Regional lung function determined by electrical impedance tomography during bronchodilator reversibility testing in patients with asthma

To cite this article: I Frerichs et al 2016 Physiol. Meas. 37 698

View the article online for updates and enhancements.
Regional lung function determined by electrical impedance tomography during bronchodilator reversibility testing in patients with asthma

I Frerichs1, Z Zhao2, T Becher1, P Zabel3, N Weiler1 and B Vogt1

1 Department of Anaesthesiology and Intensive Care Medicine, University Medical Centre Schleswig-Holstein, Campus Kiel, Kiel, Germany
2 Department of Biomedical Engineering, Furtwangen University, Villingen-Schwenningen, Germany
3 Department of Pneumology, Medical Clinic, Research Center Borstel, Germany

E-mail: frerichs@anaesthesie.uni-kiel.de

Received 3 December 2015, revised 28 February 2016
Accepted for publication 4 March 2016
Published 20 May 2016

Abstract
The measurement of rapid regional lung volume changes by electrical impedance tomography (EIT) could determine regional lung function in patients with obstructive lung diseases during pulmonary function testing (PFT). EIT examinations carried out before and after bronchodilator reversibility testing could detect the presence of spatial and temporal ventilation heterogeneities and analyse their changes in response to inhaled bronchodilator on the regional level. We examined seven patients suffering from chronic asthma (49 ± 19 years, mean age ± SD) using EIT at a scan rate of 33 images s⁻¹ during tidal breathing and PFT with forced full expiration. The patients were studied before and 5, 10 and 20 min after bronchodilator inhalation. Seven age- and sex-matched human subjects with no lung disease history served as a control study group. The spatial heterogeneity of lung function measures was quantified by the global inhomogeneity indices calculated from the pixel values of tidal volume, forced expiratory volume in one second (FEV₁), forced vital capacity (FVC), peak flow and forced expiratory flow between 25% and 75% of FVC as well as histograms of pixel FEV₁/FVC values. Temporal heterogeneity was assessed using the pixel values of expiration times needed to exhale 75% and 90% of pixel FVC. Regional lung function was more homogeneous in the healthy subjects than in the patients with asthma. Spatial and temporal ventilation distribution improved in the patients with asthma after the bronchodilator administration.
as evidenced mainly by the histograms of pixel FEV1/FVC values and pixel expiration times. The examination of regional lung function using EIT enables the assessment of spatial and temporal heterogeneity of ventilation distribution during bronchodilator reversibility testing. EIT may become a new tool in PFT, allowing the estimation of the natural disease progression and therapy effects on the regional and not only global level.

Keywords: EIT, electrical bioimpedance, respiratory system, obstructive lung disease, lung imaging

(Some figures may appear in colour only in the online journal)

1. Introduction

Chest electrical impedance tomography (EIT) is able to measure dynamic changes in regional electrical bioimpedance in the thoracic cross-section at high scan rates. The continuously acquired EIT data make regional lung volume changes occurring during ventilation accessible to examination.

In the clinical setting, EIT is almost exclusively used to examine the distribution of lung ventilation and regional aeration changes in critically ill, typically mechanically ventilated lying patients (Frerichs et al 2014, Leonhardt and Lachmann 2012). In this group of patients, EIT enables the continuous assessment of the regional effects of mechanical ventilation and, consequently, the adjustment of ventilator settings depending on EIT (and other) clinical findings (Hinz et al 2006, Lowhagen et al 2010, Miedema et al 2012, Blankman et al 2013, Zick et al 2013, Becher et al 2014, Mauri et al 2015). The use of EIT in patients treated in intensive care units (ICU) aims mainly at securing the so-called lung-protective ventilator settings. These settings guarantee adequate gas exchange and impose the least mechanical harm on the lung tissue. The use of EIT in other patient groups is far less frequent.

Spontaneously breathing pulmonological patients with lung diseases not requiring mechanical ventilation and ICU treatment represent a potentially relevant population for EIT monitoring. EIT examinations of these patients have sporadically been documented (Serrano et al 2002, Smit et al 2002, de Lema et al 2008, Vogt et al 2012, Zhao et al 2013), but they are currently not the major focus of EIT research. Nonetheless, it can be postulated that the positive features of EIT, such as its non-invasiveness, radiation-free measuring principle, easy repeatability of examinations independent of specialized labs, the measurement of regional lung function and not only lung morphology (as is the case in most radiological imaging methods), make this method potentially suitable for monitoring the natural history of lung diseases and the therapy effects over long time periods.

