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Aimed Breathing into Different Parts of the Lung

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Abstract: Further knowledge of the regional pulmonary air distribution would deliver additional information of respiratory mechanics and could potentially improve lung therapy and oxygen supply. An electrical impedance tomograph and a spirometer were used to investigate whether regional air distribution in the lungs can be influenced by aimed breathing. It was examined whether four lung healthy volunteers were able to influence their breathing and breathe into specific parts of the lungs. The results showed that the air distribution within the lungs can be influenced in certain limits, even in untrained subjects. This indicates that improvements in lung therapy (e.g. drug treatment) might be influenced by trained patients.

Keywords: Aimed breathing, Lung ventilation, Electrical Impedance Tomography.

1 Introduction

Science and research have long been interested in the pulmonary air distribution, as the knowledge of air distribution would allow profound insights into respiratory mechanics and could improve lung therapies. Already in 1962, Bryan et al. conducted research on factors influencing the pulmonary distribution of air and blood flow to the lungs [1]. In 1966, together with Milic-Emili, Bryan et al. discovered that gravity has a significant influence on the pulmonary distribution [2]. Furthermore, subsequent studies have shown, that in addition to gravity, body position influences pulmonary air distribution as well. However, this influence could also be related to gravity effects [3].

The examination of the pulmonary air distribution requires imaging procedures. Standard functional lung tests, such as spirometry or body plethysmography, are not capable of examining the pulmonary air distribution. Imaging

procedures such as computed tomography (CT) or magnetic resonance imaging (MRI) are in some cases disadvantageous for this application. High costs, complicated handling and the fact that the person being examined might be exposed to radiation restricted the use for examining air distribution.

The development of the electrical impedance tomography (EIT) by Henderson and Webster provided new insights into this field of research [4]. While EIT is primarily used for pulmonary bedside monitoring of mechanically ventilated patients in the intensive care unit (ICU), it can also be used to analyse pulmonary air distribution and regional changes in lung ventilation [5], [6] or lung perfusion [7]. The basic principle of EIT is based on the analysis of impedance changes in the lung tissue, which are caused by an increase or decrease in the air and blood volume in the lungs. The increase of air volume in the lungs leads to a reduction in lung tissue conductivity, while a decrease in air volume increases conductivity. In EIT, small alternating electrical currents are applied to the upper body at the level of the lungs via an elastic belt with e.g. 16 electrodes. The current is applied in series to two neighbouring electrodes and the resulting voltages are then measured at the other 14 electrodes. These voltages are a function of the impedance distribution of the tissue in the cross-section area of the upper body in height of the EIT belt. Thus, image reconstruction algorithms allow a visualization of the ventilation distribution in the lung.

Based on EIT measurements, Pavia et al. [8] analysed pulmonary air distribution and the influence of body position in more detail in 1987 [9]. Recent studies have investigated whether chest and abdominal breathing affect air distribution. It was found that chest breathing leads to a more even distribution of air in the lungs, while abdominal breathing causes more air to reach the lower part of the lungs [10] [11]. This influence is produced by the use of different breathing muscles. While the diaphragm creates negative pressure in the lungs during abdominal inspiration, the auxiliary respiratory muscles and the intercostal muscles on the chest are used during thoracic breathing. However, the forces acting are distributed around the lungs due to the negative pressure in the pleural cavity. Nevertheless, it can be assumed that the distribution of forces leads to varying pulmonary ventilation. Targeted ventilation could improve the respiratory performance of patients with lung disease by breathing to healthy lung areas or aimed ventilation to damaged lung areas could improve healing processes and might allow targeted drug delivery [12], [13].

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This study investigated whether the use of various respiratory muscles allows to influence regional air distribution in different lung areas (figure 1), although other studies have shown that the underlying breathing movements have strong symmetries in the breathing-induced upper body movements [14] [15].

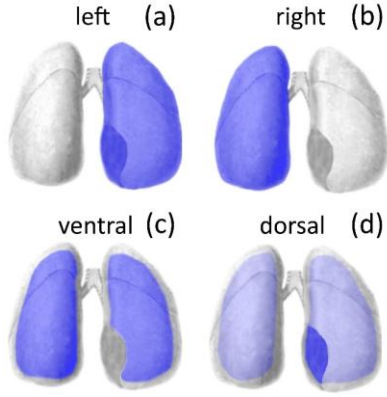


Figure 1: Aimed breathing in the left lung (a), in the right lung (b), in the ventral part of the lungs (c) and in the dorsal part of the lungs (d).

2 Methods

2.1 Measurement setup

In this study, regional pulmonary air distribution was analysed via an EIT device (Pulmovista 500®, Dräger Medical, Lübeck, Germany), deploying an EIT belt with 16 electrodes. The electrode belt was attached around the upper body in the third (ICS 3) and fifth (ICS 5) intercostal space of the subjects (Figure 2) and the frame rate was set to 40 Hz.



