Effects of body position on lung density estimated from EIT data

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Abstract. Normal subjects took the sitting, supine, prone, right lateral and left lateral positions during the measurement procedure. One minute epochs of EIT data were collected at the levels of the 3rd, 4th, 5th and 6th intercostal spaces in each position during normal tidal breathing. Lung density was then determined from the EIT data using the method proposed by Brown⁵. Lung density at the electrode level of the 6th intercostal space was different from that at almost any other levels in both male and female subjects, and lung density at the electrode levels of the 4th and 5th intercostal spaces in male subjects did not depend upon position.

1. INTRODUCTION

In principle, Electrical Impedance Tomography (EIT) can produce tomographic images of tissue resistivity. However, the technique has many problems which arise mainly from the 3-D spread of current, the need for many electrodes and the fact that body size and shape affect the measured potentials at least as much as tissue resistivity distribution. Several research workers have partially avoided the problem of body shape by imaging only changes in tissue resistivity as opposed to the absolute value of resistivity. However, whilst this difference technique can provide interesting data on physiological changes, such as those which arise during the respiratory and cardiac cycles, it is of little use in characterizing the absolute resistivity of tissue. For example, differences in absolute resistivity are associated with malignancy, ischemia and lung water [1, 2, 3, 4].

Relatively recently a method was described to determine the electrical resistivity of the lungs in neonates [5, 6], and was extended to adults [7]. This method was based upon a minimization of the differences between potentials calculated using a computer model of the thorax and potentials measured from 8 electrodes placed around the thorax.

Because the soft tissue of the lungs contains material with a relatively high relative permittivity, lung resistivity is a function of frequency. The main source of the high permittivity is cell membranes. Lung tissue at high frequency will consist of only two components, air with almost infinite resistivity, and condensed matter with an almost homogeneous resistivity determined by that of the intracellular and extracellular fluids. If these resistivities are known, then it is possible to calculate both lung density and air volume.

Lung disease that affects lung water will change lung density so that lung density is expected to be used for the evaluation of the recovery from lung disease in patients treated in intensive care units. In clinical practice, EIT data are collected from patients in the supine, prone or lateral positions. Accordingly, control EIT data should be collected from normal subjects in these positions. However,
normal lung density only in the sitting position has been reported to date. In the present study, normal lung density was estimated at different levels of electrode placement in different body positions.

2. METHOD
2.2 Determination of absolute lung resistivity and lung density
The method of determination of lung tissue resistivity was as described by Brown et al [5] for the neonatal thorax. In summary, this method returns the best estimate of the absolute value of lung tissue resistivity by comparing the measured data to computed data sets. The computed data sets were generated via a 3-D finite difference analysis of the thorax. The elements within the 3-D model were ascribed resistivity values in accordance with their anatomical tissue type, as defined by CT imaging. The finite difference analysis was performed for a range of lung resistivities from 1 to 80 Ωm in order to generate the comparison data sets. Elements which did not form part of the lung tissue were given fixed values of resistivity. This fixation minimized the effects of the mediastinum on determined lung resistivity. Because of the long computational times involved the model data sets were pre-computed and then made available in a look-up table.

The 3D finite difference model of the thorax (Dmodel) was developed, based upon CT cross sections of a normal subject. (Segmented model provided by George Zubal, Yale). The features within the model to which values of resistivity can be assigned include fat, muscle, bone, blood and the lungs. The model is used to determine a data set of transfer impedance measurements scaled to take into account the circumference, chest depth and chest width of a particular subject.

Having calculated the data sets Dmodel, scaled for the shape of the particular adult, a set of EIT difference images was then produced by filtered back projection [6] for the measured data set, with reference to the Dmodel sets. One minute epochs (1500 frames) of EIT data were collected during tidal breathing in each subject. The 1500 frames within each epoch were averaged to provide a single data set Dmean. This averaging was performed over time. The changes with frequency between 4kHz and 813kHz (24 frequencies) were used to provide absolute lung resistivity spectra. The mean data for the three highest frequencies of the 24, i.e. 512kHz, 645kHz and 813kHz, were used to calculate the lung resistivities.

