# WHITE PAPER

## Generation, application and adaption of device specific prediction equations to analyze body composition of adults in various ethnic groups based on Bioelectrical Impedance Analysis (BIA)

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## Introduction

The accuracy and precision of the BIA method are affected by instrumentation, client factors, technical skill, environmental factors, and the prediction equations used to estimate fat free mass (FFM) (Kushner 1992, Lohmann 1989b, Van Loan 1990). In addition to that, ethnic-specific impedance-based equations for body composition are justified because of differences in body shape among ethnic groups. Failing to adjust for differences in FFM density in ethnic groups may result in systematic biases of up to 3%.

## Study objective

Aim of the study is to develop prediction equations for calculating FFM, total body water (TBW) and extracellular water (ECW) based on the gold standard reference methods air displacement plethysmography (ADP), dual-energy X-ray absorptiometry (DXA), deuterium dilution ($D_2O$) and sodium bromide solution (NaBr) on the one hand and measurement data of the seca medical Body Composition Analyzer 514/515 (seca mBCA) on the other hand. The equations are necessary to use the seca mBCA as a Body Composition Analyzer with an acceptable accuracy level for clinical practice. If equations from literature had been taken the accuracy would not be known and the clinical use would be doubtful. After the generation of these equations they shall be applied and adapted to device specific body composition formulas to various ethnic groups.

## Subjects and methods

124 Caucasian men and women (BMI 18.5-35 kg/m$^2$) aged 18-65 years were recruited at the Institute of Human Nutrition and Food Science in Kiel, Germany.
For the validation of the developed equations in a multiethnic sample 130 men and women (BMI 19.8-33.7 kg/m$^2$) aged 18-65 years (32 Caucasians, 36 Asians, 31 Afro-Americans and 31 Hispanics) were recruited at the New York Obesity Nutrition Research Centre, USA (phase 2).

### Anthropometrics

Body height and weight were obtained as well as some other values for plausibility checks.

### BIA

Resistance (R) and reactance (Xc) values at frequencies of 1, 1.5, 2, 3, 5, 7.5, 10, 15, 20, 30, 50, 75, 100, 150, 200, 300, 500, 750 and 1,000 kHz were recorded. The measurement was done for all body segments: right arm, left arm, right leg, left leg, trunk, right body side and left body side. In total resistance and reactance at 19 frequencies for 7 body segments was measured.

### Four compartment model

- Fat mass (FM) was calculated using the four compartment model that includes body volume (by ADP), TBW (by $D_2O$) and bone mineral content (BMC) by DXA using the equation from Fuller et. al 1992:

$$\text{FM (kg)} = 2.7474 \times \text{body volume (l)} - 0.7145 \times \text{TBW (l)} + 1.4599 \times \text{BMC (kg)} - 2.0503 \times \text{weight (kg)}$$

- FFM was calculated as the difference between body mass and FM.
- ADP was performed using the BOD-POD device. FM was calculated from body density using Siri's equation.
- A whole-body DXA scan was performed to measure BMC and FM. $FFM_{DXA}$ was calculated as weight - $FM_{DXA}$.
- $D_2O$ was used to estimate TBW. After obtaining 10 ml of venous blood samples, each participant received an oral dose of deuterium oxide. Four hours later, a second blood sample was taken. 2H/1H enrichment of the serum samples was measured by serum samples was measured by isotope ratio mass spectrometry. Plasma samples were analysed for their $^2H_2O$ content using an isotope ratio mass spectrometer.

### ECW

An oral dose of NaBr administered simultaneously with deuterium-enriched water. Bromide was quantified in plasma samples using a non-destructive liquid X-ray fluorescence technique, with reproducibility of ±0.8%.

## Development of BIA algorithms

A stepwise multiple regression analysis is used to determine the optimum combination of prediction parameters for the target quantities FFM, TBW and ECW. Independent variables were only included in the model for predicting the dependent variables in those cases where they contributed to a significant improvement in the explained variance ($R^2$) and to a clear change (more than 10%) of the beta coefficient of the independent variables.

