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Abdominal Perfusion visualized by Electrical Impedance Tomography

<https://doi.org/10.1515/cdbme-2025-0223>

Abstract: The perfusion diagnostic of the abdomen, especially the liver, is usually done via computer tomography, which implies radiation exposure for the patient. Based on a standard electrical impedance tomograph (EIT) it was investigated, if abdominal perfusion can be visualized. Three subjects attended this study. They did breathe-holding manoeuvres, while wearing the EIT belt in the height of the liver. Respiratory artefacts were removed with a bandpass filter, thus pulsatile signals in the regions of the liver and spleen are visible. Despite its relatively low spatial resolution, abdominal perfusion can be visualised with a standard EIT and opens up new diagnostic opportunities for dynamic perfusion monitoring.

Keywords: Abdominal Perfusion, Liver Perfusion, Electrical Impedance Tomography, Imaging Technique.

1 Introduction

Medical diagnostics is a central part of medicine, as a good diagnosis is the basis for good treatment. When diagnosing internal organs, various diagnostic approaches provide information about the state of health of the organs.

In addition to various functional tests and blood tests, imaging techniques, such as X-ray, computer tomography (CT), magnetic resonance imaging (MRI) and electrical impedance tomography (EIT) can be used.

However, each of these methods has certain disadvantages. While X-ray and CT procedures are associated with radiation exposure for patients, the high costs of MRI are a key factor. MRI has a very good spatial resolution, but the temporal resolution is limited, while the EIT has a very good temporal resolution, but the spatial resolution shows deficits. Due to the respective advantages and disadvantages of the methods, they are used for different diagnostic purposes.

The basic principle of EIT is based on the analysis of impedance changes caused by an increase or decrease in the volume of air or blood in the examined tissue. In perfusion diagnostics, an increase of the blood volume in the observed tissue leads to an increase in the conductivity of the tissue, while a decrease in the blood volume reduces the conductivity. To determine these changes in conductivity, small alternating electrical currents are applied to the tissue via electrodes. The current is applied to two neighbouring electrodes in series, and the resulting voltages are recorded at the other electrodes. The magnitude of the voltages is a function of tissue impedance at the level of the EIT electrodes. Image reconstruction algorithms allow the impedance distribution of the examined tissue to be visualized.

EIT is typically used to analyse lung ventilation, such as pulmonary monitoring of mechanically ventilated patients in the intensive care unit [1], [2], [3]. However, EIT can also be used to analyse pulmonary perfusion [4], [5], [6].

Studies [7][8] have shown that respiration-induced movements of the upper body are highly correlated and symmetrical. However, the organs in the abdomen are not symmetrical ordered. Regarding the liver, the part of the liver in the right upper abdomen is significantly larger than the part of the liver in the left upper abdomen. The liver is a highly perfused organ. The blood flow of an average adult through the liver is about 1.5 liters per minute, whereas the blood flows via the hepatic artery into the liver and out via the portal vein, as shown schematically in figure 1. Other organs, such as the spleen, which has as well a high blood supply, do not show symmetry either.

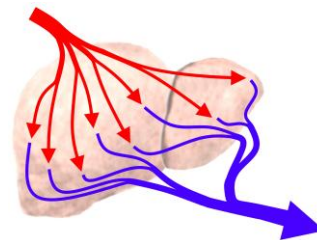


Figure 1: Schematic of liver perfusion.

In medical diagnostics, perfusion of the liver is usually visualised using CT imaging [9], [10], [11], [12]. This exposes the patient to radiation what makes an alternative method advantageous. Some other studies are using MRI or advanced multifrequency EIT devices [13], [14].

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In this study, it was investigated whether the perfusion of the abdominal organs can be analysed using a basic EIT device which is normally used for ventilation monitoring. This would have considerable advantages from a diagnostic point of view, as the patients would not be exposed to radiation and basic EIT devices are commonly found in doctor's offices and clinics.

2 Methods

2.1 Measurement setup

In this study, the abdominal perfusion was analysed via a standard EIT device (Pulmovista 500®, Dräger Medical, Lübeck, Germany), using an elastic EIT belt with 16 electrodes (Figure 2). The electrode belt was attached around the subject's upper body, approximately in the height of the liver at the eighth intercostal space (ICS 8). The frame rate of the EIT device was set to 40 Hz.



Figure 2: Schematic of the EIT measurement. EIT device (left), subject 1 wearing the EIT belt at ICS8 (right), in the height of the liver below the lungs.

