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## Does thorax EIT image analysis depend on the image reconstruction method?

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**Abstract.** Different methods were proposed to analyze the resulting images of electrical impedance tomography (EIT) measurements during ventilation. The aim of our study was to examine if the analysis methods based on back-projection deliver the same results when applied on images based on other reconstruction algorithms. Seven mechanically ventilated patients with ARDS were examined by EIT. The thorax contours were determined from the routine CT images. EIT raw data was reconstructed offline with (1) filtered back-projection with circular forward model (BP<sub>C</sub>); (2) GREIT reconstruction method with circular forward model (GREIT<sub>C</sub>) and (3) GREIT with individual thorax geometry (GREIT<sub>T</sub>). Three parameters were calculated on the resulting images: linearity, global ventilation distribution and regional ventilation distribution. The results of linearity test are  $5.03 \pm 2.45$ ,  $4.66 \pm 2.25$  and  $5.32 \pm 2.30$  for BP<sub>C</sub>, GREIT<sub>C</sub> and GREIT<sub>T</sub>, respectively (median  $\pm$  interquartile range). The differences among the three methods are not significant ( $p=0.93$ , Kruskal-Wallis test). The proportions of ventilation in the right lung are  $0.58 \pm 0.17$ ,  $0.59 \pm 0.20$  and  $0.59 \pm 0.25$  for BP<sub>C</sub>, GREIT<sub>C</sub> and GREIT<sub>T</sub>, respectively ( $p=0.98$ ). The differences of the GI index based on different reconstruction methods ( $0.53 \pm 0.16$ ,  $0.51 \pm 0.25$  and  $0.54 \pm 0.16$  for BP<sub>C</sub>, GREIT<sub>C</sub> and GREIT<sub>T</sub>, respectively) are also not significant ( $p=0.93$ ). We conclude that the parameters developed for images generated with GREIT<sub>T</sub> are comparable with filtered back-projection and GREIT<sub>C</sub>.

### 1. Introduction

Electrical impedance tomography (EIT) is a non-invasive, radiation-free imaging technique that can be used at the bedside for monitoring regional lung ventilation and aeration distribution [11]. EIT measures the electrical potentials at the chest wall surface and detects air volume changes based on the phenomenon that changes in regional air content modify the electrical impedance of lung tissue [4].

The reliability of EIT has already been confirmed by comparison with different conventional methods [6, 9, 10]. Unfortunately, due to the limited number of electrodes the resolution of the reconstructed EIT images is relative low compared to computed tomography (CT). Another problem that prevents wide acceptance of EIT in the clinical environment is the difficult interpretation of the results. Because of the ill-posed problem, the electrical impedance within the thorax cannot be perfectly reconstructed. Up to now, most EIT devices idealize the thorax to a 2D circular forward model to simplify the image reconstruction. The shape distortion of the lungs and thorax impair the quality of the EIT images [8].

Recently, the so-called GREIT (Graz Consensus Reconstruction Algorithm for EIT) was developed [1]. With the help of extensible software based EIDORS [2], EIT raw data can be reconstructed for individual thorax geometry, which improves the EIT images [13].

Since the EIT measurements contain large amount of information, different parameters were proposed to analyze the EIT images [5, 7, 12, 14]. Most of them were based on the images reconstructed with filtered back-projection and circular forward model. The aim of our study was to examine if the analysis parameters based on back-projection are still valid when they were applied on images reconstructed with GREIT.

## 2. Methods

A total of seven mechanically ventilated patients with acute lung injury were studied (4 male, 3 female; age  $60 \pm 8$  years; height  $177 \pm 13$  cm; weight  $81 \pm 12$  kg; mean  $\pm$  SD). The patients were ventilated under pressure controlled mode with individual positive end-expiratory pressure (PEEP). Immediately preceding the examination, PEEP was temporarily reduced to zero end-expiratory pressure without changing any other ventilation settings for one minute. Then a stepwise increase in airway pressure to 35 cmH<sub>2</sub>O was induced for one minute followed by a stepwise decrease to the initial zero end-expiratory pressure (figure 1). EIT data were acquired during the whole measurement period at a rate of 25 images/s (Goe-MF II device, CareFusion, Höchberg, Germany). The study was approved by the local ethics committee. Written informed consent was obtained from all patients prior to the study.

The individual thorax contours were determined from routine computed tomography (CT) images (Brilliance CT 64 channel scanner, Philips, Andover, USA) based on a threshold value of  $>800$  Hounsfield units as well as dilation and erosion filtering. The CT analysis was performed in the fifth intercostal space, i.e. in the same cross-sectional plane as EIT. EIT raw data was reconstructed offline with (1) filtered back-projection with circular forward model (BP<sub>C</sub>) [3]; (2) GREIT reconstruction method with circular forward model (GREIT<sub>C</sub>) and (3) GREIT with individual thorax geometry (GREIT<sub>T</sub>). Three parameters calculated from the resulting images based on these reconstruction methods were examined: (1) linearity, i.e. the ratio of tidal and deep inflation impedance changes obtained during the final five breaths preceding the stepwise increase in airway pressure and between the beginning and end of the 1-min long inflation (figure 1,  $D_2/D_1$ ); (2) global ventilation distribution, indicated by the tidal impedance changes in the right and left lungs (figure 2,  $D_{\text{Right}}/(D_{\text{Right}}+D_{\text{Left}})$ ); (3) regional ventilation distribution, indicated by the global inhomogeneity (GI) index [14].

