Influence of ambient temperature on whole body and segmental bioimpedance spectroscopy measurements

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Abstract. Bioimpedance spectroscopy (BIS) measurements are easy to implement and could be used for continuous monitoring. However, several factors (e.g. environment temperature) influence the measurements limiting the accuracy of the technology. Changes in skin temperature produced by changes in ambient temperature are related with changes in skin blood flow and skin impedance. It is assumed that skin impedance change is responsible for the error observed in whole body and segmental measurements. Measurements including body parts more distant from the torso seem to be more affected. In the present article skin and segment impedance have been performed on healthy subjects under extreme changes in environment temperature (13-39 °C). A commercial BIS device with a range between 5 kHz and 1 MHz has been used for the measurements. The results indicate that not only skin impedance, but also impedance of deeper tissue (e.g. muscle) may be responsible for the influence of environment temperature on BIS measurements. Segmental (knee-to-knee) BIS measurements show a relative change of only 2 %, while forearm and whole body impedance changed 14 % and 8 % respectively.

1. Introduction
Bioimpedance spectroscopy (BIS) constitutes an easy to use and easy to implement technology, which could be used together with intelligent textile electrodes [1] to monitor fluid changes during hemodialysis treatment or during sports. Despite of these advantages, several factors (e.g. environment temperature) affect the measurements [2], therefore requiring trained personnel and laboratory conditions, which can not be fulfilled in continuous monitoring applications all the time.

Changes in ambient temperature activate several mechanisms in order to preserve the body ‘core’ temperature [3]. Skin temperature of body parts distant from the torso (e.g. hands, forearms, feet and underlegs) can experience, on the contrary, extreme changes [4]. Changes of skin temperature produced by ambient temperature are related to changes in skin blood flow [5] and impedance. It is supposed that changes in skin impedance are responsible for the influence of ambient temperature on BIS measurements. BIS measurements including peripheral limbs are more influenced by temperature changes than measurements excluding them [6].

The first purpose of the present study was to investigate the magnitude of impedance change at the skin-electrode interface compared to the whole segment. The second purpose was to compare the magnitude of change produced by ambient temperature on measurements excluding peripheral limbs (e.g. knee-to-knee) and other including them (e.g. whole body and forearm).
2. Theoretical background

2.1. The skin-electrode interface

Electrodes constitute an interface between electron current (measurement circuit) and ionic current (tissue). In a routine BIS procedure, a four point measurement will be used (see figure 1). Two electrodes are used for the current injection $I(t)$ and the other two for the voltage measurement $V(t)$. In doing so, the influence of the skin-electrode impedance ($Z_{\text{Skin-Electrode}}$) on the measurement is reduced ($I_{\text{Bias}} \cdot Z_{\text{Skin-Electrode}} \ll I_{\text{Meas}} \cdot Z_{\text{Body}}$) and the following equation and approximation is valid:

$$
Z_{\text{4 point}} = \frac{V(t)}{I(t)} = \frac{I_{\text{Meas}} \cdot Z_{\text{Body}} + 2 \cdot Z_{\text{Skin-Electrode}} \cdot I_{\text{Bias}}}{I(t)} = \frac{I_{\text{Meas}} \cdot Z_{\text{Body}}}{I(t)} = \frac{Z_{\text{Body}}}{I(t)}
$$

(1)

Figure 1. Tetrapolar configuration for a typical BIS measurement (left) and equivalent circuit (right).

Figure 2. Low and high frequency current flow through body tissue

2.2. Intracellular ($R_i$) and extracellular ($R_e$) resistances.

A biompedance spectroscopy (BIS) measurement on tissue can be represented by an electrical model composed of two resistances ($R_e$ and $R_i$) representing the extracellular and intracellular fluids respectively and a capacitor representing the cellular membrane [7], [8]. Accordingly a low frequency current only flows around the cells through the extracellular fluid and resistance, whereas a high frequency current will also pass through the cell membrane and the intracellular fluid and resistance (see figure 2). Once $R_e$ and $R_i$ have been calculated from a bioimpedance measurement, the amount of extracellular and intracellular fluids can be calculated (see [9] for further details).

