The 4th IEEE International Conference on E-Health and Bioengineering - EHB 2013
Grigore T. Popa University of Medicine and Pharmacy, Iaşi, Romania, November 21-23, 2013

Monitoring of Pulmonary Embolism using Electrical Impedance Tomography: a Case Study

Vladimir Sobota, Jan Suchomel
Department of Biomedical Technology
Faculty of Biomedical Engineering, Czech Technical University in Prague
Sitna Sq. 3105, 272 01, Kladno, Czech Republic
vladimir.sobota@fbmi.cvut.cz

***Abstract*-Electrical impedance tomography (EIT) offers a non-invasive, radiation free, bedside alternative to conventional medical imaging systems. Studies have shown that monitoring of pulmonary perfusion or detection of pulmonary embolism (PE) could be a field of use for this technology in the future. The aim of this case study is to evaluate the possibilities of PE detection with PulmoVista 500, a commercial EIT system designed for monitoring of pulmonary ventilation distribution. Mechanically ventilated animal model was created with its vital signs monitored. PE was induced artificially six times by blood clots injection. Significant changes in the waveforms of relative impedance were observed four times. The analysis of the EIT data acquired during the whole experiment suggests that PulmoVista 500 is capable to detect the resulting impedance changes and roughly localize them. However, the detection of less significant perfusion defects seems to be unreliable and thus require performing of additional studies.**

Keywords: electrical impedance tomography, pulmonary embolism, pulmonary perfusion.

I. INTRODUCTION

Electrical impedance tomography (EIT) is an imaging technique which provides information about the distribution of tissue resistivity within the selected tomographic cross-section of the body. Since the first EIT systems were developed in 1980s, the possibility of the technology application has been found in several medical areas, especially in lung ventilation monitoring where commercial devices are now available [1,2].

Using EIT systems for ventilation imaging, the obtained data are not affected by the ventilation parameters only. In numerous studies has been shown that cardiac-related impedance changes as well as defects and abnormalities in pulmonary perfusion can also be recorded by EIT [1-4].

The possibilities of EIT in pulmonary embolism (PE) detection were described by McArdle [5] and Leathard et al. [6]. Both experiments showed the presence of large emboli creates significant changes in respective EIT images but although promising, the studies were limited by the number of patients with PE. In the studies made by Frerichs et al. [4] and Nguyen et al. [7] PE was induced artificially by a balloon catheter and saline solution was used as a contrast agent.

The purpose of this case study is to determine whether the PE induced by injection of blood clots can be detected by PulmoVista 500 (Dräger Medical, Lübeck, Germany), a commercial EIT system designed for monitoring of lung ventilation distribution.

II. METHODS

The study protocol was approved by the Institutional Animal Care and Use Committee of the First Faculty of Medicine, Charles University in Prague. The study was performed at an accredited animal laboratory in accordance with Act No. 246/1992 Coll., on the protection of animals against cruelty.

A crossbred Landrace female pig (*Sus scrofa domestica*) four months old with a body weight of 60 kg has been used in this case study.

A. Anesthesia and Preparation

The animal was premedicated with azaperone (2 mg/kg IM). Anesthesia was performed with atropine sulphate (0.02 mg/kg IM) and ketamine hydrochloride (20 mg/kg IM) followed by initial boluses of morphine (0.1 mg/kg IV) and propofol (2 mg/kg IV). The animal was intubated by a cuffed endotracheal tube (I.D. 7.5 mm) and connected to conventional ventilator Hamilton G5 (Hamilton Medical AG, Bonaduz, Switzerland). Maintaining of anesthesia was performed with propofol (8 to 10 mg/kg/h IV) combined with morphine (0.1 mg/kg/h IV) and heparin (40 U/kg/h IV). Myorelaxant pipecuronium bromide (4 mg boluses every 45 min) was administered during artificial lung ventilation to suppress spontaneous breathing. Initial rapid infusion of 1 000 mL of normal saline was given intravenously, followed by a continuous IV drip of 250 mL/h to reach and maintain central venous pressure of 6 to 7 mmHg. A vein and arterial cannulation for central venous pressure (CVP, *v. femoralis*) and arterial blood pressure (ABP, *a. femoralis*) monitoring

978-1-4799-2373-1/13/$31.00 ©2013 IEEE

was performed. Continuous cardiac output (CO), mixed venous blood oxygen saturation (SvO_2) and pulmonary artery pressure (PAP) were measured by Vigilance (Edwards Lifesciences, Irvine, CA, USA) monitor.

