Chapter 8

Conclusion

This thesis investigated the role of mesh refinement and internal electrodes in perfusion imaging. EIT has very low sensitivity in the centre of the thorax where majority of the perfusion changes of interest occur. The source of the cardiosynchronous EIT signal is also controversial, and many factors may contribute to the measured perfusion signal. This thesis presents several contributions to the field of perfusion imaging in EIT. We investigated the limitations of current EIT perfusion imaging and compared the difference between measures of perfusion using a contrast agent and those relying on the cardiosynchronous signal. A technique to control mesh refinement was developed to enable meshes with adequate sensitivity accuracy throughout an entire model. This technique can also guide refinement strategies in high sensitivity regions surrounding internal electrodes. A 3D EIT configuration is presented with 4 internal electrodes that gives high sensitivity in the centre of the model, and accurately reconstructs a conductive target in the presence of Gaussian measurement noise. Finally, we develop a method to calculate movement of an internal probe and correct for positioning error in a model. Electrode motion can add artefacts to images that overpower the component of interest, and background noise to the reconstructed images. This technique uses charactersitic information in the reconstructed image related to probe movement to estimate the actual probe location and create a corrected model. The corrected model reduced the effect of movement on reconstructed images.

8.1 Summary of Findings

Chapter 3 compared two established methods of perfusion imaging and found that perfusion estimation techniques using cardiosynchronous signals were comparable to bolus injection methods. Despite the different signal origins, both techniques resulted in similar perfusion estimates. One of the challenges with both bolus- and filtering-based perfusion imaging is the unwanted contribution of blood flow in the heart. In 2D images that have low sensitivity in the centre of a subject, it is challenging to identify and correctly remove the contribution of the heart from the perfusion signal.

In chapter 4 we explore techniques to improve sensitivity accuracy in meshes, and ensure mesh density is adequate around electrodes. When mesh density dissipates evenly away from electrodes, we recommend the balance point of the nodes in a mesh should be towards the electrodes. A balance point is at 80% of the distance between the lowest sensitivity region of a model and the electrodes minimized error when calculating sensitivity. This recommendation can be used to generate meshes that are highly accurate when calculating the sensitivity, with fewer elements than meshes that are uniformly refined.

In chapter 5 a tool to generate accurate, custom meshes from CT images was presented. This tool automatically segmented the lung and external boundaries from CT images, and allowed manual verification of the segmented boundaries. The segmented boundaries were used to generate custom EIT meshes. Ventilation images on a small number of subjects showed a small improvement over generic models when measuring the centre of mass of the ventilated region. The tool created meshes with individualized, accurate boundaries for patients with CT data.

Chapter 6 presented a sensitivity analysis and simulated reconstruction accuracy of novel electrode configurations with internal electrodes. These simulations show an increased sensitivity in internal regions. Reconstructions of a conductive object also show that internal electrodes can reconstruct the location of a conductive target in the presence of noise. From this work we determined that internal electrodes could be used in 3D to image conductivity changes within the body and could improve sensitivity to internal conductivity changes.

In chapter 7 we analyze the effect of motion on reconstructed images with internal electrodes. Moving the probe only 1% of the model radius added artefacts to images reconstructed without motion correction strategies. Available motion correction techniques reduced the impact of electrode movement up to 5% of the tank boundary, but still showed an increase in image noise. We present a technique to reconstruct motion artefacts and use these images to estimate the true probe location. A new model with the new probe location was used to reconstruct images. Images reconstructed with the new technique accurately located a conductive object when the probe moved up to 10% of the model radius between measurements, and reduced noise in all probe movement scenarios.

8.2 Future Work

There are several avenues that could be explored further from the work and projects presented in this thesis.

- Work is currently underway to test the automatic segmentation tool on a wider number of subjects. We are currently working with the Peking Union Medical College in Beijing, China to obtain more CT and EIT data from ARDS patients.
- The effect of electrode placement errors on reconstruction accuracy when creating custom meshes from CT images is unclear. Incorrectly modelled electrodes degrade reconstruction accuracy (Boyle and Adler, 2011), and incorporating the correct electrode location into the custom meshes could yield more accurate EIT images. We discuss some possibilities in chapter 5 to identify the correct electrode locations, including using photographs to identify electrode locations and estimating electrode placement from the movement jacobian. Chest expansion can have a large effect on EIT images (Adler *et al.*, 1994), and may impact the accuracy of a custom model as the patient moves. Correctly modelling the impact of electrode and boundary movement during breathing could help to improve reconstruction accuracy.

- When creating meshes from CT images, errors often occur when electrode placement does not work well on the irregular boundary. There is a need for a method to facilitate meshing and electrode placement on arbitrary boundary shapes. Some existing techniques allow electrode placement on arbitrary mesh surfaces (Grychtol and Adler, 2013), but these techniques do not natively offer features for advanced mesh refinement control or use with internal structures.
- Further work is required to determine the safety requirements for internal electrodes in human use. The IEC guidelines (International Electrotechnical Commission, 2021) have strict requirements for the injection of electrical current near the heart, and the current density on internal electrodes should be examined to ensure that it does not exceed current safety standards. It is also possible to use internal electrodes without injecting currents internally, but this could reduce the sensitivity benefits found when using internal electrodes. Further investigation could determine the if there are benefits to using internal electrodes for voltage measurements alone.
- When reconstructing images using internal electrode with GREIT, internal electrode motion caused artefacts in the image. We plan to create an addition to GREIT that enables reconstruction of internal electrodes with internal probe movement. It is not clear which aspect of the electrode motion introduces extra artefacts in GREIT.
- It has been suggested that the contact impedance of internal electrodes should be matched to the external electrodes (Nasehi Tehrani *et al.*, 2012b), but it is not clear to what degree differences in contact impedance and size impact

the reconstruction. An investigation into the ideal size, shape and electrical properties of internal electrode could help to inform their use in a clinical setting.

- The novel technique introduced to correct for probe location uses reconstructed images to determine the position of the internal probe. Further investigation is required to determine if the electrode position can be calculated directly from the reconstruction matrix. Previous work has shown that the movement direction of individual electrodes can be calculated directly from the reconstruction matrix (Soleimani *et al.*, 2006), but this technique does not reconstruct for position. A comparison between techniques to compare the accuracy of each could help to estimate the probe locaiton more accurately more accurately.