WHITE PAPER

Generation and validation of device specific prediction equations to analyze skeletal muscle mass (SMM) and visceral adipose tissue (VAT) of adults in various ethnic groups based on Bioelectrical Impedance Analysis (BIA)

Introduction

The accuracy and precision of the BIA method are affected by instrumentation, client factors, technical skills and environmental factors. In addition, ethnic-specific impedance-based equations for body composition may be justified because of differences in body shape among ethnic groups.

Study objective

Aim of the study was to develop prediction equations for calculating skeletal muscle mass (SMM) and visceral adipose tissue (VAT) based on the reference method Magnetic Resonance Imaging (MRI) on the one hand and measurement data of the seca medical Body Composition Analyzer 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. After the generation of these equations they were cross-validated in an independent sample of different ethnic groups.

Subjects and methods

153 Caucasian men and women (BMI 20-34,7 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 129 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, weight and waist circumference 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 were measured. The measurement at 19 frequencies took 75 seconds.
Measurements at 4 frequencies for non-scientific purposes take less than 20 seconds.

SMM and VAT

SMM for the total body, left arm (SMM_{LA}), right arm (SMM_{RA}), trunk (SMM_{Trunk}), left leg (SMM_{LL}) and right leg (SMM_{RL}) as well as VAT were determined using MRI technology. Therefor a whole-body-scan was conducted.

Development of BIA algorithms

A stepwise multiple regression analysis was used to determine the optimum combination of prediction parameters for the target values SMM and VAT. 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) of the independent variables.

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=75)	males (n=78)	all (n=153)
age [y]	40.7 ±12.8	38,6 ±11.9	39,6 ±12.4
weight [kg]	67.8 ±12,5	84,2 ±11.2	76,1 ±14.4
height [cm]	168 ±7	180 ±6	174 ±9
BMI [kg/m²]	23,9 ±3.5	25.9 ±3.2	24,9 ±3.5

BMI, Body Mass Index

Indices for body shape from segmental BIA

Two different indices, index $R_{50\ tr/ex}$ and index $Xc_{50\ tr/ex}$, 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).

$$\text{index } R_{50\ tr/ex} = \frac{R_{50kHz}\ \text{trunk}}{R_{50kHz}\ \text{mean}_{arms} + R_{50kHz}\ \text{mean}_{legs} / 2}$$

$$\text{index } Xc_{50\ tr/ex} = \frac{Xc_{50kHz}\ \text{trunk}}{Xc_{50kHz}\ \text{mean}_{arms} + Xc_{50kHz}\ \text{mean}_{legs} / 2}$$

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 SMM and VAT

Table 2 to 7 show the coefficient of determination (R^2) and standard error of estimation (SEE) for SMM and VAT explained by their respective predictors Ht^2 / R_{50}, Xc_{50}, index $R_{50tr/ex}$, index $Xc_{50tr/ex}$, weight, height, gender, age and waist circumference.

Table 2 Results of regression analyses for SMM [kg]

Predictors of SMM [kg]	R²	SEE [kg]
Ht^2/R_{50}[Ω]	0.90	2,1
Ht^2/R_{50}[Ω]; Xc_{50} [Ω]; index $R_{50\ tr/ex}$ [Ω]; index $Xc_{50\ tr/ex}$[Ω]; weight [kg], gender, age [y]	0.97	1,2

SMM, total body skeletal muscle mass; R², coefficient of determination; SEE, standard error of estimation; R, Resistance; Xc, Reactance; Ht, height

Table 3 Results of regression analyses for SMM_{RA}[kg]

Predictors of SMM_{RA} [kg]	R²	SEE [kg]
Ht^2/R_{50RA}[Ω]	0.90	0,18
Ht^2/R_{50RA}[Ω]; Xc_{50RA} [Ω]; age [y]	0.92	0,16

SMM_{RA}, skeletal muscle mass of right arm; R², coefficient of determination; SEE, standard error of estimation; R, Resistance; Xc, Reactance; Ht, height

Table 4 Results of regression analyses for SMM_{LA}[kg]

Predictors of SMM_{LA} [kg]	R²	SEE [kg]
Ht^2/R_{50LA}[Ω]	0.89	0,18
Ht^2/R_{50LA}[Ω]; Xc_{50LA} [Ω]; age [y]	0.93	0,15