A few recent studies imply that EIT is able to provide relevant information on regional lung function during examinations using spirometry (Frerichs et al 2004, Vogt et al 2012, Zhao et al 2012, Zhao et al 2013). During conventional pulmonary function testing (PFT), different lung function measures (lung volumes, air flow rates and their ratios) are determined that allow the assessment of the overall, global functional status of the lungs. The use of EIT would enable the measurement of regional lung function measures and, thus, a more comprehensive assessment of the functional lung condition.

In our study, we wanted to examine whether EIT was capable of identifying the deteriorated lung function on a regional level during PFT and whether EIT-derived lung function measures were also able to detect an improvement of lung function in response to treatment. In order to accomplish these goals, we studied a small group of patients with the established
obstructive lung disease bronchial asthma, who were subjected to bronchodilator reversibility testing.

2. Methods

2.1. Study populations and protocol

The study was performed on seven patients (four women, three men; 49 ± 19 years, mean age ± SD; 171 ± 9 cm, mean body height ± SD; 75 ± 21 kg, mean body weight ± SD) with an established diagnosis of chronic bronchial asthma of atopic (four patients) and non-atopic origin (three patients). Patients’ medications are summarised in Table 1. All patients used inhaled corticosteroids, long-acting β2-agonists and short-acting β2-agonist on demand. Some patients were treated with additional systemic corticosteroids, theophylline, anti-IgE agents, leukotriene receptor antagonists and anticholinergic agents. The patients were admitted to the hospital for optimization of their therapy and they were examined by spirometry and EIT on the second day of their stay in the hospital. None of the patients was studied during an acute asthmatic attack. An age- and sex-matched group of seven subjects (169 ± 6 cm, mean body height ± SD; 80 ± 25 kg, mean body weight ± SD) with no history of lung disease and smoking were examined as a control group. The study was approved by the Institutional Ethics Committee, and written informed consent was obtained from all study participants.

The patients with asthma were examined in a lung function lab during PFT using a conventional spirometer (Jaeger pneumotachograph, CareFusion, Höchberg, Germany) before and after bronchodilator reversibility testing with salbutamol. The flowmeter used in the study exhibited the flow resistance of <0.5 cmH2O/l/s at 10 l/s and the added air filter of 0.34 cmH2O/l/s at 1 l/s during inspiration and 0.25 cmH2O/l/s at 1 l/s during expiration. We studied the patients in a seated position during tidal breathing and a forced full expiration manoeuvre. A total of four PFT examinations were carried out: 5 min before and 5, 10 and 20 min after the administration of the bronchodilator agent. The subjects with healthy lungs were examined once during baseline conditions.

EIT data were recorded in parallel with spirometry using the Goe-MF II EIT device (CareFusion, Höchberg, Germany). This is a 16-electrode EIT system using the adjacent pattern of electrical current application and voltage measurement. EIT images were acquired at a scan rate of 33 images s−1. EIT electrodes (Blue Sensor L-00-S, Ambu, Ballerup, Denmark) were placed on the chest in one transverse plane in the 5–6th intercostal space (parasternal line), and the reference electrode was on the abdomen.

<table>
<thead>
<tr>
<th>Table 1. Patients’ medications.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
</tbody>
</table>

ICS, inhaled corticosteroid; LABA, long-acting β2-agonist; SABA, short-acting β2-agonist on demand; CS, systemic corticosteroid; THEO, theophylline; Anti-IgE, anti-immunoglobuline E agents; LTRA, leukotriene receptor antagonist; Antichol., anticholinergic agent.
2.2. Data analysis

EIT data were evaluated offline. The raw images were generated using the GREIT reconstruction algorithm (Adler et al. 2009). The images consisted of 820 pixels. The lung regions-of-interest (ROI) were defined using the functional approach described by (Pulletz et al. 2006). The pixel EIT waveforms were analysed as follows: During tidal breathing, the end-expiratory minima and the end-inspiratory maxima were identified and the amplitudes of the tidal impedance variations were calculated on a breath-by-breath basis. The average tidal impedance variations were then determined in all image pixels. They represented the pixel tidal volumes ($V_T$). During the forced expiration manoeuvre, the following typical time points were identified in the pixel waveforms at full inspiration, directly preceding the forced expiration, and at residual volume after full expiration. The amplitude of the impedance change between these two time points in each pixel corresponded to the pixel forced vital capacity (FVC). The EIT signal variation between the full inspiration and after one second of full expiration corresponded to pixel forced expiratory volume in 1 s (FEV$_1$). The rate of impedance decline between 25% and 75% of FVC equalled the mean forced expiratory flow between 25% and 75% of FVC (FEF$_{25-75}$) and the maximum rate the peak expiratory flow (PEF) in each pixel. Finally, we determined the pixel expiration times needed to expire 75% ($t_{75}$) and 90% ($t_{90}$) of respective pixel FVC.

