Electrical Impedance Tomography for Perfusion Imaging and Monitoring

Thesis Defence Presentation

Symon Stowe

symonstowe@sce.carleton.ca

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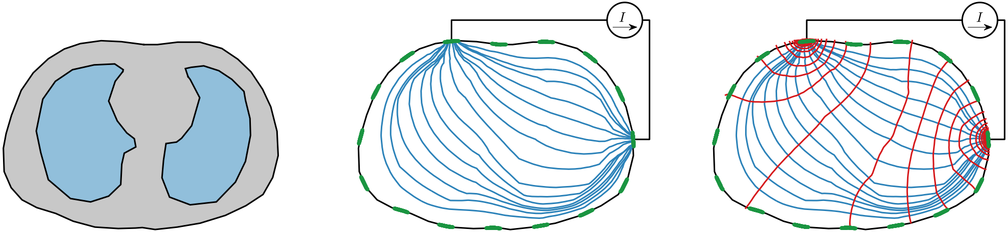
Overview

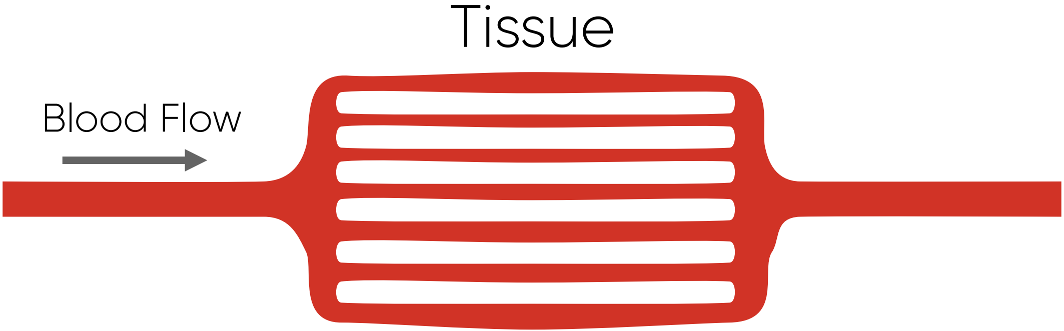


Electrodes on the body surface are used to inject current and measure the resulting voltages.

Thoracic EIT typically images impedance changes due to the movement of fluid in the chest.

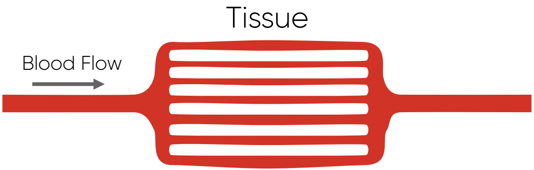
Perfusion

What is perfusion?



EIT Measures of Perfusion

Blood perfuses into the tissue.



The perfusion signal can come from:

- Change in blood volume in the tissue
- Change in blood volume in vessels
- Physical deformation of structures due to movement
- Ballistic forces in the body
- The orientation of red blood cells (very small change)

EIT Perfusion Imaging

Compared to other techniques used to image perfusion EIT is:

- Fast
- Does not use ionizing radiation
- Can be used continuously
- Cost efficient

Challenges of perfusion imaging with EIT:

- Unclear source of cardiac-frequency (cardiosynchronous) signal
- Low amplitude of cardiac-frequency signal
- Low sensitivity in the centre of a subject

Challenges of EIT Perfusion Imaging

Not all perfusion results in a cardiac-frequency change

- e.g. Continuous flow

Non-perfusion effects can result in heart-frequency EIT signals

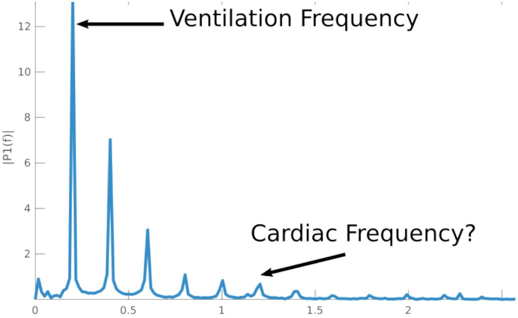
- e.g. Movement

Challenges of perfusion imaging with EIT:

- **Unclear source of cardiac-frequency (cardiosynchronous) signal**
- Low amplitude of cardiac-frequency signal
- Low sensitivity in the centre of a subject

Background

EIT Perfusion Imaging

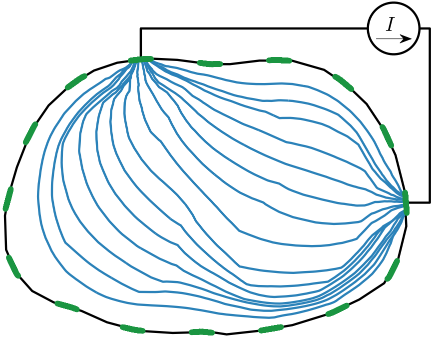


Example FFT of an EIT signal with only external electrodes (frequency in Hz).

