Impedance Ratio as a Measure of Water Shifts

Abstract
Total and segmental body compositions (left arm and left leg) were measured by bioelectrical impedance analysis at 5 and 100 kHz and by dual-energy X-ray absorptiometry (DXA) in 14 healthy young males (body mass index, mean ± SD, 23.5 ± 2.7 kg/m²) every 20 min for a period of 100 min. During the measurements the subjects remained in the supine position on the examination table, except for the time between the last two measurements, where they got up to walk around. This study focuses on the impact of orthostatic fluid shifts on impedance ratios in body segments and the total body. After 20 min of lying supine lean tissue (DXA) was slightly but significantly lower for the total body and the left leg, but all other consecutive DXA measurements at different times did not differ. Total body impedance and leg impedance increased during the time the subjects were in the recumbent position. Impedance changes in the leg were more pronounced than in the total body, and at 5 kHz the changes were more pronounced compared to 100 kHz. After the subjects got up the impedance values again decreased. Impedance ratios ($Z_5/Z_{100}$) increased for both the leg and to a lesser extent for the total body during the time lying supine, but again decreased after getting up. The results of this study indicate a fluid shift from the legs to the trunk after lying supine and show that this fluid shift is mainly extracellular water. DXA measurements were not able to detect these changes, probably because the magnitude of these changes is below the detection level for lean tissue with DXA methodology. The observations have important implications in the interpretation of impedance measurements in the clinical situation when measurements are made in patients who have been reclining for some time.

Key Words
Dual-energy X-ray absorptiometry
Impedance
Body position
Body water shifts
Introduction

For impedance measurements a small alternating current is applied to the body. The impedance of the body to that current is a measure of body water [1–3]. At low frequencies the current is not able to pass the cell membrane due to its capacitive properties, and hence low frequency impedance measurements are a measure of extracellular water only. At high frequency the capacitive properties of the cell membranes disappear which means that at high frequency body impedance is a measure of total body water. Hence, multi-frequency impedance enables the independent assessment of body water compartments [4–8]. The ratio of impedance at low frequency to impedance at high frequency can be used as a measure of body water distribution [9, 10]. During dialysis weight loss and an increase in body impedance at 50 kHz were highly correlated [11]. The ratio of impedance at 1 and 100 kHz increased [12] indicating that multi-frequency impedance offers the possibility of assessing changes in body water distribution by measuring the impedance ratio at low and high frequency. It could therefore be an important parameter in clinical practice because in many diseases body water distribution is disturbed. Roos and Westendorp [13] observed that impedance at 50 kHz increases with time when a subject is lying supine for a long time. This phenomenon is explained by the fact that fluid shifts may occur as a result of altered body position. Gudivaka et al. [14] reported that impedance values at lower frequencies show a greater increase with time compared with impedance values at higher frequencies. This indicates that the fluid shift is mainly a shift in extracellular water. Segmental multi-frequency impedance measurements can be used to obtain information on the regional body water distribution [15]. When the increase in impedance due to altered body position is indeed due to a shift of extracellular water from the lower extremities to the trunk, the ratio of impedances at low and high frequencies have to change to a higher extent in the leg compared to the total body as the impact of volume is relatively larger in the extremities. The recent development of dual-energy X-ray absorptiometry (DXA) methods for estimating body composition represents an important advance in technology. Although originally developed to estimate bone mineral content, DXA can also be used to estimate regional and total body soft tissue [16]. Going et al. [17] showed that DXA can provide accurate estimates of changes in body weight due to alterations in hydration status, which are accurately reflected by changes in total mass and soft tissue mass. The aim of this study was to investigate the effects of time and body position on total and segmental impedance at different frequencies and to compare them with DXA measurements.

Methods

The study was performed on 14 healthy males. The aim of the study was explained and all subjects signed an informed consent form. The study protocol was approved by the Medical Ethical Committee of the University Tor Vergata in Rome. Some characteristics of the volunteers are given in table 1.

The subjects were measured in the fasting state in the morning after voiding. Body weight and body
Table 2. Repeated measures (mean ± SD) of total body lean mass (kg), left leg lean mass (kg) and left arm lean mass (kg)

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Lean mass total body</th>
<th>Lean mass left leg</th>
<th>Lean mass left arm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>56.12 ± 5.22</td>
<td>9.60 ± 1.09</td>
<td>3.48 ± 0.73</td>
</tr>
<tr>
<td>20</td>
<td>55.88 ± 5.13*</td>
<td>9.54 ± 1.18*</td>
<td>3.46 ± 0.75</td>
</tr>
<tr>
<td>40</td>
<td>56.16 ± 5.23</td>
<td>9.62 ± 1.17</td>
<td>3.50 ± 0.77</td>
</tr>
<tr>
<td>60</td>
<td>56.13 ± 5.27</td>
<td>9.57 ± 1.17</td>
<td>3.45 ± 0.70</td>
</tr>
<tr>
<td>80</td>
<td>56.03 ± 5.10</td>
<td>9.58 ± 1.13</td>
<td>3.55 ± 0.95</td>
</tr>
<tr>
<td>100</td>
<td>55.90 ± 5.29</td>
<td>9.65 ± 1.09</td>
<td>3.57 ± 0.74</td>
</tr>
</tbody>
</table>

* Significant compared to preceding measurement.

height were measured to the nearest 0.1 kg and 0.5 cm, respectively.