B. Ventilation

Conventional ventilator Hamilton G5 was used in the INTELLiVENT-ASV mode. The ventilator setting was following: respiratory rate 18 bpm, FiO_2 21 %, I:E 1:1 and PEEP 5 cmH_2O. The initial tidal volume was set to 8.5 mL/kg of the actual body weight and was titrated to reach normocapnia ($PaCO_2$ 40 ± 1 mmHg). The ventilator setting was kept constant during the whole experiment.

C. Induction of Pulmonary Embolism

PE was induced artificially by injection of 20 ml of blood clots suspension in normal saline into *v. femoralis*. PEs were induced repeatedly, each followed by a time period of 30 min.

D. EIT Measurement

The EIT measurement was performed with PulmoVista 500 EIT system. The electrode belt (size S) was placed on the chest of the animal at the level of the 6th and 7th intercostal space. The frequency of the applied electrical current was set to 110 kHz with the amplitude of 9 mA. The pattern of the current application and the resulting voltage measurement ("adjacent drive configuration") is described in [2] more in detail. EIT data were acquired continuously during the whole experiment in order to record the thoracic impedance changes caused by each blood clots injection for sufficiently long time period. The frame rate used was 50 Hz.

E. Data Evaluation

The data recorded by the EIT system were collected and the relative impedance waveforms were calculated. The intervals depicting the application of blood clots suspension were selected and the end-expiratory frames were reconstructed using EIDORS algorithms (version 3.6). For each set of reconstructions the same reference frame was used. The applied color map is equal to the one utilized in PulmoVista 500.

III. RESULTS

Six applications of blood clots were performed during the experiment. The impedance waveforms depicting these interventions are shown in Fig. 1. Two intervals corresponding with the blood clots injection were selected and are shown in a detail in Fig. 2 and 3. The transversal reconstructions were chosen with respect to the cardiac activity of the animal.

