DYNAMICAL FUNCTIONAL EIT IMAGING FOR MONITORING OF REGIONAL LUNG FUNCTION

Taras Dudykevych[1a], Günter Hahn[a], Harald Richter[b], Inéz Frerichs[a], José Hinz[a], Onnen Mörer, Gerhard Hellige[a]

[a]Department of Anaesthesiological Research, Centre of Anaesthesiology, Emergency and Intensive Care Medicine, University of Göttingen, Robert-Koch-Str. 40, TL195, D-37075 Göttingen, Germany;
[b]Institute for Informatics, Clausthal University of Technology, Julius-Albert-Str. 4, D-38678 Clausthal, Germany

ABSTRACT: EIT, used as a monitoring tool, could offer the unique information about regional lung function directly at the bedside. However it is not evident, which kind of information is especially suitable for monitoring and how this can be efficiently done. Using a conventional EIT movie interpretation is inherently difficult due to the continuously changing image content. We propose a novel monitoring method of dynamical functional EIT (df-EIT) image generation. This method is derived from offline generation of functional EIT images, which was initially introduced by Hahn et al in 1995 for quantification of different ventilatory conditions. In the current work it has been extended to work online on the last acquired images in such a way that the functional image is continuously updated during data acquisition each time a new frame is sampled. From the physiological point of view the advantage is that for steady state physiological condition the df-EIT image does not alter facilitating in this way visual interpretation. Different df-EIT images acquired under laboratory and clinical conditions with the Goe-MF II system developed in our lab will be presented and compared with the information obtained from a sequence of single EIT images.

Keywords: Electrical impedance tomography, EIT, ventilation monitoring

1. INTRODUCTION

Many authors concluded, that EIT is the only imaging technique, capable for monitoring of different regional pulmonary parameter directly at the patient's bedside without exposure to radiation and at a relatively low cost [1-3]. The demand for regional lung function monitoring exists e.g. in the intensive care unit (ICU) for mechanically ventilated patients, where the information can be used for proper therapy planning and decision feedback. However, to our knowledge, this monitoring approach has not been implemented yet on any commercially available EIT device or for research purposes: the physiologically relevant information can only be extracted during some offline evaluation steps. Furthermore, it has not been investigated, which kind of information extracted from EIT measurement can be used for monitoring purposes.

In this paper we propose a novel monitoring approach based on on-line generation of dynamical functional EIT (dfEIT) images and the results will be compared to the well-known conventional EIT movie for data obtained in healthy volunteer and ICU patient.

2. METHODOLOGY

The method of off-line generation of functional EIT images was initially introduced by Hahn et al in 1995 [4] for quantification of different ventilatory conditions. This approach is now the state-of-the-art in the evaluation of EIT data and has been used in a number of EIT projects [4], [5]. Briefly, the standard deviation of each local time course from the series of single EIT images, representing a steady state physiological condition, is calculated as a variability measure of the impedance change and the underlying physiological process. Since this is performed on all pixels' time courses, a series of tomograms will be reduced to a single synthetic image. To reconstruct individual EIT images the modified filtered back-projection algorithm [6] is used. In the current work this method has been extended to work online on the last acquired images using a concept of sliding window, that is the functional image is updated during data acquisition each time a new frame is sampled (fig. 1, right). Each image is scaled automatically to provide

[1] tdudyke@gwdg.de ; phone +49 551 39-8829; fax +49 551 39-8676

the maximal color dynamic range and the color bar on the image's right is used to provide the quantitative information, which represents the instantaneous physiological variation in the cross-section. Obviously, a stable df-EIT image is obtained, when the sliding window length at least matches or exceeds the periodicity of a physiological process to be monitored. This concept was implemented in the ventilation monitoring software, running with frame rates of 13, 25 and 44 Hz on Goe-MF II EIT device [7], developed in our lab.

