Continuous Hand-to-Foot and Segmental Bioimpedance Spectroscopy Measurements within a Period of Five Days

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Abstract— **The possibility of monitoring the body hydration during the day on elderly people has been proposed by several authors. The aim of this investigation was to examine the variation of the measured body fluids during the day and during five days with hand-to-foot (HF) and knee-to-knee (KK) BIS measurements. Measurements on seven elderly and four young test subjects during the day show a repetitive pattern from day to day (circadian rhythm), indicating a possible influence due to changes of body position and amount of movement. The measured change in body fluids during a day is higher than the measured change in weight and than the necessary loss to define a mild dehydration. Age seems to have less influence than movement in the amplitude of oscillation observed during five days.**

Keywords— **continuous bioimpedance monitoring, BIS, hand-to-foot (HF), knee-to-knee (KK).**

I. INTRODUCTION

The determination of the human body composition enables physicians to draw conclusions about an individual's state of health. For example, knowing the amount of body water content could be useful to detect dehydration in elderly people, but also to determine the amount of fluid that has to be removed in a dialysis session. Furthermore, identifying the amount of fat or muscle tissue can help to detect malnutrition problems.

So far, "dilution methods" have been the gold standard for the determination of body water [1]. However, they are time- consuming, expensive and not suitable for continuous use in clinical or home environment. Bioimpedance Spectroscopy (BIS), by contrast, involves low costs, allows a fast measurement and an implementation into a portable application [2], but has suffered from non-credibility due to limited accuracy when compared to the gold standard. Recent research, however, has shown that BIS could be as precise as the traditional dilution methods or even better if a proper physiological model were used [3]. Nevertheless several factors (e.g. body position) affect the measurements [4], [5], [6], [7], therefore requiring trained personnel and laboratory conditions. A continuous monitoring application should correct the measurements, in order to give a right diagnostic assistance to the physician.

One of the recommendations of the devices manufacturers is to perform the measurements always at the same time during the day in order to improve the comparability between data [6]. The measurements of Slinde *et al.* [8] showed a decrease of the measured impedance and an increase of the measured extracellular fluid (ECF) during a normal working day (mostly sitting and standing position). Their measurements during the day on twelve subjects in lying position show a continuous increase of the impedance [9] and therefore a reduction of the calculated ECF. From these results, it may be assumed that in continuous BIS measurements during a week, on subjects working during the day and sleeping during the night, a kind of cycle with a period of a day will be observed, showing a reduction of the impedance during the day and an increase of the impedance during the night. From our knowledge, nobody has published such an experiment, showing measurements several times a day and for a period longer than a day.

The purpose of this article was to test the hypothesis of the existence of an oscillatory impedance change with a period of a day and to measure the amplitude in a group of test subjects. Hand-to-foot (HF) and segmental (knee-to-knee, KK) BIS measurements on seven elderly and on four young test subjects were performed three times a day during five days. It has been shown that segmental measurements are a possible alternative for HF measurements in the determination of ECF [10].

II. THEORY AND METHODS

A. Bioimpedance Spectroscopy (BIS)

The determination of body composition by BIS is based on the fact that the electrical characteristics of the human body change according to the relative amount of body fluid in tissues. Materials such as blood or muscle have a higher conductivity as compared to bone or fat [11].

The water content in human tissue (total body fluid, TBF) can be divided into intracellular (ICF) and extracellular fluids (ECF), which are separated by the cellular membrane. The ECF and the ICF are predominantly electrical resistive

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entities, whereas the cellular membrane due to its lipid layer, has an isolating (capacitive) behavior. According to that, the path of an injected current will be different depending on the frequency: low frequency current only flows around the cells through ECF, whereas a high frequency current will also pass through the cell membrane and ICF (see Fig. 1 left).

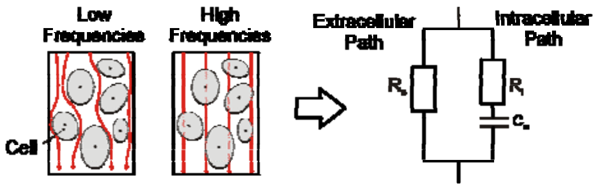

Fig. 1 Low and high frequency current flow through body tissue and equivalent electrical circuit (Cole-Cole Model).

This phenomenon can be represented by the electrical model given in Fig. 1 (right), known as the Cole-Cole model [12]. Considering a heuristic factor (α) representing different tissues in parallel with specific time constants and a time delay (T_D) produced by measurement cables, the measured impedance can be written as follows [4]:

$$Z(j\omega) = \left(\frac{R_E}{R_E + R_I}\right)\left(R_I + \frac{R_E}{1 + (j\omega C_M (R_E + R_I))^{\alpha}}\right)\left(e^{-j\omega T_D}\right) \quad (1)$$

The parameters of the electrical model R_e, R_i and C_m can be determined by measuring the body impedance (Z) at different angular frequencies (ω) and solving the eq. (1). In fact, frequencies between 5 kHz and 1 MHz and curve fitting methods are used to calculate the parameters of the Cole-Cole model (R_e, R_i, C_m).