Challenges of perfusion imaging with EIT:

- Unclear source of cardiac-frequency (cardiosynchronous) signal
- **Low amplitude of cardiac-frequency signal**
- Low sensitivity in the centre of a subject

EIT Perfusion Imaging



Sensitivity is proportional to current density.

Challenges of perfusion imaging with EIT:

- Unclear source of cardiac-frequency (cardiosynchronous) signal
- Low amplitude of cardiac-frequency signal
- **Low sensitivity in the centre of a subject**

Current State of EIT Perfusion Imaging

Bolus Injection

- A conductive contrast agent is injected
- The transit of the conductive contrast agent is imaged

- Occurs during apnoea
- Saline solution is typically used

Frequency Filtering

- The signal at the cardiac frequency is isolated
- An image of activity at the cardiac frequency is generated
- Can be done during either ventilation or apnoea

Ensemble Averaging

- Many heartbeats are averaged together
- An image of the impedance change over the averaged heartbeat is generated
- Can be done during either ventilation or apnoea

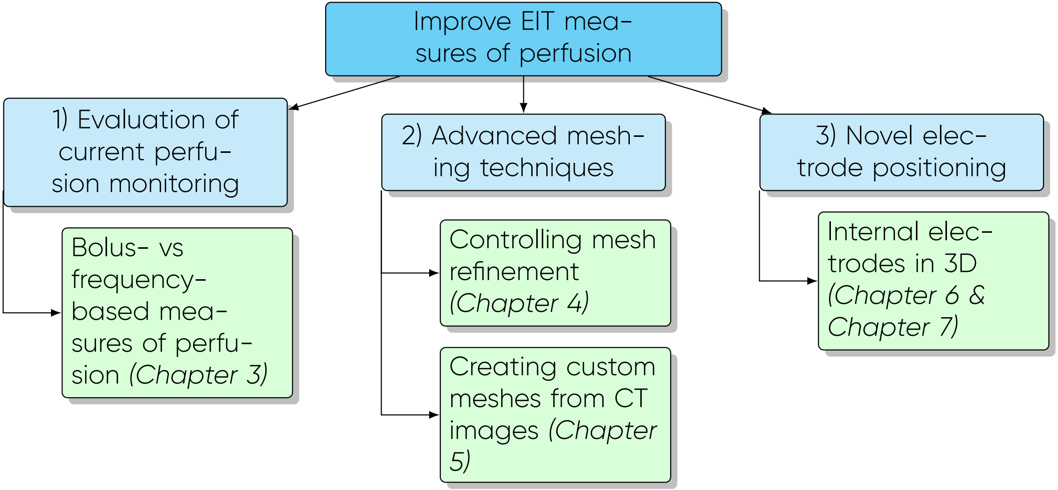
Shortcomings of EIT Perfusion Measures

- Bolus-based measures cannot be used continuously and are invasive
- Filtering-based methods have low sensitivity to cardiosynchronous activity
- Low internal sensitivity

How can measures of perfusion be improved?

1. Investigate the source of perfusion and cardiosynchronous EIT signals
2. Increase sensitivity near where perfusion is measured

Thesis Goals



Contributions

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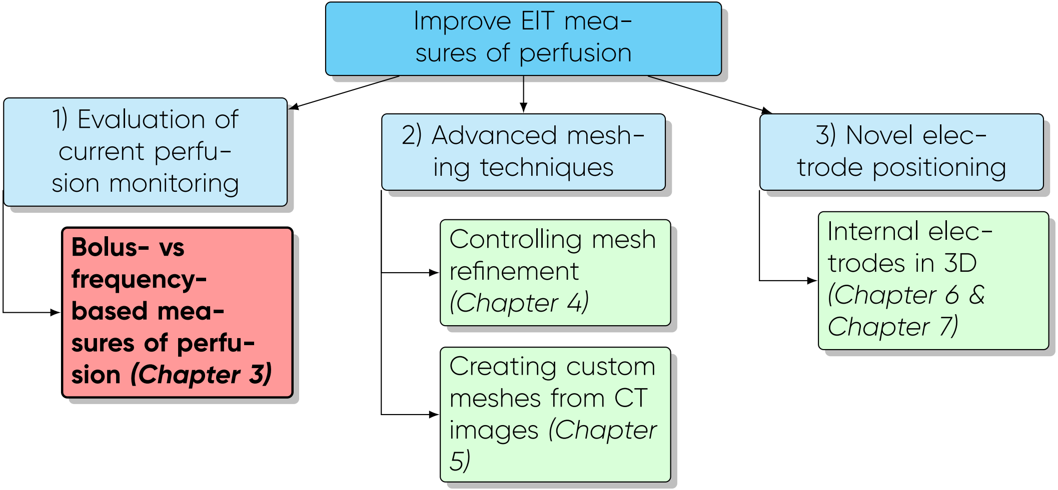
1. A mesh analysis technique to reduce error in sensitivity calculations on cylindrical meshes (Chapter 4).
2. A tool to generate custom meshes of exterior and lung boundaries from CT images (Chapter 5).
3. An analysis of 3D electrode placements with internal electrodes on internal sensitivity (Chapter 6).
4. A method to reconstruct images using internal electrode measurements in the presence of movement (Chapter 7).