SMM_{LA}, skeletal muscle mass of left arm; R², coefficient of determination; SEE, standard error of estimation; R, Resistance; Xc, Reactance

Table 5 Results of regression analyses for SMM_{RL}[kg]

Predictors of SMM_{RL} [kg]	R²	SEE [kg]
Ht^2/R_{50RL}[Ω]	0.80	0,58
Ht^2/R_{50RL}[Ω]; Xc_{50RL} [Ω]; weight [kg]; age [y]	0.90	0,40

SMM_{LA}, skeletal muscle mass of right leg; R², coefficient of determination; SEE, standard error of estimation; R, Resistance; Xc, Reactance

Table 6 Results of regression analyses for SMM_{LL}[kg]

Predictors of SMM_{LL} [kg]	R²	SEE [kg]
Ht^2/R_{50LL}[Ω]	0.79	0,58
Ht^2/R_{50LL}[Ω]; Xc_{50LL} [Ω]; weight [kg]; age [y]	0.90	0,40

SMM_{LA}, skeletal muscle mass of left leg; R², coefficient of determination; SEE, standard error of estimation; R, Resistance; Xc, Reactance

Table 7 Results of regression analyses for VAT (l)

Predictors of VAT [l]	R²	SEE [l]
Waist circumference [cm]	0.68	0,78
WC (cm); WC^2(cm); Ht^2/R_{50}[Ω]; height [m], age [y]; WC *gender; WC^2*gender	0.81	0,59

TBW, total body water; R², coefficient of determination; SEE, standard error of estimation; R, Resistance; Xc, Reactance; WC, waist circumference [cm]; Ht, height

SMM_{trunk} is calculated as the difference between total SMM and the sum of SMM of arms and legs.

$$SMM_{trunk} = SMM_{total} - (SMM_{RA} + SMM_{LA} + SMM_{RL} + SMM_{LL})$$

Figure 2 Calculation of the SMM of the trunk.

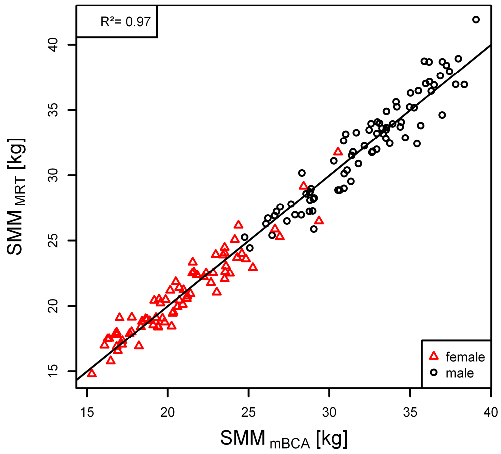

Figure 3 Regression analysis for total body skeletal muscle mass (SMM) between MRI and BIA

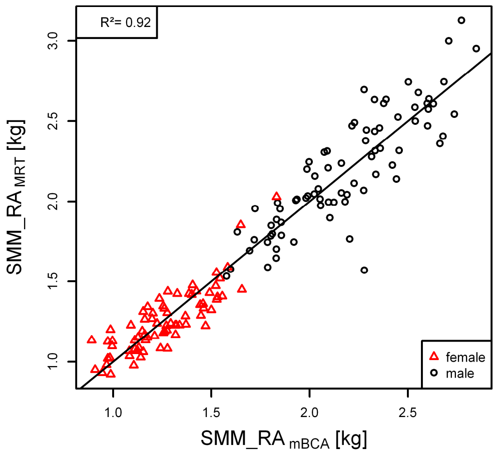

Figure 4 Regression analysis for skeletal muscle mass of right arm (SMM_{RA}) between MRI and BIA

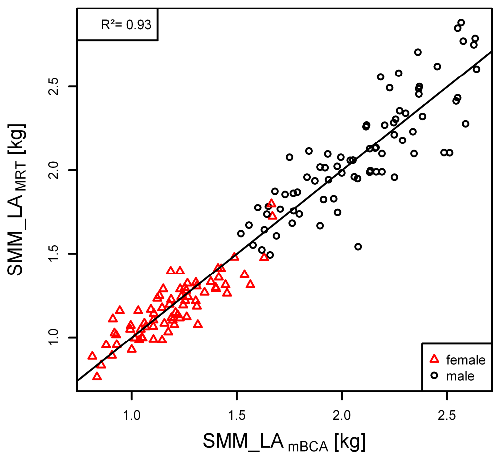

Figure 5 Regression analysis for skeletal muscle mass of left arm (SMM_{LA}) between MRI and BIA

