Regional lung compliance: Coupling ventilation and electrical data

Henry Tregidgo[1], Michael Crabb[2], William Lionheart[3]

[1]University of Manchester, Manchester, UK, henry.tregidgo@postgrad.manchester.ac.uk
[2]michael.crabb@postgrad.manchester.ac.uk
[3]bill.lionheart@manchester.ac.uk

Abstract: Before it is possible to use EIT for respiratory monitoring of critical care patients, regional conductivity must be converted to useful diagnostic parameters. This work proposes a road map for dynamically retrieving quantities, such as lung compliance, from data available at the bedside. Combining electrical and ventilator data with other imaging modalities such as MRI or CT where available.

1 Introduction

In a clinical setting it is difficult to interpret the physical meaning of conductivity reconstructions. For EIT to become a useful diagnostic tool we need to have a model in place for converting a conductivity image into more clinically relevant parameters.

Models of the lungs generally focus on a static relationship between air volume and pressure, leading to parameters such as compliance. Hence an obvious approach would be to estimate the air volume fraction from local conductivity. Due to the high temporal resolution EIT provides, an ODE model could allow calculation of the other dynamic parameters such as airflow resistance, and even model the effects of high frequency oscillatory ventilation.

This work sets some research directions for improved retrieval of useful clinical parameters and anticipated challenges in their completion.

2 Research Directions

We believe that the essential steps required to retrieve useful information from EIT must include:

1. Segmenting regions in the chest cavity and assigning specific micro-structures to these sections of the reconstruction,
2. Determining the air volume fraction change from the change in conductivity,
3. Calculating regional air volume from air volume fractions,
4. Using an ODE model to calculate the required diagnostic parameters.

2.1 Chest Segmentation

Defining likely contents of specific anatomic regions in advance has several uses. These include refining models for retrieving air volume fractions as well as labelling functional units of the lung for which diagnostic parameters will be required.

MRI and CT data can be used to segment specific regions of the chest cavity and assign properties to them based on anticipated microstructure. It would then be necessary to model how this structure changes during the breathing cycle. This modelling will require coupling of neighbouring regions through mass and volume conservation, as well as comparisons with typical deformations of the lung, chest cavity and abdomen under forced ventilation.

2.2 Air Volume Fractions

We would like to create a homogenisation scheme, mapping an underlying microstructure to bulk conductivity. We will then need to invert this to find the air volume fraction of a region from reconstructed conductivity values. The assumed microstructure can be as simple as spherical inclusions dispersed in a homogeneous substrate [1], or can further reflect the anisotropic structures identified while segmenting the lung image [2].

However, air content is not the only quantity which will affect the bulk conductivity. In addition other features such as blood flow or lung fluid content may need to be incorporated. This could be done by combining heart rate and blood pressure measurements with dispersion relations from multi-frequency EIT to discern blood content.

2.3 Regional Air Volume

As previously noted, at different times throughout the breathing cycle the domain will have deformed, changing the physical volume occupied by the lung. The volume change is non-uniform, complicating the conversion of air volume fractions to regional volumes. Models created for chest segmentation could help with this problem while the ventilator itself provides information on the amount of air passed into the lung, which can be used to constrain the total air volume within the lung.

2.4 ODE Coupling

We can model each functional unit of the lung as a simple physical system with parameters such as compliance and resistance. Different functional units of the lung can be coupled through their physical locations. We can use the calculated air volume fractions as states of a time series differential equation, and set up a series of coupled second order ODEs relating the air volume, flow and pressure states of the system [3]. Using the airway opening measurements as constraints, we can use techniques from inverse problems for ODEs to estimate the clinically meaningful parameters.

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Systems and Computer Engineering
Carleton University, 1125 Colonel By Drive
Ottawa, Ontario, K1S 5B6, Canada
adler@sce.carleton.ca
+1 (613) 520-2600

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