2.2 Participants and Respiratory Manoeuvre

Three subjects voluntarily participated in this study. Details to the subjects are provided 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	1.8	60	18.9	64	male

This study deals with the analysis of abdominal perfusion. For this purpose, it is advantageous to reduce breathing movements to a minimum to be able to concentrate solely on perfusion. The subjects were asked to perform several times a breath-holding manoeuvre at end-expiration during normal

spontaneous breathing, as shown in Table 2 and Figure 3. Therefore, no lung tissue should be located at the level of ICS8, which might occur after inhalation of large volumes. During the breath holding manoeuvre, perfusion measurements were performed.

Table 2: Details of the respiratory manoeuvre.

Number	Breathing style	duration /sec
1	normal spontaneous breathing	60
2	holding breath	15
3	normal spontaneous breathing	60
4	holding breath	15
5	normal spontaneous breathing	60
6	holding breath	15

The timing of the measurement was not strictly predetermined; after each phase of normal spontaneous breathing and before each breath-holding phase, the subjects were instructed to hold their breath at the end of an expiration whenever they felt ready to do so. The respiratory curve of such a breathing manoeuvre is shown in Figure 3.

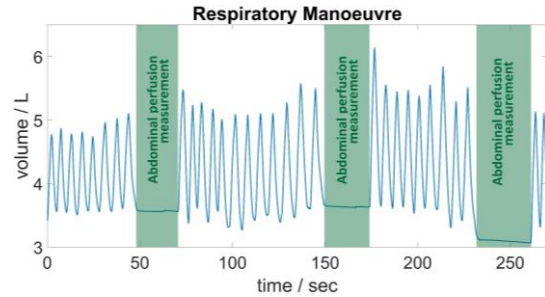


Figure 3: Respiratory volume curve of the manoeuvre. The green areas indicate the periods in which abdominal perfusion is measured.

2.3 Data Processing

On the EIT data measured during the breath-holding phases, a band-pass filter with a lower cut-off frequency of 30 min⁻¹ and a higher cut-off frequency of 80 min⁻¹ was applied for subject 1 and subject 2. Due to a lower heart rate, the cut-off frequencies of the band-pass filter of subject 3 was set to 30 min⁻¹ and 50 min⁻¹. Thus, even minor respiration induced changes were filtered out and perfusion effects were in the focus. After data filtering, EIT data reconstruction was conducted with a FEM-based linearized Newton-Raphson algorithm (Dräger, Germany, EIT Analysis Tool 6.3) and images with a resolution of 32 × 32 pixels were produced. MATLAB (R2024b, The MathWorks, Natick, USA) was used to visualize five EIT images during one heart beat (figure 5).

3 Results

Figure 4 shows exemplarily a CT image of the organs for orientation in the EIT measurement plane. It is intended as an example of the anatomical conditions of the corresponding transverse plane to which the EIT measurement relates. Organs with a high blood supply are coloured; the liver is highlighted in red and the spleen in blue.



Figure 4: Exemplary CT image of the transversal EIT measurement plane. The liver is highlighted in red and the spleen in blue.

The abdominal perfusion is illustrated in figure 5 for all three subjects at different time points during a heartbeat. On the left, the impedance curve during a couple of heartbeats is shown; on the right, the EIT images of the individual marked timepoints are illustrated.

