In Vivo Measurements of Structure/Electrode Position Changes during Respiration for Electrical Impedance Tomography

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Abstract. For pulmonary applications of EIT systems, the electrodes are placed around the chest in a 2D ring, and the images are reconstructed based on the assumptions that the object is rigid and the measured resistivity change in EIT images is only caused by the actual resistivity change of tissue. Structural changes are rarely considered. Previous studies have shown that structural changes which result in tissue/organ and electrode position change tend to introduce artifacts to EIT images of the thorax. Since EIT reconstruction is an ill-posed inverse problem, any inaccurate assumptions of object may cause large artifacts in reconstructed images. Accurate information on structure/electrode position changes is necessary to understand factors contributing to the measured resistivity changes and to improve EIT reconstruction algorithm. In this study, in vivo structure/electrode position changes from a healthy male volunteer are investigated during respiration cycle at two levels, the nipple line level and the level approximately 5 cm below. For each level, sixteen fiduciary markers are equally spaced around the surface, the same as the electrode placement for EIT measurements. A MR scanner with respiration-gated ability is used to acquire images of the thorax. MR thoracic images are prospectively acquired corresponding temporally to specific time periods within respiration cycle (FRC, mid tidal volume, tidal volume). The chest expansions in anterior-posterior and lateral directions and inside tissue/organ position changes are then analyzed. The electrode position changes corresponding to different phases of respiration cycle are also measured.

1. Introduction
Electrical impedance tomography (EIT) has shown promise in monitoring pulmonary ventilation and fluid volume changes¹². As the largest organ in the thorax, the lung resistivity change may be more accurately measured by EIT images compared to other thoracic organs or tissues³. The advantages of EIT are non-invasive, relatively inexpensive and non-cumbersome compared with other imaging techniques such as Computed Tomography (CT), Magnetic Resonance Imaging (MRI), etc. However, the poor spatial resolution of EIT significantly limits its applications. Different from other imaging techniques, where tissues/organisms and the changes of anatomic structures can be perceived, EIT image shows resistivity distribution or resistivity changes relative to a reference frame within a body from which no specific organ/tissues can be identified directly.
For pulmonary application of EIT systems, the electrodes are placed around the chest in a 2D ring, and the images are reconstructed based on the assumption that the object is rigid. It has often been assumed that the measured resistivity change in EIT images is only caused by the actual resistivity change of tissue or in some cases the volume change of the vessel. Structural changes and the resulted electrode position changes are rarely considered. During inspiration, the chest expands as much as 10% in the anterior–posterior (AP) direction, and the tissues/organs inside the thorax move down with the diaphragm. Since image reconstruction of EIT is an ill-posed inverse problem, EIT is noise sensitive. Any changes in the structures and electrode positions will cause the errors in the measurements therefore introduce larger artefacts in the image.

Simulation study using a thoracic 3D model as virtual phantom has been played a major role in understanding factors that contribute to the measured resistivity changes of EIT image. Adler et al. studied the influence of chest expansion during respiration on EIT images using a 2D thorax finite element model. The results showed that chest expansion contributed to the measured change in conductivity and accounted for 2% to 20% of the reconstructed image amplitude in a broad zone at the center of the image. Another study using a 3D thorax finite different model showed that both chest expansion and tissue movements during respiration significantly contributed to the lung resistivity changes. The averaged resistivity changes in the lung region caused by chest expansion were between 0.65% and 18.31%. The artifacts in the center ranged from –2% to 31% of the image magnitude.

The investigation using thoracic models is potentially limited due to lack of in vivo measurements of structural changes as well as corresponding electrode position changes. Any small error in the assumed electrode position changes may result in false estimations of artefacts in EIT image. Therefore, accurate information on structure/electrode position changes is necessary to understand factors contributing to the measured resistivity changes and to improve EIT reconstruction algorithm. In this study, we investigate in vivo structure/electrode position changes during respiration cycle.