Using the Cole-Cole parameters, the basics of the Hanai theory [13] and taking into account the influence of the individual body mass index (BMI) the following equations for the calculation of body fluids volumes (ECF, ICF, TBF) can be derived [3]:

$$ECF = \left(\frac{a}{BMI} + b\right) \cdot \left(\frac{H^2\sqrt{W}}{R_e}\right)^{\frac{2}{3}} \quad (2)$$

$$ICF = \left(\frac{c}{BMI} + d\right) \cdot \left(\frac{H^2\sqrt{W}}{R_i}\right)^{\frac{2}{3}} \quad (3)$$

$$TBF = ICF + ECF\ , \quad (4)$$

where H is the height [cm], W the weight [kg], and the parameters a = 0.188, b = 0.2883, c = 5.8758 and d = 0.4194 were determined by means of cross validation [3] in a population including healthy subjects and patients.

B. Bioimpedance Spectroscopy (BIS) Measurements

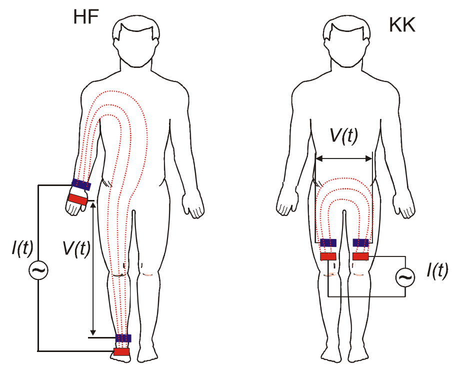

Fig. 2 Position of electrodes and current path by HF and KK BIS measurements.

HF and KK BIS measurements on four healthy young test subjects and on seven healthy elderly (age > 60 years) test subjects (three males and four females) were performed three times a day during five days, procuring to measure every day at the same time. The measurements were performed at a senior residence in a room with controlled temperature (24±1°C). The subjects were allowed to perform their normal activities inside the residence and wait sitting 5-10 minutes followed by 4 minutes recumbency before the beginning of the measurements. The characteristics of the test subjects are shown in Table 2.

Table 2 Characteristics of the test subjects

Subject	Sex	Age [years]	Height [cm]	Weight [kg]	Mobility
1	M	60	176	75.0	Normal
2	M	69	167	81.9	Normal
3	M	79	174	78.0	Normal
4	F	82	175	66.6	Restricted
5	F	88	157	73.4	Restricted
6	F	86	154	50.0	Restricted
7	F	84	156	59.0	Restricted
Mean ±SD (elderly)		**78.3 ±10.2**	**1.66 ±0.1**	**69.1 ±11.3**	
8	M	32	170	78.1	Normal
9	M	29	184	94.2	Normal
10	F	26	163	84.5	Normal
11	F	27	162	75.9	Normal
Mean ±SD (young)		**28.5 ±2.6**	**1.70 ±0.1**	**83.2 ±8.**	

Four of the elderly subjects presented a restricted mobility (difficulty or impossibility to walk), while the rest was active during the day (performing activities in the kitchen or in the garden). Extenuating activities (e.g. with production of sweat) before (48 hours) and during the week were not allowed.

The distance between the legs as well as between arms and torso were controlled. HF measurements were performed 4 and 8 minutes, while KK measurements 6 and 10 minutes after recumbency. Every measurement consisted of 6 samples (runs) every 5 seconds. The measurements were performed with a commercial BIS measurement device (Xitron Hydra 4200, Xitron Techologies Inc. Florida, USA). Standard Hydrogel-Aluminium BIS electrodes from Fresenius Medical Care, Bad Homburg, Germany were used.

For HF measurements, the electrodes were located as indicated by the manufacturer [5]. For KK measurements, a mold was designed which assures a distance between voltage and current electrodes of 5 cm and allows a reproducibility of ± 1.5 %. Excessive body hair was removed if necessary without shaving (in order to avoid changing the impedance characteristics of the skin). The position of the electrodes was marked. In nine subjects the electrodes were removed every day at the end of the day; while in the other two subjects the electrodes were removed after every measurement.

III. Results

A. ΔR_e in HF and KK BIS Measurements

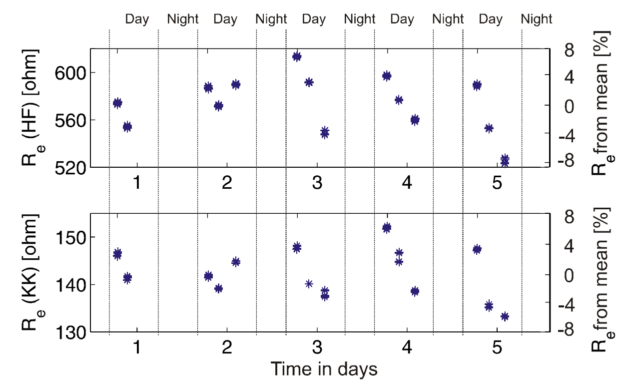

Fig. 3 Measured ΔR_e for test subject 3 during the day and possible change during the night for HF and KK BIS measurements.

