Ventilation mapping of chest using Focused Impedance Method (FIM)

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Abstract: Focused Impedance Method (FIM) provides an opportunity for localized impedance measurement down to reasonable depths within the body using surface electrodes, and has a potential application in localized lung ventilation study. This however needs assessment of normal values for healthy individuals. In this study, localized ventilation maps in terms of electrical impedance in a matrix formation around the thorax, both from the front and the back, were obtained from two normal male subjects using a modified configuration of FIM. For this the focused impedance values at full inspiration and full expiration were measured and the percentage difference with respect to the latter was used. Some of the measured values would have artefacts due to movements of the heart and the diaphragm in the relevant anatomical positions which needs to be considered with due care in any interpretation.

1. Introduction
Monitoring of physiological events by impedance has become a subject matter of great interest for the last few decades. Dielectric properties of lungs tissue change as a function of air content [1], therefore lungs ventilation makes a potential area of application of electrical impedance techniques. Electrical Impedance Tomography (EIT) has been applied in the study of lungs ventilation successfully to explore lungs physiology as well as to monitor and diagnose lungs disorders and injury [2][3]. A relatively new development in the field of bio-impedance measurement is the Focused Impedance Method (FIM) [4][5], developed at the authors’ laboratory at Dhaka University, in which two pairs of current drive electrodes perpendicular to each other over a common zone at the center are used to apply alternating currents of constant amplitude separately. Two potential measuring electrodes with a smaller separation, placed at the centre at an angle of 45° to either of the current drive directions, are used to measure the potentials resulting from each of the current drives. The sum of the two measured potentials has a dominant contribution from the central region, approximately a square with the potential electrodes at the diagonal points. Therefore this gives localized sensitivity at the central region which has been termed as the focused region. Because of a 3D sensitivity, FIM electrodes, placed on the skin surface, may be used to monitor changes at a depth, and has been successful in measuring gastric emptying [5]. FIM applied to a localized region of lung showed a linear relationship to change in expired volume of air in a subject [6]. It needs to be seen if FIM could be used to detect and quantify changes in localised lung ventilation, for potential use in detection and diagnosis of localized lung ventilation disorders. In this preliminary study, the FIM impedance change between
maximum inspiration and maximum expiration at different localized segments of the thorax of some healthy human subjects was measured using the 6 electrode FIM system to get a ventilation mapping matrix, with the above aim.

2. Methods and Measurements
Here the FIM has been applied with some modifications in order to facilitate measurement and standardization as shown in figure 1. A 10kHz alternating current of constant amplitude (approx. 0.5mA) was passed, in sequence, through two orthogonal electrode drive pairs A-A’ and B-B’ as shown, by switching the pairs manually. These electrodes were placed such that they make the largest possible approximate square on the chest. Using a hand-held probe, two potential measuring electrodes, 10cm apart, were then placed vertically at different places, such as at 1&2, 3&4, etc. on the chest. For each placement, the two potentials developed due to the two orthogonal current drives were recorded and summed, which essentially gave a value proportional to the focused impedance within the respective zones F1, F2, etc., since the current amplitudes were constant. Measurements were taken with the subject taking a deep breath (maximum inspiration) and then with the subject breathing out as much as possible (maximum expiration). The difference was expressed as a percentage of the value at maximum expiration, which is described as the %change of focused impedance in this work. Each measurement was repeated once and averaged to minimise the effect of changing blood volume in the heart. This %change in impedance is essentially a ventilation parameter of the lungs in the respective focused region, down to a certain depth. The procedure was then repeated with the potential electrode pair placed at different points on the chest in a predefined matrix. Similar measurements were carried out on the back as well. The breast nipple level (indicated by n-n) was taken as an anatomical reference for placement of potential electrodes. Measurements were made with the subject standing upright. The total volume of air exhaled by the subject in each of these procedures is a function of the lungs volume and is known as the Vital Capacity (VC), which was measured using a bellows type spirometer and recorded. Measurements were carried out on two normal healthy young male subjects having no complaints regarding respiration.

3. Results and observations
The %change of focused impedance between maximum inspiration and maximum expiration at localized segments of the thorax were calculated for each subject to get the ventilation mapping matrix, from the front and from the back, and are presented in figures 2 and 3 respectively. These are superimposed on the outline of a human thorax giving the outline of the lungs and the heart as well. The positions of the current electrodes are shown as grey circles. The matrix positions obtained from the back were flipped horizontally to give the same right and left orientation. Some relevant subject
information including their vital capacity (VC) are given in the respective figure captions. Two extreme left and right regions on ventilation mapping matrix represent the impedance changes on lateral curved parts of the thorax. The back side offered measurements on a few extra matrices at the top, and are also shown. The positions of the nipples of the breasts are shown as black dots.

Figure 2. Ventilation mapping of a subject from front (a) and back (b). Matrices from back has been arranged to match the view from the front. Subject age: 26 yrs, height: 1.71m, weight: 52 kg, Vital Capacity: 4.8 litres, non-smoker.

Figure 3. Ventilation mapping of another subject from front (a) and back (b). Subject age: 20yrs, height: 1.68m, weight: 56 kg, Vital Capacity: 4.1 litres, non-smoker.

4. Discussions
The present work was taken up to have an overall idea of localized impedance change throughout the thorax due to lung ventilation using the newly developed 6-electrode FIM system. It is expected that the change in air content will be reduced if part of the lung is filled with water, blood of injury, or any
other substance. In such cases, the impedance change measured in that region would be significantly reduced and this can possibly be detected by FIM. However to predict such distinction between localized zones of a healthy lung and a diseased lung a standard set of values are needed, and this should be based on measurements taken on a large number of healthy normal subjects.

The changes in air contents during ventilation in different regions of the lungs are different depending on the anatomical structure of the lungs. The expected change of impedance due to change in air content is visible from the maps in figures 2 and 3. The values in the corresponding matrices along the level of the nipple in the frontal measurement are similar for both the subjects; however for matrices above and below, there appears to be some difference. For subject 1 values of corresponding zones from the front and from the back are similar for nipple level, but are different at other levels. On the other hand, values from the front and back for subject 2 are different even at nipple level. Further work is required to resolve, or understand the cause for such discrepancies. The differences in VC between the two subjects need to be noted. Besides, there could be experimental error due to variation in the effort a person exerts in full inspiration and full expiration and posture of the subject. The inter-electrode separation plays a big role in the measurement [7] and has to be considered to set up a standard. The contribution of perfused blood should also be taken into account, however, by averaging the readings over a few seconds with breath-hold, this effect may be eliminated.

FIM looks at a limited region of the lungs, however, there is some spread in sensitivity including negative values beyond the focused zone [7] which may become significant in certain situations, and should be considered to get an improved result and standardization. Again, if the sensitive zone includes a boundary of the lungs, particularly on the lower side, it may cause a large error since the changes will be due to several factors including the movement of the diaphragm, besides lung ventilation. Therefore these areas need to be avoided. Similarly the cardiac region is best avoided because of the movement of the heart between the breathing cycles. Measurements from the sides and back may be useful for measurements around the heart. Again for female subjects, frontal measurements of lungs may be difficult because of fatty tissues, and measurement from the back may be desired.

Although EIT appears to offer pixel level resolution, 2D EIT images are cluttered by objects in 3D, and have limited accuracy. Therefore, for applications such as studies of lungs, the much simpler FIM may offer an acceptable solution for clinical applications, and therefore it seems justified to take up further study in this direction.

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6. References:

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