Chapter 3: Bolus- and Frequency-Based Perfusion



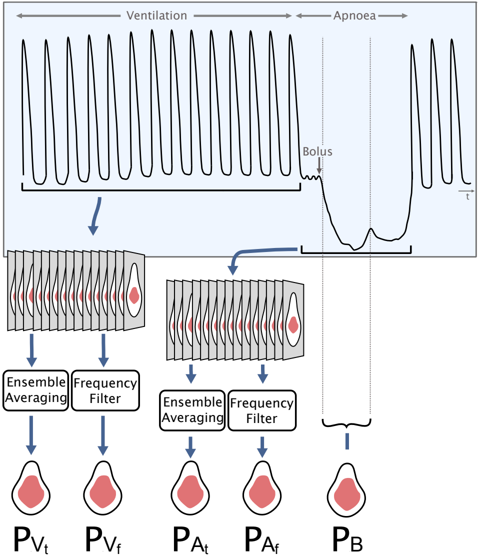
Introduction

There are three common techniques to measure perfusion with EIT.

1. Bolus injection
2. Frequency filtering
3. Ensemble averaging

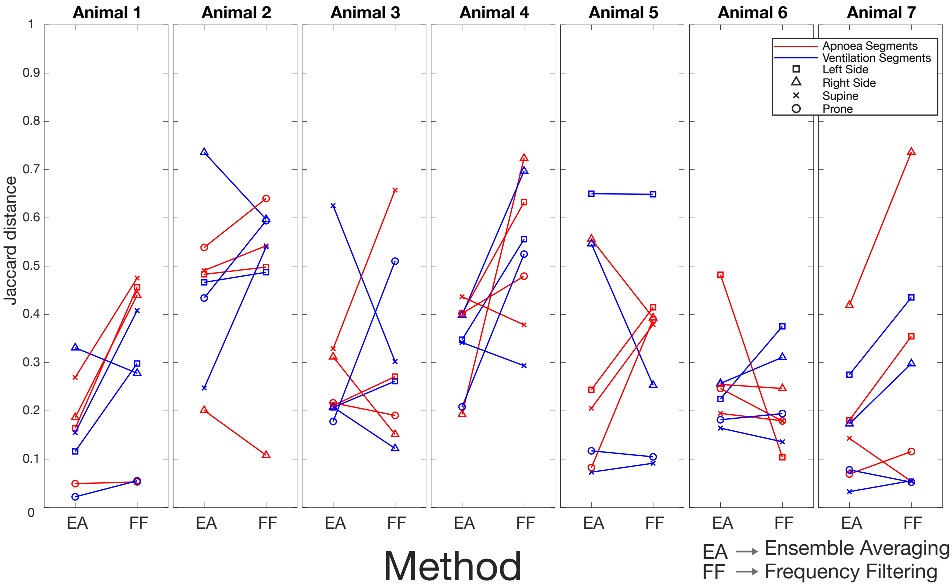
Goals

- Compare different measures of perfusion.
- Investigate the source of cardiosynchronous EIT signals.



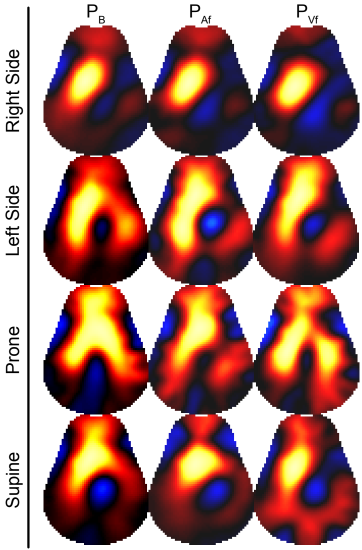
- Data segment with ventilation and apnoea segments
- 7 animals, 4 postures (supine, left side, right side, prone)
- Frequency filtering (P_V) and ensemble averaging (P_A) methods used during both ventilation and apnoea
- Compared to a bolus injection during apnoea