The measured ΔR_e for HF and KK measurements for a test subject are shown in Fig. 3. The figure shows a change pattern for R_e suggesting a circadian cycle as hypothesized. R_e reduces its value during the day, while it increases during the night, reproducing a very similar pattern (see specially day 3, 4 and 5). The reason for the different pattern on day 2 is unknown. For day 1 just two measurements were performed. The change in HF measurements for subject 3 are almost the same as the change registered in KK measurements. Nevertheless, the ΔR_e for the whole 5 days period (maximum –minimum R_e value) in % for all the subjects was slightly higher in KK than in HF (see Table 3).

Table 3 Measured ΔR_e (maximum –minimum value) in [%] per subject during a five days period (Mean values ±SD) for groups characterized by its age and by its mobility

Group	ΔR_e (HF) [%]	ΔR_e (KK) [%]	ΔR_e (KK) [%]/ ΔR_e (HF) [%]
Elderly (≥ 60 years)	12.25 ± 4.85	13.31 ± 3.38	1.19 ± 0.4
Young (< 60 years)	9.03 ± 2.36	16.51 ± 9.46	1.28 ± 0.98
Restricted mobility	14.49 ± 2.06	14.49 ± 9.38	1.06 ± 0.9
Normal mobility	9.13 ± 4.28	14.12 ± 5.47	1.32 ± 0.62

B. ΔECF and TBF in HF BIS Measurements

The estimated ECF and TBF for HF measurements using eq. (2) and eq. (4) respectively, and the application of the concept for a mild dehydration (isotonic) [14] are shown in Fig. 4. The estimated ECF and TBF showed the opposite behavior than the measured R_e (as expected, considering eq. 2 - 4).

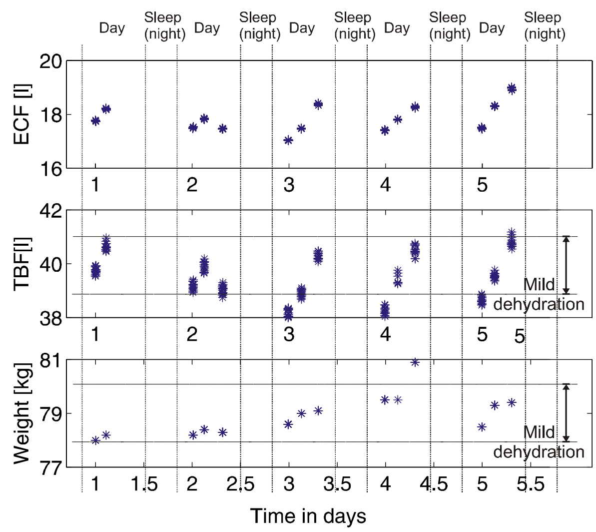

Fig. 4 Measured ΔECF for test subject 3 during the five days period (HF BIS measurements) and definition of mild dehydration according to [14].

IV. Discussion

In KK measurements ΔR_e is near to the one measured using HF measurements, which makes the method at a first look suitable for continuous monitoring. Because this method could be combined with textile electrodes integrated into clothing (e.g. pants), it would offer a better alternative than the traditional HF method. Nevertheless further research (e.g. in the difference between ΔR_e in [%] for KK and for HF measurements) should be performed in order to confirm its suitability.

The reproducibility of the measurements from day to day is a proof that other factors affecting the reproducibility of the measurements from measurement to measurement and from day to day were avoided (e.g. electrodes position, temperature, etc.). Therefore, the change of impedance during the day may mainly reflect physiological changes that are part of the biological rhythm.

The fact that the change in weight is almost one half of the ΔECF suggests that fluid shifts part of the daily rhythm should be present. According to the results of measurements during the day reported by other authors [8], [9] it seems that the body position is the main influence in the results obtained in the present investigation. The start of measurements after 4 or 8 (HF) and 6 or 10 (KK) minutes after recumbency did not produce a visible effect on the results.

An interesting finding was that the change in ΔR_e was higher in test subjects with a restrictive movement (HF measurements). This suggests that the activity of the lymphatic pump in those subjects may be reduced, due to the slower muscle activity and that persons with movement problems have higher fluid shifts than persons with normal mobility. Nevertheless further research is necessary to confirm this observation for HF and KK measurements.

V. Conclusions

In the present article bioimpedance measurements were performed on eleven subjects. The results show daily changes in R_e, ECF and TBF, which reproduces an oscillating signal. One of the main factors having an influence on the oscillating character seems to be the body position. The difference in the observed change between subjects with mobility and subjects with restricted mobility and results reported by other authors support this thesis. As far as we know, this is the first time someone has studied the change of impedance during several days in several subjects.

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