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Generalized predictive equation for hematocrit by biological impedancemetry

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Abstract. Bioelectrical impedancemetry (BIA) has been used to evaluate hemorheological parameters from whole body measurements. In a previous study, we have determined a set of predictive equations for hematocrit, whole blood viscosity and plasma viscosity in athletes. In another previous study, we also found other predictive equations in sedentary lean and obese subjects. This study aims at developing more generalized BIA-derived predictive equations for hemorheological parameters in both sedentary and trained individuals. 72 subjects, either athletes, sedentary obese or insulin resistant patients (33.57 ± 1.60 yr; 80.81 ± 2.06 kg; 171.03 ± 1.19 cm) were enrolled into the study. Body composition was assessed with a multifrequency bioelectrical impedancemeter (Dietosystem Human IM Scan) using low intensity at the following frequencies: 1, 5, 10, 50 and 100 kHz. Viscometric measurements were done at 1000 s^{-1} with a falling ball viscosimeter (MT 90 Medicatest). Hematocrit (Hct) was measured with microcentrifuge. Hematocrit was correlated with impedance (Z) measurements at 50 kHz ($r = -0.591$, $p = 0.01$). A generalized empirical predictive equation can thus be proposed. These findings further suggest that one can predict hematocrit in the general population with whole body electric properties.

Keywords: Impedance, body fluids, blood viscosity, hemorheology, hematocrit, athlete, sedentary population

1. Introduction

Bioelectrical impedance analysis (B.I.A.) is widely used for the routine assessment of fat mass, fat free mass and body fluid volumes [1–15].

However, electric properties of the body give a lot of other relevant information about the physiological status of the body. Recently we investigated the possibility to indirectly evaluate hemorheological parameters, since electric charge carriers in body fluids are ions and proteins that determine blood viscosity and since BIA is used *in vitro* for measuring hematocrit and red cell rheological properties. In a previous paper [16] we determined predictive equations for predicting viscosity parameters with whole body BIA in athletes:

$$\text{Hct} = 50.42 \exp(-3.07 \cdot 10^{-4} Z_1), \quad r = -0.485 \text{ and } p = 0.01$$

in this equation Z_1 is whole body impedance at a frequency of 1 kHz.

$$\text{WBV} = -513.4069 Z_{100} + 4.1466, \quad r = 0.518 \text{ and } p = 0.01$$

in this equation Z_{100} is whole body impedance at a frequency of 100 kHz.

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In another study, we tried to extend this analysis to a sedentary population and also found other predictive equations, as follows:

$$\text{Hct} = -0.0352Z_{50} + 58.741, \quad r = -0.686,\ p = 0.01$$

in this equation Z_{50} is whole body impedance at a frequency of 50 kHz.

$$\text{WBV} = -0.0032Z_{50} + 4.8621, \quad r = -0.541,\ p = 0.01$$

in this equation Z_{50} is whole body impedance at a frequency of 50 kHz.

This study aims at developing more generalized BIA-derived predictive equations for hemorheological parameters in both sedentary and trained individuals.

2. Methods

2.1. Study subjects

72 subjects (44 men and 28 women) included in this study were either athletes, sedentary obese or insulin resistant patients. Their characteristics are shown on Table 1. Subjects' characteristics were as follows (mean ± SEM): age 33.57 ± 1.60 yr; weight 80.81 ± 2.06 kg; height 171.03 ± 1.19 cm.

2.2. Bioelectrical impedance measurements

Body composition was assessed with a four terminal impedance plethismograph Dietosystem Human IM-Scan. The four electrode method minimizes contact impedance and skin–electrode interactions. Measurements were made in fasting subjects after 15 min resting in a supine position. A low intensity (100 to 800 μA) current is introduced into the subject at various frequencies (1, 5, 10, 50 and 100 kHz). The measurement of the voltage drop allows the determination of total body reactance and impedance (Z). These values are used with software Master 1.0., provided by the manufacturer, for calculating body water (intracellular and extracellular), fat mass, fat-free mass, and body cell mass [17,18], that gives the choice among 25 published equations for body composition calculation. However, we also included crude values of Z at various frequencies in our statistical analysis.

