A model of end-expiratory lung impedance dependency on total extracellular body water

J Suchomel\textsuperscript{1} and V Sobota\textsuperscript{1}

\textsuperscript{1} Czech Technical University in Prague, Faculty of Biomedical Engineering, Sitna Sq. 3105, 272 01 Kladno, Czech Republic
E-mail: jan.suchomel@fbmi.cvut.cz

Abstract. Electrical impedance tomography (EIT) is an attractive method for clinical monitoring of patients during mechanical ventilation. This study evaluates lung impedance measurements using Dräger PulmoVista 500 EIT system on an animal model. Mechanically ventilated model was created. Vital signs were monitored as well as mechanical ventilation parameters. Extracellular fluid balance and blood volume were handled as follows: 30-40\% of total blood volume were removed and returned back, 0.5 to 1 litre of Ringer’s solution was injected afterwards. The quantity of injected fluids was recorded for each animal. During this process thoracic electrical impedance measurement was performed. Recorded data from PulmoVista 500 EIT system were analysed using the official Dräger EIT Data Analysis Tool. The dependency of end-expiratory (minimum impedance value) frames and changes of fluid balance is shown. Preliminary results strongly support the expectation that electrical impedance of thorax can be affected by total extracellular fluid change.

1. Introduction
Electrical Impedance Tomography (EIT) can produce tomographic images of tissue resistivity. This method is based on the visualization and quantification of tissue impedance determined by injecting small electrical currents and measuring the resulting voltages on the surface of the torso [1]. Lungs have high electrical resistivity relative to other tissues because of the air content [2]. In inspiration the ratio of air to condensed matter in lungs increases and the structures as alveolar walls become thinner. Electrical current applied to lung tissue flows through the condensed matter hence resistivity increases with inspired air volume [3].

However, the EIT has many problems which arise from the three dimensional spread of current, the need of many electrodes and the fact that the body size and the shape affect measured potentials as well as resistivity distribution [4]. Regarding this, the total impedance of the thorax could be affected by fluid balance of the body.

This preliminary study describes the possibility of utilization of PulmoVista 500 EIT system (Dräger Medical, Lübeck, Germany) for monitoring of lung impedance dependency on the fluid balance of mechanically ventilated animal. Although the system is designed for monitoring of lung ventilation and operates only with relative impedance changes (displayed as arbitrary units – AU) it has a potential to be a suitable tool for the purposes of this study.
2. Methods and material
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 of the Department of Physiology, First Faculty of Medicine, Charles University in Prague, in accordance with Act No. 246/1992 Coll., on the protection of animals against cruelty.

Five large female pigs (Sus scrofa domestica) four to five months old with an average body weight of 52 kg (Tab. 1) were used in the study.

2.1. Premedication, anesthesia, preparation
Animals were premedicated by azaperone (2 mg/kg IM), followed by anesthesia with atropine sulphate (0.02 mg/kg IM) and ketamine hydrochloride (20 mg/kg IM). When placed on the operating table, initial boluses of propofol (2 mg/kg IV) and morphine (0.1 mg/kg IV) were administered. Dräger PulmoVista 500 electrode belt (size S) with 16 electrodes and one reference electrode was placed on the animal. ECG gel has been used several times to establish a good connection between the animal and the electrode belt. The signal quality has been checked by the EIT system. Animals were orotracheally intubated by a cuffed endotracheal tube (I.D. 7.5 mm) and connected to the conventional ventilator Hamilton G5 (Hamilton Medical AG, Bonaduz, Switzerland) in INTELLiVENT-ASV mode. An ear vein was cannulated and a continuous infusion of propofol (8 to 10 mg/kg/h IV) combined with morphine (0.1 to 0.2 mg/kg/h IV) and heparin (40 to 50 U/kg/h IV) was initiated to maintain anesthesia. The drugs dose was adjusted to keep the animals in the stage of surgical anesthesia throughout the procedure. The depth of anesthesia was checked according to the reflex responses and to the brain monitoring bispectral index (BIS).

2.2. Normoventilation
Conventional ventilator Hamilton G5 was used in the (S)CMV volume controlled ventilation mode with respiratory rate 18 bpm, FiO\textsubscript{2} 21%. The initial tidal volume was set to 8.5 mL/kg of the actual body weight and was titrated to reach normocapnia (PaCO\textsubscript{2} = 40 ± 1 mmHg). Reaching the normocapnia the EIT system has been calibrated to get a baseline for measurement (Fig. 1 and 2).

