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Electrical Impedance Tomography for Perfusion Imaging and Monitoring

Thesis Defence Presentation

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EIT for Perfusion Imaging and Monitoring

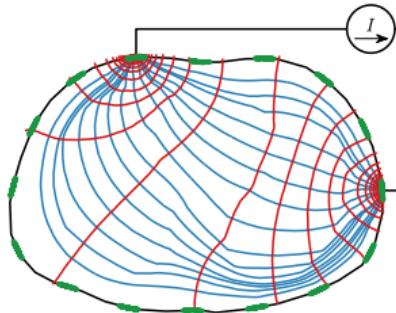
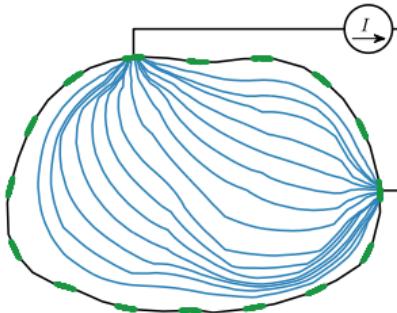
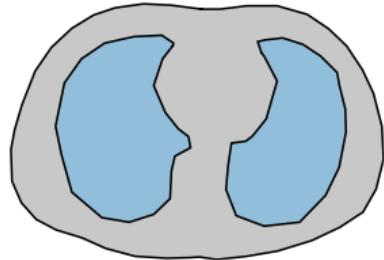
Overview



- ① Background
- ② Thesis Goals
- ③ Contributions
- ④ Methods and Results
- ⑤ Conclusions
- ⑥ Future Work

Background

EIT

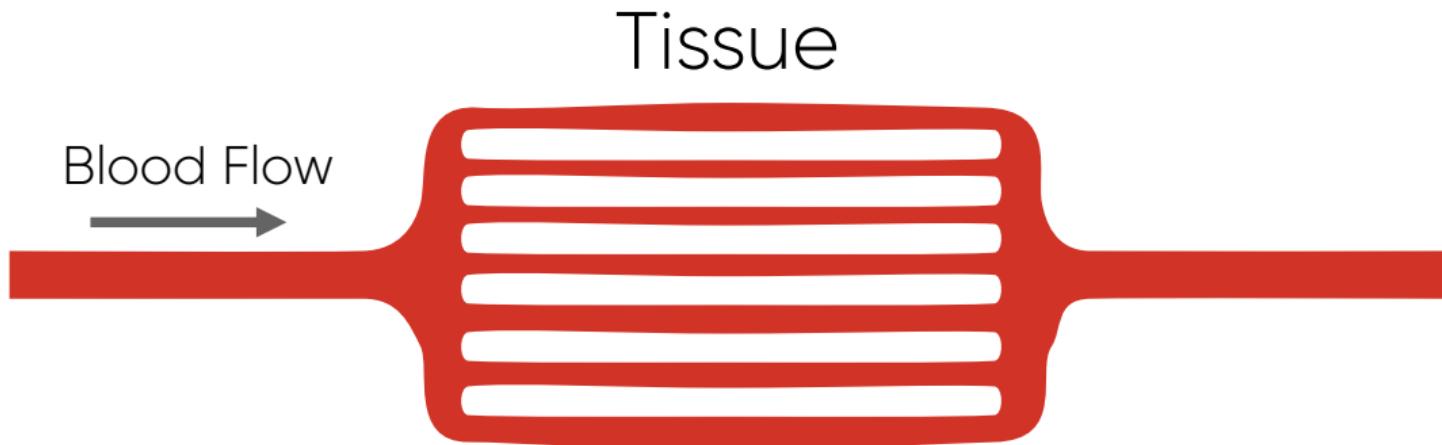


Electrodes on the body surface are used to inject current and measure the resulting voltages.

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

Background Perfusion

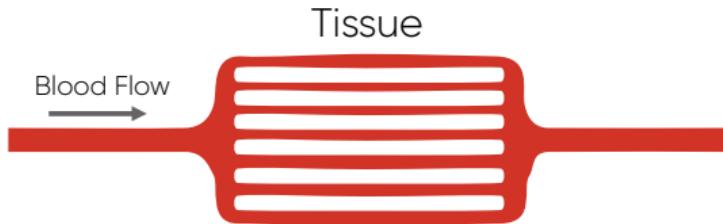
What is **perfusion**?



Background

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)

Background

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 or cardiosynchronous signal
- Low amplitude of cardiac-frequency signal
- Low sensitivity in the center 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

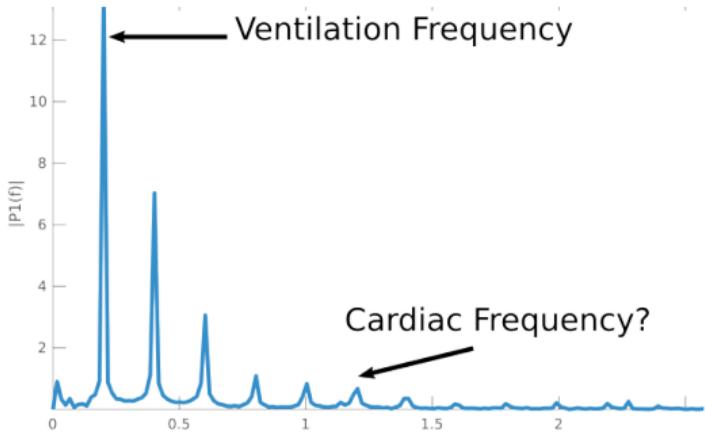
- e.g. Movement

Challenges of perfusion imaging with EIT:

- **Unclear source of cardiac-frequency or cardiosynchronous signal**
- Low amplitude of cardiac-frequency signal
- Low sensitivity in the center of a subject

Background

EIT Perfusion Imaging



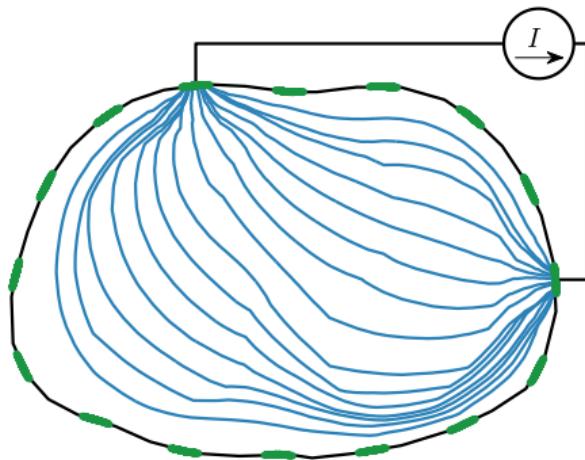
Example FFT of an EIT signal with only external electrodes (**frequency in Hz**).

Challenges of perfusion imaging with EIT:

- Unclear source of cardiac-frequency or cardiosynchronous signal
- **Low amplitude of cardiac-frequency signal**
- Low sensitivity in the center of a subject

Background

EIT Perfusion Imaging



Sensitivity is proportional to current density.