Chapter 3: Bolus- and Frequency-Based Perfusion Results



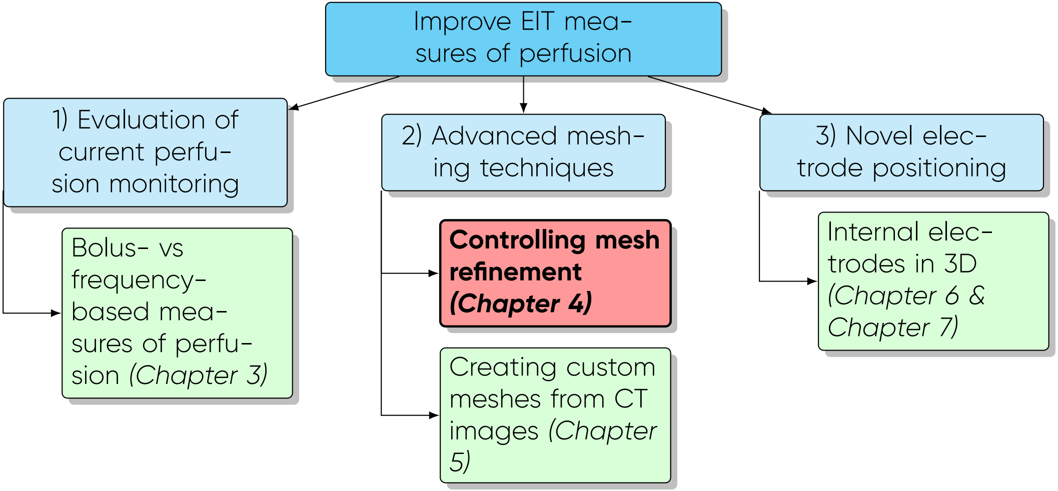
EA → Ensemble Averaging
FF → Frequency Filtering

Chapter 3: Bolus- and Frequency-Based Perfusion Results



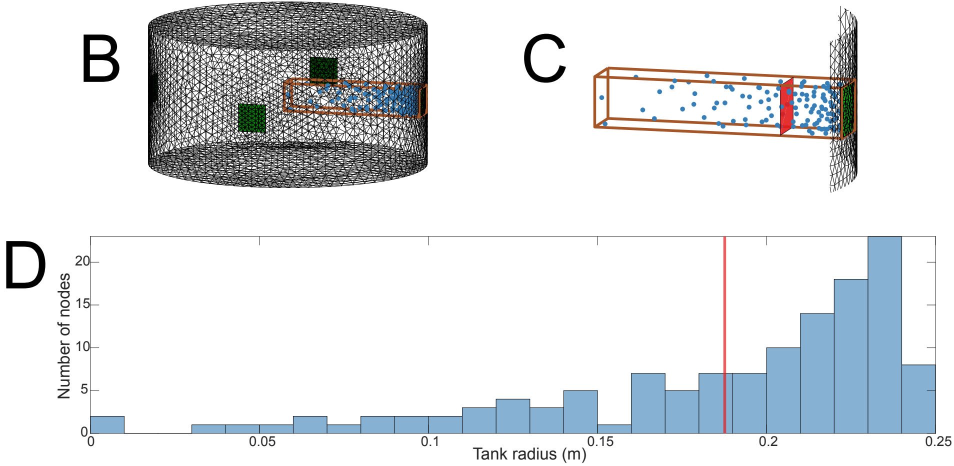
- Frequency filtering corresponds better to the bolus injection compared to ensemble averaging
- Challenging to isolate the lung regions
- Large contribution from the heart in the perfusion estimate

Chapter 4: FEM Mesh Refinement for 3D EIT



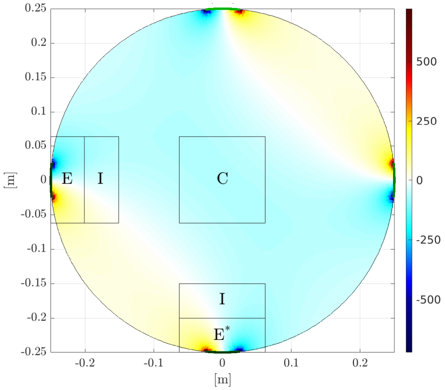
Introduction & Methods

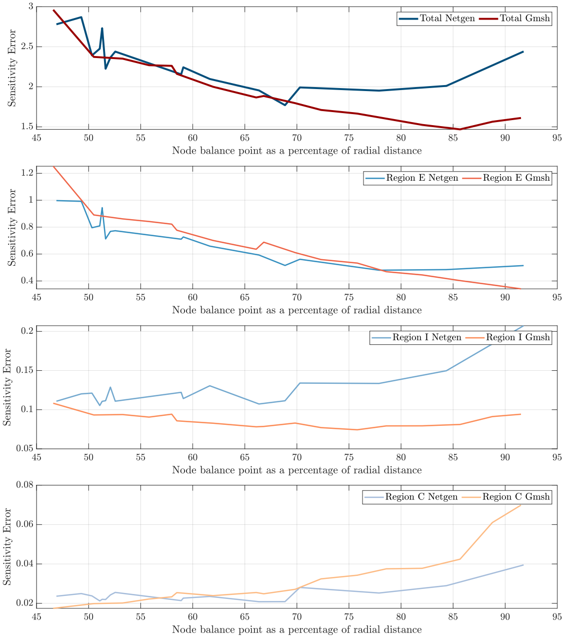
What distribution of nodes minimizes error in the sensitivity calculation?