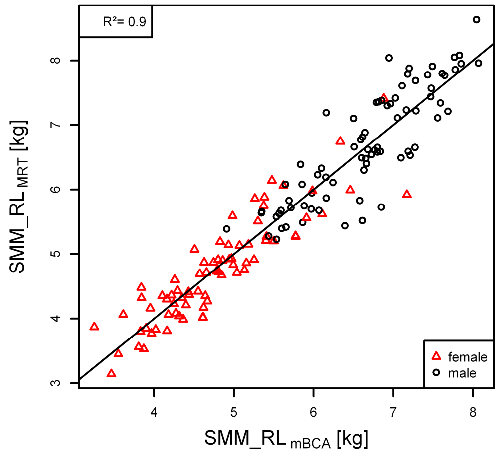

Figure 6 Regression analysis for skeletal muscle mass of right leg (SMM_{RL}) between MRI and BIA

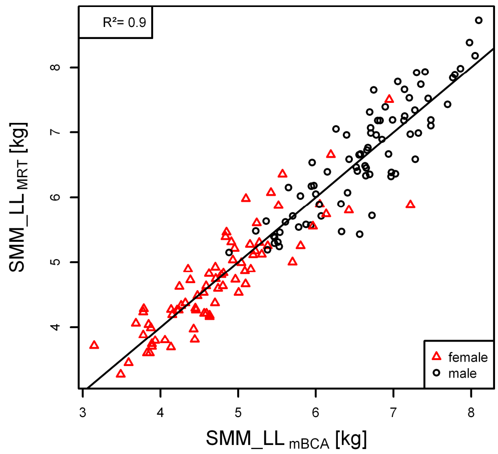

Figure 7 Regression analysis for skeletal muscle mass of left leg (SMM_{LL}) between MRI and BIA

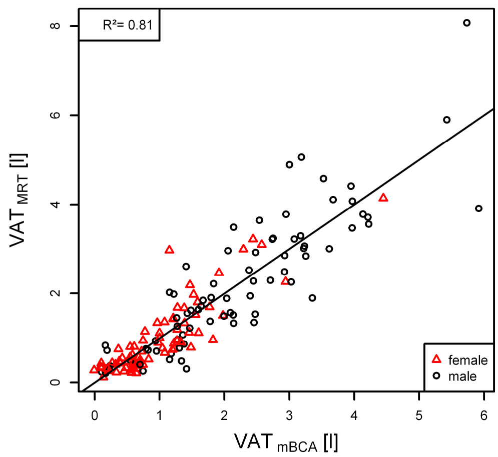

Figure 8 Regression analysis for visceral adipose tissue (VAT) between MRI and BIA

Validation of BIA equations in an independent sample

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

Table 8 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	81.8±15.0	74.9 ±15.1
height [cm]	164 ±5,0	175 ±7,0	170 ±8.0
BMI [kg/m^2]	25.2 ±4.2	26.8 ±4.6	26.0 ±4.4
Asians	(n=18)	(n=18)	(n=36)
age [y]	40.1 ±12.2	40.8 ±13.6	40.4±12.8
weight [kg]	58.1 ±6.4	69.4 ±11.1	63.7 ±10.6
height [cm]	160 ±5,0	172 ±6	166 ±8.0
BMI [kg/m^2]	22.6 ±1.9	23.5 ±3.8	23.1 ±3.0
Afro-Americans	(n=14)	(n=16)	(n=30)
age [y]	36.1 ±10.2	40.9 ±11.7	38.7 ±11.1
weight [kg]	68.2 ±10.3	81.3 ±16.7	75.2 ±15.3
height [cm]	167 ±5	176 ±8	172 ±8.0
BMI [kg/m^2]	24.6 ±3.8	26.0 ±3.8	25.3 ±3.8
Hispanics	(n=16)	(n=15)	(n=31)
age [y]	40.4 ±13.4	39.0 ±12.5	39.7 ±12.8
weight [kg]	69.3 ±4.1	80.3 ±12.1	74.6 ±10.4
height [cm]	158 ±7.0	174 ±5	166 ±10.0
BMI [kg/m^2]	27.9 ±2.9	26.7 ±4.2	27.3 ±3.6

BMI, Body Mass Index

The Bland-Altman Plots (figures 9 to 14) show small but significant differences in the mean bias for prediction of SMM and VAT between Caucasians (ca), Asians (as), Afro-Americans (af) and Hispanics (hi), respectively.