Challenges of perfusion imaging with EIT:

- Unclear source of cardiac-frequency or cardiosynchronous signal
- Low amplitude of cardiac-frequency signal
- **Low sensitivity in the center of a subject**

Background

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

Background

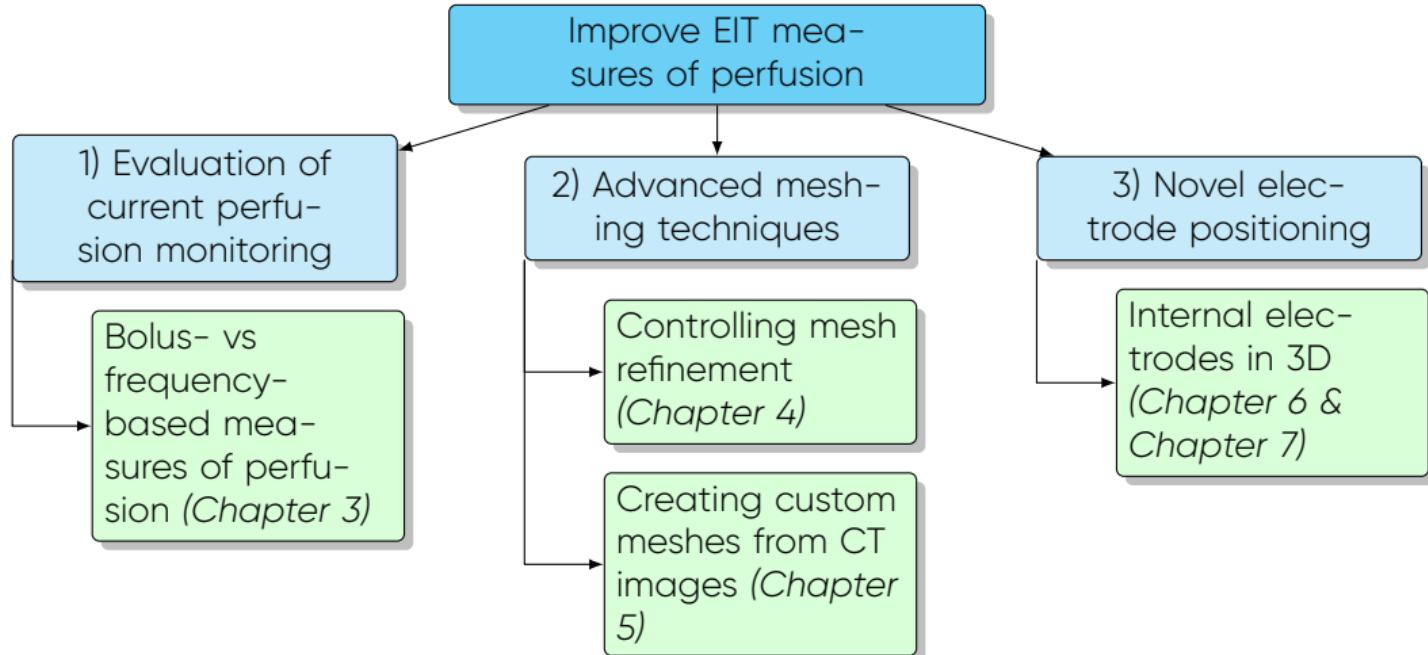
Shortcomings of EIT Perfusion Measures

- ① Bolus-based measures cannot be used continuously and are invasive
- ② Filtering-based methods have low sensitivity to cardiosynchronous activity
- ③ Low internal sensitivity

How can measures of **perfusion** be improved?

- Investigate the source of perfusion and cardiosynchronous EIT signals
- Increase sensitivity near where perfusion is measured

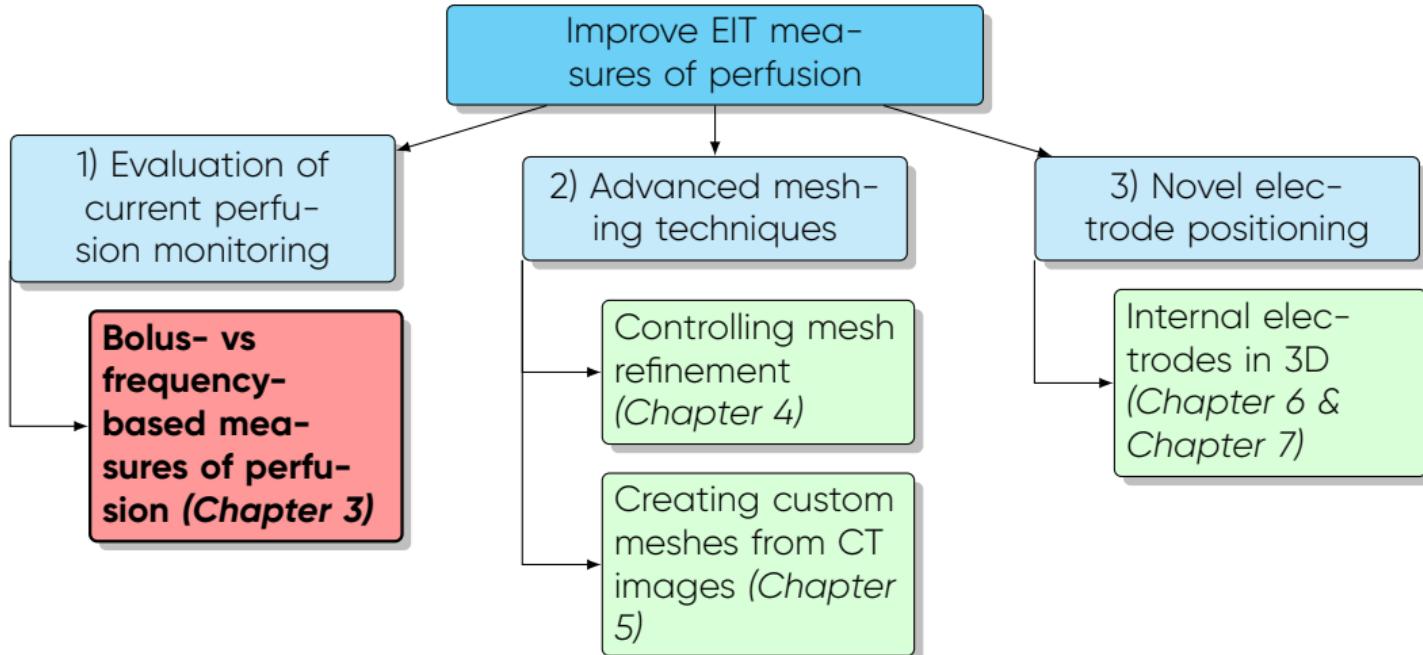
Thesis Goals



Contributions

- 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



Chapter 3: Bolus- and Frequency-Based Perfusion Introduction

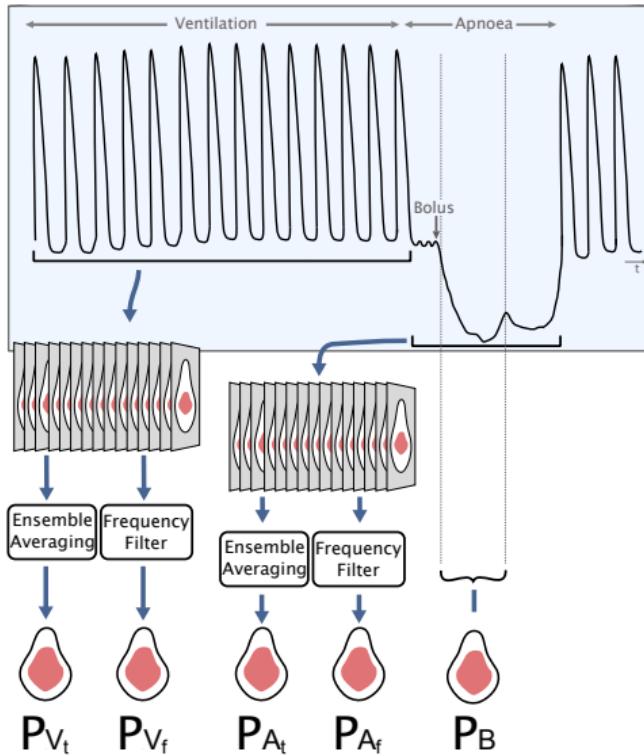
There are **three common techniques** to measure perfusion with EIT.