Data analysis was performed using MATLAB 7.2 (The MathWorks Inc., Natick, MA, USA). For non-normally distributed data, results were expressed as median value and interquartile range. Kruskal-Wallis test was applied to assess the differences among reconstruction methods for each parameter. A P value  $< 0.05$  was considered statistically significant.

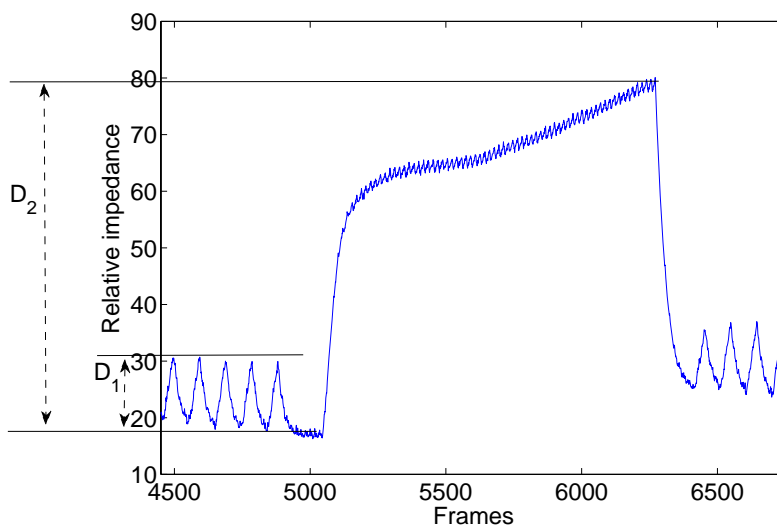


Figure 1. A typical total relative impedance (arbitrary unit) curve of one patient during the EIT examination. During the initial phase, the patient was temporarily ventilated at zero end-expiratory pressure followed by an increase in airway pressure to 35 cmH<sub>2</sub>O. D<sub>1</sub> represents the mean tidal impedance change during zero end-expiratory pressure. D<sub>2</sub> denotes the impedance change caused by the large airway pressure step. The impedance curve is based on GREIT<sub>C</sub>. Similar curves are obtained with other reconstruction methods (BP<sub>C</sub>, GREIT<sub>T</sub>).

### 3. Results

Table 1 summarizes the parameters derived for images with different reconstruction methods and the results of Kruskal-Wallis test. Although the parameter values vary among patients, no significant differences are found in any of these three parameters among different reconstruction methods.

Table 1. Parameters obtained using different reconstruction methods.

	Linearity D <sub>2</sub> /D <sub>1</sub>	Global distribution D <sub>Right</sub> /(D <sub>Right</sub> +D <sub>Left</sub> )	Regional distribution The GI index
BP <sub>C</sub>	5.03 (2.45)	0.58 (0.17)	0.53 (0.16)
GREIT <sub>C</sub>	4.66 (2.25)	0.59 (0.20)	0.51 (0.25)
GREIT <sub>T</sub>	5.32 (2.30)	0.59 (0.25)	0.54 (0.16)
P value	0.93	0.98	0.93

Data are expressed as median values and interquartile ranges. P values are calculated with Kruskal-Wallis test.

### 4. Discussion and conclusion

In the present study, we chose three representative parameters for EIT image analysis and examined their variation in different reconstruction methods. P values in Kruskal-Wallis test close to 1 suggest that the methods used for EIT image reconstruction do not influence the results of image analysis. The parameters developed for images generated with GREIT<sub>T</sub> are comparable with filtered back-projection and GREIT<sub>C</sub>. Since the former algorithm is adapted to individual thorax geometry it improves the EIT image quality and may accelerate the acceptance of EIT in routine clinical use compared with older image reconstruction methods. The variation of parameters among different patients emphasizes the importance of individual monitoring and strategy optimization in mechanical ventilation therapy.

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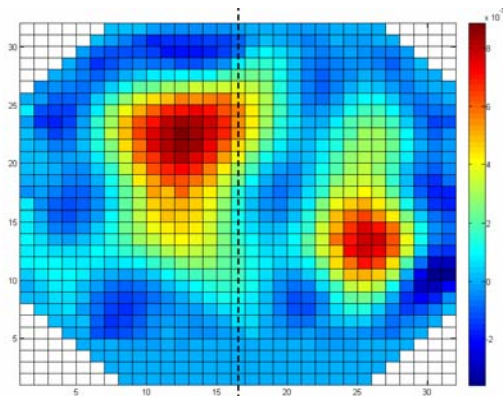


Figure 2. Functional EIT of the same patient in figure 1 during ventilation at zero end-expiratory pressure, reconstructed with GREIT<sub>c</sub>. Colour bar indicates the magnitude of relative impedance values in each pixel (arbitrary unit). Dashed line divides the image into identical halves. Note that EIT images have the same orientation as CT images.

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