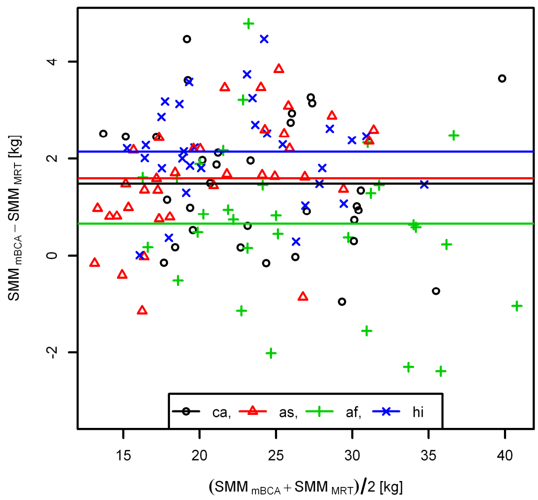

Figure 9 Bland-Altman Plot for the skeletal muscle mass of the total body (SMM) between MRI and BIA for different ethnicities

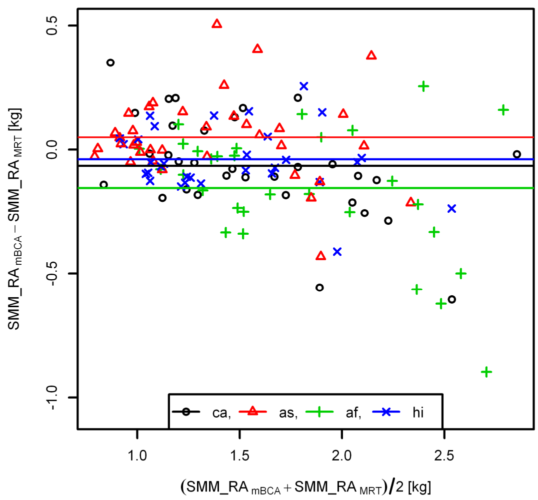

Figure 10 Bland-Altman Plot for the skeletal muscle mass of the right arm (SMM_{RA}) between MRI and BIA for different ethnicities

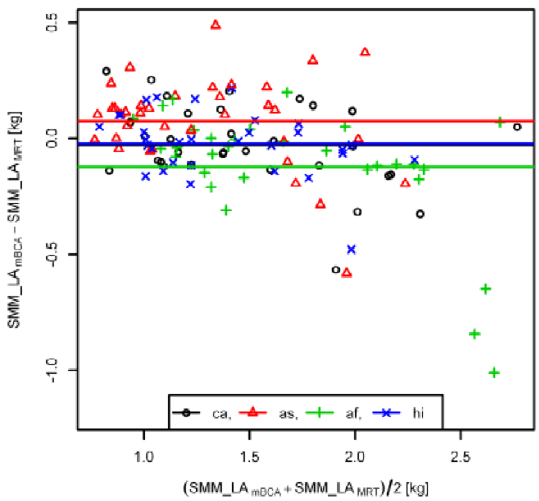

Figure 11 Bland-Altman Plot for the skeletal muscle mass of the left arm (SMM_{LA}) between MRI and BIA for different ethnicities

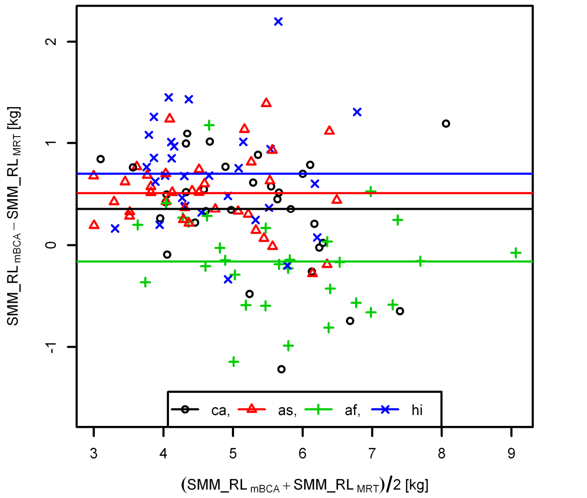

Figure 12 Bland-Altman Plot for the skeletal muscle mass of the right leg (SMM_{RL}) between MRI and BIA for different ethnicities