Figure 2: Schematic of the EIT measurement. EIT device (middle), subject 3 wearing the EIT belt in height of ICS3 (left) and in height of ICS5 (right).

While the subjects tried to performed aimed breathing wearing the EIT belt, they breathed through a spirometer (SpiroScout and LFX Software 1.8, Ganshorn Medizin Electronic GmbH, Niederlauer, Germany). The spirometer measurement was performed as a reference measurement of tidal volume.

2.2 Participants and Respiratory Manoeuvre

Four subjects participated in this study. Details of the subjects are shown in Table 1.

Table 1: Details of the subjects participated in this study.

Subject	Height /m	Weight /kg	BMI /kg/m ²	Age /years	Gender
1	1.8	73	21.8	31	male
2	1.7	56	19.4	30	male
3	1.9	75	21.4	20	male
4	1.8	60	18.9	64	male

The subjects did normal spontaneous breathing for 60 seconds. Subsequently, they tried to breathe into the left lung, the right lung, the ventral lung area and the dorsal lung area for 90 seconds each. Between these different breathing manoeuvres, they did again normal spontaneous breathing for 30 seconds for recovery reasons.

2.3 Data Processing

To focus on respiration, a low-pass filter with a cut-off frequency of 15 min⁻¹ less than the heart rate of a subject was used to restrict to respiration induced impedance changes in the EIT images. EIT data was reconstructed by a FEM-based linearized Newton-Raphson algorithm provided by the EIT device manufacturer (Dräger, Germany, EIT Analysis Tool 6.3). EIT images of 32 × 32 pixels were generated. The subsequent analysis of the EIT images was done using MATLAB (R2024b, The MathWorks, Natick, USA). Pixels not belonging to the lungs were excluded defining a region of interest (ROI) within the EIT images by applying a linear regression fit (threshold 20%) [16]. For the ROI definition the whole measurement containing all different breathing styles was used. The resulting ROI contained the estimated lung area excluding other thoracic tissues.

For further analysis, mean tidal images of each breathing style (left, right, ventral and dorsal) were generated. Afterwards, the mean tidal images were divided into two parts, either left and right or ventral and dorsal (Figure 3). For these two parts the percentage of impedance changes compared to the impedance change of the whole mean tidal image was calculated (Figure 3, red numbers). All calculations were done for the data collected in the 3rd and 5th ICS, respectively.

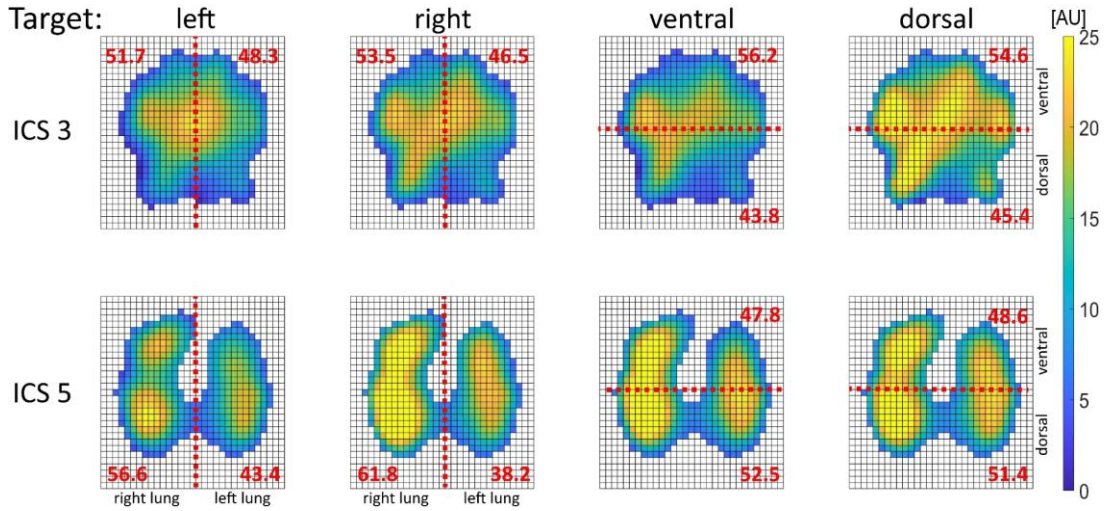


Figure 3: Aimed breathing of subject 1 – the subject tried to breathe in the left lung (left), in the right lung (right), in the ventral part of the lungs (ventral) and in the dorsal part of the lungs (dorsal). The upper part illustrates the EIT measurement at ICS 3 and the lower part at ICS 5. The red numbers are the percentages of ventilation distribution.

3 Results

The pulmonary air distribution for each breathing style is exemplarily illustrated for subject 1 in figure 3. The figure shows the air distribution within the lungs when the subject tried to breathe into the left lung (left), into the right lung (right), into the ventral regions of the lung (ventral) and into the dorsal regions of the lung (dorsal). The percentage to which each part is ventilated is shown in red. The corresponding percentages for all subjects are given in Table 2 for ICS 3 and in Table 3 for ICS 5.