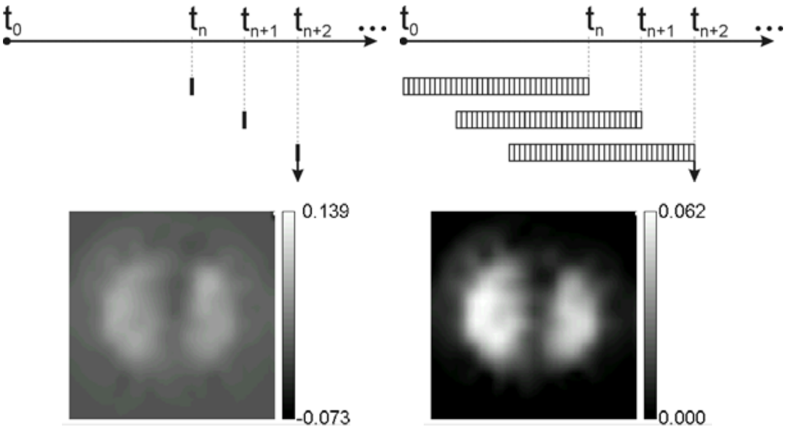

Fig. 1. Comparison of generation procedure of series of the individual EIT images (left) and df-EIT images (right) and the examples images of a healthy spontaneously breathing volunteer.

Additionally the ventilation monitoring software can generate the conventional EIT movie (i.e. online presentation of consecutive single EIT images) as well (fig 1, left). However, the scaling problem arises on-line (in contrast to the off-line case, where each series can be scaled retrospectively using series' global minimum and maximum values) due to the fact that future images cannot be taken into account for proper scaling of the past and current images and therefore the scaling range is not known a priori before any measurement starts. This problem is approached by starting with initial low range and adjusting the images' scale range by 10 % each time new image falls below or above current scale. So the headroom of maximal 10 % must be taken into account e.g. in the ventilatory steady-state condition.

3. RESULTS

Figure 2a depicts the global time course of relative impedance change for a healthy spontaneously breathing volunteer. EIT scanning was performed at an acquisition rate of 13 frames/s. The series of individual EIT images and df-EIT images have been generated online. For the time period of about 1,2 s, depicted by two vertical solid lines, corresponding to the one half of the breathing cycle from the expiration to the inspiration both series are plotted in a 4x4 arrangement in the figures 2b and 2c respectively. As expected, the EIT movie runs from dark at the expiration through gray at the mean lung volume to light shades at the inspiration. The transition from the expiration to the inspiration is relatively smooth since the limits of physiologically induced relative impedance change do not vary in this steady state. In contrast, the df-EIT images remains almost unaltered from frame to frame, because the physiological state – ventilation and fluid distribution in the thoracic cross-section – does not change.

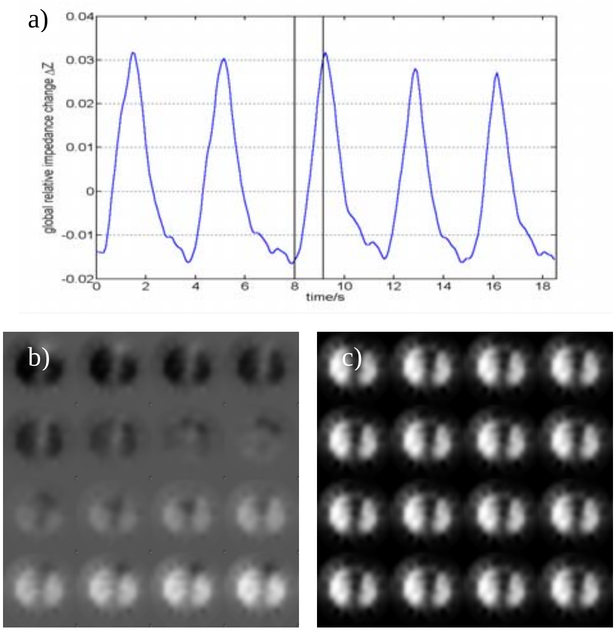

Fig. 2. a) Global time course of relative impedance change, b) series of individual EIT images, and c) series of df-EIT images of a healthy spontaneously breathing volunteer.