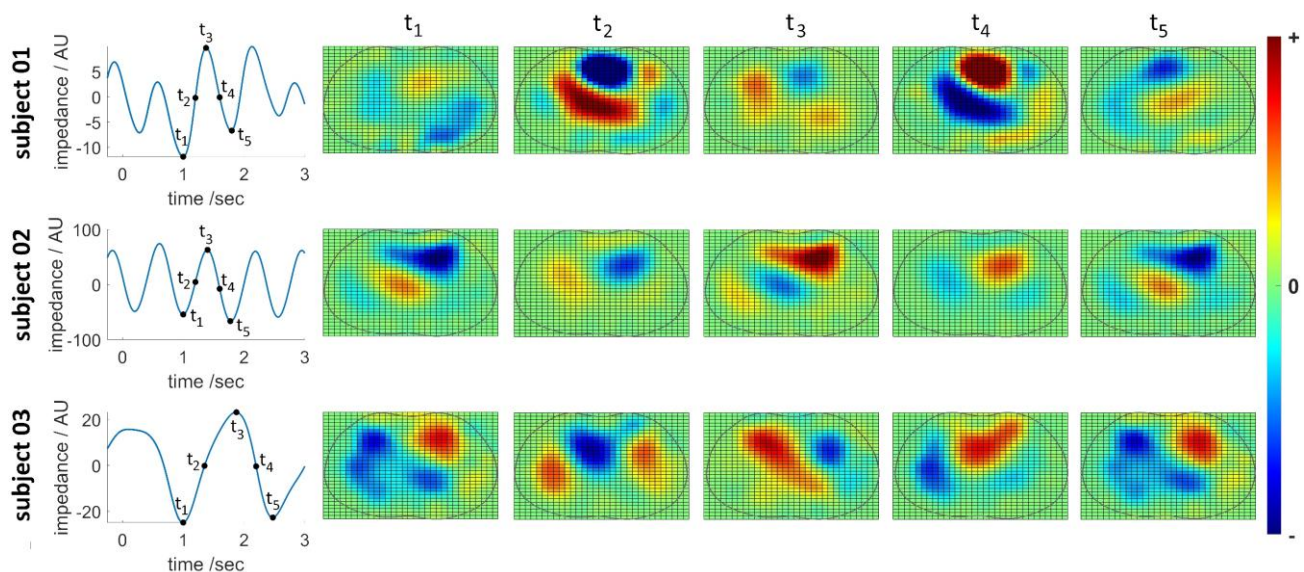


Figure 5: Illustration of the pulsatile signal of abdominal perfusion for all three subjects at different time points during a heartbeat. The impedance curve during a number of heartbeats is shown on the left, and the corresponding EIT images for the individual timepoints are illustrated on the right

4 Discussion

In medical diagnostics, hepatic blood flow is usually examined using CT imaging, which involves exposure to radiation. In this study, we investigate if abdominal perfusion, especially liver perfusion, can be visualized with a basic EIT device, which would enable a perfusion diagnosis without radiation exposure.

Figure 5 illustrates the blood flow through the abdomen in height of the liver at different time points of the heartbeat for all three subjects. Individual images presented here show the pulsatile visualisation only to a limited extent. The pulsatile signal becomes much more apparent when viewing the entire image sequence of the pulsed waveforms. In the entire image sequence, a filling phase of the liver and spleen can be recognised. Both the liver and the spleen are organs that are well supplied with blood and are located at the same level - the measuring level (Figure 4). Subsequently, the blood flow through the liver and finally an emptying phase can be monitored.

The known disadvantage of EIT imaging is evident in the visualization of abdominal perfusion; the low spatial resolution. However, EIT measurements of abdominal perfusion show clear pulsatile signals (blood circulation), which opens up new diagnostic opportunities for dynamic perfusion monitoring. In conjunction with ECG monitoring, time and phase shifts in the blood flow of individual organs could be analysed and used for diagnostic purposes.

However, the extent to which EIT perfusion visualisation is suitable for further diagnosis of abdominal perfusion disorders must be investigated in further studies.

Furthermore, due to the limited spatial resolution of the images, a CT reference would be particularly helpful in this case in order to incorporate prior knowledge, such as the position and boundaries of organs, especially the liver and spleen. Research groups are currently working on multi-frequency EIT devices, which have the potential to improve spatial resolution. This would allow abdominal perfusion to be visualized more effectively.

Further studies with a larger number of subjects of different body shape, age and gender are planned to confirm the results of this study. For this purpose, it is planned to include CT reference images in order to obtain prior knowledge of the subject's anatomy.

Furthermore, studies should be carried out with patients suffering from circulatory disorders of abdominal organs, such as patients with liver cirrhosis. In liver cirrhosis, blood flow through the liver can be impaired. These studies can investigate the extent to which EIT devices facilitate further diagnosis of circulatory disorders. However, the present study has shown the potential of a commercially available EIT for this purpose.

5 Conclusion

EIT offers the possibility to visualize the abdominal perfusion. The pulsatile signal shows the perfusion from liver and spleen. Despite the limited spatial resolution of EIT, abdominal perfusion can be visualised with a standard EIT and opens up new and promising diagnostic possibilities for dynamic perfusion monitoring. Further studies should show the extent to which EIT visualisation is suitable for further diagnosis of abdominal organ perfusion disorders.

Author Statement

Research funding: This research was partially supported by the European Commission H2020 MSCA Rise (#872488—DCPM).

Conflict of interest: Authors state no conflict of interest.
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) and the Furtwangen University Ethics Committee.

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