The sums of all pixel values of $V_T$, FVC, FEV$_1$, FEF$_{25-75}$ and PEF were then calculated to determine the regional lung volumes and air flow rates in the examined lung regions. Global inhomogeneity (GI) indices were calculated from all pixel values of the stated measures according to (Zhao et al. 2009) to assess the heterogeneity of their distribution. The ratios of FEV$_1$ and FVC were determined in all image pixels and the average value was calculated. The heterogeneity of the spatial FEV$_1$/FVC distribution was also evaluated using the GI index. In addition, the frequency distribution of pixel values of FEV$_1$/FVC was visualised in histograms. The temporal distribution of ventilation was characterised by histograms of $t_{75}$ and $t_{90}$, from which the centre expiration times were calculated.

The described analysis was identically performed using all patient EIT data at four examination time points and the control data obtained in subjects with no lung disease.

Statistical analysis was performed with GraphPad Prism 5.01 (GraphPad Software Inc., San Diego, CA, USA). Data are presented as mean values ± SD, unless otherwise indicated. The repeated measures ANOVA with Bonferroni multiple comparison test was used to examine the effects of bronchodilator inhalation on the EIT-derived regional lung volumes, air flow rates and expiration times. The differences among the patient and control data were assessed using the Kruskal–Wallis test with Dunn’s multiple comparison test. $P$ values <0.05 were considered to be significant.

3. Results

The results of global PFT using spirometry are summarised in figure 1. As expected, the lung function measurements obtained from spirometry revealed worse lung function in the patients compared with the control group, except for FVC, where no significant differences were found. The inhalation of the bronchodilator did not significantly affect any of the measured global lung function measurements.

The regional lung function was analysed by EIT within lung ROIs. The ROIs consisted of $244 ± 104$, $255 ± 92$, $256 ± 101$ and $254 ± 103$ pixels at 5 min before and 5, 10 and 20 min after the administration. The size of the lung ROIs was not affected by bronchodilator inhalation ($p = 0.623$). The number of pixels in the patients’ ROIs did not differ significantly from those in the control subjects ($262 ± 44$) ($p = 0.925$).
The results regarding regional lung volumes and the heterogeneity of their spatial distribution are shown in figure 2. Regional $V_T$ values were similar at all four examination time points in the patients and comparable with the values of the control subjects (figure 2(a)). The spatial distribution of $V_T$ tended to be more homogeneous after the bronchodilator administration in the patients (figure 2(d)). Low interindividual variation of GI $V_T$ was noted among the subjects without lung disease. Regional FEV$_1$ increased significantly in the patients in response to bronchodilator inhalation (figure 2(b)) and slightly improved homogeneity of its distribution was found 20 min after bronchodilator administration (figure 2(d)).

Figure 1. Global lung function determined by spirometry in the patients with asthma (filled symbols) in comparison to the healthy subjects (empty circles). The values in the asthma patients were determined 5 min before and 5, 10 and 20 min after bronchodilator inhalation. FEV$_1$, forced expiratory volume in 1 s; FVC, forced vital capacity; FEF$_{25–75}$, mean forced expiratory flow between 25% and 75% of FVC; FEF$_{75}$, forced expiratory flow at 75% of FVC; $-5\,'$, 5 min before; $+5\,'$, 5 min after; $+10\,'$, 10 min after; $+20\,'$, 20 min after bronchodilator inhalation; *, significantly different from control ($p < 0.05$); ***, significantly different from control ($p < 0.01$), $p$ values indicate the significance of reversibility testing on the examined lung function values in the patients with asthma.
The bronchodilator was administered (figure 2(e)). Regional FVC was also positively affected by the bronchodilator (figure 2(c)) but its spatial distribution did not change (figure 2(f)). Both regional air flow rates of $\text{FEF}_{25-75}$ and $\text{PEF}$ determined by EIT increased significantly after the bronchodilator administration (figures 3(a) and (b)). The inhomogeneity of pixel air flow rates was not affected by the bronchodilator, except for PEF, where the GI index fell significantly 20 min after its inhalation (figure 3(d)). Also, in the case of the air flow rates, low inter-subject variability of the GI values was found in the control group.

