Qualitative Human Body Composition Analysis assessed with Bioelectrical Impedance - T.Talluri  Akem R&D, Florence, Italy

Abstract

Body composition is generally aiming at quantitative estimates of Fat Mass, inadequate to assess nutritional states that on the other hand are well defined by the intra/extra cellular massess proportion (ECM/BCM). Direct measures performed with phase sensitive bioelectrical impedance analyzers, can be used to define the current distribution in normal and abnormal populations. Phase Angle and Reactance nomogram is directly reflecting the ECM/BCM pathways proportions and body impedance analysis (BIA) is also validated to estimate the individual content of Body Cell Mass (BCM). A new Body Cell Mass Index (BCMI) obtained dividing the weight of BCM in kilograms by the body surface in square meters is confronted to the scatterplot distribution of Phase Angle and Reactance values obtained from controls and patients, and proposed as a qualitative approach to identify abnormal ECM/BCM ratios and nutritional states.

Introduction

All substances with exception of superconductors, offer resistance to the flow of electricity. Live tissues in particular, when crossed by alternating currents oppose Resistive (Rz) and Reactive (Xc) forces, together forming the Bioelectric Impedance Modulus (BIM) where Resistance is a direct expression of the quantity of fluids and Reactance of the relevant distribution between intra and extra cellular spaces. Body Impedance Analysis (BIA) is routinedly utilized to assess body composition, to study hydration states or to monitor fluid shifts during blood purification procedures. The analytical approach is always applied to obtain estimates of fat and fat free masses, in other words, all the equations so far developed are addressed to assess the quantity of a studied compartment.

We felt that, prior to assessing the quantity of fat mass which provided no evidence on illnes states, as obese subjects can be ill or healthy, well nourished or malnourished, independently from the amount of body fat, it is necessary to assess the quality of the fat free mass, since in many pathological states, especially those influencing the nutritional state there is an altered proportion between intra and extra cellular fluids. One of the strongest malnutrition sign is the altered ratio between extracellular and intracellular masses (ECM/BCM). Also the Body Mass Index (BMI) can be utilized to indicate malnutrition when its value is very low, but it lacks specificity. We already know that a single bio-electrical measurement is correlated with and is a significant index of "well being"(1,2,3).

Bioelectric impedance of living tissues is characterized by the presence of a phase shift generated by cell membranes that reach peak value at a characteristic frequency (5) which varies in different species. However at one fixed frequency (50 Khz), the changes of phase angle can provide evidence of edema and/or membrane disruption. (6)

The equivalent electrical model of Fat Free Mass is shown in figure 1

![Figure 1](image-url)

R1 = EXTRACELLULAR WATER RESISTIVE PATHWAY
R2 = INTRACELLULAR WATER RESISTIVE PATHWAY
C = CAPACITANCE FROM CELL MEMBRANE

The BIA constant alternating current of 800 µAmperes at 50KHz applied to the model shows flow phenomena compatible with the parallel conductors principles:

- Conduction of R1 resistor without current outphasing - Conduction of the R2 resistor and C capacitor with some current outphasing from the capacitor Any variation of R1 will influence the quantity of current flowing through the outphasing parallel circuit and causing a proportional variation of phase angle. A different approach to discriminate the current flow in the two parallel pathways is to apply a low and a high frequency where the low frequency (in the range of 5 KHz) is expected to flow almost entirely in the R1 branch and the high frequency (in the range of 100 Khz) also in the R2C pathway.

Both approaches have yielded comparable estimates of extracellular and total body fluids, however the 50KHz phase-sensitive approach is to be preferred since it is more practical, rapid and less subject to measurement faults due to the difficulty at low frequencies of obtaining homogeneous current distributions with surface electrodes. We have applied this concept to assess the possibility of obtaining...
a bioelectrical normalization index that would identify the proportion between extra and intra cellular spaces, without associating the measurements to anthropometric variables such as height and weight.