Chapter 4: FEM Mesh Refinement for 3D EIT

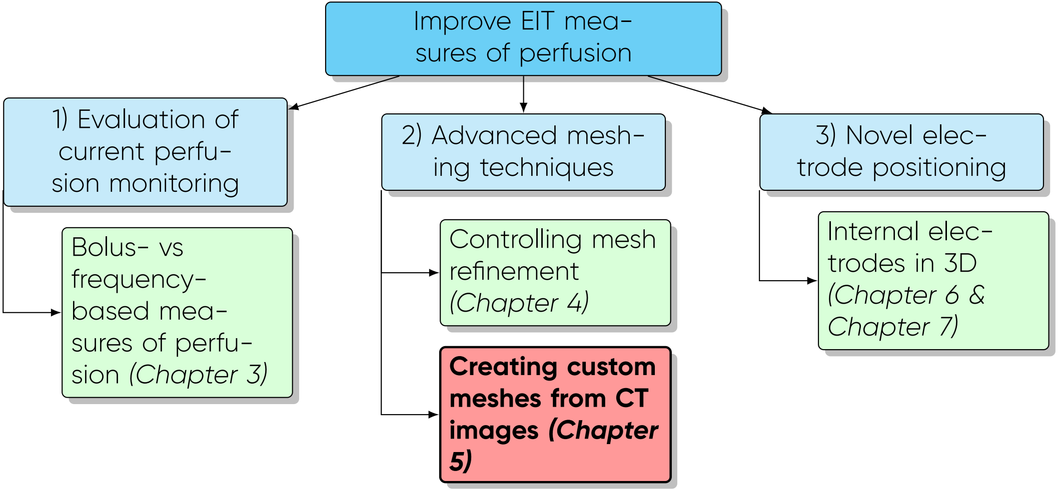
Results



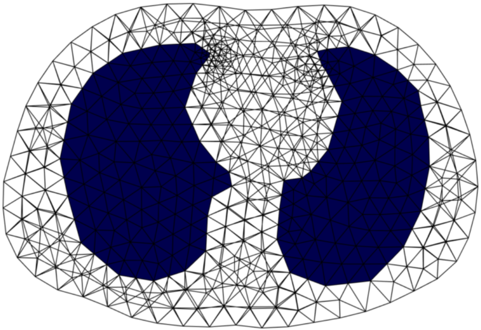


- Lowest error at approximately 85% of tank radius

Chapter 5: Custom EIT Meshes



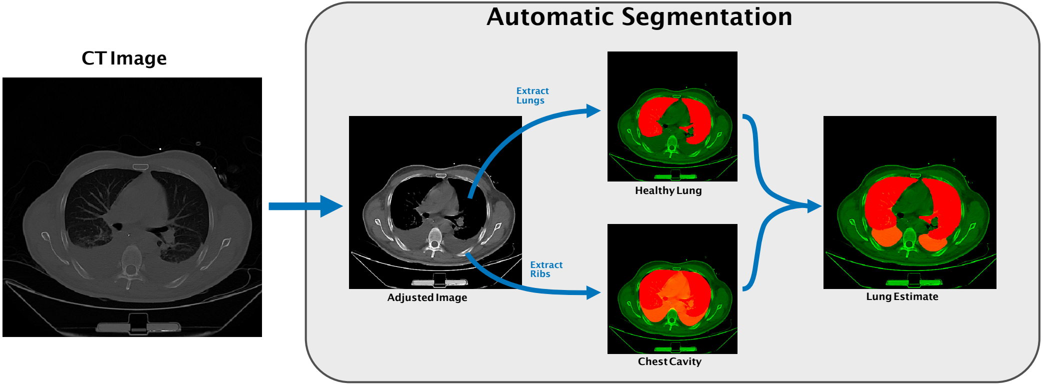
Introduction



- A finite element model is required to reconstruct voltages into images
- The more accurate the FEM, the better the reconstruction
- More prior information regarding the body conductivity
- For some patients (ARDS) we have diagnostic CT images

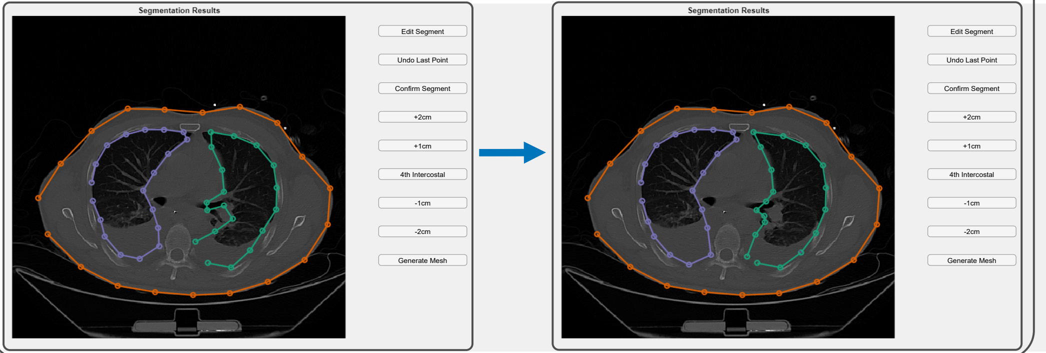
Can we use this to improve EIT image reconstruction and monitoring of patients?

