Monitoring of body fluid in patients with chronic heart failure using Bioimpedance-Spectroscopy

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Abstract— **Patients with chronic heart failure (CHF) often suffer from the formation of edema within their body. To monitor the appearance of such edema in lung and limbs as early as possible would improve the medical treatment fundamentally. Bioimpedance–Spectroscopy is a non-invasive, easy-to-implement measurement method that allows determining the water content of a patient. However, stable long term measurements are difficult to perform and so the optimal measurement conditions have to be defined precisely. In the past, a lot of work was focused on the development of the optimal measurement setup that allows stable and reproducible long-term monitoring of edema. Based on these investigations, a measurement protocol was developed and within this study, case reports shall be presented in which five patients suffering from acutely decompensated CHF were monitored during their complete medical treatment in the clinic. Every day, the whole body- and thoracic impedance were measured to monitor the progress of edema in the limbs and lung, respectively.**

Keywords— **Bioimpedance-Spectroscopy, body fluid, lung edema, thoracic impedance**

I. Introduction

Heart failure is one of the most commonly diagnosed diseases today. In Europe, more than 8 million people are affected and with the advancing age and longer life span of our population, these numbers are likely to increase drastically. Heart failure can be caused by many different heart diseases and may lead to volume overload in the body or the lung. Clinical syndromes of a lung edema do not evolve until the interstitial fluid volume in the lung is sextupled [1]. So that as a result the treatment intervention is delayed. Bioimpedance-Spectroscopy (BIS) may solve this problem. BIS allows the determination of the human body content (e.g. water content) by measuring the body impedance of a person. The measurement method itself is very easy to use and non-invasive which is very advantageous compared to other body composition measurement methods. Apart from that it is known that the transthoracic impedance changes with the relative amount of water in the lung and therefore correlates to changes of the clinical syndromes of a lung edema [2], [3]. Furthermore, the thoracic impedance changes considerably before the first clinical syndromes appear, so that BIS measurements can detect lung edema well during their appearance and disappearance [2], [4].
Unfortunately, the thoracic impedance of a person is very small, approximately 20-50 Ω and therefore difficult to monitor. The absolute impedance change during the appearance of a lung edema is different and varies between 17-30Ω and 15-24 Ω [2]. The varying impedance values can be explained by the measurement setup. During a transthoracic BIS measurement not only the lung is measured but also the surrounding tissue. The lung itself represents only 15-20% of the measured thoracic impedance. Besides this, the thoracic impedance is further influenced by effects like breathing, arm- or electrode position. Thus, the measurement procedure must be as ideal as possible to receive good results.
To optimize the BIS measurement, several investigations using FEM simulations have been done during the last years relating the optimal measurement setup, electrode position and frequency ranges [5], [6]. Based on this research the measurement conditions for a case study were carried out. Within this study, the thoracic impedance of five patients as well as the whole body impedance was measured during their treatment in the clinic. Thus, the healing process of the five patients could be monitored under very controlled conditions.

II. Theoretical Background

A. Basics of Bioimpedance-Spectroscopy

The determination of a person's body composition is based on the fact that the electrical characteristics of the human body change according to the relative amount of body fluid and tissue. Blood and muscle tissue, for example, have a higher conductivity than bones and fat [7] and a lung filled with air has a lower conductivity than a wet lung, respec-

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tively. The water content in human tissue can be divided into intracellular (ICW) and extracellular water (ECW), which are separated by the cellular membrane. The ECW and ICW are predominately electrical resistive entities, whereas the cellular membrane, due to its lipid layer, has an isolating (capacitive) behavior. According to that, the behaviour of an injected current will be different for low and high frequencies: low frequency current only flows around the cells trough the ECW, whereas a high frequency current will also pass through the cell membrane and the ICW (see figure 1).

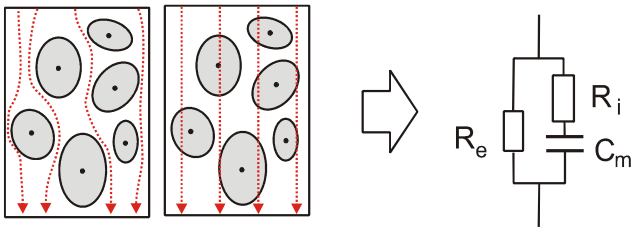

Fig. 1 Low and high frequency current flow through body tissue

This phenomenon can be represented by an electrical model given in figure 1 (right), known as the Cole-Cole model [8]. The values of the electrical model R_e, R_i and C_m can be determined by measuring the body impedance at frequencies between 0 and ∞ Hertz as it is visible in Figure 2. Using the Cole-Cole parameters, the basics of the Hanai theory [9] and defining the body as a cylindrical volume, we can estimate the extracellular and the intracellular water volume [10].

