EFFECT OF ELECTRODE BELT USED FOR LUNG MONITORING WITH ELECTRICAL IMPEDANCE TOMOGRAPHY ON TIDAL VOLUME IN HEALTHY SUBJECTS

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Abstract

Electrical impedance tomography is a radiation free, non-invasive lung monitoring method that is increasingly coming to the forefront of the interest of researchers and clinicians. The most frequently used EIT system PulmoVista 500 (Dräger Medical, Germany) uses stiff silicone electrode belt that is applied around the patient's thorax to monitor the distribution of ventilation. To achieve proper electrode-skin connection and obtain high-quality signal, the electrode belt needs to be placed tightly at the level of 4th to 6th intercostal space. There is a possibility that tightly placed belt affects the compliance of the chest wall, tidal volume, and respiratory effort of the patient. In this study, we monitored tidal volumes using spirometer in 10 healthy, spontaneously breathing volunteers with and without the electrode belt applied around the thorax. Potentially clinically significant, but not statistically significant changes occurred in 70% of the subjects during calm breathing and in 90% of the subjects during forced breathing. The study did not determine whether the use of the electrode belt increases or decreases the value of tidal volume. However, when monitoring lung ventilation with EIT system, the possible influence of the stiff electrode belt on chest wall compliance and tidal volumes should be considered.

Keywords

tidal volume, electrode belt, spirometry, electrical impedance tomography

Introduction

Electrical impedance tomography (EIT) is non-invasive, radiation free lung monitoring method that uses low frequency alternating currents to display tissues and internal structures of the body based on their electrical impedance [1, 2]. This method can be used to monitor total and regional changes of ventilation [3] and is attracting more and more attention in research and clinical practice in recent years [4]. However, EIT still faces several methodological ambiguities and has not yet become a routine tool in clinical practice [5].

Currently, several EIT systems are available for lung monitoring and each use slightly different way to attach measurement electrodes around the patient´s thorax. One uses special vest-like single use system (BB^2, Swisstom, Switzerland), other standard single use electrodes (Maltron Sheffield, UK) and another single use electrode belts (Timpel, Brazil). However, currently the most frequently used EIT system PulmoVista 500 (Dräger Medical, Germany) uses a reusable silicone belt with 16 equidistantly placed integrated electrodes. The manufacturer recommends placing the belt between 4th to 6th intercostal space at the parasternal line. The belt is produced in five sizes to fit chest circumference from 70 to 150 cm [6, 7]. Since the belt is relatively stiff and the manufacturer recommends putting the belt on tightly [8], there is a possibility that it affects compliance of the chest wall and the breathing effort of spontaneously breathing patients, which could possibly lead to lower tidal volumes. Zhang et al. [9] determined the effect of EIT electrode belt (PulmoVista 500, Dräger Medical, Germany) on lung function by spirometry in a sitting position in 30 subjects (10 healthy and 20 with lung diseases). They concluded that the electrode belt could reduce lung volumes in subjects with pre-existing lung diseases. Changes of lung function in healthy subjects were not detected. Leonhardt et al. [10] mentions that there is a possibility of ulcers and necrosis in the back area due to the pressure of the electrode belt. No other studies have been found addressing the issue of the

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negative effect of the electrode belt pressure on the patient´s chest wall compliance, breathing effort, tidal volumes, or other ventilation parameters.

Tidal volume of the lungs is a static parameter which represents the volume of air moved into or out of the lungs in one calm breath. It measures around 500 ml in an average healthy adult male and 400 ml in a healthy female, or approximately 7 ml/kg of ideal body weight [11]. It plays a significant role during mechanical ventilation to ensure adequate ventilation without causing trauma to the lungs. Decrease in tidal volume as well as increased stiffness and decreased compliance can indicate number of both obstructive and restrictive lung diseases [11, 12]. If the application of the electrode belt would lead to a decrease in tidal volume, the question is whether this could be misinterpreted as a symptom of a disease, or it could affect the conclusions about the patient´s health conditions and possibly lead to wrong therapeutic decisions. Tidal volume is an easy to measure parameter affected by the chest wall compliance and breathing effort.

The aim of this study is to analyze whether the tightly placed EIT electrode belt has any impact on the tidal volume of spontaneously breathing healthy subjects in semi-sitting position.

Methods

This prospective interventional study with cross-over design was conducted on 10 healthy volunteers in the ICU-simulated laboratory of the Faculty of Biomedical Engineering, Czech Technical University in Prague, Czech Republic and was approved by local ethical committee on March 22, 2017 with Reference No. C3/017. The study was registered in ClinicalTrials.gov with an identifier NCT06419790. All the subjects signed an informed consent form prior the enrolment.