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

Goals

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

Chapter 3: Bolus- and Frequency-Based Perfusion Methods

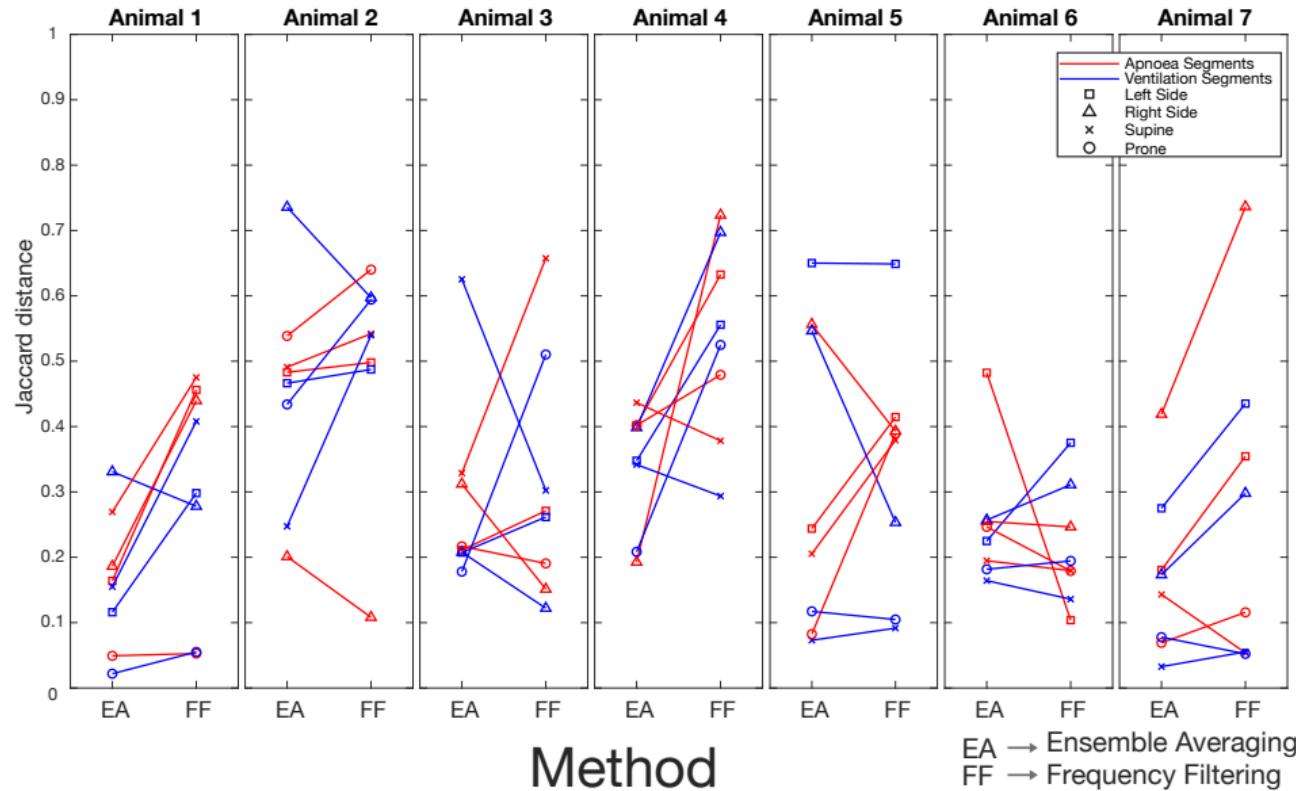


- Data segment with ventilation and apnea segments
- 7 animals, 4 postures (supine, left side, right side, prone)
- Frequency filtering (P_V) and ensemble averaging (P_A) methods used during both ventilation and apnoea
- Compared to a bolus injection during apnoea

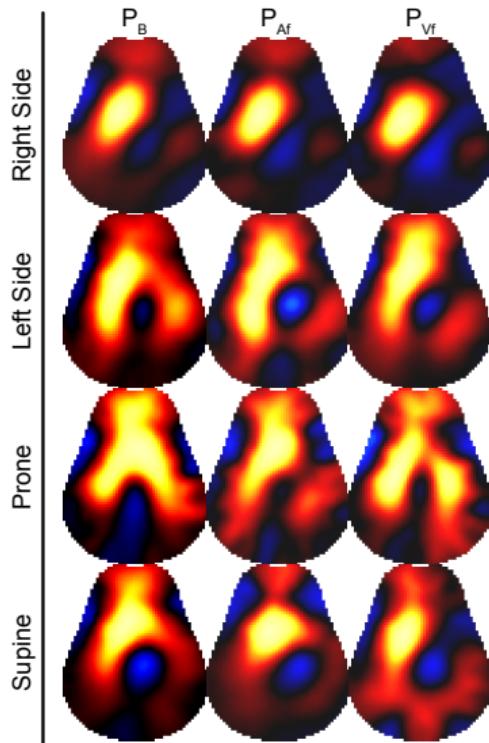
Chapter 3: Bolus- and Frequency-Based Perfusion Results



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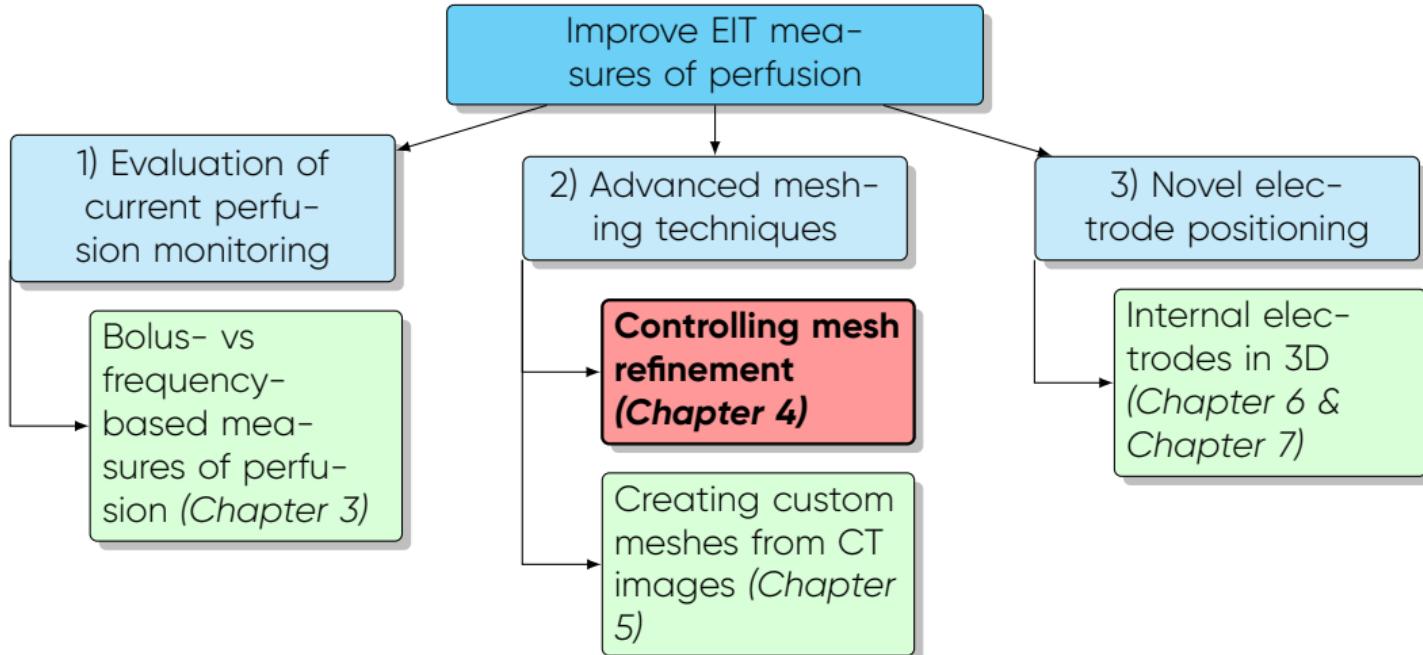


