THE EFFECT OF FRAME RATE AND CALIBRATION ON LUNG MONITORING WITH ELECTRICAL IMPEDANCE TOMOGRAPHY

Kristyna Koldova, David Slajfercik

Department of Biomedical Technology, Faculty of Biomedical Engineering,
Czech Technical University in Prague, Kladno, Czech Republic

Abstract

Electrical impedance tomography (EIT) is a non-invasive method that records changes in tissue impedance in the selected cross-section of the body and is mainly used to monitor patient's lung ventilation. The aim of this study was to analyze the effect of the pre-set frame rate and how calibration of the EIT system affects final record when monitoring lungs using EIT system PulmoVista 500 (Dräger Medical, Germany). Ten healthy male volunteers were measured with frame rates 10, 20, 30, 40 and 50 Hz for analysis, followed by calibrated and uncalibrated measurements. The subjects were breathing spontaneously in a horizontal supine position. In case of the frame rate analysis, data were statistically analyzed using ANOVA for repeated measures. Paired T-test was used for comparing data from calibrated and uncalibrated records. This study shows that the effect of both frame rate and calibration is negligible.

Keywords

electrical impedance tomography (EIT), EIT calibration, frame rate, lung monitoring

Introduction

Electrical impedance tomography (EIT) is a non-invasive, side-effect free, bedside monitoring system that is becoming a useful alternative to conventional imaging systems. However, EIT provides functional monitoring rather than anatomical imaging. Using alternate small currents (approx. 8–9 mA, 80–130 kHz), EIT is able to provide information about the distribution of tissue impedance within a selected tomographic cross-section of the body. Application of EIT has been found in several medical areas, especially in lung ventilation monitoring. Currently, PulmoVista 500 (Dräger Medical, Germany) is one of the most frequently used EIT systems in clinical practice. In the user manual, the manufacturer of PulmoVista 500 states that frequencies up to 30 Hz should be used for lung monitoring. Higher frequencies are recommended mainly for monitoring impedance changes caused by cardiac activity. However, we are aware that in clinical practice and research, higher frame rate values are often used for lung monitoring as well. In the beginning of the measurement when switching from *Standby* to *Start*, short calibration is performed. When the measurement is paused and then started again only by pushing the *Record* button, the calibration is not performed automatically. That means that in practice, series of several measurements can be performed without any calibration [1–5].

The aim of this study is to find whether and how the signals differ when obtained using various frame rates. Another aim of this study is to analyze the differences between calibrated and uncalibrated measurements, in case that the measured subject remains in the same conditions.

Methods

This prospective interventional study was approved by the institutional Ethical committee of the Faculty of Biomedical Engineering, Czech Technical University in Prague in March 2018. A group of 10 healthy male volunteers (Table 1) was monitored using EIT system PulmoVista 500 in a supine position, breathing spontaneously. Every subject underwent a spirometry examination using spirometer Ergostik (Geratherm Medical, Germany) and, among other parameters, Tiffaneau index was measured, since a value below 0.7 is considered an exclusion criterion for the monitoring using EIT system PulmoVista 500. Weight, BMI and subcutaneous fat were measured using body composition monitor BF511 (OMRON Healthcare, Japan). An electrode belt of a proper size was placed around the subject's chest at

Lekar a technika – Clinician and Technology 2019, vol. 49(4), pp. 107–111, DOI: 10.14311/CTJ.2019.4.01
ISSN 0301-5491 (Print), ISSN 2336-5552 (Online)

the level of the fifth intercostal space in the medio-clavicular line.

When the subject was placed in a supine horizontal position for the monitoring, the quality of the signal was checked and, if not sufficient, ECG gel was applied between the respective electrode and the skin to assure proper contact resistance. The subject was breathing through the spirometry sensor in order to monitor the breathing volumes during the whole procedure of EIT measurement. Also, the subject was asked to avoid any movements but breathing, since an extra movement could cause artifacts in the recorded data. For each measurement, a 3-minute record was obtained from the EIT system.

Table 1: Characteristics of the measured subjects.

Male/Female	10/0
Age (years)	21.9 ± 1.0
Height (cm)	182.7 ± 6.1
Weight (kg)	87.6 ± 15.6
BMI (kg/m^2)	26.2 ± 4.1
Subcutaneous fat (%) *	23.1 ± 5.9
Tiffaneau index	0.8 ± 0.1

Data are means ± standard deviation.
* Measured by the impedance method.

Measurements with various frame rates

The operating frequency of the EIT system PulmoVista 500 was set to automatic for all measurements. Prior each measurement, the EIT system was calibrated. For each frame rate (10 Hz, 20 Hz, 30 Hz, 40 Hz and 50 Hz) a 3-minute record was obtained from every subject.

