IMPEDANCE IMAGING OF LUNG VENTILATION: DO WE NEED TO ACCOUNT FOR CHEST EXPANSION?

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ABSTRACT - **Electrical Impedance Tomography uses surface electrical measurements to image changes in the conductivity distribution within a medium. When used to measure lung ventilation, however, measurements depend both on conductivity changes in the thorax and on rib cage movement. Given that current reconstruction techniques assume that only conductivity changes are present, certain errors are introduced. We use a finite element model to calculate the effect of chest expansion on the reconstructed conductivity images. Results indicate that thorax expansion accounts for approximately 20 percent of the reconstructed image amplitude, and its contribution is relatively independent of inspiration depth. We propose that chest expansion can contribute significantly to the conductivity images of lung ventilation, and should be taken into account in interpreting these images.**

Introduction

One of the promising applications of Electrical Impedance Tomography (EIT) is in cardio-pulmonary monitoring of intensive care patients. The phenomena of interest, lung ventilation, lung perfusion, cardiac output, and lung fluid content, induce conductivity changes large enough to be measured by EIT. The principal advantages of EIT in a monitoring environment are that it is non-invasive and minimally cumbersome.

All imaging algorithms which have been proposed for EIT reconstruct the conductivity distribution assuming that the electrical measurements depend uniquely on the conductivity (for example see [1]). Respiratory activity, however, causes a movement of the chest as much as 10 percent of the anterior-posterior dimension. In this paper we describe the effect of this movement on the EIT measurements and on the reconstructed conductivity distribution.

Finite Element Model

Although the three dimensional movement of the rib cage is complicated, movement in the upper chest can be approximated as an up-down movement of the sternum and the anterior portion of the ribs while the posterior portion of the ribs remains fixed at the spine. We model this movement in two dimensions as a uniform outward expansion of the rib cage. In order to simulate the effect of this movement on EIT measurements, we use the finite element model in figure 1. Elements drawn with thicker lines form the lungs, the arrows pointing toward the thorax show the location of the electrodes, and the arrows pointing outward show the displacement of the rib cage during inspiration.

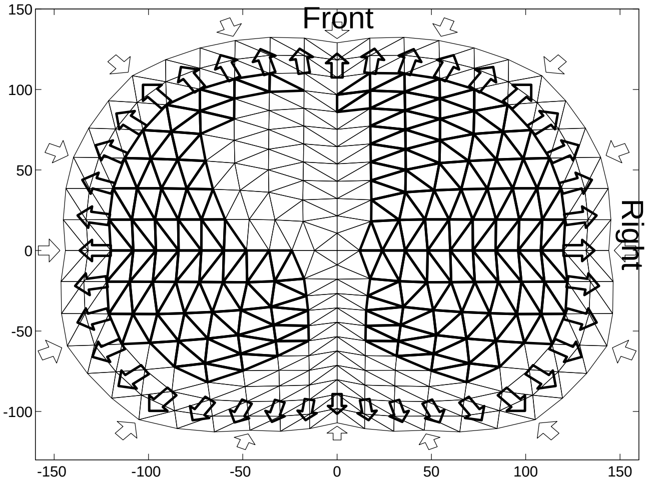

Figure 1: Finite Element Model of the electrical and mechanical properties of the Upper Thorax.

Using the finite element method to solve the equations of elasticity[2], the displacement of all nodes can be calculated as a function of the applied displacements, the model geometry, and the elastic properties of each element. In our model, we specify the lungs as having one tenth the rigidity of the surrounding tissues. Our calculations indicate that the movement is not significantly affected by the actual values used for the rigidity of the lungs, providing the lung rigidity is much less than the surrounding tissues. During inspiration, most of the space created be the movement of the rib cage is filled by the expansion of the lungs.

A set of EIT measurements for a given thorax geometry and conductivity distribution is simulated using the same finite element model while solving for the electrical potential due to the application of currents between each pair of electrodes.

Image Reconstruction

We use a dynamic image reconstruction algorithm based on a regularised inverse of the sensitivity matrix calculated from the finite element model of the thorax[3]. This technique calculates the change in conductivity distribution in a medium during the interval t_1-t_2 given sets of EIT measurements $\mathbf{V}_1$ at time t_1, and $\mathbf{V}_2$ at time t_2. In order to represent the amplitude of the conductivity changes we define the image energy, E_{img}, as the sum of all image pixels. This measurement is roughly proportional to the product (area)×(conductivity change) of a region of interest and is relatively constant with respect to the radial position of the region.

Dynamic image reconstruction presents two advantages in this application. It linearises the image reconstruction, allowing fast algorithms for viewing of conductivity changes, and is insensitive to the variations in electrode contact resistance and placement which remain stable between measurements. This property is important in this application as it is difficult to measure the positions of the electrodes with high accuracy.