Regional ratio of $\text{FEV}_1$ and FVC was significantly lower (figure 4(a)) and the inhomogeneity of pixel $\text{FEV}_1$/FVC distribution was significantly higher (figure 4(b)) in the patients with asthma (filled symbols) in comparison to the healthy subjects (empty circles). The values in the asthma patients were determined 5 min before and 5, 10 and 20 min after bronchodilator inhalation. $V_T$, tidal volume; $\text{FEV}_1$, forced expiratory volume in 1 s; $\text{FVC}$, forced vital capacity; rel. $\Delta Z$, relative impedance change; GI, global inhomogeneity index; *, $p < 0.05$; **, $p < 0.01$. 

Figure 2. EIT-derived regional lung volumes (a)--(c) and the heterogeneity of their distribution (d)--(f) in the examined chest cross-section in the patients with asthma (filled symbols) in comparison to the healthy subjects (empty circles). The values in the asthma patients were determined 5 min before and 5, 10 and 20 min after bronchodilator inhalation. $V_T$, tidal volume; $\text{FEV}_1$, forced expiratory volume in 1 s; $\text{FVC}$, forced vital capacity; rel. $\Delta Z$, relative impedance change; GI, global inhomogeneity index; *, $p < 0.05$; **, $p < 0.01$. 

the bronchodilator was administered (figure 2(e)). Regional FVC was also positively affected by the bronchodilator (figure 2(c)) but its spatial distribution did not change (figure 2(f)).

Both regional air flow rates of $\text{FEF}_{25-75}$ and $\text{PEF}$ determined by EIT increased significantly after the bronchodilator administration (figures 3(a) and (b)). The inhomogeneity of pixel air flow rates was not affected by the bronchodilator, except for PEF, where the GI index fell significantly 20 min after its inhalation (figure 3(d)). Also, in the case of the air flow rates, low inter-subject variability of the GI values was found in the control group.

Regional ratio of $\text{FEV}_1$ and FVC was significantly lower (figure 4(a)) and the inhomogeneity of pixel $\text{FEV}_1$/FVC distribution was significantly higher (figure 4(b)) in the patients with
Figure 3. EIT-derived regional air flow rates (a) and (b) and the heterogeneity of their distribution (c) and (d) in the examined chest cross-section in the patients with asthma (filled symbols) in comparison to the healthy subjects (empty circles). The values in the patients were determined 5 min before and 5, 10 and 20 min after bronchodilator inhalation. FEF_{25-75}, mean forced expiratory flow between 25% and 75% of forced vital capacity; PEF, peak expiratory flow; rel. ΔZ, relative impedance change; GI, global inhomogeneity index; *, p < 0.05.

Figure 4. EIT-derived regional ratios of forced expiratory volume in 1 s and forced vital capacity (a) and the heterogeneity of their distribution (b) in the examined chest cross-section in the patients with asthma (filled symbols) in comparison to the healthy subjects (empty circles). The values in the patients were determined 5 min before and 5, 10 and 20 min after bronchodilator inhalation. FEV_{1}, forced expiratory volume in 1 s; FVC, forced vital capacity; rel. ΔZ, relative impedance change; GI, global inhomogeneity index; *, p < 0.05; #, significantly different from control (p < 0.05).
asthma during the initial examination preceding the reversibility test when compared with the subjects with no lung disease. After the bronchodilator administration, the average FEV1/FVC ratios increased at two of the three subsequent examination time points.

The histograms shown in figures 5(a)–(d) clearly demonstrated the different distributions of pixel values of FEV1/FVC between the asthma patients and control subjects. A shift of the values to the right was noted after the bronchodilator administration, corresponding to the findings presented in figure 4(a).

Dissimilar temporal distributions of ventilation were found in the asthma patients when compared with the subjects with no lung disease (figures 6 and 7). The initial frequency distributions of pixel \( t_{75} \) (figure 6(a)) and \( t_{90} \) values (figure 7(a)) were very broad, whereas the control subjects exhibited a narrow distribution peak. After the bronchodilator administration, the values shifted to the left, i.e. the expiration was more rapid and the distribution of values was narrower, i.e. the expiration times became more uniform.