Calibrated and uncalibrated measurements

In order to be able to analyze the effect of calibration of the EIT system on the record, two measurements were performed for each subject. The first measurement was recorded after the calibration took place, and the second measurement was recorded after a small pause without a new calibration. Both measurements were recorded with the frame rate set at 50 Hz and automatic operating frequency.

Data evaluation

An acquired cross-section image of the thorax was divided into four regions of interest (ROI), quadrants and horizontal layers, as standardly used by the data evaluation software Dräger EIT Data Analysis Tool 6.1. The percentage of regional ventilation in each ROI for each breath was evaluated. For every record, one mean value representing the percentage of ventilation in each ROI was calculated. Then, distribution of ventilation for all records acquired in every subject was compared for each ROI, separately for measurements with various frame rates and un/calibrated measurements.

Normality of the data was tested and confirmed by the Shapiro-Wilks test. In the frame rate analysis, data were statistically analyzed using ANOVA test for repeated measures. Paired T-test was used for comparing data from calibrated and uncalibrated records.

Results

When analyzing the changes of distribution of ventilation in particular ROIs for the various frame rates, no statistically significant differences were found at $\alpha = 5\%$. Examples of results of the changes of distribution of ventilation in the 1st ROI in layers are shown in Figure 1 and for the 1st ROI in quadrants are shown in Figure 2. Similarly, no statistically significant differences were found in any other ROI.

There was no statistical significance when comparing the calibrated and uncalibrated measurements at $\alpha = 5\%$, as shown in Figure 3 for the 1st ROI in layers, and in Figure 4 for the 1st ROI in quadrants.

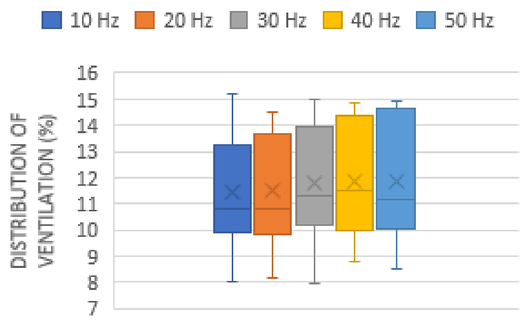

Fig. 1: Box plot of mean values for various frame rates for the 1st ROI when divided into layers.

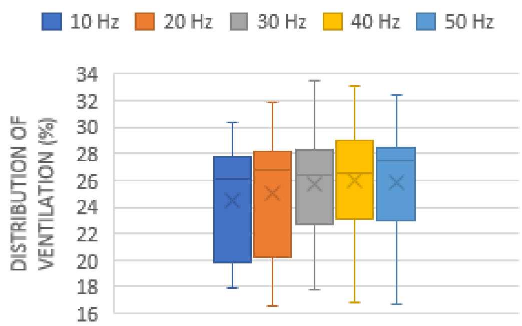

Fig. 2: Box plot of mean values for various frame rates for the 1st ROI when divided into quadrants.

Lekar a technika – Clinician and Technology 2019, vol. 49(4), pp. 107–111, DOI: 10.14311/CTJ.2019.4.01
ISSN 0301-5491 (Print), ISSN 2336-5552 (Online)

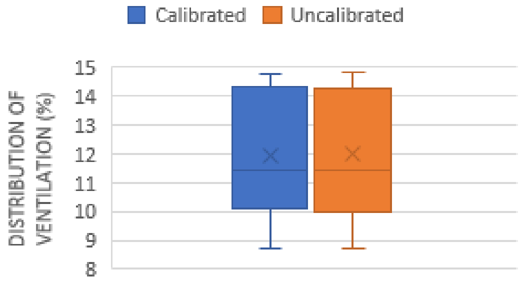

Fig. 3: Box plot of mean values of calibrated and uncalibrated records for the 1st ROI when divided into layers.

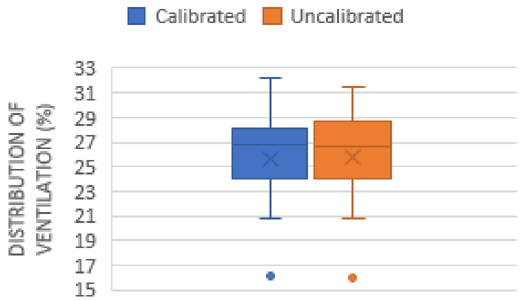

Fig. 4: Box plot of mean values of calibrated and uncalibrated records for the 1st ROI when divided into quadrants.

Discussion

Primarily, the results show no statistically significant differences in any of the evaluated set of measurements. That means that the setting of the frame rate or performing the calibration when the patient remains in the same conditions will not greatly affect the obtained data, also from a clinical perspective.

