

# The Sheffield Mk3.5 Absolute Resistivity aEIT System – Review of Recent Updates and Future Trends

S. Mohammad-Samuri\*, M. A. Denai\*, G. Panoutsos\*, M. Mahfouf\*, D. A. Linkens\*,  
T. Meekings\*\*, G. H. Mills \*\*, B. H. Brown\*\*\*

\*Department of Automatic Control and Systems Engineering, The University of Sheffield, UK

\*\*Dept. of Critical Care and Anaesthesia, Northern General Hospital, Sheffield, UK

\*\*\*Dept. of Medical Physics, Royal Hallamshire Hospital, Sheffield, UK

## Abstract

The Mk3.5 absolute EIT system provides the ability to non-invasively and continuously monitor the absolute resistivity and regional ventilation distribution in the lungs. This can greatly enhance clinical diagnosis of lung diseases such as edema and emphysema and guide the proper setting of ventilation therapy in critically ill patients. To produce the absolute resistivity, the transfer impedance measurements obtained from the boundary data are compared, over a pre-determined fixed region of interest, to those predicted from a model of the human thorax adjusted to the subject's size and geometry.

The purpose of this study is to continue the series of amendments carried out by the authors to enhance the accuracy and consistency of the estimated lung absolute volume and resistivity in the Mk3.5 aEIT and to develop further the zone of interest of the lungs in relationship with the thoracic shape which will also allow the estimation of lung ventilation distribution in the anterior/posterior left and right lung quadrants to be improved.

## Introduction

The Mk3.5 aEIT system uses eight electrodes with adjacent drive and receive combinations. The system injects small alternating currents at 30 frequencies typically within the range 2 kHz to 1.6 MHz. The resulting potentials recorded at a rate of 25 frames.s<sup>-1</sup> are used to evaluate the transfer impedance and solve the inverse problem. A detailed description of the system hardware components can be found elsewhere [1]. The method of determination of lung absolute resistivity [2] is based on a 3D finite difference model of the thorax developed from CT cross sections of a normal subject and scaled to take into account the geometry of the chest (circumference and ellipse ratio) of a particular subject. The elements in the model are assigned fixed resistivity values in the range 1-80  $\Omega$ -m depending on their anatomical location (fat, muscle, bone, blood or lung) in the CT images. The modeled data are compared with the real measurements over a pre-determined region of interest for values of the lung resistivities between 3 and 80  $\Omega$ -m. The value of lung resistivity which minimizes the mean difference between these data sets is returned as the value of the absolute lung resistivity, an EIT image is reconstructed by filtered back projection [3]. Current EIT systems suffer from some limitations that may prevent their adoption for routine medical diagnosis. Their major limitations are low spatial resolution, susceptibility to noise and electrode errors, and large variability of images between subjects [4], [5]. The purpose of this paper is to review a series of attempts made by the authors to improve the accuracy and consistency of the estimated absolute lung volume and resistivity in the Mk3.5 aEIT [6].

## Material and Methods

The study involved eleven healthy volunteers (Table 1). The subjects were connected to the Mk3.5 aEIT system via the 8 electrodes array and simultaneously breathing through the spirometer tube (SensorMedics). Data were recorded for 60 sec involving quiet breathing; one litre breathing and

maximum inspiration and expiration manoeuvres in sitting and supine positions respectively. In body plethysmography, the subjects were sat into an airtight cabin and asked to inhale and exhale to minimum and maximum volumes respectively and perform panting. A series of MRI scans involving the same breathing patterns was also conducted on each subject.

Table 1 Subject's data and body measurements.

Subject	Gender	Height (cm)	Chest Circumf. (cm)	Ellipse ratio
1	F	150	86	1.44
2	F	171	76	1.42
3	F	163	82	1.36
4	F	147	88	1.50
5	M	181	113	1.37
6	M	172	94	1.44
7	M	175	94	1.62
8	M	185	107	1.35
9	M	170	91	1.50
10	M	185	110	1.39
11	M	178	97	1.29

## Data Analysis and Results

The recorded EIT data was analysed off-line and compared with spirometry and body plethysmography and the results are summarized in Fig. 1.

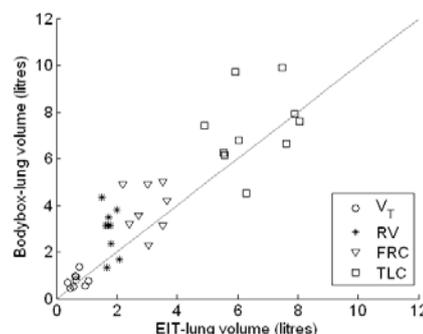


Fig. 1 EIT vs. Bodybox comparing  $V_T$ , RV, FRC and TLC in the sitting position.

### A. Improvement of lung region of interest (ROI) based on MRI scans

The Mk3.5 aEIT system uses a fixed pre-determined ROI to derive the absolute lung resistivity and therefore does not take into account the differences in body size and thorax shape between subjects. This study attempts to produce a more accurate lung ROI from the above population of subjects having large, medium and small chest circumference and eccentricity values. The ROIs are defined from MRI scans of the subjects taken at level of EIT electrode plane. Fig. 2 illustrates the processing sequence of the ROI from an MRI image taken at FRC level using Matlab's image processing toolbox.