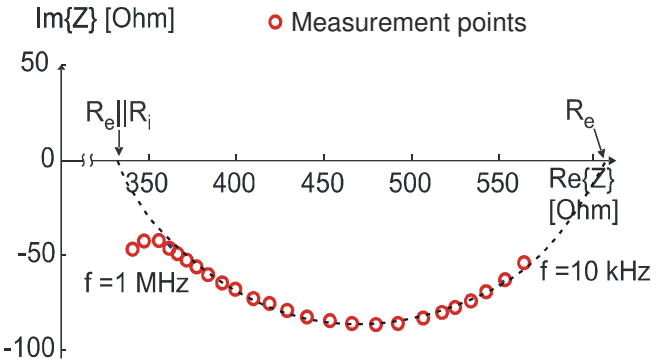

Fig. 2 Example of a complex Bioimpedance measurement, i.e. the real versus the imaginary part of the circuit

B. Measurement Method

During a Bioimpedance-Spectroscopy measurement four electrodes are used. One pair to inject a current I into the body and a second pair to measure the resulting voltage V. Knowing I and V the body impedance can be calculated using the Ohm's law. Depending on the location of the electrodes different body segments can be analyzed as it is shown in Figure 3. On the left side the measurement setup for a whole body measurement is shown, whereas on the right site a thoracic BIS measurement is represented.

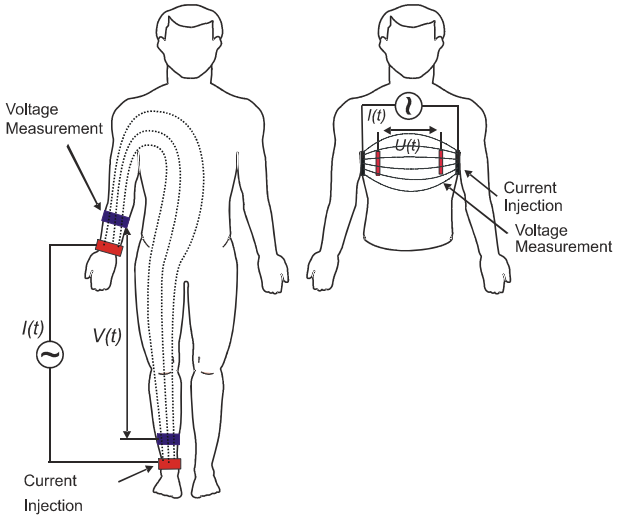

Fig. 3 Whole body and Thoracic Bioimpedance Measurement

Within this case study five patients suffering from acute lung edema were measured during their treatment in the clinic with the Bioimpedance-Spectroscopy device Xitron Hydra 4200 from Xitron Technologies. All five patients joined the study at their second or third day in the clinic and their thoracic impedance was monitored every day in the morning. Since most of the patients suffering from lung edema also have additional edema e.g. in the legs, the whole body Bioimpedance was also monitored. The combination of these two BIS measurements allows monitoring comprehensively the changes of the body water and lung water respectively in patients with acute heart failure. The five patients were all male and could be measured between one and eight days. Table 1 shows the personal data of the five patients.

Table 1 Patient data

Patient	Gender	Age	Monitoring days
1	male	75	3
2	male	68	2
3	male	64	1
4	male	73	8
5	male	64	3

III. Measurement Results

During our study, the whole body impedance as well as the thoracic impedance of the patients was measured. The Bioimpedance data of all five patients showed similar results. However, in this result chapter we will concentrate on the measurements of patient 4, since this patient could be measured the longest time (8 days).

As reference data for the monitoring of the body water content during the study, we measured the body weight of every patient before each measurement and supervised their daily water balance. Table 2 shows the data of patient 4 during his clinic stay.

Table 2 Weight and Water balance of patient 4

Measurement Day	Weight [kg]	Water balance (difference between water intake and output)
1	93	n/a
2	92,5	-500 ml
3	92	-300 ml
4	92	-550 ml
5	91	-500 ml
6	90,4	+500ml
7	91,3	n/a
8	91,6	+300ml