Chapter 3: Bolus- and Frequency-Based Perfusion Conclusion



- 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

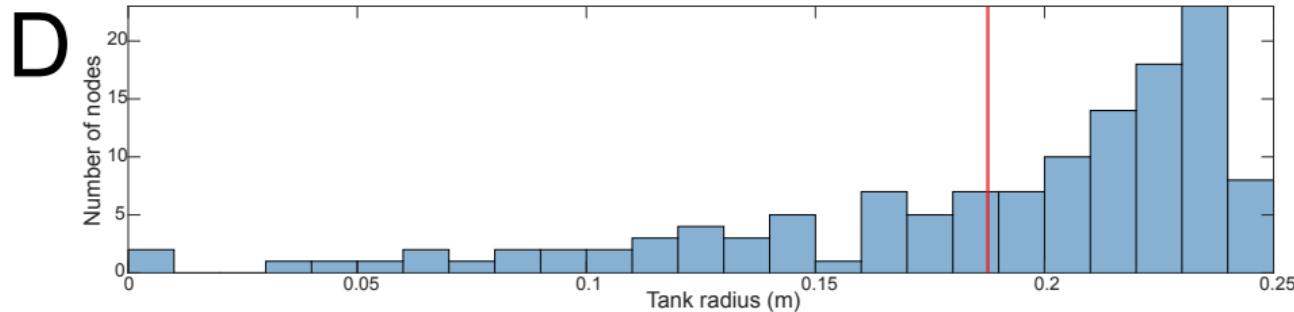
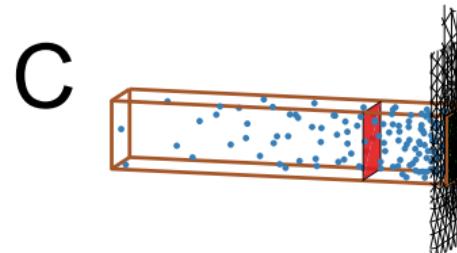
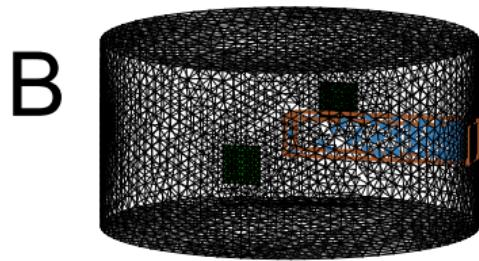
Chapter 4: FEM Mesh Refinement for 3D EIT



Introduction & Methods

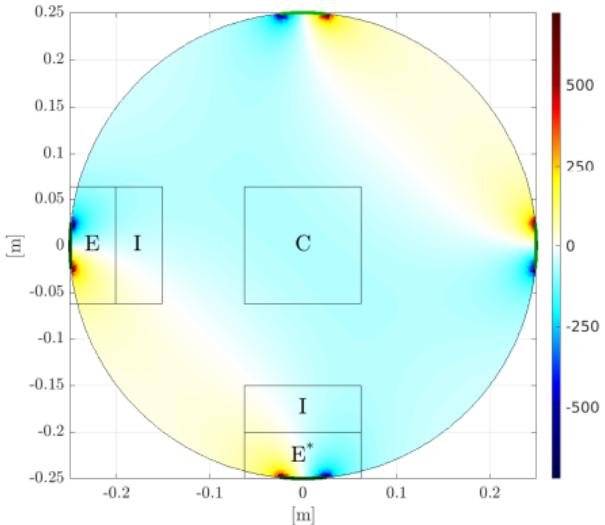


What distribution of nodes minimizes error in the sensitivity calculation?