We conclude that when higher frequencies, such as 40 and 50 Hz, are used for lung monitoring instead of the lower frequencies as recommended by the manufacturer, the user does not make any major mistake that could be affecting the conclusions about the monitored lungs.

However, the size of the obtained record can be an interesting factor for selection the frame rate for various (especially clinical) purposes of lung monitoring using EIT. Choosing lower frequencies will significantly reduce the file size and the associated time needed for data upload and evaluation in Dräger EIT Data Analysis EIT record is shown in Figure 5.

It is clear that the size of the record increases linearly with the frame rate. This fact should be considered when EIT is used for long term monitoring of the patients, where higher frequencies of the frame rate could cause complications with the data analysis.

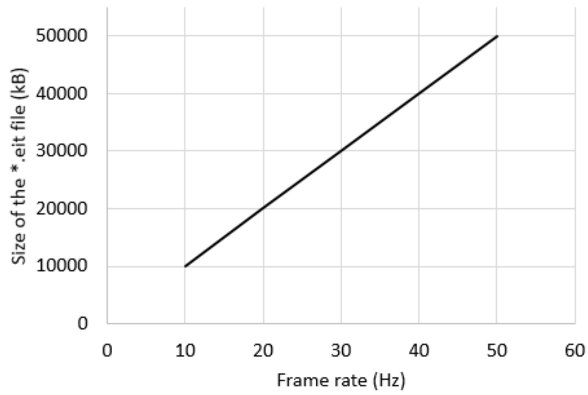

Fig. 5: Dependency of the size of the EIT record on the set frame rate.

When analyzing the calibrated and uncalibrated measurements, we found out that there was no statistical difference between those two types of records. By performing the calibration, the system optimizes its settings and, if we continue with the monitoring after a pause with the same conditions, such as e.g. the position of the electrode belt, it is not necessary to perform the calibration again.

However, we would like to know if significant changes occur when the calibration is not performed, and the position of the electrode belt is changed (e.g. shifted cranially). This change could be needed in order to monitor lungs in different cross-sections, e.g. during certain types of abdominal surgery [6]. Even though the calibration takes about 30 seconds, the possibility to avoid the calibration process when switching the monitored cross-sections of the body would be helpful and time-saving during the specific surgeries.

One of the limitations of this study was the spontaneous breathing of the subjects. We wanted to analyze the records with different technical settings of the EIT system, but, of course, every time we compared two EIT records that were obtained in different time in real subjects. (An example of the impedance curve representing the spontaneous breathing of the randomly chosen subject is shown in Fig. 6 and 7.) That means that we observed not only the changes caused by the different settings, but also changes caused e.g. by different breathing of the subjects and by anatomical and other inter-individual differences. This could be partially eliminated by monitoring mechanically ventilated subjects, whose ventilation pattern is stable, by increasing the number of subjects, or by using an artificial EIT phantom. Too few analyzed subjects could be considered as another limitation of this study.

Lekar a technika – Clinician and Technology 2019, vol. 49(4), pp. 107–111, DOI: 10.14311/CTJ.2019.4.01
ISSN 0301-5491 (Print), ISSN 2336-5552 (Online)

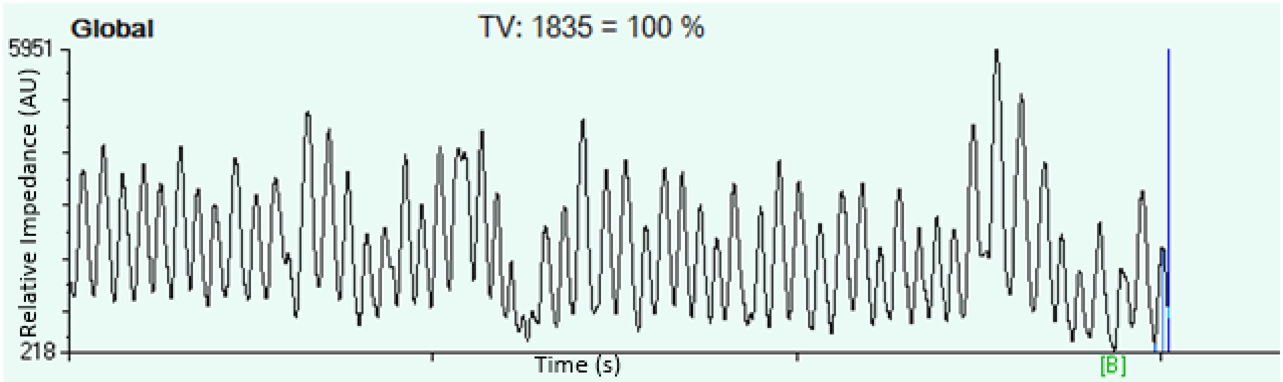

Fig. 6: Change of impedance representing the spontaneous breathing of one subject – calibrated EIT measurement.