Inclusion and Exclusion Criteria

The subjects had to be overall healthy, without any wounded skin in the electrode belt location. Also, according to the manufacturer, it is not possible to use EIT system in subjects with Body Mass Index (*BMI*) greater than 50 kg/m^2. Another exclusion criterion for our study was Tiffeneau index (*FEV1/FVC*), which is defined as a ratio of forced expired volume in one second and forced vital capacity, lower than 70%. Healthy subjects, without any obstructive diseases of respiratory system, are supposed to have Tiffeneau index above 70% [13, 14].

Monitored Subjects

Ten subjects participated voluntarily in this study and their characteristics are summarized in Table 1. Thorax circumference was measured between the 4th and 6th intercostal space at the parasternal line. All subjects were healthy and were breathing spontaneously during the whole experiment. All involved subjects completed the study without any complications or needs to interrupt the measurement process.

Table 1: Characteristics of the involved subjects. Average values are presented as mean ± standard deviation.

Number of males / females	5 / 5
Age (years)	21.5 ± 0.7
Weight (kg)	76.6 ± 13.4
Height (cm)	178.2 ± 13.2
BMI (kg/m^2)	24.0 ± 1.9
Thorax circumference (cm)	89.0 ± 11.4

Measurements

For basic spirometry examination and tidal volume monitoring, spirometer Ergostick (Geratherm Respiratory, Germany) and its software Blue Cherry were used. Based on the software instructions, volume calibration of the spirometer was performed using a 3-liter calibration syringe (Hans Rudolph, USA). The subjects were breathing using a spirometry probe Ergoflow (Geratherm Respiratory, Germany) with a clip on their nose.

EIT system PulmoVista 500 (Dräger Medical, Germany) uses a silicone electrode belt with 16 electrodes implemented in the belt. In this study we analyzed the effect of the belt pressure on the chest; the monitoring of the lungs with the EIT system was not performed, so the electrode belt was not attached to the system. Available sizes of the EIT system PulmoVista 500 electrode belts are summarized in Table 2. In our study, electrode belts of sizes S, M and L were used. Fig. 1 shows the placement of size S electrode belt on a male subject.

Table 2: Sizes and colors of the electrode belt of EIT system PulmoVista 500 based on thorax circumferen ce at 5th intercostal space of the patient [8].

Size	Color	Chest circumference
S	Medium blue	70 to 85 cm
M	Dark blue	80 to 96 cm
L	Dark red	92 to 110 cm
XL	Gray	106 to 127 cm
XXL	Violet	124 to 150 cm

Experimental protocol

First, all subjects underwent basic spirometry examination to determine their functional lung capacity, expiratory volume in one second and Tiffeneau index.

The subject was in supine position between lying and sitting in approx. angle of 45°. The subject was breathing spontaneously and calmly through the

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spirometry probe for 15 min. In the last minute, the subject was asked to perform about 10 forced deep breaths. Based on the thorax circumference, appropriate size of the electrode belt was placed around the subject´s chest in the 4th to 6th intercostal space, as shown in Fig. 1. The subject was seated into the same position as in the first part of the measurement and the tidal volumes were again measured for 15 min, with 10 forced breaths at the end.

In order to avoid the subject´s focus on the breathing habits and remain breathing without any intentional changes during the whole measurement, the subject was asked to engage in any calm, but mind-distracting activities of his choice, such as reading a book or playing a game on their mobile phone.

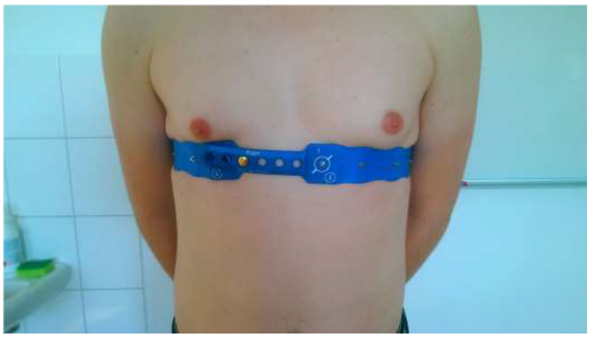

Fig. 1: Subject with size S electrode belt placed in the 5th intercostal space.