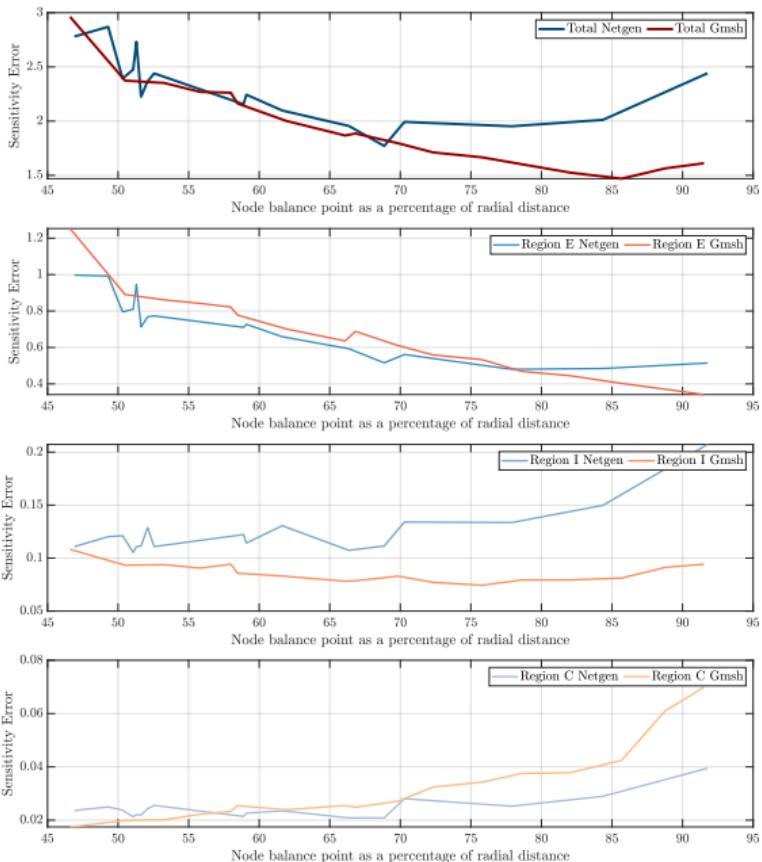


Chapter 4: FEM Mesh Refinement for 3D EIT

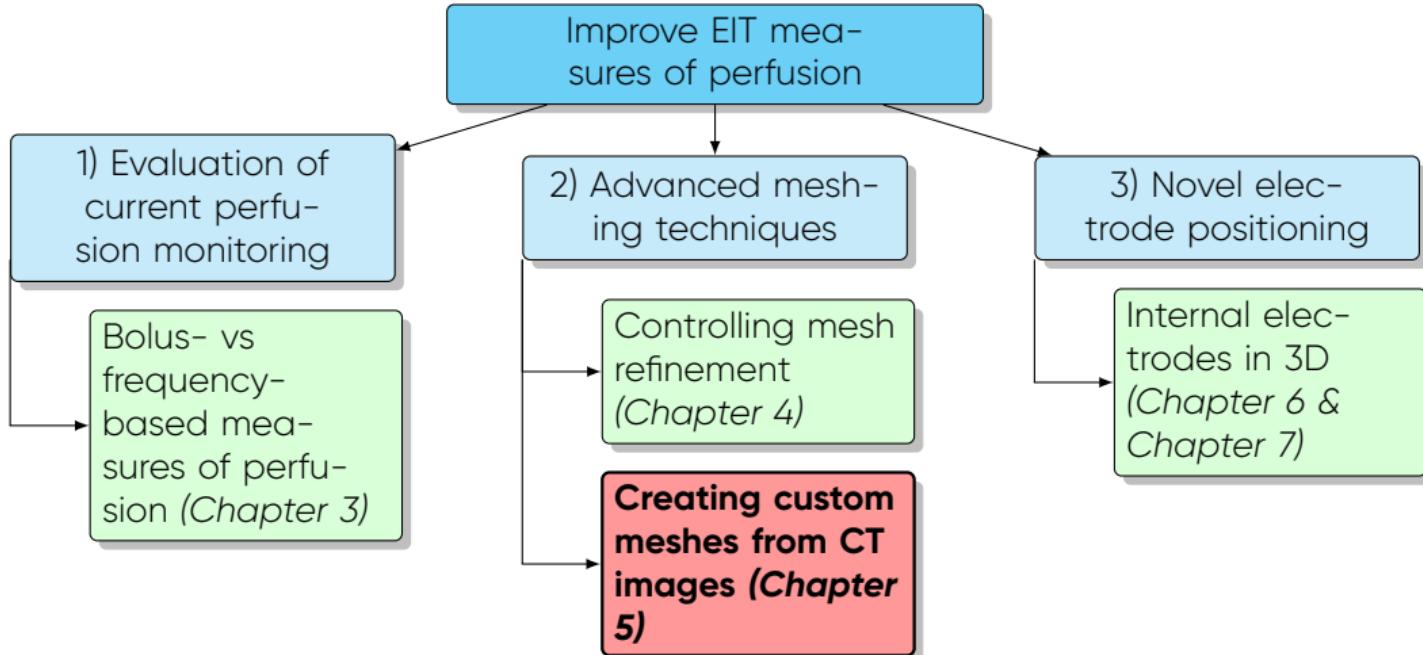
Results & Conclusions



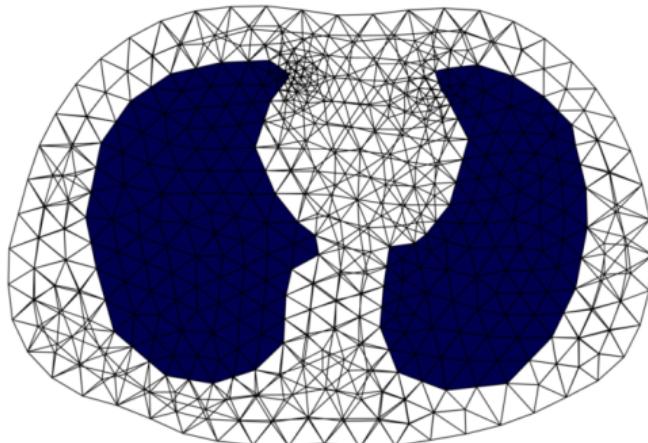
- Lowest error at approximately 80% of tank radius



Chapter 5: Custom EIT Meshes



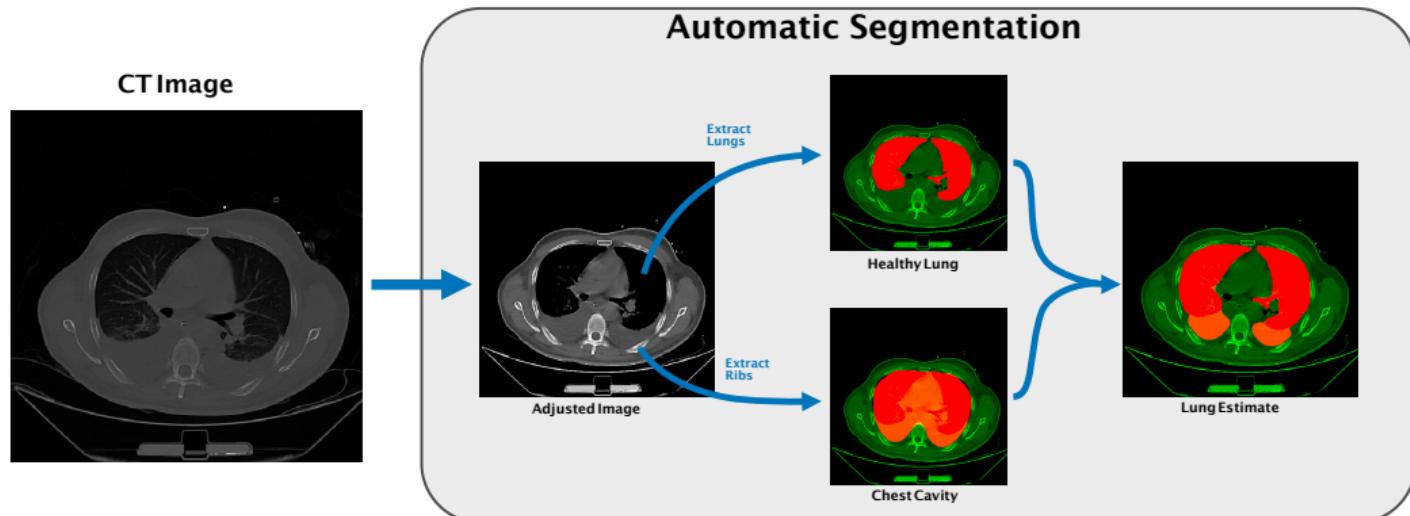
Introduction



- 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

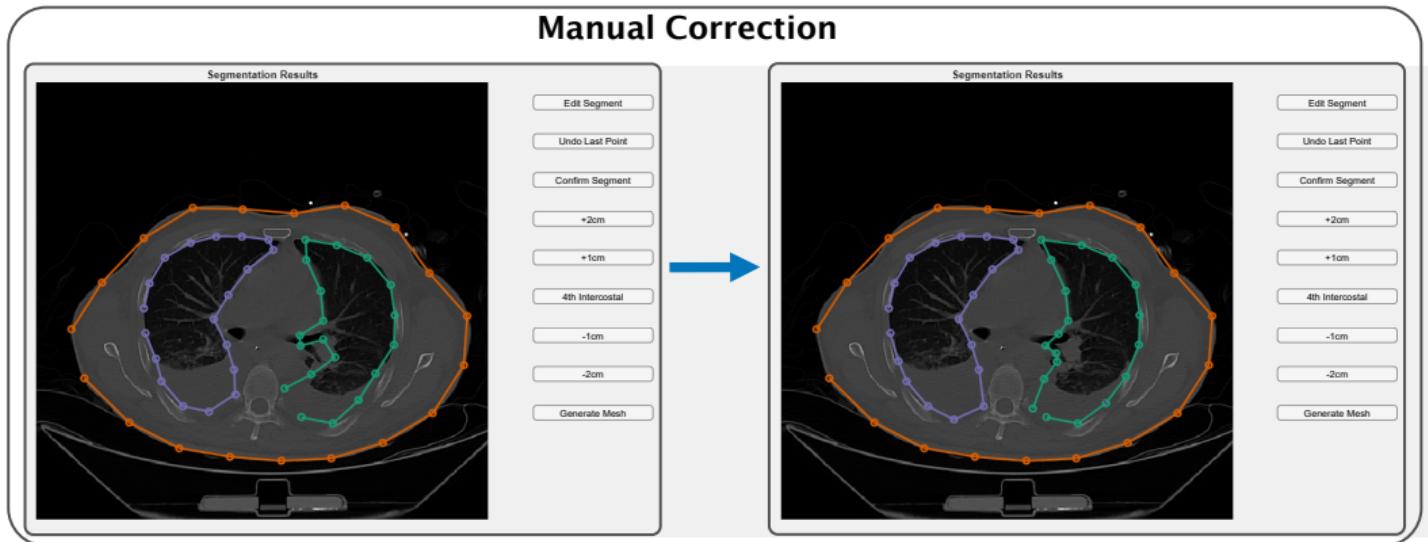
Can we use this to improve EIT image reconstruction and monitoring of patients?