Methods: Automatic Segmentation

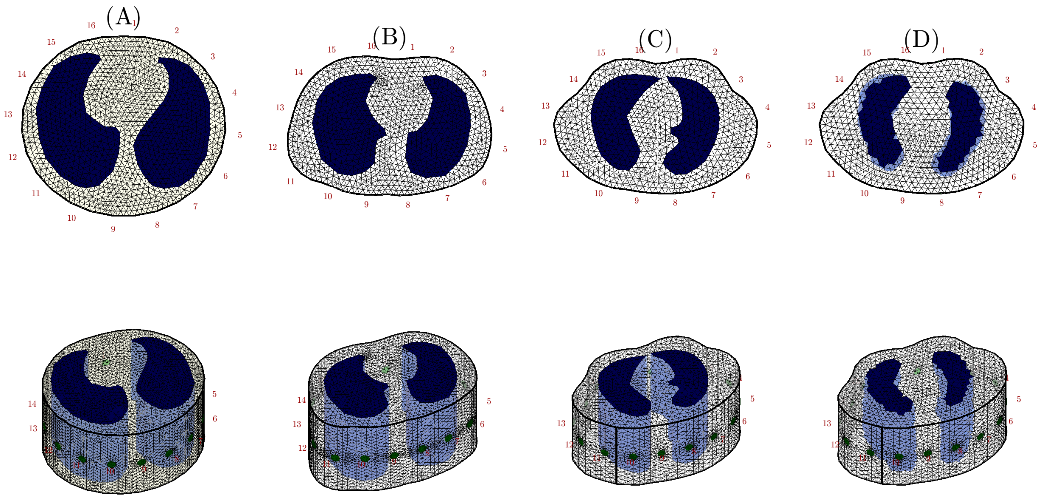


Methods: Manual Correction

Manual Correction

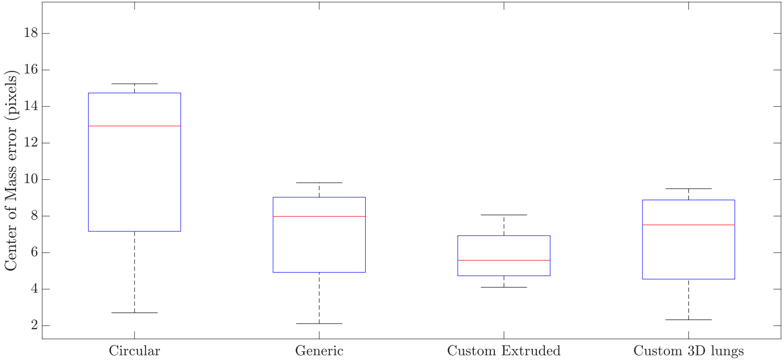


Methods: Meshing



Results

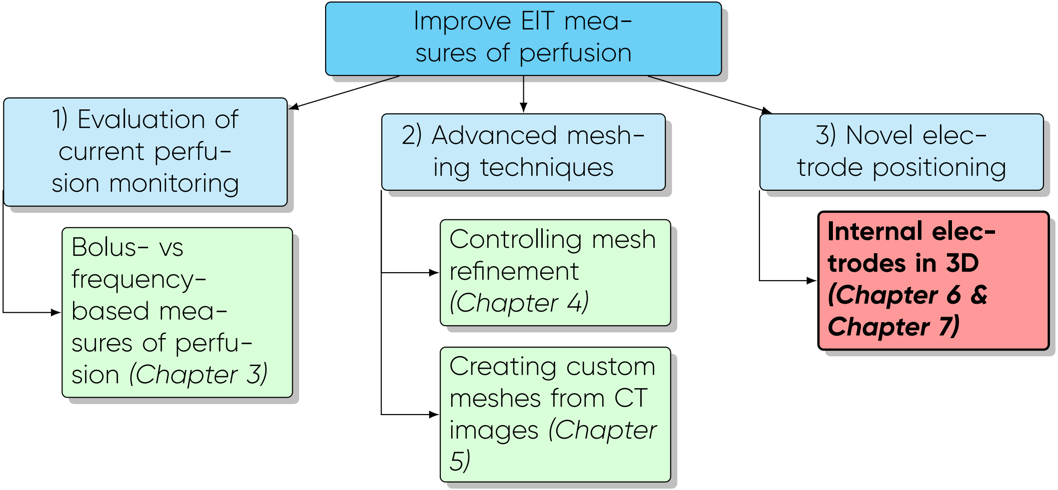
Center of ventilation error relative to the CT centre of ventilation.



Custom model is lower, but not consistently.