The centre expiration times determined from the histograms are shown in each panel of figures 6 and 7 as dotted lines representing the average value and as individual values in figures 8(a) and (b). Both centre \( t_{75} \) (figure 8(a)) and \( t_{90} \) values (figure 8(b)) were significantly lower than the corresponding values in the subjects with no lung pathology before the reversibility test was started. A highly significant expiration time reduction was found for \( t_{75} \), and a trend for reduction was determined for \( t_{90} \).

4. Discussion

The results of our study show that regional lung function can be examined by EIT during PFT. Various lung function measures representing different lung volumes, and air flow rates known from conventional PFT can be determined from the pixel EIT waveforms. Additional measures, like the pixel expiration times \( t_{75} \) and \( t_{90} \), can be calculated. Thus, instead of single, global values of lung function calculated from airflow measurements at the airway opening that provide only an estimate of average lung properties, the heterogeneity of lung function can be analysed.

It is well known that the lungs are not homogeneously aerated and ventilated even under physiological conditions (Milic-Emili et al 1966). This is caused by anatomical factors with additional modulating effects, for instance due to gravity and posture. Further heterogeneities in lung aeration and ventilation are introduced by lung disease. The degree of ventilation inhomogeneity regarding its spatial and temporal distribution in the lungs might provide valuable information on the functional effects of disease-related lung tissue damage. It has been realised that monitoring is crucial in lifelong pulmonary diseases like asthma (Pijnenburg et al 2015) and that functional information is needed beyond anatomical lung imaging to thoroughly characterise pulmonary disease pathophysiology (Hoffman et al 2016). This functional information might be used to assess the natural development of the disease and the effects of pharmacological treatment or physical therapy. When added to the information already generated by other clinically established examination techniques it might improve the phenotyping of diseases like asthma or chronic obstructive lung disease and enable multidimensional profiling of responses to therapies. This could be used for the proper timing of interventions and assessing the patient’s responses.

In our pilot study, adult patients with a known history of asthma were examined, however, in a phase with no acute bronchoconstriction. All global lung function values determined by spirometry, except for FVC, were significantly reduced in the patients. All global spirometry measurements were not affected by the bronchodilator. EIT-derived regional lung volumes of
Figure 5. Histograms of pixel ratios of forced expiratory volume in 1 s (FEV$_1$) and forced vital capacity (FVC) (mean values ± SE) in the patients with asthma (black columns) in comparison with the healthy subjects (grey columns). The values in the asthma patients were determined 5 min before (a) and 5 (b), 10 (c) and 20 min (d) after bronchodilator inhalation.
Figure 6. Histograms of pixel times required to exhale 75\% ($t_{75}$) of pixel forced vital capacity (mean values ± SE) in the patients with asthma (black columns) in comparison to the healthy subjects (grey columns). The values in the patients were determined 5 min before (a) and 5 (b), 10 (c) and 20 min (d) after bronchodilator inhalation. Black dotted and grey dashed lines show the centre times in the patients and healthy subjects, respectively.
Figure 7. Histograms of pixel times required to exhale 90% ($t_{90}$) of pixel forced vital capacity (mean values ± SE) in the patients with asthma (black columns) in comparison to the healthy subjects (grey columns). The values in the patients were determined 5 min before (a) and 5 (b), 10 (c) and 20 min (d) after bronchodilator inhalation. Black dotted and grey dashed lines show the centre times in the patients and healthy subjects, respectively.
FEV₁, FVC, their ratio, regional flow rates of FEF₂₅₋₇₅ and PEF, as well as the expiration time \( t_{75} \) showed a significant response to reversibility testing. This implies the higher sensitivity of EIT. As shown in several validation studies, EIT is capable of measuring regional lung ventilation (Frerichs et al 2002, Richard et al 2009, Elke et al 2013). Therefore, small regional changes induced by the bronchodilator are identified by EIT, but missed in the global PFT.

The histograms of pixel FEV₁/FVC and pixel expiration times \( t_{75} \) and \( t_{90} \) seem to be very well suited to identify the spatial and temporal inhomogeneity of ventilation. We introduced these frequency distribution plots of lung function measures for the first time in a previous study where they were able to identify ventilation heterogeneity associated with aging and chronic obstructive lung disease (Vogt et al 2012). Our present data highlight their suitability to detect the time-dependent regional lung function changes in response to a bronchodilator reversibility testing.