2. Material and Methods
A Philips 1.5 T clinical MR system (Philips Medical Systems, Philips) located at the University of Minnesota-Fairview hospital was used to acquire images of the thorax. Sixteen fiduciary markers (IZI Medical Products Inc., Baltimore, MD, USA) were equally spaced around the surface of a healthy male volunteer (41 years old, 68 kg, 173cm), the same as the electrode placements for EIT measurements. No current was injected and no voltage was measured. The markers were used only for position identification purpose. The electrodes were placed at two levels, the nipple line level and the level approximately 5 cm below, as shown in Fig. 1a. MR thoracic images were prospectively acquired corresponding temporally to specific time periods within respiration cycle (Functional Residual Capacity (FRC), mid tidal volume, tidal volume (TV)). Respiration signal was detected by a sensor put on the top of the thorax and under RF coil. Parallel acquisition technique was employed with the use of Sense™ XL torso RF coil.

Thirty-two cross-sectional MR images covering from the neck to the lower abdomen were obtained corresponding to each phase (FRC, mid TV, TV) for analysis. The image resolution is 1.3 mm x 1.3 mm x 8 mm. The chest expansions in AP and lateral directions at the two levels were measured and compared to those at the phase of FRC. Inside tissue/organ position changes were also demonstrated. By tracing marker positions, the potential electrode position changes during actual EIT measurements corresponding to different phases of respiration cycle were presented.

3. Results
Fig. 1 shows the positions of fiduciary markers (a) and their corresponding changes during respiration cycle. Fig. 1(b) shows the respiration cycle and the phases (FRC, mid TV, TV) where MR images of the thorax were obtained. The comparisons between TV and FRC for the nipple line level and the level approximately 5 cm below are shown in Fig. 1 (c) and (d), respectively.
For supine position, the electrode position changes are mainly observed in the electrodes placed at anterior regions of the chest. The chest expansion during respiration in AP and lateral directions are 20.8 cm and 32.9 cm at TV, 20.7 cm and 33.1 cm at mid TV, 20.6 cm and 33.2 cm at FRC, respectively for the upper level. For the lower level, the chest expansions are 20.4 cm and 31.0 cm at TV, 20.2 cm and 31.0 cm at mid TV, 20.1 cm and 31.1 cm at FRC, respectively. The changes are smaller than the chest expansion used for previous modeling study and those measurements with breath holding at different air volumes. Some factors may influence in vivo measurements of the structure changes. The scan time of MRI is long for image acquisition, which reduces the time gap between two adjacent phases. The MRI uses prospective respiration gating technique, a few respiration cycles are needed to acquire the images of the thorax. Variability in the rate of respiration cycle may cause variation in the gating points. In addition, the use of XL torso RF coil that was placed on the top of the thorax might also limit chest expansion.

Fig. 2 shows inside tissue/organ movements at the FRC and TV during respiration cycle. Large movement is observed which appears to be a potential issue for EIT measurements, especially for lower electrode level.

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4. Conclusion
Chest expansion/electrode position changes are obviously one of the potential sources that may cause errors in EIT images. We investigated in vivo structure and electrode position changes during respiration in a healthy male volunteer. The measurement implies the error caused by chest expansion/electrode position changes may not be significant as estimated by the use of model.
However, tissue/organ position may introduce large artefact to EIT images of the thorax, depending on the electrode levels.

To secure this investigation, we also proposed to acquire CT images from patients. CT images may provide more accurate electrode position changes during respiration with its fast acquisition time and the use of retrospective respiration gating technique. The contribution of chest expansion/electrode position changes and tissue/organ movements to EIT images may be more accurately determined using 3D thoracic models developed from volume CT images with actual electrode position changes at different phases during respiration cycle.

Fig.2 Tissue/organ movements at the tidal volume (left column), mid tidal volume (middle column), and FRC (right column) during respiration cycle for the nipple line level (upper images) and the level approximately 5 cm below (lower images).

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