Table 1
Anthropometry, body composition, hemorheologic parameters of study subjects ($n = 72$)

Age (years)	33.57 ± 1.60
Weight (kg)	80.81 ± 2.06
Height (cm)	171.03 ± 1.19
Body mass index (kg/m^2)	9.41 ± 1.36
Fat mass (kg)	34.24 ± 16.42
Hematocrit (%)	40.91 ± 0.39
Blood viscosity (mPa.s)	3.07 ± 0.05
Plasma viscosity (mPa.s)	1.41 ± 0.01

2.3. Laboratory measurements

Blood samples for hemorheological measurements (7 ml) were drawn with potassium EDTA as the anticoagulant in a vacuum tube (Vacutainer). Viscometric measurements were done at very high shear rate (1000 s^{-1}) with a falling ball viscometer (MT 90 Medicatest, F-86280 Saint Benoit) [19,20]. Accuracy of the measurements was regularly controlled with the Carrimed Rheometer 'CS' (purchased from Rhéo, 91120 Palaiseau, France) [21]. The coefficient of variation of this method ranges between 0.6 and 0.8%. We measured with this device apparent viscosity of whole blood at native hematocrit, plasma viscosity, and blood viscosity at corrected hematocrit (45%) according to the equation of Quemada [22]. Hematocrit was measured with microcentrifuge.

2.4. Statistics

Values are presented as mean $\pm$ the SE of the mean. The relationships between impedance measurements and hemorheological parameters were explored. Different models were tested: linear, exponential, logarithmic and power analysis. The choice of the better model was performed on the basis of the correlation coefficient value. Stepwise linear regression analysis, after tests of normality and homoscedasticity had been verified, with the software package "Statview" from Jandel scientific. Significance level was defined as $p < 0.05$ [23].

Validation of equations against reference measurements was performed with the software "Method Validator" by Ph. Marquis, Metz, France and downloadable as freeware at http://perso.easynet.fr/~philimar/methvalfra.htm.

3. Results

3.1. Correlations

The only hemorheological parameter that appeared to be correlated with BIA measurements was hematocrit. Hematocrit was negatively correlated with impedance measurements at 50 kHz. This correlation fitted with a linear relatinship (Hct $= -0.029Z_{50} + 54.621$) ($r = -0.591$, $p = 0.01$) (Fig. 1).

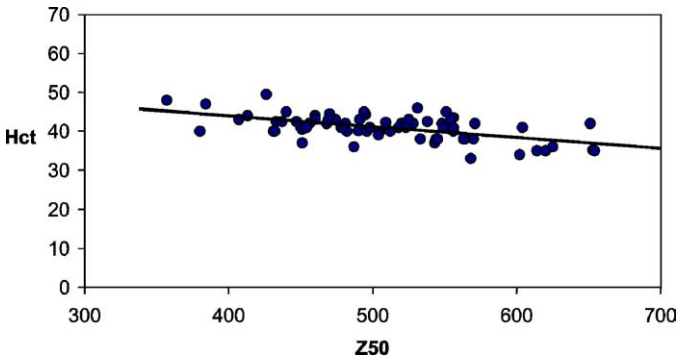

Fig. 1. Correlation between hematocrit and impedance at 50 kHz ($r = -0.591$, $p = 0.01$).

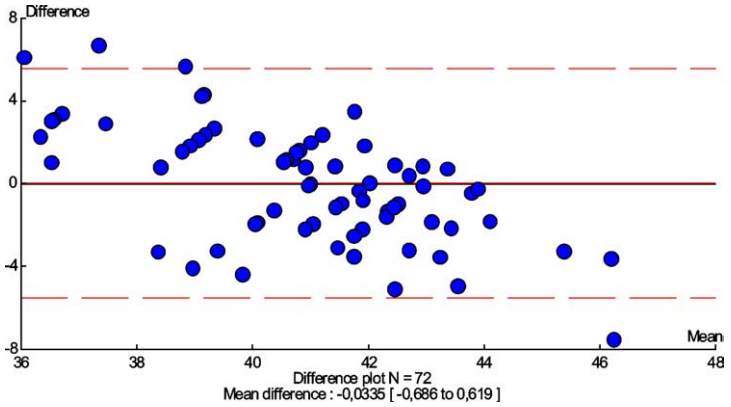

Fig. 2. Bland and Altman diagram showing the concordance of the simplified evaluation of hematocrit with the formula $\text{Hct} = -0.029Z_{50} + 54.621$ and its measurement with the full protocol procedure in 72 subjects exhibiting a wide range of hematocrit.

3.2. Validation of the predictive equations

Bland and Altman linear difference plots were tested for this predictive equation. Results show that hematocrit can be predicted with this relationship $\text{Hct} = -0.029Z_{50} + 54.621$ with a mean difference of $-0.0335 \times 10^{-5}\%$ and a 95% confidence interval of -0.686 to 0.619% (Fig. 2).

4. Discussion

These findings suggest that a generalized empirical predictive equation of hematocrit with whole body electric properties can thus be proposed. Further work is needed for developing predictive equations for other hemorheologic parameters. However, since in vitro BIA techniques have given promising results for this purpose [24,25], this issue will require further studies.

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