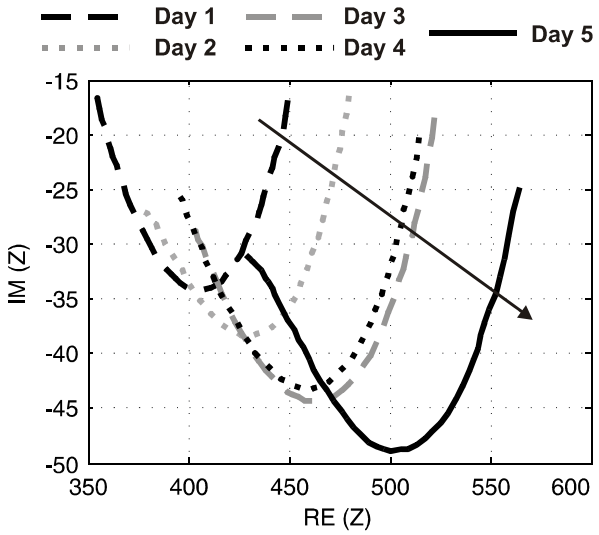

Fig. 4 Whole body impedance plot of patient 4 during the course of five days

In accordance to the constant weight loss at the first five measurement days Figure 4 presents the whole body impedance of patient 4 during these days. In the beginning of the measurement, the patient's body weight was 93 kg and the body impedance was quite small (between 350-450 Ω). The small body impedance indicates a high total body water amount. Within the next days, the water balance is always negative which implies that the body looses water, the weight reduces and also the body impedance shifts to higher values. Only the impedance at day 3 and 4 are very similar and seem to be interchanged. This effect is difficult to explain since on one side the water balance is negative which implicates an increasing of the impedance, whereas on the other side, the weight was stable which should result in a constant impedance. For a correct analysis and to exclude any measurement faults more measurements and patients would be necessary.

Next to the whole body measurements, the thoracic impedance was monitored as well. Figure 5 shows the results for patient 4. The transthoracic impedance is much smaller compared to the whole body impedance values, but still a shift from small to higher impedance values is visible. The extracellular resistance R_e between day 1 and 5 differs of approximately 16%.

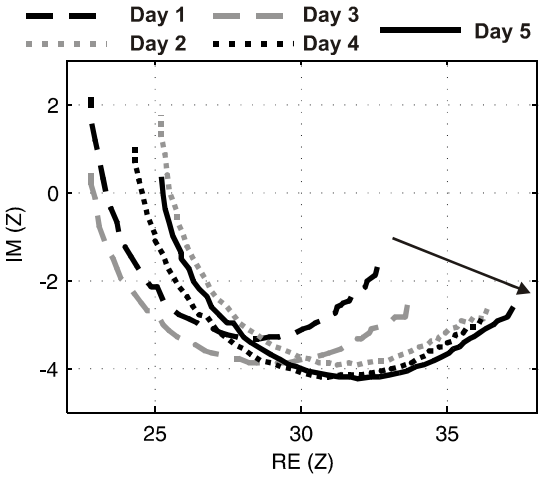

Fig. 5 Thoracic impedance plots of patient 4 during the course of five days

In this series of measurements, the impedance of day 3 and 2 seems to be interchanged regarding the theoretical expectations. In this case an explanation is even more difficult than for the whole body measurements. Since our reference data in this case study were only total body weight and total body water balance, it is not possible to predict the absolute water change in the lung. So the course of the tho-

racic impedance can not be verified without additional medical examinations (like e.g. computer tomography).

Besides these general results, another interesting observation could be done with patient 4. As it is shown on Table 2, Patient 4 had a negative water balance of -500 ml on day 5. On day 6, patient 4 had a special heart treatment which leads to a positive water balance of +500 ml. For both days whole body impedance measurements were made and the Cole parameters were calculated. Figure 6 shows the course of the extracellular water resistance R_e over the measurement day 3 to 7. The negative water balance that occurred between day 4 and 5 lead to a worse tissue conductivity and subsequently increased R_e at day 5. The positive water balance on the following day had the opposite effect and therefore decreased the R_e value.

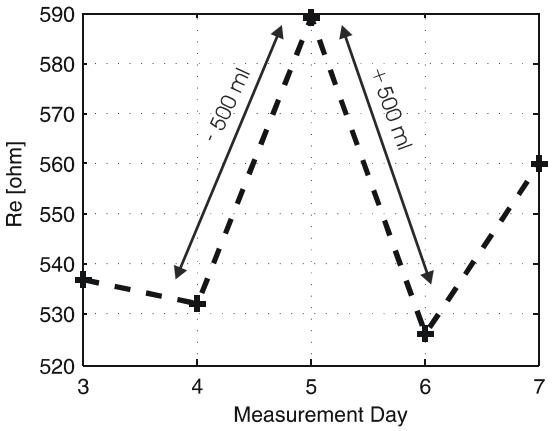

Fig. 6 Extracellular resistance of patient 4

In both cases, the absolute value of the water balance was the same and so the R_e value at day 6 corresponds very well to the R_e value of day 4. This result shows the good correlation between BIS measurements and changes of the body water content.

IV. Conclusions

BIS offers a good possibility to monitor the water content of a person. This can be used in monitoring decompensated CHF patients. Since most patients with acute heart failure suffer not only from lung edema, but also from edema in limbs a combination of segmental and whole body BIS measurements offers the best options to supervise the course of diseases. In this paper, both Bioimpedance-Spectroscopy measurements show a strong correlation with the water balance and weight loss. In both measurement cases, a shift to higher impedance values is visible and ranges from approximately 100 Ω for the whole body measurement to approximately 5 Ω for the thoracic impedance. These changes correspond to an increasing impedance of 12-16 %. In addition to the general shift, the direct correspondence between water balance and extracellular resistance changes could be demonstrated. In the future, this study should be continued so that more patients can be monitored and statistical significance of the findings can be tested.

V. Acknowledgments

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