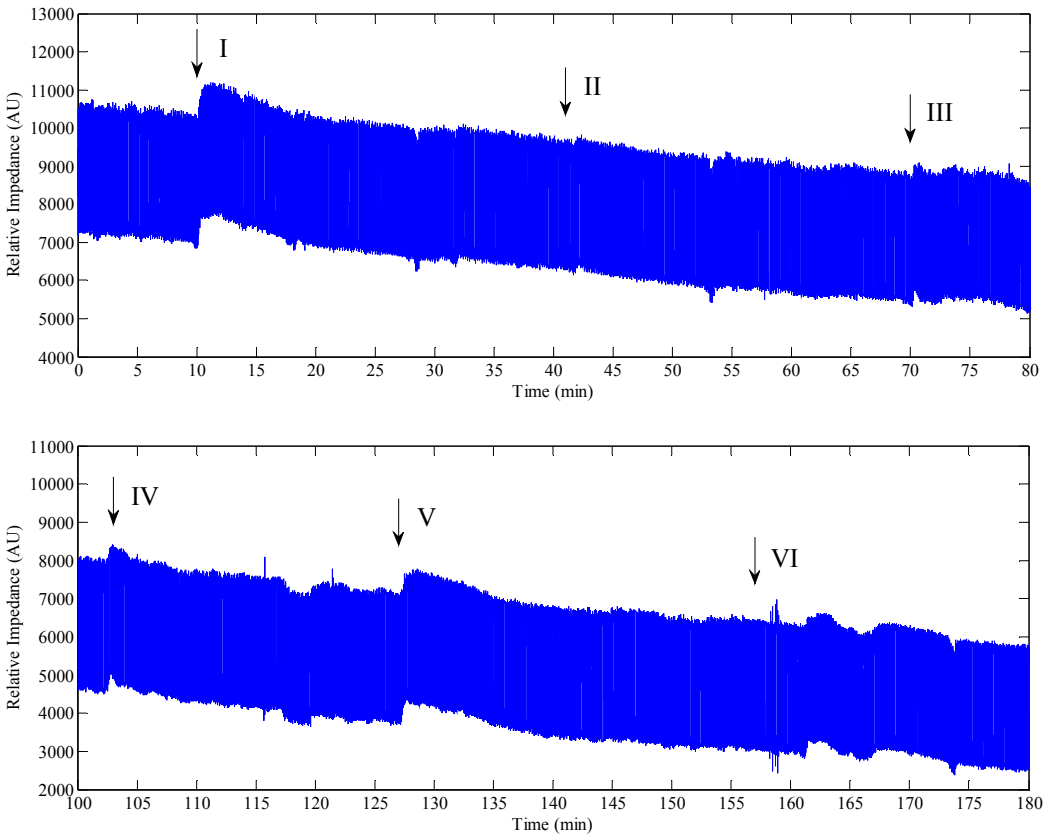

Fig. 1: The waveforms of relative impedance as recorded by PulmoVista 500. The application of blood clots is marked with an arrow.

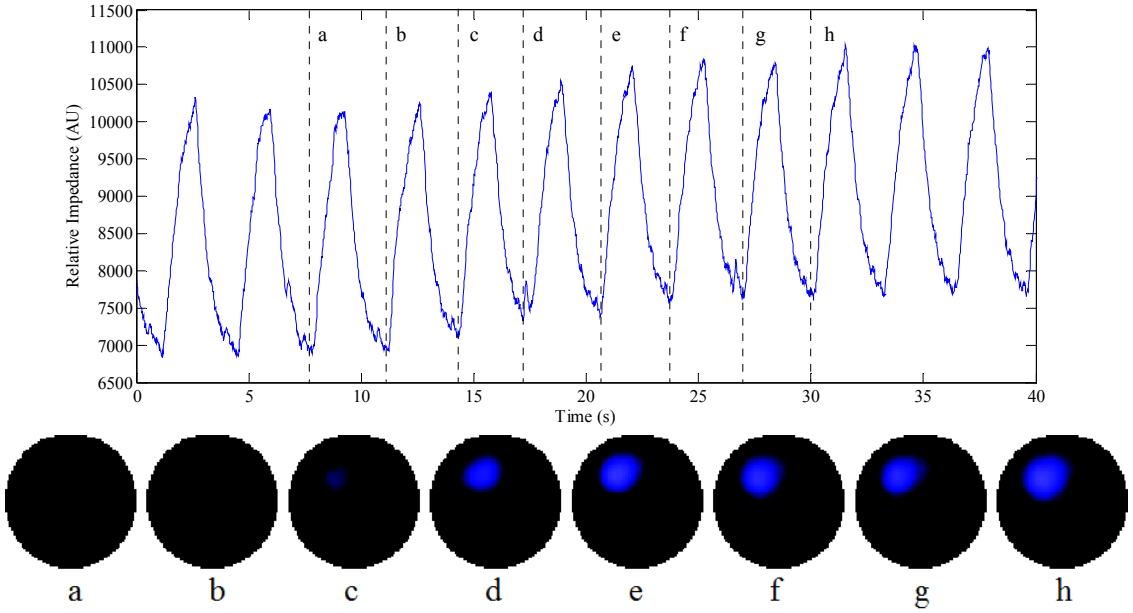

Fig. 2: The detail of the waveform from Fig. 1 after the blood clots injection Nr. I. with the respective end-expiratory frames (a-h). Ventilation parameters were kept constant during the depicted period.