Results

In order to model the worst case effect of the chest movement on EIT image reconstruction in the thorax, we calculated the measurements due the largest normal changes in lung conductivity and rib cage movement during breathing. Lung conductivity was modelled to change from 120 mS/m to 60 mS/m during inspiration, while the conductivity of other tissues remained constant at 480 mS/m, and the rib cage expansion was taken to be 10 percent. The images reconstructed are shown in figure 2; each conductivity distribution is shown as a wire frame on the left side, where the *z* axis represents the log(conductivity), and as a grey scale plot on the right, where darker regions correspond to decreased conductivity. Each grey scale plot is normalised individually.

Using our model of tissue elasticity, the following measurements were simulated:

Measurement	Lung Conductivity	Expansion
$\mathbf{V}_0$	120 mS/m	0 %
$\mathbf{V}_1$	60 mS/m	0 %
$\mathbf{V}_2$	60 mS/m	10 %

Figure 2A images the change in measurements associated with inspiration due to both conductivity change and chest expansion, $\mathbf{V}_2$-$\mathbf{V}_0$; this is what is actually measured on a patient. By using the hypothesis that there are only conductivity changes, one is effectively imaging $\mathbf{V}_1$-$\mathbf{V}_0$, shown in figure 2B. The difference between these images is the effect of chest expansion, figure 2C. For purposes of comparison, we include an image of conductivity changes during inspiration using thoracic impedance measurements from one of the authors (Adler), figure 2D. The energies, E_{img}, of the images in figure 1 are:

Figure	2A	2B	2C	2D
E_{img}	14.0	11.4	2.6	12.5

Discussion

The simulated images in both figures 2A and 2B are qualitatively similar to those produced experimentally. the effect of the chest expansion is to add a large, low amplitude artifact in the centre of the thorax, which adds to the image energy, and "moves" the reconstructed lungs regions closer to the centre. In this application, expansion of the thorax contributes constructively to the measured change in conductivity, as both phenomena tend to reduce the voltages measured. The perturbation introduced into EIT images by the expansion of the thorax is less than 20 percent of the total image energy. This relative contribution to the image due to expansion remains constant to within 10 percent for physiological rib cage movements.

According to these simulations, the expansion of chest contributes significantly to the EIT image reconstructions of cardio-pulmonary function, and should be accounted for in interpreting these images. For certain applications in which we are only interested in changes in cardio-pulmonary function, the effect of the expansion can be neglected because it varies linearly with impedance changes.

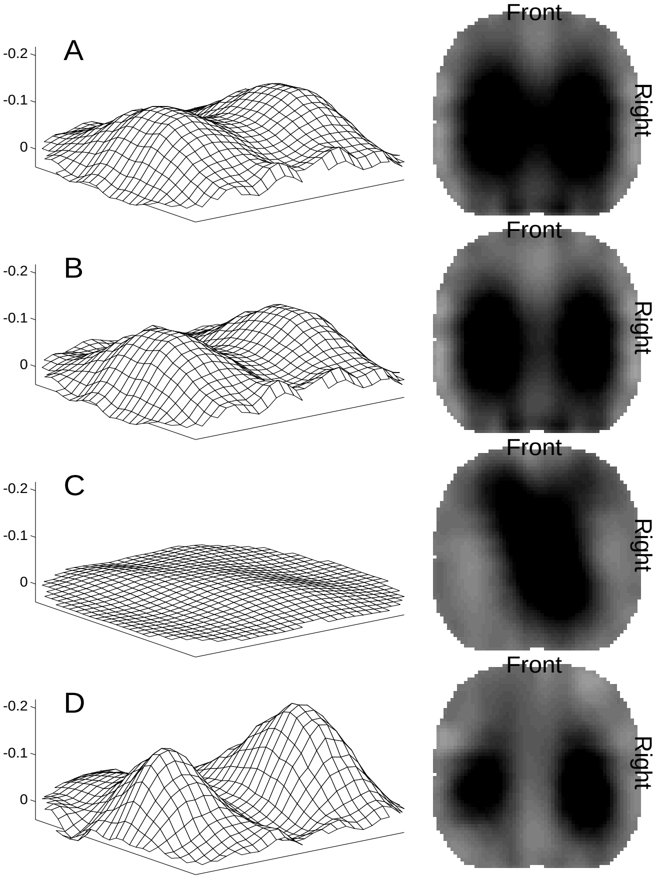

Figure 2: Images of conductivity change in the thorax.
A: Simulated expansion and conductivity change.
B: Simulated conductivity change only.
C: Simulated expansion only.
D: Image using measured data from one of the authors.

References

[1] J.G. Webster, *Electrical Impedance Tomography*, Adam Hilger, New York, 1992.

[2] J.N. Reddy, *An Introduction to the Finite Element Method for Engineers*, McGraw-Hill, New York, 1989

[3] A. Adler, R. Guardo, "An Iterative Reconstruction technique for Electrical Impedance Tomography", *Proc. 1993 Conf. Canadian Med. Biol. Eng. Soc.,* pp. 264-265