The subjects lay down on the table of a dual energy X-ray absorptiometer and remained there for a period totaling 80 min. The subject's position and scan procedures were similar to those described by Mazess et al. [16]. Total body impedance and segmental impedance were measured on the left side every 20 min and also a total body scan was made repeatedly by DXA. The system produces radiation only when electric voltage is applied and current flows through the X-ray tube. For the total body fast scan mode, the patient's average skin entrance dose is 0.02 mrem. Two photon energies, therefore, allow discrimination of two substances in a given system. We used the R value as the ratio of soft tissue attenuation at 38 keV to that at 70 keV. After 80 min the subjects got up and walked around for 20 min, at a speed of 2 km/h, after which impedance and DXA measurements were again performed. Room temperature was 24 °C, relative humidity was 50% and barometric pressure was 750 mm Hg. At this level of exercise and environmental conditions, wetness of the skin due to sweating will not have influenced bioelectrical impedance.

Impedance was measured at 5 and 100 kHz [7] with a Xitron 4000 Impedance Analyzer (Xitron Technologies Inc., San Diego, Calif., USA) using Littmann 2325VP (3M, St. Paul, Minn., USA) adhesive electrodes. The places where the electrodes were attached were marked with a marker pencil to ensure exact replacement of the electrodes for the repeated measurements. For total body impedance the injection electrodes were placed on the dorsal surfaces of the hand and foot at the distal metacarpals and metatarsals and the sensor electrodes between the lateral and medial malleoli of the ankle and between the distal prominences of the radius and the ulna [3]. Total leg impedance was measured with the sensor electrodes between the lateral and medial malleoli of the ankle and on the iliac crest, and the injection electrodes were placed 10 cm distal to those positions. Arm impedance was measured with the injection electrodes on the dorsal surface on the hand and on the acromion, and the sensor electrodes between the distal prominences of the radius and the ulna, 10 cm distal to the acromion, respectively. The reproducibility of the impedance instruments is 1–3 Ω (<0.5%), whereas its accuracy is 2–5 Ω (about 1%), depending on the value of the impedance measured. The reproducibility of duplicate measurements, after removal and replacement of the electrodes, is about 0.5%. It is important to correctly reapply the electrodes. The day-to-day variability of impedance in weight-stable subjects is about 1–2% [3]. Impedance ratios, Z5/Z100, were calculated as a measure of body water distribution [10]. Total body composition was measured by DXA (Lunar Corp., Madison, Wisc., USA) in the fast scanning mode using software version 3.6. The scanner was calibrated daily against the standard calibration block supplied by the manufacturer to control for possible baseline drift. Only the body composition data of the left extremities were used and also impedance was measured on the left side of the body. DXA measures total bone mineral content with a precision (coefficient of variation) of 0.7%. For lean tissue these values were 0.8, 1.6 and 8.4% for total body, left leg and left arm, respectively.

Statistical analyses were performed using the SPSS software program [18]. Descriptive statistics were used to examine the subject characteristics. A one-way repeated measure ANOVA was carried out for full time series to determine whether or not values varied significantly with time. Significance is indicated as p < 0.05. Values are means and standard deviations (SD).

Results

Table 2 summarizes the mean values of lean tissue in the total body as well as of the left extremities at different times. For total body lean tissue and left leg lean tissue the differences after 20 min were slightly but significantly lower than the values measured at time
zero. Table 3 shows the impedance values at 5 and 100 kHz at different times for total body, left leg and left arm. As can be seen there were no significant changes in the left arm impedance with time but the impedance values of the left leg and the total body increased with the time lying supine and decreased again after getting up. The increase was more pronounced at 5 kHz for both the left leg and total body and the increase in left leg impedance was more pronounced compared with that of the total body. The changes in impedance ratio with time spent lying supine for the total body, leg and arm are shown in figure 1. It is clear that with time there is a continuous increase in the impedance ratio of the leg and to a lesser extent for the total body, which decreased after the subjects got up. There were no significant changes in the impedance ratio of the arm.
Discussion