Data analysis and statistics

Data were exported as *.asc from Blue Cherry software (Geratherm Respiratory, Germany) to Microsoft Excel 365 (Microsoft, USA). For statistical analyses, program Statistica v. 7 (StatSoft, USA) was used. Normality of the data was confirmed by Shapiro-Wilks test on 0.05 significance level. Paired Student´s *t*-test was used to determine the statistical significance of the changes of tidal volume for both spontaneous and forced breathing. Mean values of tidal volume during spontaneous and forced breathing were compared for each subject with and without the electrode belt. Changes with a *p*-value lower than 0.05 were considered statistically significant.

Results

Mean values of tidal volumes during spontaneous and forced breathing with and without the electrode belt for all subjects are summarized in Table 3. Subject 1 to 5 were female, subjects 6 to 10 were male. Standard deviation (*SD*) is also given.

Fig. 2 and Fig. 3 below show changes of mean values of measured tidal volumes after the electrode belt was applied on each subject during spontaneous breathing (Fig. 2) and forced breathing (Fig. 3). At the 0.05 significance level, no statistically significant changes were found by paired Student´s *t*-test.

Table 3: Mean tidal volumes ± SD of spontaneous and forced breathing with and without the electrode belt.

	Tidal volume (l)			
	Without el. belt		With el. belt	
	Spont.	Forced	Spont.	Forced
All subjects	0.63 ± 0.19	2.50 ± 0.79	0.64 ± 0.26	2.45 ± 0.80
Women	0.54 ± 0.07	1.93 ± 0.37	0.49 ± 0.09	1.86 ± 0.49
Men	0.72 ± 0.22	3.07 ± 0.66	0.79 ± 0.28	3.03 ± 0.60

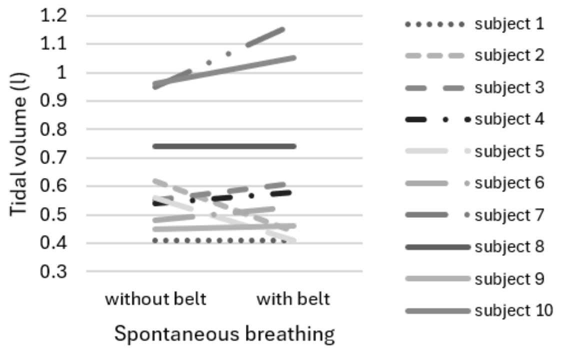

Fig. 2: The changes of tidal volume of each subject after the application of the electrode belt during spontaneous breathing. No statistically significant changes were found by paired t-test.

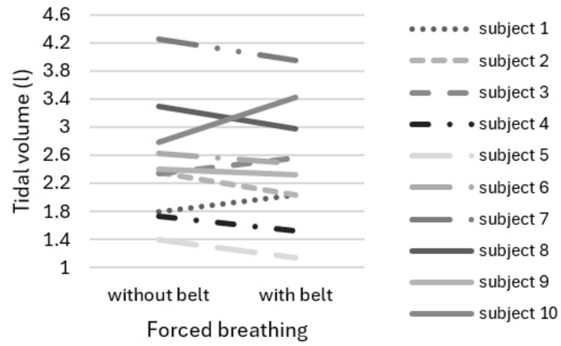

Fig. 3: The changes of tidal volume of each subject after the application of the electrode belt during forced breathing. No statistically significant changes were found by paired t-test.

Discussion

The main finding of the study is that the electrode belt from EIT system PulmoVista 500 (Dräger Medical, Germany) does, to some extent, affect the tidal volumes of spontaneously breathing healthy subjects. This study found that when electrode belt is

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put on tightly, the tidal volumes do not remain the same, but change by more than 5% in majority (70%) of the subjects. However, it was not possible to clearly determine whether the use of the electrode belt leads to an increase or a decrease of tidal volume. Statistically significant changes of the tidal volumes were not proven. Our findings correlate with conclusions of study [9], where they measured changes of vital capacity (*VC*), forced vital capacity (*FVC*) and maximum voluntary ventilation (*MVV*) and found no statistically significant differences in a healthy group comparing values obtained with and without the EIT electrode belt (PulmoVista 500, Dräger Medical, Germany).

During spontaneous breathing, tidal volumes of three subjects remained practically the same (difference was lower than 2%), increased for five subjects and decreased for two subjects with the electrode belt applied. During forced breathing, tidal volume increased for three subjects and decreased for seven subjects.