Figure 3a represents the global time course of relative impedance change for the same volunteer performing an end-expiratory breath-hold maneuver followed by spontaneous breathing. As in figure 2, the series of individual EIT images and df-EIT images have

been generated online and are shown in figures 3b and 3c respectively for the time period of about 2,5 s depicted by two vertical solid lines. Only every second image is shown. The reference for the back-projection reconstruction algorithm is calculated as mean value of first 5 s from the breath-hold phase. The color varies synchronously with cardiac-related actions during the first half and changes abruptly as the volunteer starts to breath due to rescaling process, described above. On the other hand df-EIT images only emphasize the cardiac-related variations of the relative impedance change during the breath-hold phase (images 1-6), the display alters during transition from breath-hold steady state to the tidal breathing (images 6-9) and "freezes" in this state (images 9-16) emphasizing primarily the pulmonary function.
The noticeable effect of the different referencing approaches on the EIT movie is demonstrated in figure 4. The same data as in figure 3 have been reconstructed using an averaged tidal breathing part as a reference. Now, the end-expiratory breath-hold is identified as expiration in the EIT movie and the cardiac-related oscillations have only neglected influence on the EIT movie display. This is not a case for the df-EIT image and by comparing the figures 3c and 4c, it gets obvious that, fortunately, the reference choice has no effect on df-EIT image.

a)

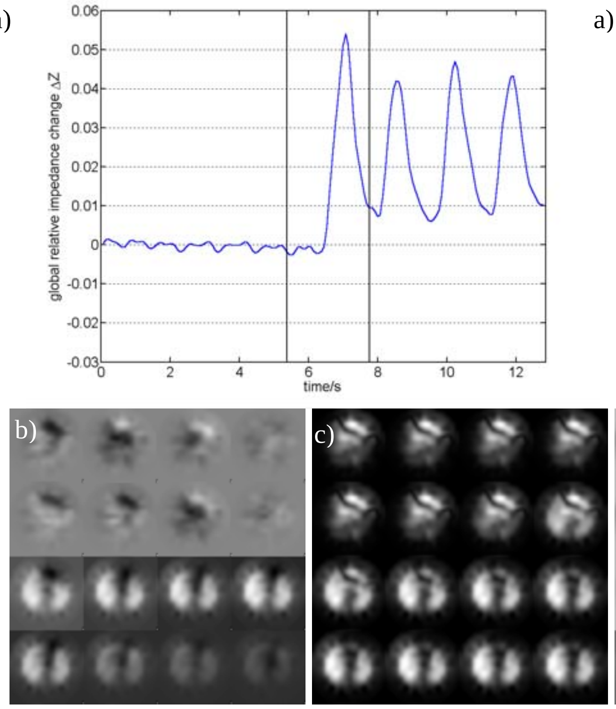

Fig. 3. a) Global time course of relative impedance change, b) series of individual EIT images, and c) series of df-EIT images of a healthy volunteer performing the end-expiratory breath-hold maneuver following by spontaneous breathing. The back-projection algorithm reference is set to the breath-hold phase.

a)

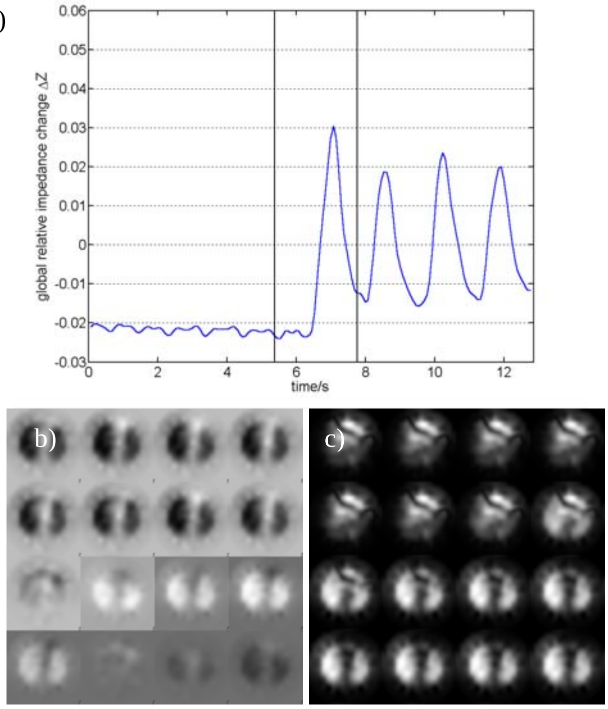

Fig. 4. a) Global time course of relative impedance change, b) series of individual EIT images, and c) series of df-EIT images of a healthy volunteer performing the end-expiratory breath-hold maneuver following by spontaneous breathing. The back-projection algorithm reference is set to the tidal breathing phase.