Methods: Automatic Segmentation



Chapter 5: Custom EIT Meshes

Methods: Manual Correction

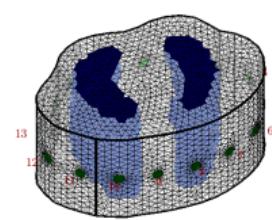
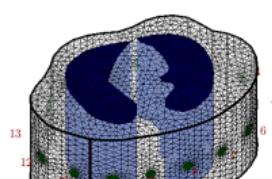
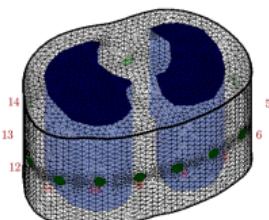
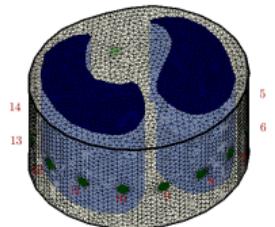
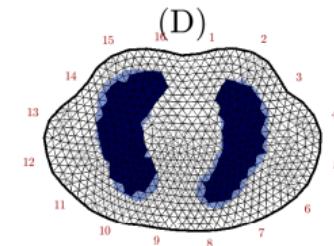
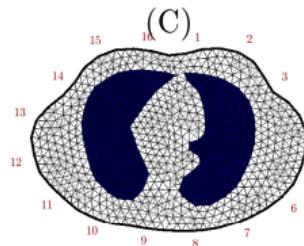
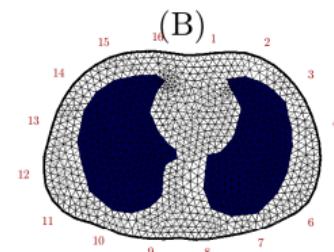
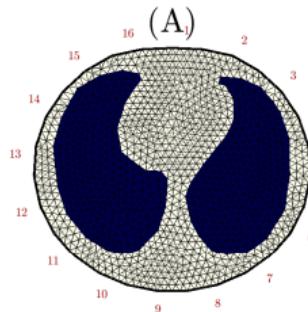


Chapter 5: Custom EIT Meshes

Methods: Meshing



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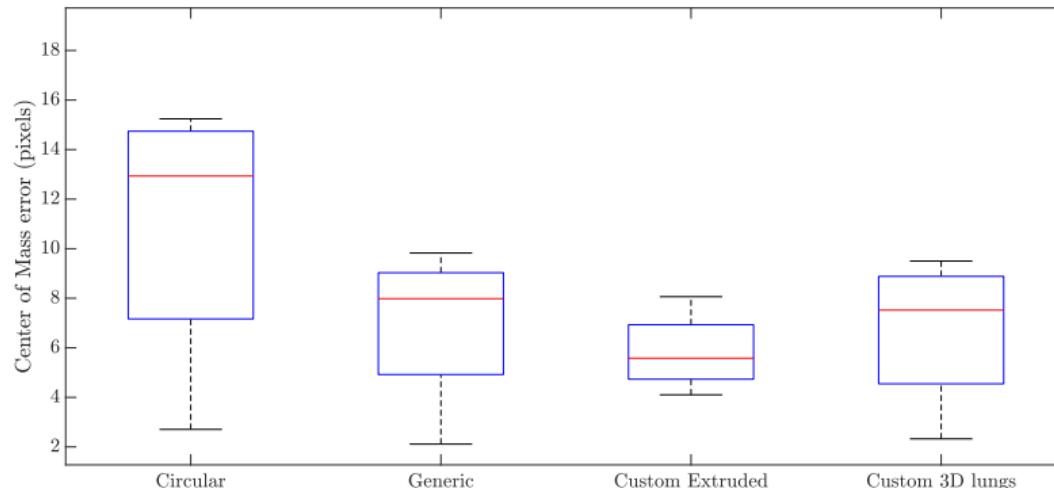


Chapter 5: Custom EIT Meshes

Results & Conclusion



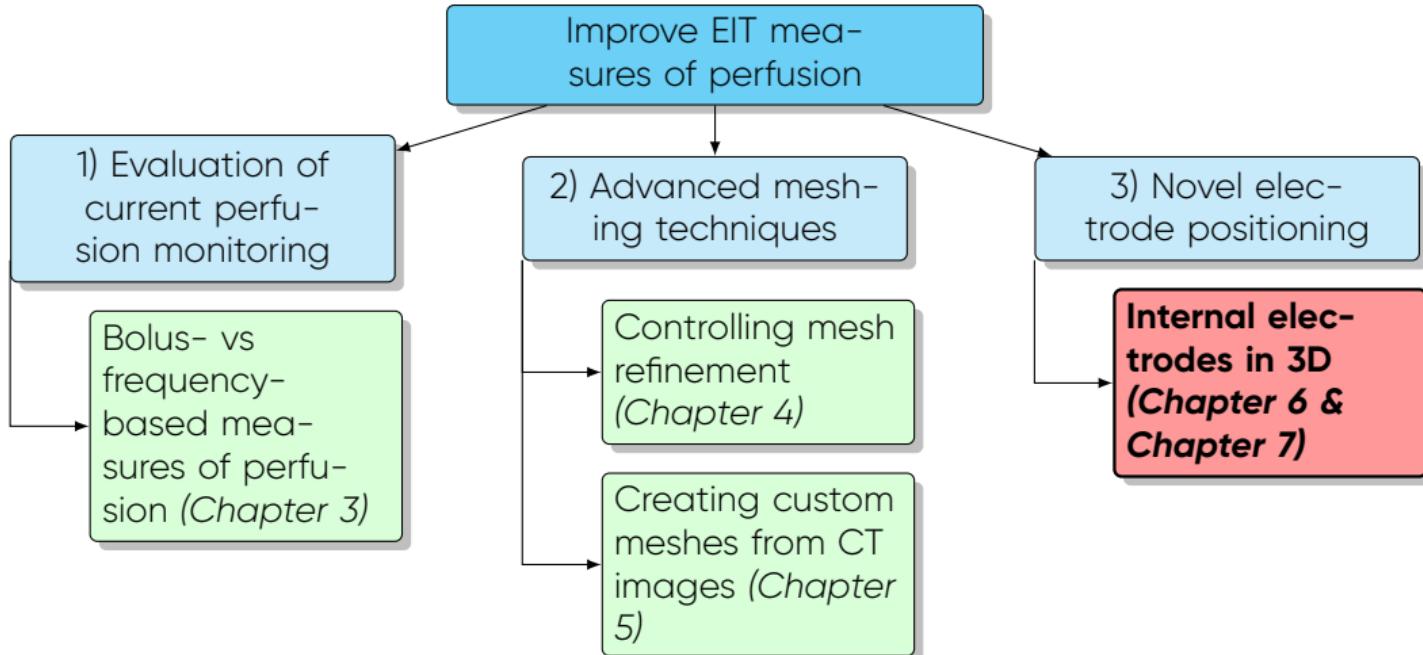
Center of ventilation error relative to the CT center of ventilation.



Custom model is lower, but not consistently.

Electrode locations are still unknown...

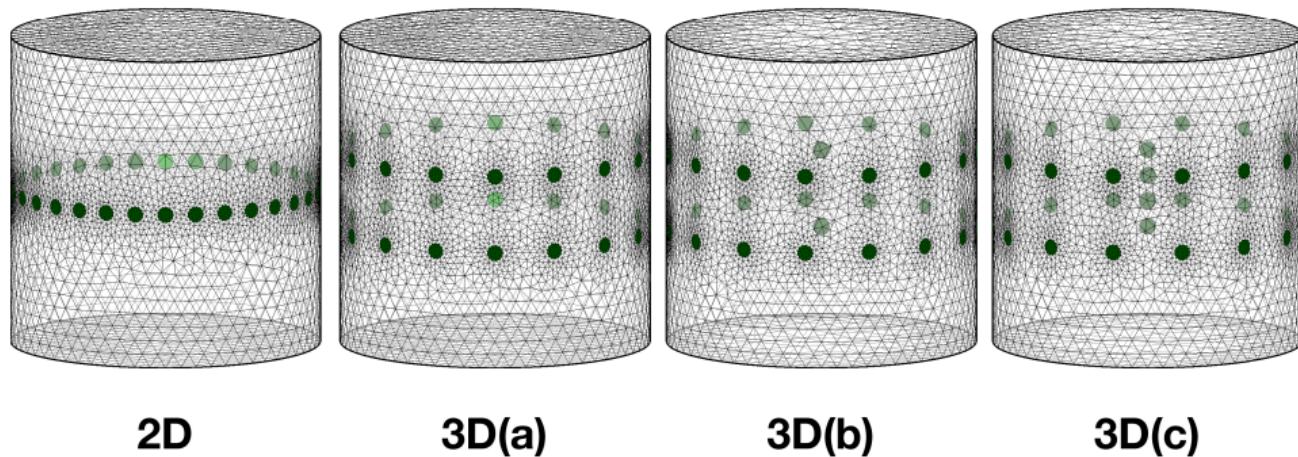
Chapter 6: Internal Electrode Sensitivity