Table 1. Parameters of experiment realizations.

| No. | Weight of animal (kg) | Calculated volume of blood (mL) | Blood loss (mL) | Blood transfusion (mL) | Ringer’s solution (mL) |
|-----|-----------------------|---------------------------------|----------------|------------------------|-----------------------|
| 1   | 54                    | 3564                            | 1260           | 1000                   | 2250                  |
| 2   | 50                    | 3300                            | 1155           | 1000                   | 1500                  |
| 3   | 54                    | 3564                            | 1260           | 1000                   | 1500                  |
| 4   | 50                    | 3300                            | 1155           | 1000                   | 1000                  |
| 5   | 54                    | 3564                            | 1050           | 1000                   | 2000                  |

2.3. Study protocol
Total blood volume was calculated as 6.6 % of total body weight. Regarding to the study protocol the first 10 % of total blood volume was removed from vein. Another 5 % steps
were performed up to 30-40% of total blood volume after a short stable phase. All blood losses were recorded by the EIT system. The returning of blood was performed in two steps by 500 ml per 30 minutes to vein. After blood returning a fluid challenge was made by 1000 ml of Ringer’s solution in 30 minutes to vein. The whole returning phase and the fluid challenge were recorded by the EIT system.

2.4. Evaluation methods
Recorded data from PulmoVista 500 were collected and the waveforms of relative impedance were reconstructed. Based on the protocol, the time intervals of fluid change were determined and the dependency of ∆EELI on the fluid change was calculated using linear regression (Fig. 4). The EIDORS software was used for reconstruction of selected frames to demonstrate the effect of the fluid change on baseline values in long term records.

![Figure 1. Relative impedance waveform of one single breath as recorded by PulmoVista 500. Points a-h correspond with respective EIDORS reconstructions in Fig. 2. Frame with the smallest value of relative impedance is used as the reference one (baseline) and is displayed as black. In this case is frame h the baseline frame. ∆EELI curve is generated by connecting the minimum impedance values (in this case a and h).](image1)

![Figure 2. EIDORS reconstructions of points of relative impedance waveform from Fig. 1.](image2)

| Fluid              | Mean (AU/L) | SD (AU/L) | SD (%) |
|--------------------|-------------|-----------|--------|
| Ringer’s solution  | -4403       | 566       | 12,9   |
| Blood              | -4797       | 1241      | 26,0   |

3. Results
First preliminary results show that PulmoVista 500 is a suitable tool for monitoring of the dependency of lung impedance on the fluid balance. The change of ∆EELI caused by blood
transfusion was recorded five times (volume 500 mL, dosing rate 1000 mL/h), the change caused by application of Ringer’s solution was recorded seven times (volumes in range 500 to 1000 mL, dosing rate 1000 or 2000 mL/h) in five realizations of the experiment. Mean decrease of ∆EELI due to blood transfusion was −4797 AU/L (SD 26.0 %), due to application of Ringer’s solution −4403 AU/L (SD 12.9 %, Tab. 2).

![Figure 3](image1.png)  ![Figure 4](image2.png)

**Figure 3.** A record of relative impedance waveform (blue) during an application of Ringer’s solution. ∆EELI (red) is counted as connections of minimum impedance values (see Fig. 1).

**Figure 4.** ∆EELI dependency on the change of injected fluid (Ringer’s solution, dosing rate 2000 mL/h, volume 1000 mL).

![Figure 5](image3.png)

**Figure 5.** EIDORS reconstructions of points of relative impedance waveform from Fig. 3.

4. Discussion
The results show an obvious dependency of ∆EELI on change of fluid balance. As is shown in Fig. 3, according to the application of Ringer’s solution or blood transfusion the mean of relative impedance waveform as recorded by PulmoVista 500 decreases and so does the respective ∆EELI curve. Although the results indicate the system is not capable to distinguish whether the change was caused by blood transfusion or by application of Ringer’s solution there is a potential for using the system to diagnose pulmonary diseases characterized by oedema or contusion.

References
[1] Leonhardt S and Lachmann B 2012 *Intensive Care Medicine* 38(12) 1917–1929 ISSN 0342-4642
[2] Duck F 1990 *Physical properties of tissue: a comprehensive reference book* (Academic Press) ISBN 9780122228001
[3] Witsoe D and Kinnen E 1967 *Medical and biological engineering* 5(3) 239–248 ISSN 0025-696X
[4] Holder D 2010 *Electrical Impedance Tomography: Methods, History and Applications* Series In Medical Physics And Biomedical Engineering (Taylor & Francis) ISBN 9780750309523