

# Classifying Lung Congestion in Congestive Heart Failure using Electrical Impedance – a 3D Model

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## Abstract

*In congestive heart failure (CHF) patients an increased interstitial fluid leads to collection of large amounts of fluids in the lungs which are major cause of mortality. Classifying and monitoring pulmonary congestions is a significant clinical challenge, due to lack of direct access to the pleural cavity. In this study, we investigate the feasibility of the Parametric Electrical Impedance Tomography (pEIT) technique in classifying and monitoring pleural effusion. The investigation is based on pEIT with a reduced number of electrodes applied in a computerized 3D model of the human thorax. The Forward Problem for Poisson's equation was implemented using Finite Volume Method (FVM) to estimate the potentials developed on the body surface.*

*Significant linear regression ( $r\text{-square} > 0.81$ ) was found in 7 and 6 out of 8 independent projections for the right and the left lung, respectively, indicating an increase in surface potential while increasing lungs fluids. Moreover, the study results show that the projection's sensitivity is higher for cross sectional projections during pleural effusion. Hence, monitoring and classifying pleural effusion can be achieved with the pEIT technique making it feasible in monitoring lung fluid status in patients with pleural effusion.*

## 1. Introduction

Pleural effusion is a pathological condition, in which fluid accumulates in the pleural space surrounding the lungs. Since congestions have high electrical conductivity values, changes in fluid content of the thorax may cause significant changes in the thorax's conductivity. Hence, bio-impedance methods, that are sensitive to changes in the thorax conductivity, are being used for congestion estimation and therefore supplying insightful information regarding CHF [1].

EIT have been extensively studied for diagnosing and monitoring of various lung diseases that involve changes in the substrate composition of the lung tissue. The

studies showed that the transthoracic electrical resistivity has a correlation to the amount of lung fluids [2]. Moreover, it was found to be able to detect specific temporal lung water changes in pulmonary edema condition during either fluid intravenous infusion or diuresis [3]. In a previous study, an EIT system was used to reconstruct the impedance distribution across a thoracic cross-section of 10 patients during sequential aspiration of unilateral pleural effusions [4]. A progressive increase in intrathoracic resistivity on the effusion side has been found. Their study consisted of a 16-electrode system.

A new parametric Electrical Impedance Tomography (pEIT) scheme, which uses reduced number of electrodes, was recently developed for several clinical applications [5-8]. It is a non-invasive technique involves applying alternating electrical current to the body using array of electrodes which also used for measuring the developed surface electrical potential.

In this study, we investigate the feasibility of pEIT technique in classifying and monitoring pleural effusion using a computerized 3D model.

## 2. Methods

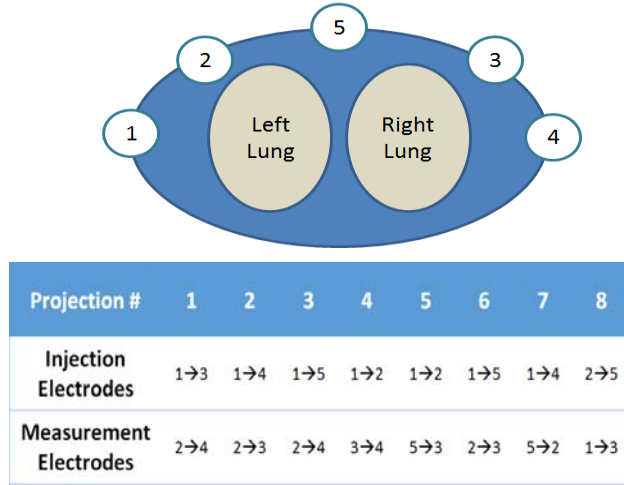
A 3D geometry MRI scan from human male torso was obtained from the XCAT Phantom in order to simulate the potential measurements due to current injections on the body surface [9]. The phantom was segmented into 17 major tissue types each assigned with an appropriate electrical conductivity value. Five electrodes were positioned around the thorax resembling a strap with evenly spaced electrodes able to inject current or to measure potential as schematically illustrated in figure 1 (up). The potentials developed in the volume conductor were obtained using the Poisson's equation with the quasi-static approximation for linear and isotropic media [10].

$$\nabla(\sigma \nabla \phi) = -I_v \quad (1)$$

$$\sigma \frac{\partial \phi}{\partial \vec{n}} = 0 \quad (2)$$

Where  $\sigma (S \cdot m^{-1})$  is the tissue conductivity,  $\nabla\phi (V)$  is the electric potential,  $I_v (A \cdot m^{-3})$  is the current source density and  $\vec{n}$  is a unit vector normal to the boundary.

Figure 1. Schematic electrodes positioning (up). The 8 independent projections (bottom).



Discretization and solving equations 1 and 2 was implemented using FVM method for estimating the potentials developed within the body (The Forward Problem) [5].