**Method**

We have obtained Resistance and Reactance data on over 888 male and female college freshmen and 69 renal patients where the same bioelectrical variables had been measured just before dialysis. All measurements were taken with BIA 101 Impedance Analyzers, manufactured by Akern, Florence-7Italy. The BIA 101 is a phase sensitive impedance analyzer that injects a sinusoidal constant (800 µA) current at 50 KHz. Out of the 888 college freshmen we have extracted all the subjects with a BMI lower than 17, in order to avoid the inclusion of malnourished and anorexic subjects. In this study the remaining 860 subjects (male and female) are used as controls, assuming that in such population the nutritional and hydration state is normal. (i.e. ECM/BCM = 1) Against these were compared the renal subjects, who due to expansion of extracellular fluids caused by the renal insufficiency, were regarded this study as abnormal. (i.e. ECM/BCM > 1)

On the controls, we obtained a scatterplot of Reactance and Phase Angle calculating the bivariate 90 and 75 centiles of the distribution. The reason for using Reactance and Phase Angle derives from previous studies (8) where we have shown that both parameters are not height or weight dependent.

Fig 2 shows the distribution of the selected population with the 75th and 90th centiles.

![Fig. 2](image)

Removing the scatters and preserving only the 75% bivariate ellipse, gives the following nomogram (Fig.3).

![Fig. 3](image)

To enquire whether the impedance measures alone were capable of distinguishing abnormality the scatterplot of impedance measurements recorded before dialysis of the 69 renal patients was overlayed on
the 75th centile ellipse of our controls. We then computed the quantity of Body Cell Mass, utilizing our standard validated equations and applied to give a new index: the Body Cell Mass Index (BCMI), as follows formula:

$$BCMI = \frac{BCM}{\text{height}^2}$$

where $BCM = \text{Body Cell Mass in Kg}$; $\text{Height} = \text{in Meters}$

The rationale for the BCMI is that a normally nourished subject would be better identified by comparing cells with height rather than weight with height, since in many cases part of the weight is contributed by compartments, such as fat or extracellular mass, that are not "live" tissue and not fully metabolically active.

**RESULTS**

Table 1

<table>
<thead>
<tr>
<th></th>
<th>Patients</th>
<th>Controls</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>BMI</td>
<td>BCMI</td>
</tr>
<tr>
<td>MINIMUM</td>
<td>16.765</td>
<td>4.263</td>
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<td>MAXIMUM</td>
<td>39.143</td>
<td>13.222</td>
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<td>RANGE</td>
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<td>8.960</td>
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<td>MEAN</td>
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<td>VARIANCE</td>
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<td>4.287</td>
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<tr>
<td></td>
<td>BMI</td>
<td>BCMI</td>
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<td>MAXIMUM</td>
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<tr>
<td>STANDARD DEVIATION</td>
<td>2.523</td>
<td>2.314</td>
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</tbody>
</table>

The BMI, BCMI and ECW% for the two groups are shown in Table 1. While the mean BMI do not differ significantly, the patients are characterized by a significantly higher mean ECW (as expected) and a lower BCMI ($p<0.0001$).

At the individual level, comparing the patients with the 75th centiles of the normals, only 16 patients (23%) lie within it and the majority of patients fall below and to the left of it (Fig. 4).

**Fig. 4**

69 Renal Patients plotted over the 75% bivariate of controls

Correlating BMI with BCMI in the two groups (Fig. 5 and 6) illustrated another difference between them.
The controls (Fig. 5) show a fair positive highly significant correlation between BMI and BCMI (PEARSON $r=0.44$), whereas in the renal subject (Fig. 6) there is no correlation (PEARSON $r=-0.04$).

**Discussion**

The normal amount of extracellular water is about 45%, and it defines also the normal proportion between intra and extracellular spaces. When ECW is expanded (i.e. ECW > 45%) the expansion can be attributed to
overhydration or malnutrition or both. In our study the significantly (p=0.0001) higher BCMI in the controls than Renal subjects in spite of a lower BMI, and a significantly (p=0.0001) lower ECW% indicate that the ratios of EC / IC spaces are significantly different in the normal and the renal patients. The difference in the correlations supports our previous statement that in abnormal populations the body mass index cannot reflect nutritional abnormalities.

**Conclusion**

The different distribution in the populations in the bivariate plot of Reactance and Phase Angle provides clear evidence of the disproportions between intra and extra cellular spaces in the patients. Discrimination is possible without using sex specific equations associated with height and weight. The Body Cell Mass Index (BCMI) appears to be a powerful tool to identify body composition abnormality caused by illness. Measurements of the phase-shift of small alternating currents at a frequency of 50 Khz appears to be suitable to assess fat free tissue normality, therefore qualitative Fat Free Mass analysis can be performed with bioelectrical impedance analysis, without the need of anthropometric data.

**Bibliography**