Chapter 6: Internal Electrode Sensitivity

Introduction

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

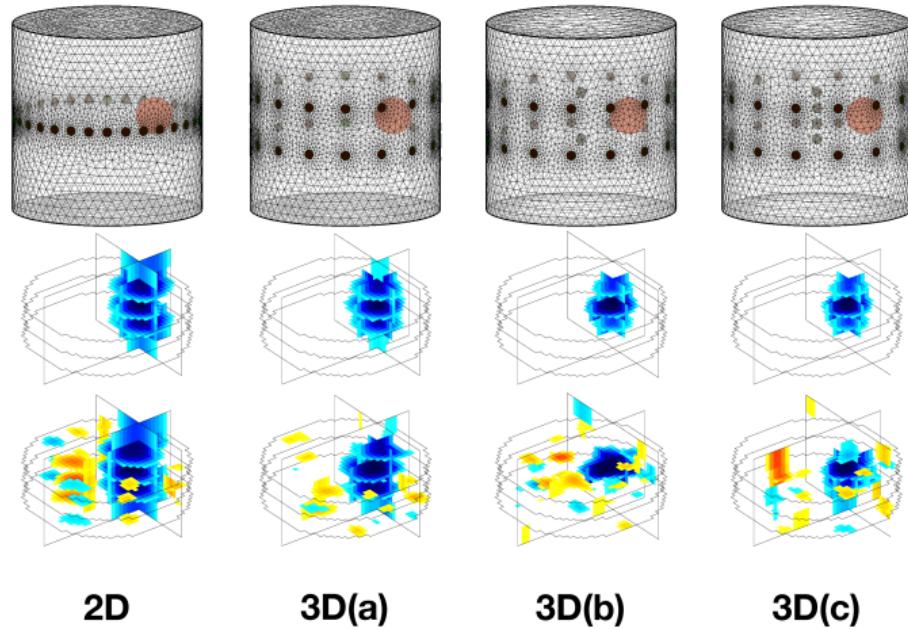


Typical 2D and 3D configurations are compared to internal electrode configurations.

Chapter 6: Internal Electrode Sensitivity Results



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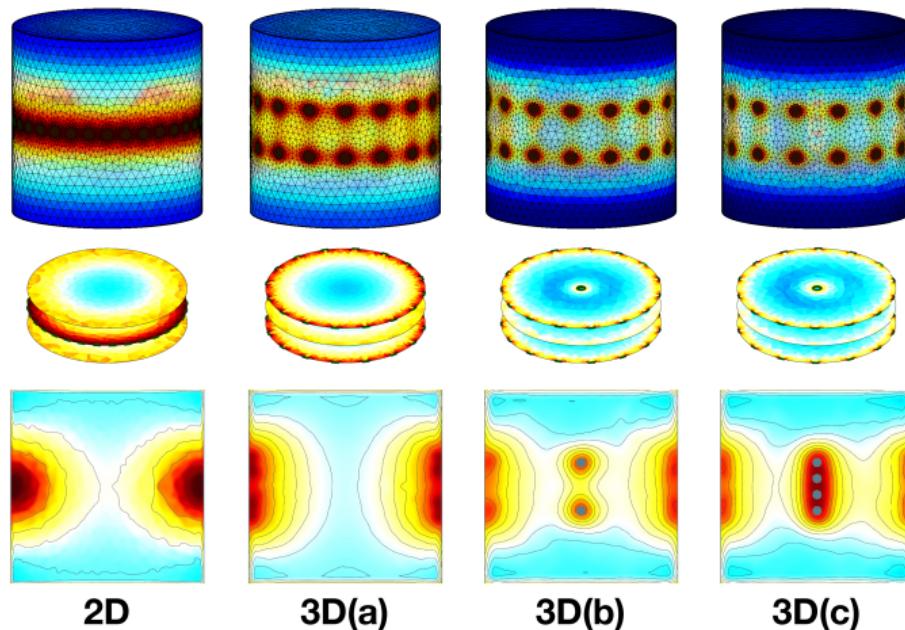
Internal electrodes were used to reconstruct the target closer to actual size.

Chapter 6: Internal Electrode Sensitivity

Results & Conclusion

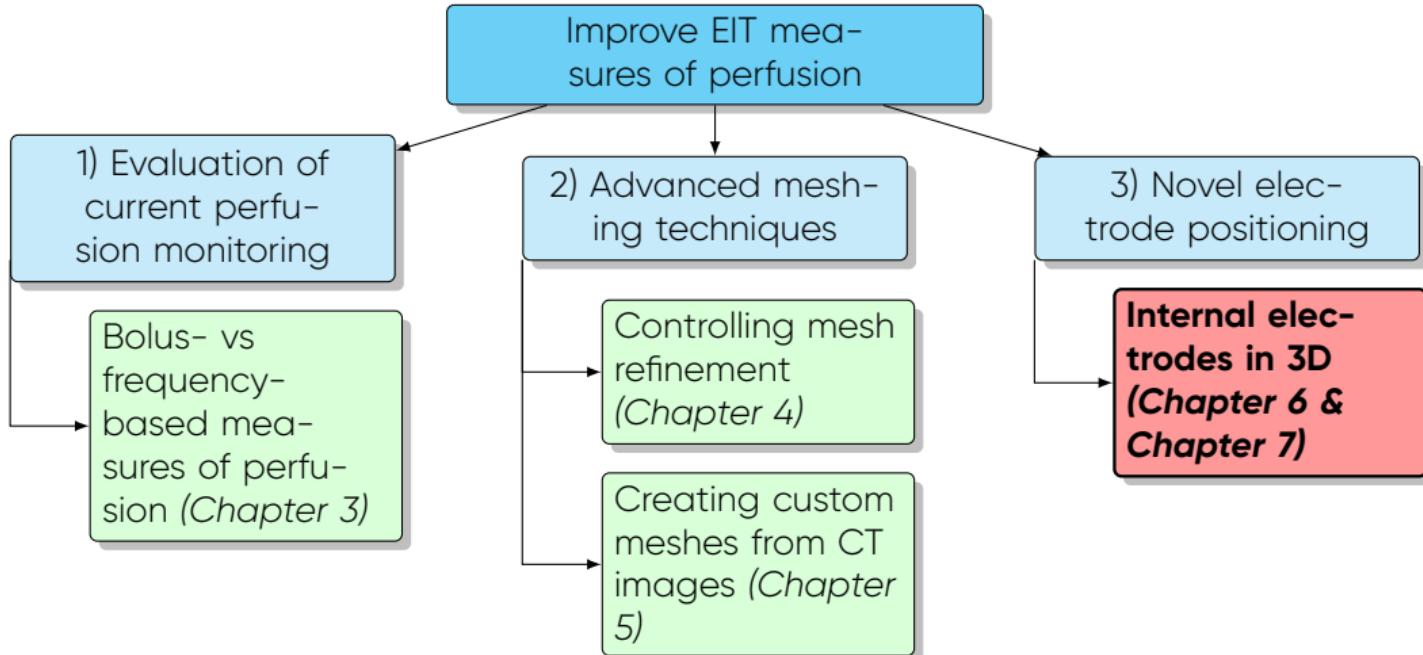


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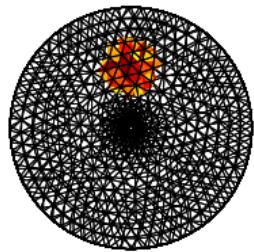
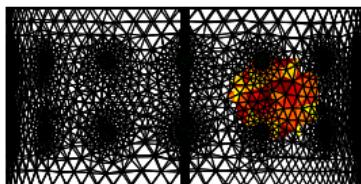
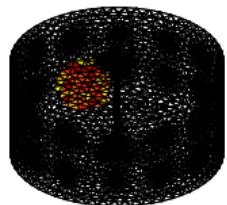
With high sensitivity near the internal electrodes, small internal errors can produce large artefacts.