Table 2: Aimed breathing in different lung areas (figure 1) at ICS 3. The percentage distribution is shown according to figure 3.

Target:	Left	Right	Ventral	Dorsal
	in %	in %	in %	in %
Subject	left / right	left / right	ventral / dorsal	ventral / dorsal
1	48.3 / 51.7	46.5 / 53.5	56.2 / 43.8	54.6 / 45.4
2	47.1 / 52.9	47.0 / 53.0	49.7 / 50.3	46.3 / 53.7
3	44.8 / 55.2	44.8 / 55.2	58.8 / 41.2	56.9 / 43.1
4	56.9 / 43.1	55.4 / 44.6	54.0 / 46.0	47.7 / 52.3

Table 3: Aimed breathing in different lung areas (figure 1) at ICS 5. The percentage distribution is shown according to figure 3.

Target:	Left	Right	Ventral	Dorsal
	in %	in %	in %	in %
Subject	left / right	left / right	ventral / dorsal	ventral / dorsal
1	43.4 / 56.6	38.2 / 61.8	47.8 / 52.2	48.6 / 51.4
2	38.3 / 61.7	37.9 / 62.1	47.7 / 52.3	45.6 / 54.4
3	39.9 / 60.1	43.4 / 56.6	52.7 / 47.3	47.8 / 52.2
4	43.6 / 56.4	45.2 / 54.8	42.8 / 57.2	39.3 / 60.7

4 Discussion

Improved knowledge of air distribution would provide deep insights into the respiratory mechanics and could have significant impact on lung therapies. Studies have shown that, in addition to gravity, targeted abdominal or thoracic breathing can influence air distribution in the lungs considerably [11]. During abdominal breathing, the air was more likely to reach the lower part of the lungs, whereas during chest breathing, a more even distribution of air in the lungs was observed.

The present study investigated aimed breathing into defined lung areas (left lung, right lung, ventral areas of the lung and dorsal areas of the lung). It could be shown that aimed breathing into predefined lung areas is possible within certain limits and thus, that pulmonary air distribution can be influenced. It could be seen in all subjects that breathing into the ventral region and into the dorsal region of the lung can be noticeably affected (up to 6.2 % in the 3rd ICS (subject 4) and up to 5.0 % in the 5th ICS (subject 3). Only subject 1 showed hardly a difference in ventilation distribution within the 5th ICS during these two breathing styles. Nevertheless, the effect is smaller or even the other way around, when breathing into the right and into the left lung. In the 3rd ICS impedance changes up to 1.8 % were achieved (subject 1) whereas in the 5th ICS changes up to 5.1 % were reached (subject 1). However, subject 3 and 4 showed negative changes within the 5th ICS.

This study was carried out on untrained subjects who were trying to breathe into the specified areas of the lungs for the first time. It is very likely that with a certain amount of training, aimed breathing into specific areas of the lungs can be intensified. Thus, to observe the influence of a feedback

(Table 4), we allowed subject 4 to observe the EIT monitor during the measurement. It turned out that this had a clear impact on the air distribution. Subject 4 was able to control the air distribution better than in the measurement without feedback. This indicates that ventilation of specific lung areas can be learnt.

Table 4: Aimed breathing in different lung areas (figure 1) at ICS 3 and ICS 5. Subject 4 conducted the measurement with (f) and without feedback (nf). The percentage distribution is shown according to figure 3.

Target:	Left in % left / right	Right in % left / right	Ventral in % ventral / dorsal	Dorsal in % ventral / dorsal
ICS 3 – nf	56.9 / 43.1	55.4 / 44.6	54.0 / 46.0	47.7 / 52.3
ICS 3 – f	50.9 / 49.1	49.7 / 50.3	70.8 / 29.2	57.9 / 42.1
ICS 5 – nf	43.6 / 56.4	45.2 / 54.8	42.8 / 57.2	39.3 / 60.7
ICS 5 – f	49.1 / 50.9	46.9 / 53.1	52.4 / 47.6	47.2 / 52.8

As all four subjects who took part in this study were within a healthy BMI range, further studies with a larger number of subjects of different age, body shape and gender should be conducted to confirm the results of this study.

5 Conclusion

This study shows that regional pulmonary air distribution can be influenced within certain limits. This could enable controlled lung ventilation. On the one hand, targeted ventilation of healthy lung areas could improve the oxygen supply to patients with lung diseases. On the other hand, targeted ventilation of damaged lung areas could enable the targeted administration of medication. In summary, this might improve lung therapies.

Author Statement

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Informed consent: Informed consent has been obtained from all individuals included in this study. **Ethical approval:** The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the University of Canterbury Ethics Committee (HEC 2019/01/LR-PS).

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