8 independent projections were performed using the 5 electrode strap. At each projection one pair of electrodes injects the current and another pair measures the potential as depicted in figure 1 (bottom).

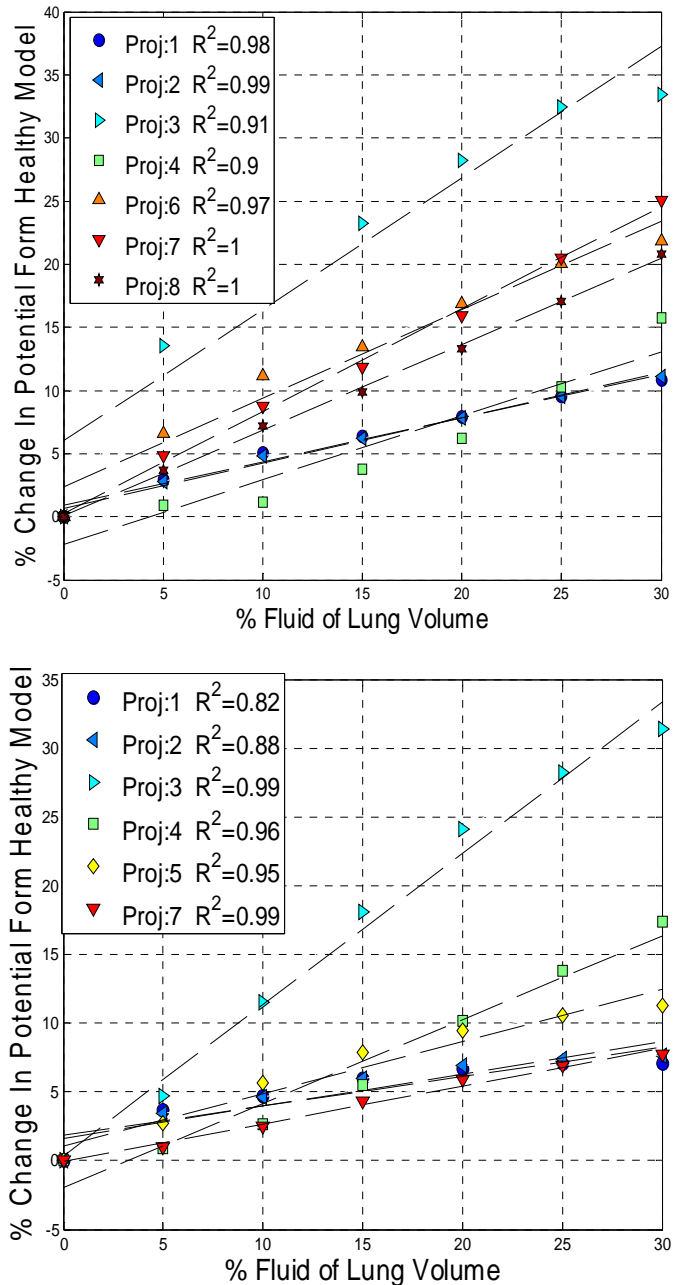
For simulating the Pleural Effusion a modification in the lungs conductivity was performed. The conductivity of the bottom part of the lungs was changed to 1.5 [S/m] [11] resembling the body fluids accumulate in the lungs cavity. Six different volumes of body fluids were examined ranging from 5% to 30% of the total lungs volume, indicating a unilateral congestion severity (changing only one lung each time).

### 3. Results

The relative change compared to a healthy model in the measured potentials was examined for unilateral effusions. Figure 2 shows the linear regression for each projection for left and right lung, respectively. For the right lung 7 projections produced significant r-square values ( $\geq 0.9$ ). For the left lung 6 projections produced significant r-square values ( $\geq 0.82$ ). Lower r-square values were produced for projections 6 and 8 for the right lung (0.52 and 0.51 respectively) and for projection 5 for left lung (0.76). The linear regression indicates an

increase in measured potential as a result to an increase in lungs fluids in all the projections with a significant r-square ( $>0.81$ ) in both lungs. In addition, projection 3 shows the highest sensitivity with maximum relative potential change of 33.4% and 31.4% for the left and right lung, respectively. However, projections 6 and 8 show low sensitivity with poor relative change of 3% and 1.5% in the left lung.

Figure 2. Relative change in potential (compared to healthy model) as function of the fluid percentage of lung volume in independent projections. Right lung (up) left lung (down).



## 4. Conclusions

From the study results, it can be seen, that while using the suggested scheme, relative change in specific projections might implies useful information regarding the pleural congestion severity and location. Moreover we conclude that cross section projections (e.g. projection 3 in both lungs) are more sensitive than other projections therefore are more significant while estimating the amount of the pleural fluid. Hence, we believe that monitoring and classifying pleural effusion can be achieved with the novel 5 electrodes pEIT scheme making it feasible in reliable monitoring of lung fluid status in patients.

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