Chapter 7: Internal Electrode Motion



Chapter 7: Internal Electrode Motion

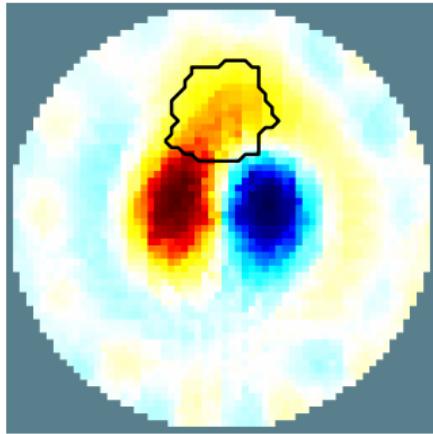
Introduction



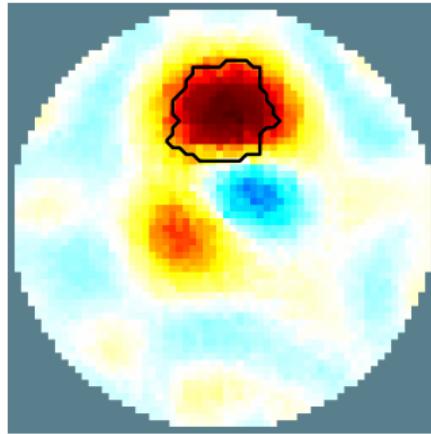
- High sensitivity near the internal probe
- A small amount of movement produces a large artefact

Chapter 7: Internal Electrode Motion Methods

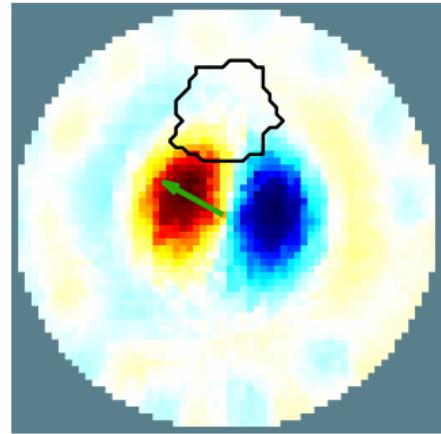
For a probe is moved 5% of the tank radius:



Regular reconstruction



Reconstruction with
original motion
correction



Reconstructing the
effect of motion only

This direction is used to generate a new model for reconstruction

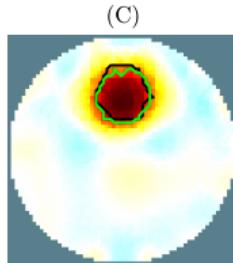
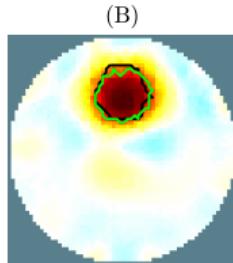
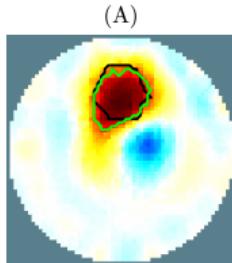
Chapter 7: Internal Electrode Motion

Results

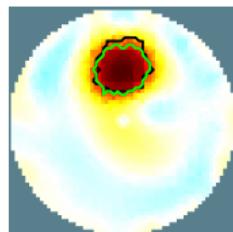
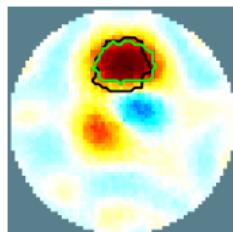
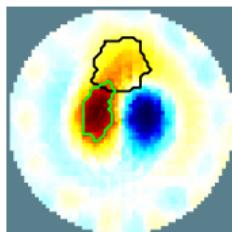


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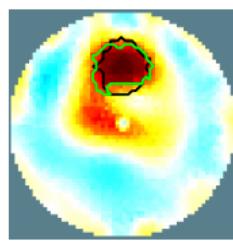
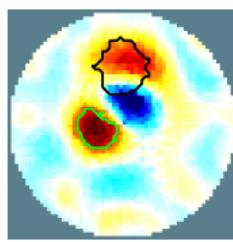
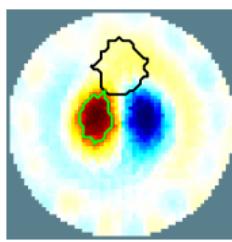
1% location error



5% location error



10% location error



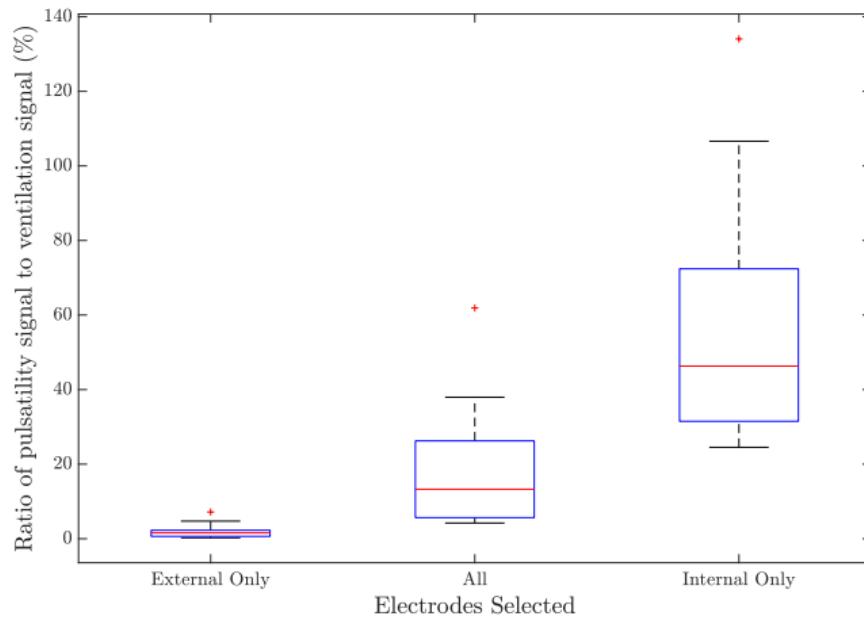
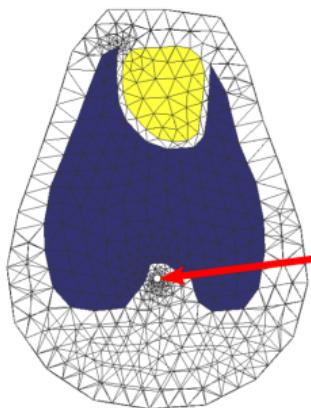
- **A** – No motion correction
- **B** – Regular motion correction
- **C** – Probe position correction

Chapter 7: Internal Electrode Motion

Conclusion



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Conclusion Summary

This thesis presented 5 results chapters:

- ③ Comparison of currently used perfusion measuring techniques
- ④ Technique to measure and set mesh distribution to reduce error in sensitivity calculations
- ⑤ Tool to create custom meshes from CT images
- ⑥ Analysis of 3D electrode placements with internal electrodes on internal sensitivity
- ⑦ Method to reconstruct images using internal electrodes in the presence of movement

Conclusion

Future Work

- ① Test the automatic segmentation tool on a number of subjects
- ② Determine the effect of incorrectly modelling the electrode location on custom meshes
- ③ Explore the safety requirements for using internal electrodes for current injection and measurement
- ④ Additional modifications to GREIT to improve reconstructions with internal electrodes
- ⑤ Directly calculate the location of the probe from the reconstructed image



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