Even though the subjects were trying not to focus on breathing and were asked to occupy their minds with other activities (such as reading etc.), we cannot rule out their effort to compensate the belt pressure by changing the breathing habits and breathing efforts. This factor would be eliminated in patients under general anesthesia breathing with a ventilator. However, the pressure of the electrode belt is also present in patients under anesthesia, and we can only estimate whether it could lead, for example, to an increase in ventilation pressures set on a ventilator to ensure sufficient ventilation in all parts of the lungs.

Another limitation of this study is that belts of some sizes are used more often than others and the elasticity of each belt can vary based on the age of the belt and a frequency of its usage. In our laboratory conditions, healthy volunteers are usually monitored by the EIT and smaller sizes (S, M) of the belts are used more often. In clinical practice, patients with greater BMI and obese patients suffer from lung diseases more often [15–17] and we can assume that in healthcare facilities, greater sizes of the electrode belt (L, XL, XXL) would be used more often and may thus lose its elasticity. Also, since the electrode belts of different sizes have the same width and are made from same material, they are more elastic as the size increases. This factor was also measured and proven in study [9].

Other factor that should be considered is that this study was conducted on healthy subjects aged 21.5 ± 0.7 years. However, compliance of the chest wall, as well as tidal volumes, change with age [18, 19] and is also affected by lung diseases, such as chronic obstructive pulmonary disease (COPD) or respiratory distress syndrome (RDS) [20, 21]. Therefore, we assume that the results could vary in a similar study conducted on a group of older subjects or on subjects with a pulmonary disease. Since the age and pulmonary diseases lower chest wall compliance and tidal volume, we can assume that the placement of the stiff electrode belt could lead to additional deterioration. Nevertheless, in the mentioned study [9] the age of the healthy subjects was higher, 51.3 ± 7.2 years and the influence of the electrode belt was not proven in healthy subjects.

In our study, the subjects were placed in semi-sitting position mainly because breathing through the spirometry probe with a nose clip is quite uncomfortable when lying, due to unpleasant feeling of dryness in the mouth that could lead even to the subjects coughing. In clinical practice, EIT lung monitoring is usually performed in lying patients in supine position.

Also, in our case, the subjects were breathing with the belt applied for approx. 15 min. In clinical practice, the time with the belt on is much longer since EIT systems are suitable for a long-time monitoring (hours or days). In that case, we assume that wearing the belt for a longer period would accentuate its effect on volumes and also pressure sores could occur, but this was not the focus of this study. Study [9] also did not analyze longer-time effect of the applied electrode belt. They did not state the length of their measurements with the electrode belt, but since only spirometry examination took place, we assume that the subjects measured in their study were breathing with the applied belt for a much shorter time.

The main recommendation for both research and clinical practice resulting from this study is that even though there is no clear evidence whether the EIT electrode belt leads to increase or decrease of tidal volumes, the personnel should consider that the belt pressure affects the chest wall compliance and might lead to changes in tidal volumes and every patient should be given an individual approach. It is possible that in some cases the change of the tidal volume caused by the electrode belt could lead to a misinterpretation of the patient's health conditions and could be wrongly evaluated as a symptom of a lung disease.

It would be desirable to conduct a follow-up study in a clinical practice environment on a greater number of mechanically ventilated patients and monitor how the distribution of ventilation changes when the electrode belt is applied. However, the only method allowing the monitoring of ventilation distribution besides EIT is computed tomography (CT) with a significant radiation exposure. It would be interesting to analyze how the ventilation parameters such as volume and pressure must be reset on the ventilator to compensate the changes and maintain the distribution of ventilation same as it was prior the application of the electrode belt.

Also, similar study with different EIT systems using other ways of attaching the electrodes around the patient's thorax should be conducted.

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Conclusion

This study shows that the application of electrode belt used for lung monitoring with electrical impedance tomography system PulmoVista 500 (Dräger Medical, Germany) leads to changes of tidal volumes of healthy, spontaneously breathing subjects. Change greater than 5% occurred in 70% of the subject during calm breathing and in 90% subject during forced breathing. The changes were not statistically significant, and the study did not clearly determine whether the use of the electrode belt increases or decreases the value of tidal volume. However, some of the detected changes could be considered clinically significant and could be mistaken for a symptom of incipient lung disease.

Therefore, when monitoring lung ventilation with EIT system, the possible influence of the stiff electrode belt on chest wall compliance and tidal volumes should be considered. To describe the effect more precisely, a greater study with mechanically ventilated patients would be needed. We also agree with study [9] conclusion that comparing lung function acquired with and without the electrode belt should be avoided.

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