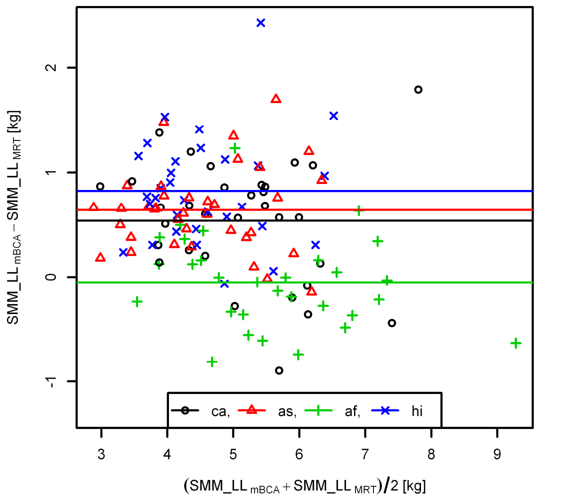

Figure 13 Bland-Altman Plot for the skeletal muscle mass of the left leg (SMM_{LL}) between MRI and BIA for different ethnicities

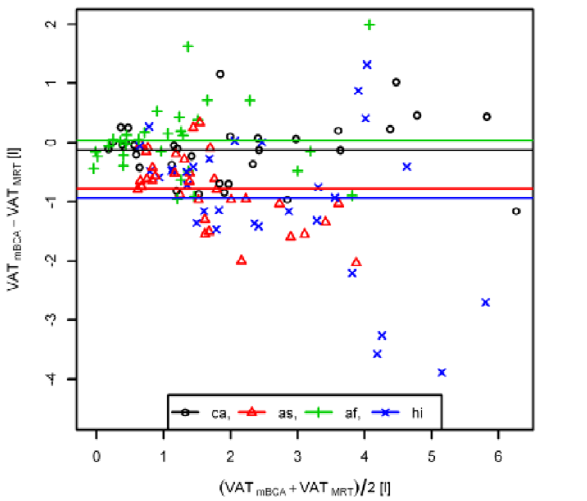

Figure 14 Bland-Altman Plot for visceral adipose tissue (VAT) between MRI and BIA for different ethnicities

Table 9 differences in the mean bias for prediction of SMM and VAT between Caucasians (ca), Asians (as), Afro-Americans (af) and Hispanics (hi)

		difference of the mean values	t value	p value
SMM	as - ca	0,109	0,4	0,73
SMM	af - ca	-0,828	-2,2	0,034
SMM	hi - ca	0,655	2,2	0,035
SMM_{RA}	as - ca	0,116	2,5	0,015
SMM_{RA}	af - ca	-0,090	-1,5	0,13
SMM_{RA}	hi - ca	0,027	0,6	0,54
SMM_{LA}	as - ca	0,103	2,3	0,026
SMM_{LA}	af - ca	-0,095	-1,6	0,11
SMM_{LA}	hi - ca	0,006	0,2	0,88
SMM_{RL}	as - ca	0,152	1,3	0,20
SMM_{RL}	af - ca	-0,520	-3,9	0,00024
SMM_{RL}	hi - ca	0,342	2,5	0,015
SMM_{LL}	as - ca	0,103	0,9	0,40
SMM_{LL}	af - ca	-0,590	-4,5	0,000034
SMM_{LL}	hi - ca	0,286	2,1	0,041
VAT	as - ca	-0,656	-4,8	0,000011
VAT	af - ca	0,162	1,1	0,29
VAT	hi - ca	-0,817	-3,5	0,0012

Conclusions

The validated eight-electrode, segmental multifrequent seca mBCA is an accurate tool for measuring body composition in healthy adults. The coefficient of determination for all generated prediction equations is high (values between 0.97 for SMM and 0.81 for VAT) and the SEE is low.

Formulas were corrected for ethnicity, when the ethnic difference of the mean bias for prediction of segmental SMM, total SMM or VAT is significant with $t > 1$ ($p < 0.3$) in the t-test.

SMM of arms and legs were only corrected when both sides (left and right) showed a significant difference with $t > 1$ ($p < 0.3$) in the t-test.

Due to its quick and non-invasive measuring procedure the seca mBCA is a recommended tool for the estimation of body composition in standing adults from different ethnic populations.