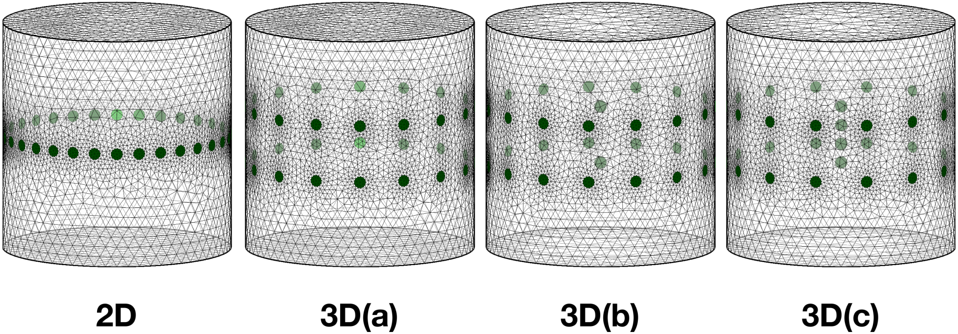
Electrode locations are still unknown...

Chapter 6: Internal Electrode Sensitivity



Introduction

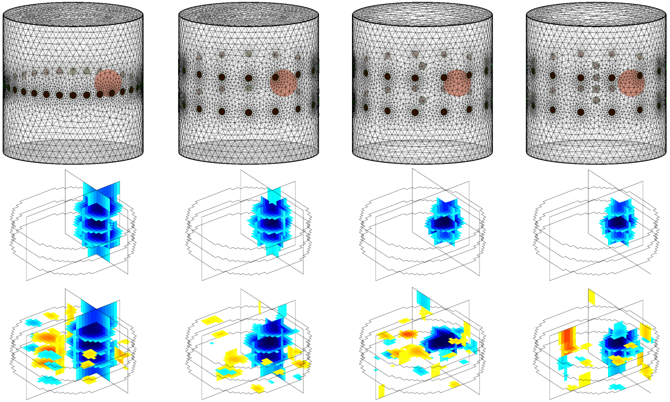
To increase sensitivity in the centre of a model internal electrodes are added.



Typical 2D and 3D configurations are compared to internal electrode configurations.

Chapter 6: Internal Electrode Sensitivity

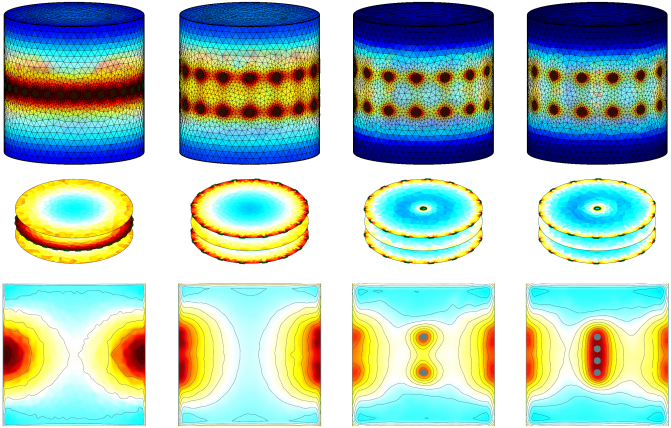
Results



2D 3D(a) 3D(b) 3D(c)

Internal electrodes were used to reconstruct the target closer to actual size.

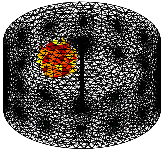
Results

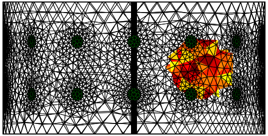


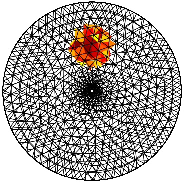
2D **3D(a)** **3D(b)** **3D(c)**

With high sensitivity near the internal electrodes, small internal errors can produce large artefacts.

Introduction



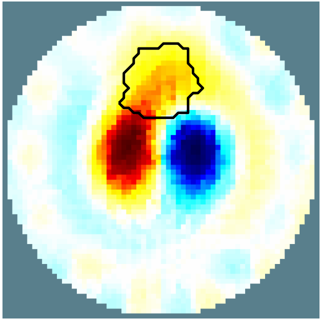


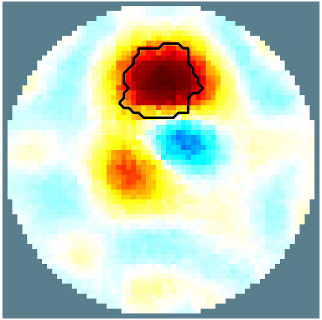


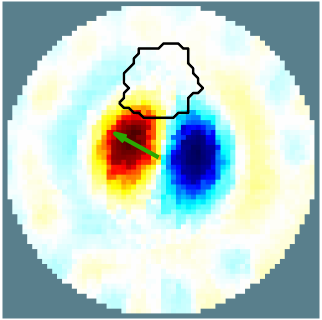
- High sensitivity near the internal probe
- A small amount of movement produces a large artefact