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## Results

Basic characteristics for the Caucasian study population (Kiel study centre only) are given in table 1 stratified by gender.

Table 1 Descriptive characteristics of the Caucasian study population in Kiel (MW ±SD)

| | females (n=62) | males (n=62) | all (n=124) |
|---|---|---|---|
| age [y] | 40.6 ±12.7 | 40.2 ±11.7 | 40.4 ±12.2 |
| weight [kg] | 67.8 ±13.1 | 83.6 ±11.4 | 75.7 ±14.6 |
| height [cm] | 167 ±7 | 179 ±6 | 173 ±9 |
| BMI [kg/m²] | 24.1 ±3.7 | 25.9 ±3.3 | 25.0 ±3.6 |

BMI, Body Mass Index

### Indices for body shape from segmental BIA

Two different indices, index $R_{50\ \text{trunk/extremities}}$ and index $Xc_{50\ \text{trunk/extremities}}$, were developed from segmental R and Xc values (means of left and right body side) to represent the relative contribution of the trunk and extremities to total body conductivity (figure 1). The new indices correlated with trunk length and waist and arm circumference. The index from segmental R-values correlated with the ratio of trunk length to mean extremity length, whereas the index from segmental Xc-values correlated with arm and leg length. In all, 40% of the variance in index $R_{50\ \text{trunk/extremities}}$ was explained by gender and the ratio of trunk length to mean extremity length; 63% of the variance in index $Xc_{50\ \text{trunk/extremities}}$ was explained by gender and arm length. Other variables (age, leg length, arm or hip circumference) were not independent predictors of either indices.

$$\text{Index } R_{50\ \text{trunk/extremeties}} = \frac{R_{50kHz}\ \text{trunk}}{R_{50kHz}\ \text{mean}_{arms} + R_{50kHz}\ \text{mean}_{legs} / 2}$$

$$\text{Index } Xc_{50\ \text{trunk/extremeties}} = \frac{Xc_{50kHz}\ \text{trunk}}{Xc_{50kHz}\ \text{mean}_{arms} + Xc_{50kHz}\ \text{mean}_{legs} / 2}$$

**Figure 1** Two different indices were developed from measured R and Xc values (mean of left and right body side) to represent the relative contribution of trunk and extremities to total body conductivity.

### Development of BIA prediction equations for FFM, TBW and ECW

98% of the variance in $FFM_{4C}$ was explained by the predictors $Ht^2$ / $R_{50}$, $Xc_{50}$, index $R_{50\ \text{trunk/extremities}}$, weight, gender, and age. 94% of the variance in $ECW_{NaBr}$ was explained by $Ht^2/R_5$, weight and Index $R_{50\ \text{trunk/extremities}}$. 98% of the variance in $TBW_{D2O}$ was explained by the predictors $Ht^2/R_{50}$, $Xc_{50}$, weight, index $R_{50\ \text{trunk/extremities}}$, index $Xc_{50\ \text{trunk/extremities}}$, age, and gender.

Table 2 Results of regression analyses for $FFM_{4C}$ (kg)

| | $R^2$ | RMSE [kg] |
|---|---|---|
| **Predictors of $FFM_{4C}$ [kg]** | | |
| $Ht^2/R_{50}$(Ω) | 0.93 | 3.24 |
| $Xc_{50}$ (Ω); index $R_{50\ \text{trunk/extremities}}$ (Ω), weight [kg], gender, age [y] | 0.98 | 2.64 |

FFM, fat-free mass; $R^2$, coefficient of determination; RMSE, root mean square error; R, Resistance; Xc, Reactance