When compared with the classical PFT methods, spirometry and whole-body plethysmography, the advantage of EIT is that no mouthpiece is needed. Thus, natural respiratory system mechanics is not changed and the subjects can breathe the physiologically humidified instead of dry air. The latter is often perceived as unpleasant by patients. Besides, the risk of cross-contamination might be minimised. Moreover, lung function can be examined during quiet tidal breathing as well. In our present study, the EIT-derived \( V_T \) did not significantly change during the four analysed phases and was not different from the control group. Nonetheless, the analysis of the spatial \( V_T \) distribution revealed higher inter-subject variability in the patients than in the control subjects. Moreover, the inhomogeneity tended to decrease after the bronchodilator inhalation (\( p = 0.063 \)). This is a promising finding, because already our previous study showed that patients with chronic obstructive lung disease could be discriminated from both young and elderly healthy subjects based on the analysis of \( V_T \) distribution alone (Vogt et al 2012). If this is confirmed in future studies, it will be a unique feature of EIT. It would simplify the examination of lung function in infants, children and non-cooperating adult patients and reduce the dependency on the correct execution of the forced expiration manoeuvre that is strongly effort-dependent. It remains to be established whether EIT has the potential to provide clinically relevant information in addition to conventional PFT or even to

**Figure 8.** Centre expiration times determined from the histograms of pixel times required to exhale 75% (\( t_{75} \)) (a) and 90% (\( t_{90} \)) of pixel forced vital capacity (b) in the patients with asthma (filled symbols) in comparison with the healthy subjects (empty circles). The values in the asthma patients were determined 5 min before and 5, 10 and 20 min after bronchodilator inhalation. *, \( p < 0.05 \); **, \( p < 0.01 \); ##, significantly different from control (\( p < 0.01 \)).
replace classical PFT in selected lung diagnoses. At this early stage of EIT use in pulmonology patients, such implications would be speculative.

Compared with highly sophisticated radiological methods, like ventilation magnetic resonance imaging (MRI) with hyperpolarized gases (Kirby et al 2010, Ouriadov et al 2015, Guo et al 2015), the spatial resolution of EIT is lower. However, EIT examinations can be carried out repeatedly using normal air instead of expensive gases, at any place (and not only in specialised labs) during arbitrary time periods. As shown in our present study using EIT and a recent study with \(^{3}\)He MRI (Zha et al 2016), both methods are capable of identifying the regional response to bronchodilator reversibility testing.

The limitation of our pilot study is that we examined only a few patients. Nonetheless, the comparison of the findings with an age- and sex-matched control group of subjects with no history of lung disease clearly allowed the identification of regional lung function deterioration in the asthma patients by EIT even with a limited number of study participants. This decline was found even under stable pulmonary conditions and is attributable to airway remodelling. Additional benefits of EIT findings regarding the baseline spatial and temporal ventilation distributions and their post-bronchodilator changes could also be manifested in this proof-of-concept study.

Another potential limitation of EIT in studying regional lung function during large volume changes, as encountered during the full expiration manoeuvre, might be related to the effects of chest expansion and organ/tissue movement. Simulation and clinical studies imply that these phenomena contribute to the EIT signal changes in lung regions (Adler et al 1996, Zhang and Patterson 2005, Zhang et al 2013).

Future examination of regional lung function using EIT could also be performed in patients with asthma not only during bronchodilator reversibility, but during bronchial provocation testing as well. Other clearly defined patient populations, like children with chronic wheezing or asthma with less pronounced morphological lung tissue changes or patients with chronic lung disease other than asthma may potentially also benefit from functional pulmonary examination by EIT.

5. Conclusion

This proof-of-concept study shows that EIT is able to assess the spatial and temporal distribution of ventilation during PFT. The effects of lung pathology and bronchodilator reversibility testing on regional lung function can be identified in the patients with asthma and differentiated from the findings obtained in the subjects with healthy lungs. The clinical relevance of this use of EIT needs to be established, but is supported by the recently identified need for functional lung imaging in the patients with lung diseases.

Acknowledgments

We acknowledge the support by the European Union 7th Framework Programme on R&D (WELCOME project, Grant no. 611223).

References


Zhao Z, Muller-Lisse U, Frerichs I, Fischer R and Moller K 2013 Regional airway obstruction in cystic fibrosis determined by electrical impedance tomography in comparison with high resolution CT Physiol. Meas. 34 N107–14