Figure 5a and 5b shows the exemplary changes in the local relative impedance change resulting from an increase in the positive end expiratory pressure (PEEP) level on the mechanical respirator from 5 to 15 mbar in a ventral and dorsal lung region for a mechanically ventilated ARDS patient. The corresponding df-EIT images captured from running ventilation monitoring software are shown in figures 5c und 5d respectively for two sliding windows depicted in 5a and b. Both the df-EIT images and the local time courses clearly show the ventilation redistribution from ventral to dorsal lung regions resulting from the PEEP step that indicates dorsal alveolar recruitment.

4. DISCUSSION

The results make clear that unambiguous color scale assignment and thus quantitative evaluation is not possible online in EIT movie. This is due to the facts that 1) the color varies periodically through the whole dynamic range without having any new physiological information (e.g. during tidal breathing in fig. 2b); 2) the choice of reference has undesirable effect on EIT movie (compare fig. 3b and 4b); 3) the scaling problem arises online in contrast to the offline case as depicted in fig. 3b and 4b. In contrast, df-EIT images produce only marginal visible changes under steady-state physiological condition (fig. 2c, 3c, 4c) facilitating in this way visual interpretation. Marked rapid changes will only occur in an unsteady-state transition phase as e.g. in transition from respiratory apnea to tidal breathing or as a result of changing mechanical ventilator settings (fig. 5c and 5d).

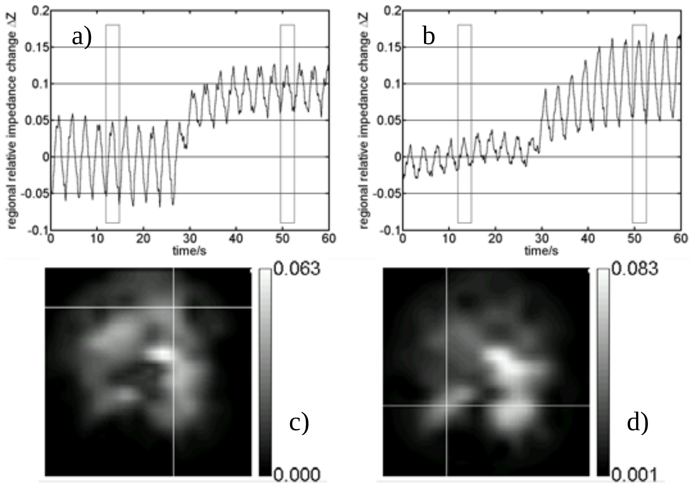

Fig. 5. a), b) Local time courses of relative impedance change in ventral and dorsal lung regions respectively c), d) df-EIT images captured from ventilation monitoring software for two sliding windows, representing instantaneous ventilation distribution for two different positive end expiratory pressure (PEEP) levels in a mechanically ventilated ARDS patient . The PEEP level on the mechanical respirator has been changed from 5 to 15 mbar at 28 s.

Other functional images than the described variation functional image can be considered to be used online to monitor different physiological information in a concise way.

5. CONCLUSIONS

The introduced and implemented technique of dynamical functional EIT imaging will expand the capability of EIT as a monitoring and imaging modality. From the technical and operational point of view, overall measurement plausibility check will be possible for the first time already during a data collection. From the medical point of view, the regional lung ventilation can be continuously monitored by EIT in a similar way as conventional heart rate or blood pressure monitoring. Furthermore, df-EIT offers an immediate visual feedback about the effects of clinical or experimental interventions. In particular, dynamical functional EIT seems to be a helpful tool to detect alveolar recruitment during mechnical ventilation and to set the respirator parameters for each individual patient in an optimal way.

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