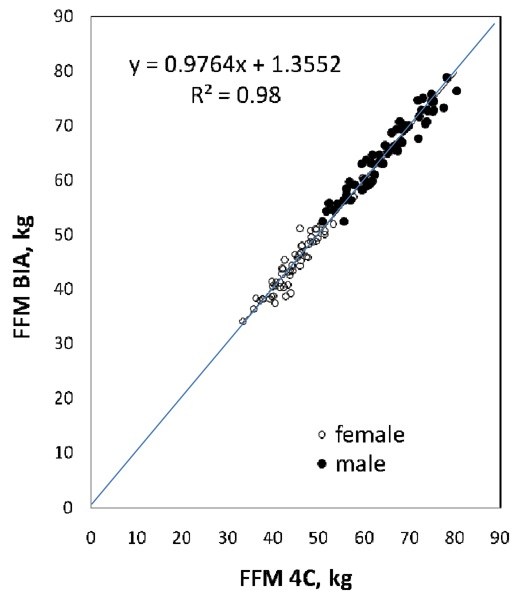


**Figure 2** Regression analysis for fat-free mass (FFM) between four compartment model (4C) and BIA

Table 3 Results of regression analyses for $TBW_{D2O}$ (kg)

| | $R^2$ | RMSE [kg] |
|---|---|---|
| **Predictors of $TBW_{D2O}$ [kg]** | | |
| $Ht^2/R_{50}$ (Ω) | 0.93 | 2.26 |
| $Xc_{50}$ (Ω); index $R_{50\ \text{trunk/extremities}}$ (Ω), index $Xc_{50\ \text{trunk/extremities}}$ (Ω); weight [kg], gender, age [y] | 0.98 | 1.34 |

TBW, total body water; $R^2$, coefficient of determination; RMSE, root mean square error; R, Resistance; Xc, Reactance

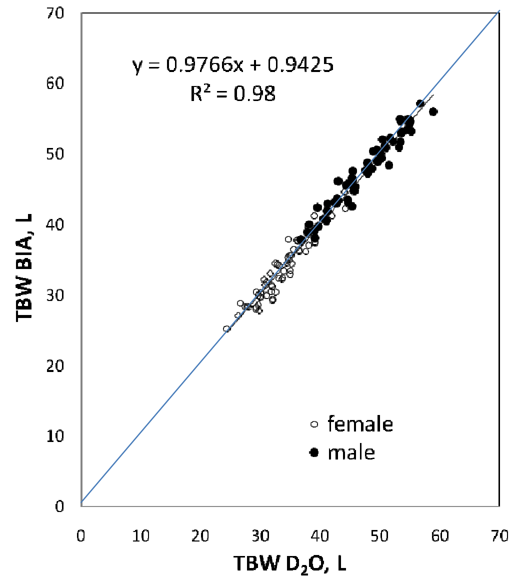


**Figure 3** Regression analysis for total body water (TBW) between deuterium dilution ($D_2O$) and BIA

**Table 4** Results of regression analyses for $ECW_{NaBr}$ (l)

| | $R^2$ | RMSE [kg] |
|---|---|---|
| **Predictors of $ECW_{NaBr}$ [l]** | | |
| $Ht^2/R_5$(Ω | 0.89 | 1.07 |
| weight [kg]; index $R50_{trunk/extremities}$ (Ω) | 0.94 | 0.79 |

ECW, extracellular water; $R^2$, coefficient of determination; RMSE, root mean square error; R, Resistance; Xc, Reactance