A region of interest was then placed over the lung regions in the set of images and the mean difference over the region of interest between the modelled and the measured data sets determined. Absolute lung resistivity was derived by determining which value of lung resistivity in the model minimized the difference between Dmean and Dmodel.

In order to relate absolute lung resistivity to lung tissue density (LD), the structure of the lung tissue and the electrical properties of the components must be known. Nopp et al [7] developed a detailed model for the human lung and used this to determine lung tissue resistivity as a function of frequency.

Lung filling factor (FF) is the ratio by volume of air to condensed matter within the lung tissue. The value can be used to set the volume of air contained within the lungs. The value was changed from 0.2 to 20 in steps of 0.2 and in every case the magnitude of the lung tissue resistivity at a frequency of 1MHz was calculated to provide absolute lung resistivity. Now, if the density ($\rho_t$) of the condensed matter of the lungs is known, then FF can be related to the overall density of lung tissue as follows:

\[
LD = \frac{\text{lungs weight}}{\text{air volume} + \text{tissue volume}} \quad (1)
\]

\[
FF = \frac{\text{air volume}}{\text{tissue volume}} \quad (2)
\]

Putting equation (2) into equation (1) gives

\[
LD = \frac{\rho_t}{FF + 1} \quad (3)
\]

Absolute lung resistivity was determined as a function of $FF$ from the Nopp model [7] and hence lung density related to absolute lung resistivity.
2.2. Experimental procedure
The subjects who participated in experiment were 21 normal male and 21 female volunteers who gave informed consent to the experimental procedures. The equipment used was a Sheffield Mk 3.5 system. Eight disposable Ag/AgCl hydrogel electrodes were spaced equally around the thorax at the levels of the 3rd, 4th, 5th and 6th intercostal spaces. The subjects took the sitting, supine, prone, right lateral and left lateral positions during the measurement procedure. One minute epochs of EIT data were collected in each position during normal tidal breathing.

We considered the difference between the means of lung density at the 4 electrode levels in the same position to be statistically significant at a p value of less than 0.05 using Steel-Dwass test. Comparisons of the means of lung density at the same electrode level in the 5 positions were made in the same way.

3. Results
Figure 1 shows lung density determined in the 21 normal male subjects, divided according to their positions. In the sitting, right lateral and left lateral positions, significant differences were found in lung density between the electrode level of the 6th intercostal space and any other levels. In the prone position, a significant difference was found in lung density between the electrode levels of the 5th and 6th intercostal spaces. In the supine position, no significant differences were found between any levels.

Figure 2 shows lung density determined in the 21 normal female subjects, divided according to their positions. In all the positions, significant differences were found in lung density between the electrode level of the 6th intercostal space and any other levels.

Figure 3 shows lung density in different positions in male subjects.
Figure 3 shows male lung density identical to that in Fig. 1 but divided according to the electrode levels. At the electrode level of the 3rd intercostal space, significant differences were found in lung density between the supine and right lateral positions and between the supine and left lateral positions.

Figure 4 shows female lung density identical to that in Fig. 2 but divided according to the electrode levels. At the electrode level of the 6th intercostal space, no significant differences were found in lung density between any positions. At the electrode levels of the 3rd, 4th, and 5th intercostal spaces, significant differences were found in lung density between several positions.

4. Discussion

These results indicate that lung density at the electrode level of the 6th intercostal space is different from that at almost any other levels in both male and female subjects, and that lung density at the electrode levels of the 4th and 5th intercostal spaces in male subjects can be regarded as independent of position.

One of the reasons why body position and electrode level affect lung density might be that the body position changes the lungs in shape and that both the body position and the electrode level were associated with the distance between the lungs and the electrodes. Chest CT imaging is necessary to confirm this hypothesis. There are also likely to be gravitational affects on lung density. There might be a further reason for the effects of the electrode level on lung density. The 3D finite difference model of the thorax used for the determination of lung density was based upon the anatomical structure at a specific electrode level. The model might not fully hold for other electrode levels. More models should be developed to enable accurate determination of lung density at other electrode levels.

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