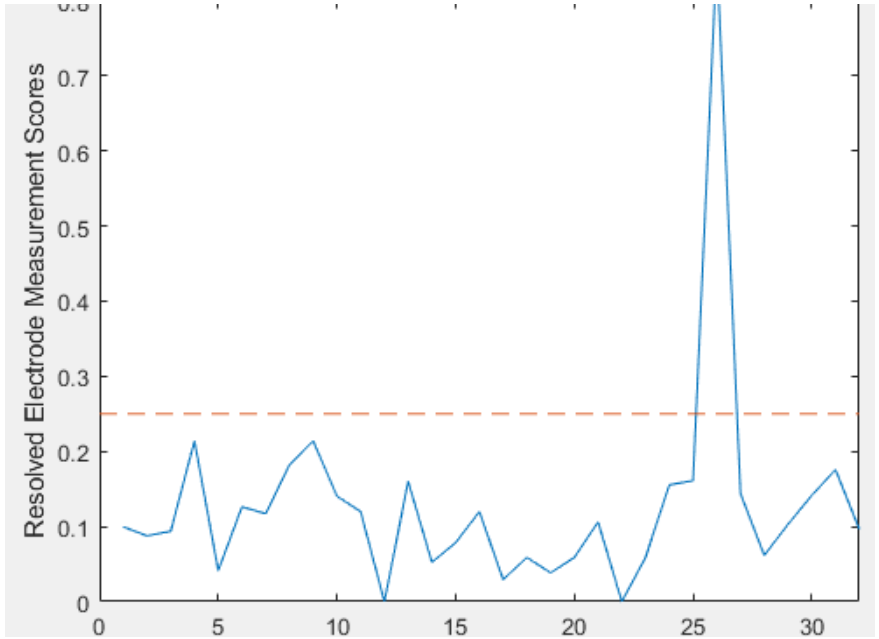
Score resolution ↓

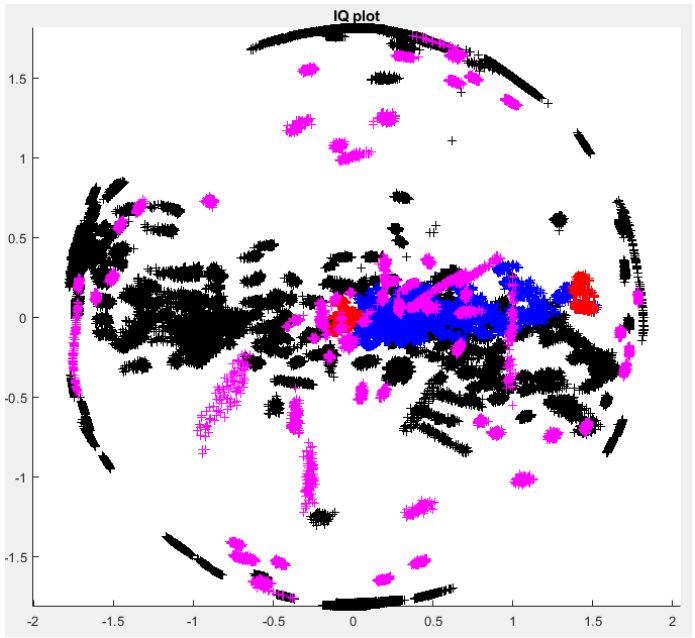


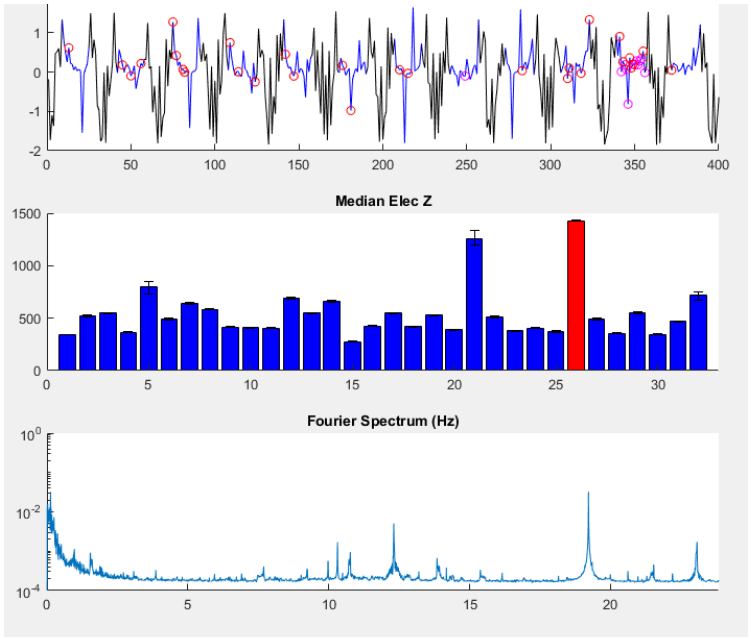
Single electrode above threshold

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