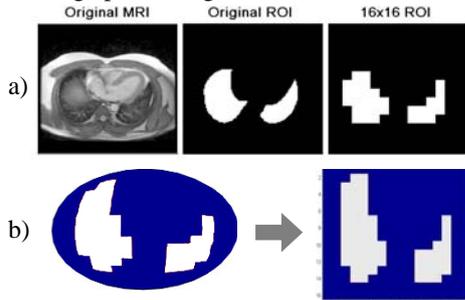


Fig. 2 ROI processing: a) extraction of 16x16 pixel ROI b) warped ROI and reajusted 16x16 ROI.

The resulting ROIs were then classified into 'small', 'medium' and 'large' depending on the subject's height and thorax shape. Fig. 3 shows the lung volumes obtained from EIT and spirometry during quiet and 1 litre breathing in the supine position and Fig. 4 compares  $V_T$ , RV, FRC and TLC obtained from EIT and Bodybox in the sitting position.

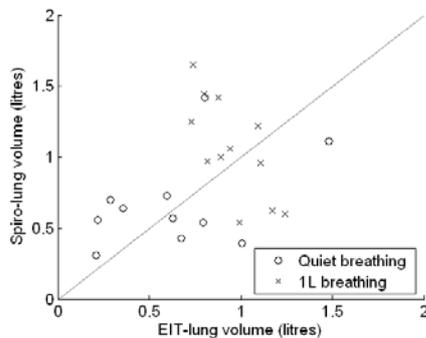


Fig. 3 EIT vs. Spirometry comparing quite breathing and 1 litre breathing in the supine position.

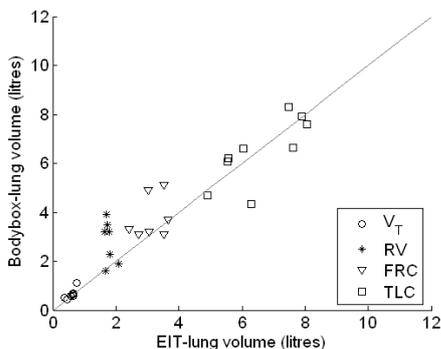


Fig. 4 EIT vs. Bodybox comparing  $V_T$ , RV, FRC and TLC in the sitting position.

The results of Fig. 4 which used multiple ROIs adapted to the subject height and chest shape demonstrate a net improvement as compared to Fig.1.

### B. Improvement of the regional lung volumes

The estimation of regional lung volumes is based on the sub-ROIs related to the anterior and posterior regions of the left and right lungs. The four quadrant displays of the regional lung volumes before and after the ROI amendments are shown in Fig. 5. These regional volumes can be further improved using estimated lung volumes calculated from MRI images.

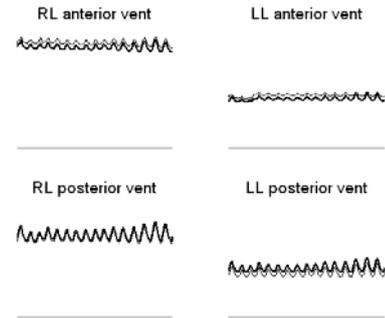


Fig. 5 Regional lung volumes of a male subject with original ROI (solid bold) and the new ROI (solid light).

### Conclusion

This paper overviewed some of the amendments that are being investigated to improve the accuracy of the Mk3.5 aEIT system. Absolute lung volumes obtained with the proposed ROIs classification rules were consistent with body plethysmography measurements. Further refinements, in particular the regional lung volumes, are needed to ensure the clinical usefulness and usability of the Mk3.5 aEIT within the framework of a new computer-based decision support system to provide advice for adjusting the ventilator parameters in future real-time clinical settings.

### Acknowledgment

The authors gratefully acknowledge the financial support of the UK Engineering and Physical Sciences Research Council (EPSRC) under Grant EP/520807/1.

### References

- [1] Wilson, A.J. et al. (2001). Mk3.5: a modular, multifrequency successor to the Mk3a EIS/EIT system, *Physiol. Meas.*, 22, 49-54.
- [2] Brown, B.H. et al., "Applied potential tomography: possible clinical applications," *Clin Phys Physiol Mea.*, 6, 1985, 109-121.
- [3] Barber, D.C. and Seagar, A.D. (1987). Fast reconstruction of resistance images, *Clinical Physics & Physiological Measurement*, 8 (a), 47-54.
- [4] Adler, A. Et al. (1996). Impedance imaging of lung ventilation: do we need to account for chest expansion?, *IEEE Trans. Biom. Eng.*, 43, 414-420.
- [5] Nebuya, S. et al. (2006). Study of the optimum level of electrode placement for the evaluation of absolute lung resistivity with the Mk3.5 EIT system, *Physiol. Meas.*, 27, S129-S137.
- [6] Panouostos, G. et al. (2008). An improved algorithm for accurate absolute EIT lung volume estimation and localization, *American Thoracic Society*, 16-21 May 2008, Toronto, Canada.