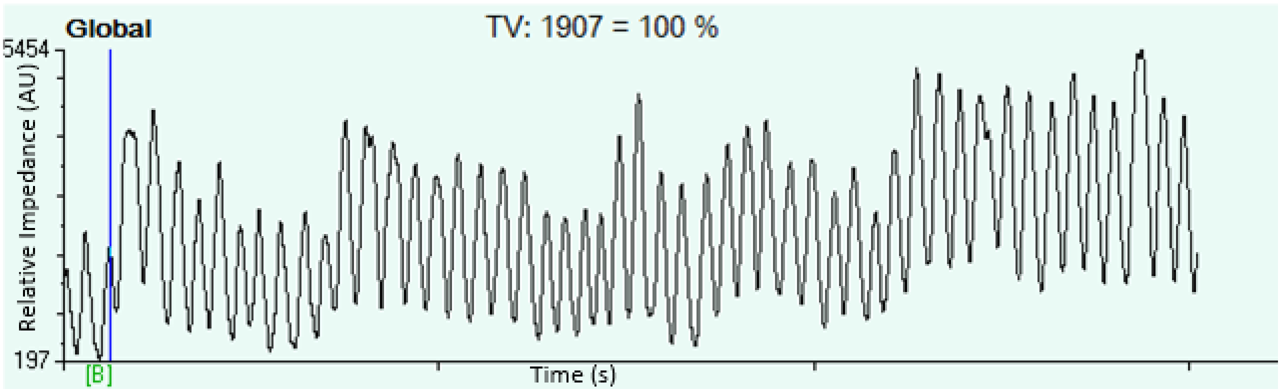

Fig. 7: Change of impedance representing the spontaneous breathing of one subject – uncalibrated EIT measurement.

Conclusion

This study showed that there is no significant difference between the EIT measurements recorded using frame rate frequencies 10 Hz, 20 Hz, 30 Hz, 40 Hz and 50 Hz. However, the manufacturer of the EIT system PulmoVista 500 (Dräger Medical, Germany) recommends using frequencies up to 30 Hz for lung monitoring, and the user should follow these directions. Even though there are no major differences when using the higher frequencies, the user should also consider the size of the data, which influences the time needed for the data evaluation.

Another finding of this study is the fact that performing a calibration after a pause in the measurement is not needed, if the conditions of the measurements remain the same. We would like to analyze the differences between the calibrated and uncalibrated measurements when the plane for placement of the electrode belt is changed, which will be the aim of another study.

Acknowledgement

The work has been supported by research grant No. SGS19/203/OHK4/3T/17 and grant No. SGS20/202/OHK4/3T/17 by Czech Technical University in Prague.

References

[1] Leonhardt S, Lachmann B. Electrical impedance tomography: the holy grail of ventilation and perfusion monitoring?. Intensive Care Medicine. 2012;38(12):1917–29. DOI: 10.1007/s00134-012-2684-z

[2] Teschner E, Imhoff M. Electrical impedance tomography: The realization of regional lung monitoring. Dräger Medical GmbH EIT Booklet, Germany, 2011.

[3] Brown BH. Electrical impedance tomography (EIT): a review. Journal of Medical Engineering & Technology. 2003;27(3):97–108. DOI: 10.1080/0309190021000059687

Lekar a technika – Clinician and Technology 2019, vol. 49(4), pp. 107–111, DOI: 10.14311/CTJ.2019.4.01
ISSN 0301-5491 (Print), ISSN 2336-5552 (Online)

[4] Bodenstein M, David M, Markstaller K. Principles of electrical impedance tomography and its clinical application. Critical care medicine. 2009;37(2):713–24. DOI: 10.1097/CCM.0b013e3181958d2f

[5] Holder DS. Electrical impedance tomography: methods, history, and applications. Philadelphia: Institute of Physics Pub. 2005, xiii, 456 p. ISBN: 9781420034462.

[6] Buzkova K, Muller M, Rara A, Roubik K, Tyll T. Ultrasound detection of diaphragm position in the region for lung monitoring by electrical impedance tomography during laparoscopy. Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub. 2018 Mar;162(1):43–6. DOI: 10.5507/bp.2018.005

Ing. Kristýna Koldová (Buzková)
Department of Biomedical Technology
Faculty of Biomedical Engineering
Czech Technical University in Prague
nám. Sítná 3105, CZ-272 01 Kladno

E-mail: kristyna.koldova@fbmi.cvut.cz
(buzkokri@fbmi.cvut.cz)
Phone: +420 728 848 785

Lekar a technika – Clinician and Technology 2019, vol. 49(4), pp. 107–111, DOI: 10.14311/CTJ.2019.4.01
ISSN 0301-5491 (Print), ISSN 2336-5552 (Online)