What Does Bioimpedance Measure?

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ABSTRACT
Measurements of bioimpedance are often used to determine water spaces in humans and this leads to the perception that it measures the sum of extra- plus intra-cellular water at high frequencies. Using a simple mathematical model it is shown that the intra-cellular water makes only a small contribution to the quantity that it actually measures.

INTRODUCTION
Bioimpedance measurements are widely used for the determination of body water spaces and fat free mass when studying body composition. Four ECG electrodes are positioned two on the ankle and two on the wrist. A constant current is injected between the outer two electrodes and voltages are measured between the inner two. The majority of instruments operate at a fixed frequency of 50 kHz, but multi-frequency instruments are now available which determine both impedance and phase at many frequencies between 5 kHz and 1 MHz.

Following Hofer et al [1], many authors have described a simple model in which the body is treated as a cylinder of uniform composition; this model predicts that the water volume is proportional to the impedance index, Height²/Impedance. At low frequencies (<10 kHz) it is assumed that the current flow is limited to the Extra-Cellular Water (ECW) because the cell membranes act as capacitors. Hence at low frequencies bioimpedance is regarded as a measure of the ECW. At higher frequencies the electric current flows through the Intra-Cellular Water (ICW) as well as the ECW, suggesting that at high frequencies the impedance index is a measure of the volume of the Total Body Water (TBW). This has created the perception that bioimpedance measures TBW, and this is seemingly supported by the excellent correlations that are observed between measurements of TBW and the impedance index.

A PREDICTION OF THE SIMPLE MODEL
The above analysis can be taken one step further by modeling the body at high frequencies as two resistors in parallel, one representing the resistance of the ECW, the other the ICW. The resultant impedance is that of the two resistors in parallel. Let \( R_\infty \) represent the resistance at infinite frequency of these two resistances in parallel. Then it can be shown that

\[
\rho_e \frac{H^2}{R_\infty} = \left[ \frac{ECW + \rho_e ICW}{\rho_i} \right]
\]

where \( \rho_e \) and \( \rho_i \) are the resistivities of the ECW and ICW, and \( H \) is the subject’s height. The term in the brackets represents the volume that is being measured. It is not TBW, i.e. the sum of ECW and ICW, but rather a weighted sum. The weight is the ratio of the resistivities which is approximately \( \frac{1}{4} \) [2].

CONCLUSION
Various papers in the engineering literature [2,3] have concluded that the flow of current is principally through the skeletal muscle which is generally modeled as cylindrical fibres rather than spheres. It is obvious from this literature that even at low frequencies current may penetrate the cell membrane and the ICW may contribute to the overall conductivity, thus invalidating one of the principal assumptions of the simple model. It is not immediately obvious how this will affect our understanding of what is actually being measured by bioimpedance.

Nevertheless, this simple model predicts that bioimpedance does not measure TBW even at very high frequencies. It is most surprising that this result has not been mentioned in the body composition literature.

REFERENCES