Methods

For a probe is moved 5% of the tank radius:







Regular reconstruction

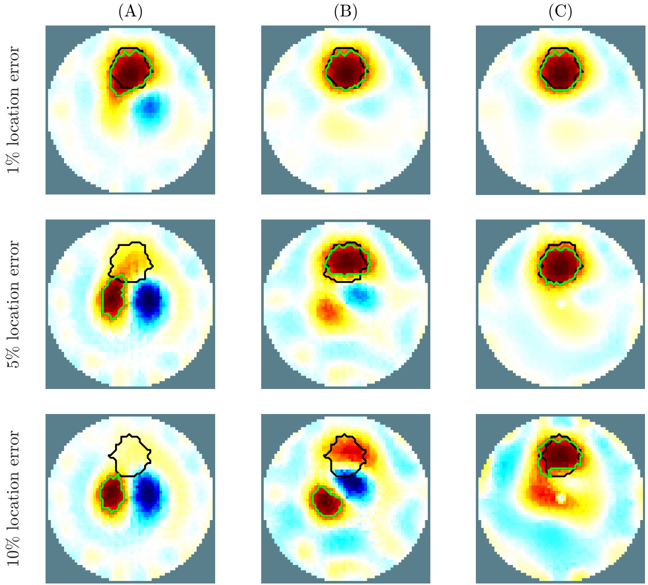
Reconstruction with original motion correction

Reconstructing the effect of motion only

This direction is used to generate a new model for reconstruction

Chapter 7: Internal Electrode Motion

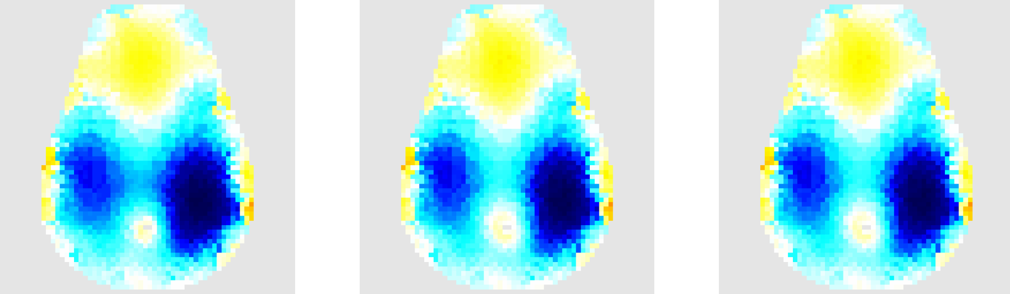
Results



- **A** – No motion correction
- **B** – Regular motion correction
- **C** – Probe position correction

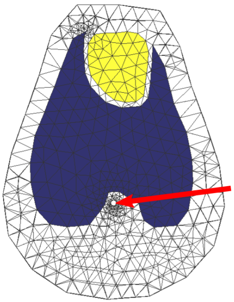
Actual (black) vs. reconstructed (green) target location.

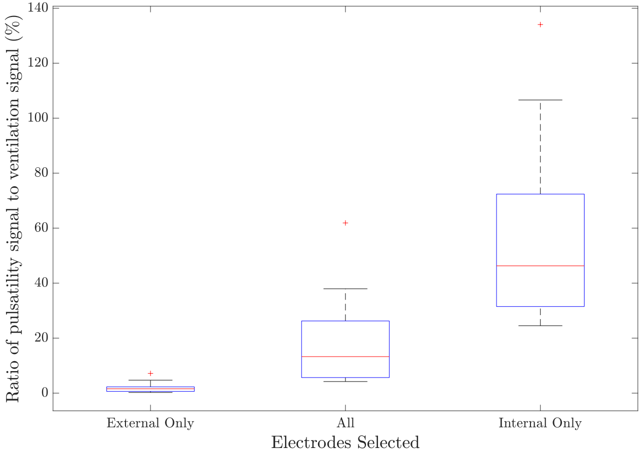
Results



Increased separability of the lungs with regular motion correction (column 2) and probe position correction (column 3)

Results




Ratio of pulsatility signal to ventilation signal (%)
140
120
100
80
60
40
20
0
External Only
All
Internal Only
Electrodes Selected

Summary

This thesis presents:

- Potential for filtering based measures of perfusion imaging
  - limited sensitivity to cardiac frequency
  - challenging to identify the lung regions
- Advanced modelling techniques to improve ventilation and lung localization
- A reconstruction technique used *in-vivo* that was able to correct for probe motion
  - Motion up to 5% of the tank radius in simulation

Future Work

1. Collect data from a range of patients to test automatic segmentation software
2. Meshing tool to control mesh dissipation on complex geometry
3. Validation of the safety of internal electrodes for clinical use
4. Incorporate internal electrode reconstruction into standard reconstruction algorithms (GREIT)

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