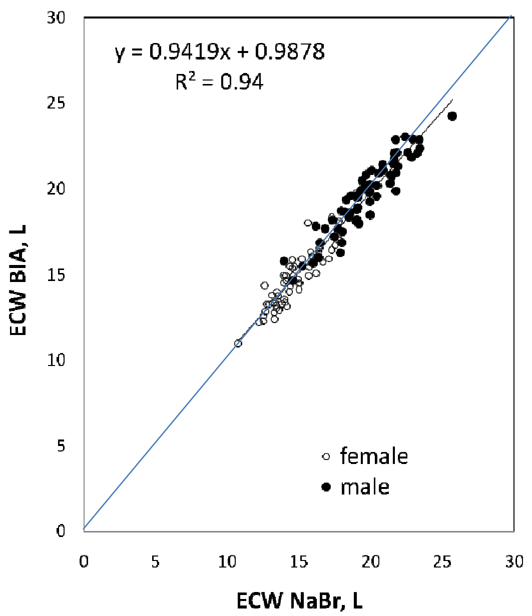


**Figure 4** Regression analysis for extracellular water (ECW) between sodium bromide dilution (NaBr) and BIA

## Validation of BIA equations in an independent sample

The study population for phase 2 (New York study centre only) is characterized as follows:

**Table 4** Descriptive characteristics of the study population from phase 2 (New York) stratified by ethnicity

| | females | males | all |
|---|---|---|---|
| Caucasians | (n=16) | (n=16) | (n=32) |
| age [y] | 42.7 ±13.7 | 43.1 ±15.7 | 42.9 ±14.5 |
| weight [kg] | 68.0 ±12.0 | 81.9 ±15.0 | 74.9 ±15.1 |
| height [cm] | 164 ±5 | 175 ±7 | 170 ±8 |
| BMI [kg/m²] | 25.1 ±34.1 | 26.8 ±4.6 | 26.0 ±4.4 |
| | | | |
| Asians | (n=18) | (n=18) | (n=36) |
| age [y] | 40.7 ±13.0 | 41.3 ±14.4 | 41.0 ±13.5 |
| weight [kg] | 58.1 ±6.4 | 69.3 ±11.1 | 63.7 ±10.6 |
| height [cm] | 160 ±4 | 172 ±6 | 166 ±8 |
| BMI [kg/m²] | 22.6 ±1.9 | 23.3 ±3.5 | 23.0 ±2.8 |
| | | | |
| Afro-Americans | (n=15) | (n=16) | (n=31) |
| age [y] | 37.1 ±10.5 | 40.9 ±11.7 | 38.7 ±11.1 |
| weight [kg] | 67.8 ±10.1 | 81.4 ±16.7 | 75.2 ±15.3 |
| height [cm] | 166 ±6 | 176 ±8 | 172 ±8 |
| BMI [kg/m²] | 24.6 ±3.7 | 26.0 ±3.8 | 25.4 ±3.8 |
| | | | |
| Hispanics | (n=16) | (n=15) | (n=31) |
| age [y] | 40.5 ±13.4 | 39.7 ±11.7 | 40.1 ±12.4 |
| weight [kg] | 69.3 ±4.1 | 80.3 ±12.1 | 74.6 ±10.4 |
| height [cm] | 158 ±7 | 174 ±5 | 165 ±10 |
| BMI [kg/m²] | 27.9 ±2.9 | 26.7 ±4.2 | 27.3 ±3.6 |

BMI, Body Mass Index

The mean bias for prediction of FFM, ECW and TBW was low in all ethnic groups and did not significantly differ between Caucasians, Asians, Afro-Americans and Hispanics, respectively.

## Conclusions

The validated eight-electrode, segmental multifrequent seca mBCA BIA device which estimates the body composition in healthy adults matches the precision of other 2-compartment reference methods, including air-displacement plethysmography, deuterium dilution and DXA. The coefficient determination for all generated prediction equations is high (values between 0.94 for ECW and 0.98 for FFM and TBW) and the RMSE is low.
The application of the generated prediction equations to the independent population for validation purposes revealed that the pure error of the prediction was in the range of the RMSE.
Due to its quick and non-invasive measuring procedure it is a valid and recommended tool for the estimation of body composition in standing adults from different ethnic populations.

For more details on the briefly described study results please refer to the official original study article *What makes a BIA equation unique? Validity of eight-electrode multifrequency BIA to estimate body composition in a healthy adult population* published in the European Journal of Clinical Nutrition