3. Materials and methods

3.1. Whole body and segmental BIS measurements

Four points whole body and segmental BIS measurements (see figure 3) were performed on 5 healthy test male subjects aged between 25 and 30, wearing only short pants and t-shirt. The measurements were performed with a commercial bio-impedance device (Xitron Hydra 4200, Xitron Technologies Inc. San Diego, CA, USA) in a temperature controlled room. After a first 30 minute phase with room temperature (24°C), a 30 minute heating phase (up to 39 °C) and a 30 minute cooling phase (up to 13°C) followed. The subjects remained in the room during the whole experiment. BIS measurements were performed 6 min after recumbency and 2-4 min after the desired temperature ±1°C was achieved. Five and 3 hours without food and beverage consumption, respectively, as well as 24 hours without performing any sports were a prerequisite for the measurements. Commercial disposable (hydrogel-aluminum) bioimpedance electrodes approx. 9x2 cm² in size (company Fresenius Medical Care, Bad Homburg, Germany) were used.
3.2. Electrode-skin impedance measurement

Additionally to the 4 point measurements, two point measurements were performed on the forearm (see figure 4). The electrode-skin impedance was calculated as:

\[ Z_{\text{Skin-electrode}} = \frac{Z_{\text{2 point}} - Z_{\text{4 point}}}{2} \]  \hspace{1cm} (3)

4. Results

4.1. Influence of ambient temperature on calculated intra (R_i) and extracellular (R_e) resistances

The relative values of R_e and R_i for whole and segmental measurements decrease during the heating phase and increase during the cooling phase (see figure 5). Changes in R_e at the arm and whole body measurements are much larger compared to changes in knee-to-knee (14 and 8% compared to 3%). Relative changes in R_i are slightly lower than R_e changes, but with the same order of magnitudes (11, 6 and 2% for forearm, whole body and knee-to-knee BIS measurements, respectively). The relative low sensibility of knee-to-knee measurements to external changes of ambient temperature, may be caused by the tendency of the body to keep central parts at constant temperature [3], [4]. Wearing of clothes by the test subjects could also have a slight influence on the results.

4.2. Influence of ambient temperature on skin-electrode (Z_{\text{Skin-electrode}}) and segment (Z_{\text{4 point}}) impedances

For the real part, the change observed in Z_{\text{Skin-electrode}} is only slightly higher than for the segment. For the imaginary part, changes at the segment impedance are approx. three times higher than the changes
for segment impedance. As local changes in skin-electrode impedance have a low influence on the segmental measurement when a 4 point measurement setup is used [10], the observed increase in $Z_{\text{skin-electrode}}$ (18.1 and 15.1 %) should do not account for the observed change in the segment (12.1 and 15.1 %). The validity of (3) could be affected by measuring two different volumes in $Z_{\text{2 point}}$ and $Z_{\text{4 point}}$ (e.g. due to current distribution between the current electrodes). However, an impedance change should indicate a change of the segment itself. Therefore, the results suggest that the ambient temperature has an effective influence on the segment impedance and not only on the skin-electrode impedance. As ambient temperatures should affect mainly skin blood flow [3], changes on segment impedance could be due to effect of temperature on electrolyte conductivity of the fluids contained in the segment.

Table 1. Relative change (mean values) in segment and skin-electrode impedance (50 kHz) by changing from high (39°C) to low (13°C) ambient temperatures compared to measurements at 24°C.

| Temperature | Forearm (segment) Real part (%) | Forearm (segment) Imaginary part (%) | Skin-electrode Real part (%) | Skin-electrode Imaginary part (%) |
|-------------|---------------------------------|-------------------------------------|-----------------------------|----------------------------------|
| 39-13°C     | ↑12.1                           | ↑15.1                               | ↑18.1                       | ↑5.1                             |

5. Conclusions
A first result of this experiment is that knee-to-knee measurements are in comparison to whole and forearm impedance measurements almost insensitive to changes in environment temperature. This could be important for measurements were the change of ambient temperature can not be avoided.

The second result of the experiment indicates that both the calculated skin-electrode impedance and the segment impedance itself are affected by changes in ambient temperature in almost same order of magnitude. This may indicate that ambient temperature has also an influence on the impedance of tissue under the skin.

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