Due to alterations in body position after 80 min of lying supine, the total body impedance increased as well as the impedance of the left leg. These results are in accordance with the data of Roos and Westendorp [13] and Gudivaka et al. [14]. After getting up the values tended to return to the original values. There were only minor changes in impedance and in the impedance ratio of the arm, which is understandable as the effect of gravity on water in the arm is likely to be less compared to that of the leg. The impedance changes in the leg were more pronounced than the changes in the total body, which can be explained by the geometry of the leg, with its smaller diameter. Apart from the geometry it may be argued that the increase in leg impedance is counteracted by the coinciding decrease in trunk impedance (as its water content will increase) when measuring total body impedance. Trunk impedance was not measured as reproducible measures are difficult to obtain due to low trunk impedance [19, 20] and the relatively high instrument error at low impedance value. In addition, because of the large effect incorrect electrode replacements will have on trunk impedance, it was decided not to measure and evaluate the impedance of the trunk.

The observations in this study agree with the fact that the impedance of the leg is much higher than the impedance of the trunk [19, 20]. The fact that a change in impedance at low frequency, which measures the extracellular water [4, 5, 7, 21], is relatively higher indicates that the shift in body water is indeed a shift in extracellular water [14]. The ratio of impedance at 5 kHz to impedance at 100 kHz can be used as an indicator of body water distribution [10]. As we have shown earlier the use of modelling data has no advantage over impedance values measured as fixed frequencies [22], and therefore we did not measure a spectrum of frequencies. This study observed changes in the impedance ratio, an increase after lying supine, followed by a decrease after getting up, showing that the changes are likely to be due to a redistribution of extracellular water over the body.

We tried to confirm this shift in body water by an independent technique, for which we used DXA. DXA enables the measurement of body composition in terms of bone mineral, lean mass and fat mass, both of the total body as well as of body segments [23, 24]. The present study requires rapid measurements of the total and segmental body composition. Therefore we used the fast scanning mode of the DXA instrument. However, the disadvantage of the fast scanning mode is that the data obtained are slightly less precise. This could be a reason why no coincided changes in lean mass with time were observed with DXA as compared with impedance. Only the change in left leg lean mass from 0 to 20 min was significant (table 2), but the observed change was very small. Another reason that there are no changes in lean mass from DXA may be that the DXA software assumes a constant hydration factor of the lean mass, and as impedance data show, there is a shift in body water from the legs to the trunk. Thus assumptions are violated which will have an impact on the reliability of the measures. How large the shift in body water is, can be calculated from the changes in impedance of the leg. When it is assumed that volume and impedance are inversely proportional (V = ρ·L²/Z, where V = volume, ρ = specific resistivity, L = length of the leg, Z = impedance [25]), the observed change in leg impedance at 5 kHz (9%) should theoretically be due to a decrease in extracellular water of about 9%. It is likely that this calculated decrease in water is an overestimation, as it would equal an amount of about 2.5 kg extracellular water, assuming that the lean
tissue of the leg (about 9 kg in these subjects; table 2) consists of 70% water of which about 40% may be extracellular [26]. Due to the loss of extracellular water the specific resistivity of the remaining fluid will increase [4, 27] resulting in a higher than expected increase in the impedance of the leg, thus in an overestimation of the water shift. From the repeated DXA measurement it can be calculated that the variability in left leg lean mass is about 2% [8] which equals an amount of body water in the leg of about 125 g. It seems likely that the real changes in body water in the leg will be of this magnitude, which moreover, explains that the shift in body water cannot be detected by the DXA methodology [17].

When the impedance ratio is used as an indicator of body water distribution in clinical practice, it is important to realize that the time the patient is recumbent influences the impedance ratio. For a bedridden patient different ‘normal’ values have to be used compared to values for an outpatient who was not recumbent for a longer time immediately before the measurement. This could be useful for physiological and pharmacological studies on vessel system compliance and for the diagnosis and management of patients with edema. Further research may reveal the utility of the index $Z_s/Z_{100}$ for detecting and monitoring the effects of pharmacological and dietetic treatment.

In conclusion, leg impedance ratios and total body impedance ratios ($Z_s/Z_{100}$) increase after lying supine. This increase in impedance ratio is more pronounced in the leg compared with total body, indicating a shift of extracellular water from the legs to the trunk. It is likely that the change in impedance overestimates the shift in body water. The dependence of the impedance ratio on the time recumbent has consequences for the use of impedance and impedance ratios in clinical practice. The ratio $Z_s/Z_{100}$ can become a reliable index for the evaluation of hydro-electrolyte homeostasis of body segments. Furthermore, it appears that the periodically conducted measures are reproducible, and it is possible to detect significant variations that occur in a small time period. Bioelectrical impedance analysis seems to be simple and noninvasive, and can easily be conducted in the outpatient department and in the field.

References