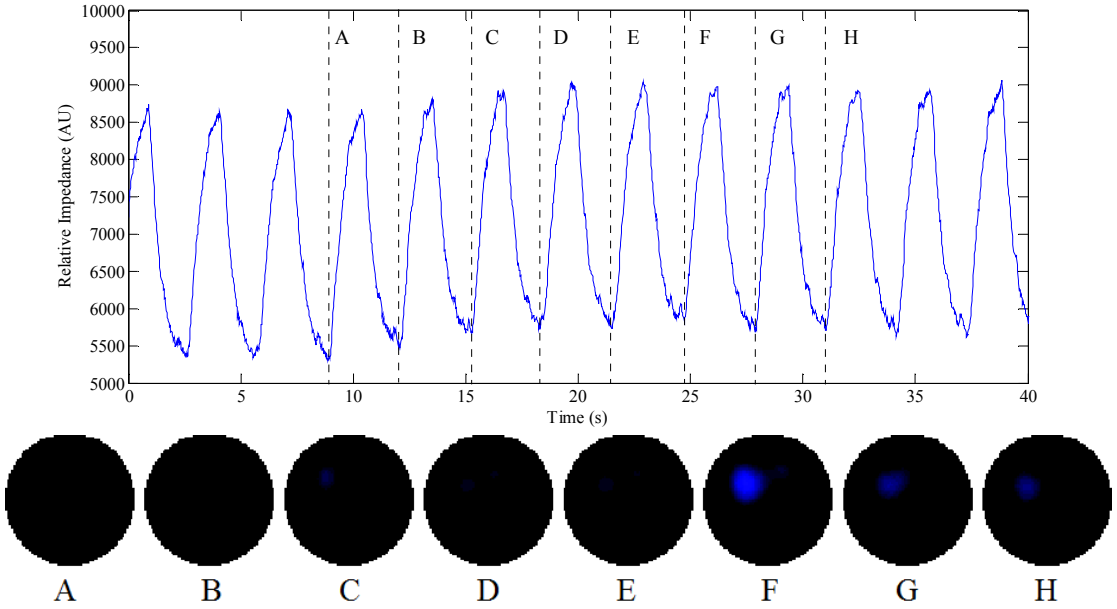

Fig. 3: The detail of the waveform from Fig. 1 after the blood clots injection Nr. III. with the respective end-expiratory frames (A-H). Ventilation parameters were kept constant during the depicted period.

IV. DISCUSSION

Transversal reconstructions in Fig. 2 and 3 suggest that EIT systems are capable to roughly localize the position of PE which is in agreement with [4]. However, the selection of appropriate frames is very demanding especially because of cardiac activity which often appears in end-expiratory EIT images. Another necessary condition for detection of PE using EIT is the presence of perfusion defect large enough to evoke a sufficient change of thoracic impedance. Otherwise the reconstructed end-expiratory images are displayed as black (Fig. 3, B-E) and it is impossible to distinguish them from those without any perfusion defect (see [8] for comparison).

The waveforms depicted in Fig. 1 show the impedance responses of the artificial PE induction can vary from the vertical shift of the waveform values reaching almost 25 % of its amplitude (blood clots injections Nr. I. and V.) to absolutely insignificant and barely observable changes (injections Nr. II. and VI.). This variability is apparently caused by the way the PEs were induced. The studies [4] and

[7] where a balloon catheter was used instead of blood clots and the impedance changes were emphasized by the application of impedance contrast agent (saline solution) show more expressive results. However, the impedance changes are then manifested as a decrease of thoracic impedance which makes it impossible to compare them with the results presented in this study.

The acquired transversal reconstructions in Fig. 2 and 3 are equivalent to those presented in [4]. Comparing them with the respective EIT images from [5] and [6], the EIT system used in this case study enables to display the local impedance changes more clearly. This is mainly due to the technical progress made in the last two decades and the development of more sophisticated reconstruction algorithms.

The results of this case study support the idea of further use of EIT systems in lung perfusion monitoring and PE detection. It has been shown that PE can cause significant changes in impedance waveforms so the application of impedance contrast agents might not be necessary in the case of large PEs. Additional studies thus have to be made to determine whether the method is also applicable for small perfusion defects.

ACKNOWLEDGMENT

The authors would like to thank the employees of the animal laboratory of the Department of Physiology, First Faculty of Medicine, Charles University in Prague.

This work has been supported by the grant of Czech Technical University in Prague No. SGS OHK4-030/11 "Optimization of non-conventional techniques of artificial lung ventilation II.

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