WHITE PAPER

Generation of normal ranges to analyze body composition of adults based on Bioelectrical Impedance Analysis (BIA)

S Peine[1], S Knabe[1], I Carrero[1], M Brundert[1], J Wilhelm[1], A Ewert[1], U Denzer[1], G Splettstoesser[2], A Bosy-Westphal[3,4]

Introduction

BIA has long been used in clinical settings as well as for research purposes. The current state of scientific knowledge, on risks and benefits of bioelectrical impedance analysis can be summarized as follows: clinical trials have clearly shown the use of BIA as a non-invasive diagnostic tool to examine fat and lean mass, total body water (TBW), extracellular water (ECW) and to determine prognosis of patients.

The seca medical Body Composition Analyzer 514/515 (seca mBCA) uses the BIA method. The medical device is validated against respective gold standard reference methods. To interpret measurements normal range, data from a healthy population are necessary. The target of this study is the collection of according reference data.

Study objective

The aim of the study was to generate normal ranges for Phase Angle (φ), Bioelectrical Impedance Vector Analysis (BIVA) and Body Composition Chart (BCC) by measuring a population of healthy subjects using bioelectrical impedance with the seca mBCA.

Subjects and methods

The study group was divided by sex (male and female), age (< 40 and > 40) and two individual Body Mass Index (BMI) classes. Basis of the calculation are 124 subjects for each normal range group. The total number of subjects was calculated by the multiplication of one normal range group by characteristic of influence factors: N = 124 x 2 (age group < and > 40) x 2 (sex male and female) x 2 (BMI classes) = 992.

The study was carried out in the blood donation centre of the University Medical Centre Hamburg-Eppendorf, Germany, during the opening times of the blood donation centre. Blood donors were available during the opening times at all time. Every blood donor under 65 years was a potential study subject.

All subjects had to be suitable for blood donation according to "Hämotherapie-Richtlinien §§ 12 a and 18 TFG", chapter 2.1.4 "Untersuchung zur Eignung als Spender und zur Feststellung der Spendetauglichkeit". All subjects had to be measured before blood donation. Treatment and follow-up were not necessary.

The study is a cross sectional observation study. The BIA measurement was taken with the seca mBCA. The impedance was measured multifrequent 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. In addition to that, the measurement was done segmental for the body segments as follows: right arm, left arm, right leg, left leg, trunk, right body side and left body side. In total, Impedance (Z) and Phase Angle (φ) were measured 19 x 7 = 133 times for each subject.

To determinate the reference values of φ, it was verified - by using a normal quantile plot- that a normal distribution exists. The percentiles of φ were calculated by using the mean value and the standard deviation. Tolerance ellipses of bivariate Z-Scores (RXc-score graph) for BIVA were calculated according to Antonio Piccoli from the University of Padova, Italy (Piccoli et al. 2002). For Z transformation the mean value and the standard deviation of the resistance and reactance divided by the length of the patient were calculated. The tolerance ellipses were calculated according to the following formulas:

$$a, b = \sqrt{K} \times \sqrt{2\,(n-1) \pm 2r\,(n-1)}$$

where

$K = F / n\,(n-2)$ for confidence ellipses

$K = F\,(n+1) / n\,(n-2)$ for tolerance ellipses

For the BCC, the fat mass (FM) and fat free mass (FFM) were divided by the square of the length (Ht^2) to generate the two indices fat mass index (FMI) and fat free mass index (FFMI). For these indices, the mean value and the standard deviation are calculated in order to do a Z transformation. The tolerance ellipses were calculated analogous to the BIVA ellipses.

Results

The study covered 1050 healthy adults whereof 532 men and 518 women in an age range of 18 to 65 years were recruited. The valid study population after monitoring and closing the study is the following:

- 263 female subjects with age < 40
- 255 female subjects with age > 40
- 264 male subjects with age < 40
- 268 male subjects with age > 40

Basic characteristics of the Caucasian study population of the study for the objective is given in table 1 stratified by gender. Age and BMI ranges of participants were 18-65 years and 18.2-42.6 kg/m².

Table 1 Descriptive characteristics (mean values ± 1 standard deviation) of the Caucasian study population for the primary objective of the study

	females (n=518)	males (n=532)	all (n=1046)
age [y]	38.7 ±13.4	39.3 ±13.2	39.0 ±13.3
weight [kg]	69.68 ±12.2	86.43 ±12.5	78.14 ±14.9
height [m]	1.679 ±0.1	1.814 ±0.1	1.747 ±0.1
BMI [kg/m²]	24.7 ±4.2	26.3 ±3.4	25.5 ±3.9

BMI, Body Mass Index

[1]Institute of Transfusion Medicine, Center for Diagnostics, University Medical Center Hamburg-Eppendorf, Germany; [2]Coordination Centre for Clinical Studies (KKS) of the Charité, Berlin; Germany; [3]Institute for Human Nutrition and Food Science, Christian-Albrechts-University, Kiel, Germany; [4]Institute for Human Nutrition, University of Hohenheim, Stuttgart, Germany

φ

For φ percentiles for 1%, 5%, 10% and 99% were calculated. The percentiles were calculated by using the mean value and the standard deviation

Table 2 Percentile calculation by means of mean value and standard deviation

gender	variable	Phase Angle[°]	uncertainty
female	mean	5.057	0.021
	sd	0.477	0.015
	1% perc.	3.948	0.040
	5% perc.	4.273	0.032
	10% perc.	4.446	0.028
	99% perc.	6.167	0.040
male	Mean	5.873	0.022
	Sd	0.513	0.016
	1% perc.	4.679	0.043
	5% perc.	5.029	0.034
	10% perc.	5.216	0.030
	99% perc.	7.067	0.043

perc, percentile; sd, standard deviation

Figure 1 shows an example of the interpretation of the phase angle plotted over age in the seca mBCA software. The 5th and 10th percentile represent the lower ranges.

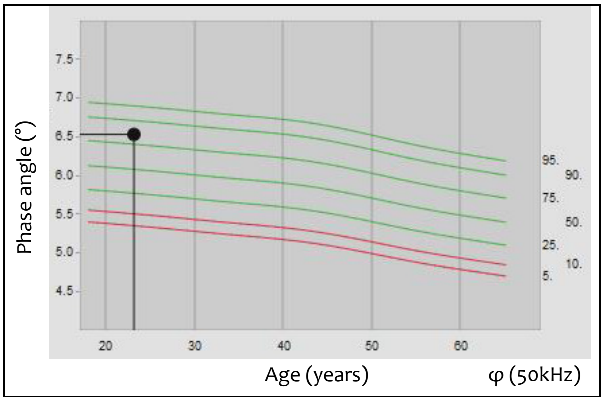

Figure 1 Phase angle percentile plot

BIVA

The BIVA results show the mean values for resistance (R) and reactance (Xc) at 50 kHz divided by height as well as the lengths of the semi-axes for the 50th, 75th and 95th percentile of the Z transformed reference values.

Table 3 BIVA calculation according to Piccoli et. al

gender	variable	value	uncertainty
female	R50/h mean [Ω/cm]	3.9342	0.018
	R50/h sd [Ω /cm]	0.4078	0.0127
	Xc50/h mean [Ω /cm]	0.3477	0.002
	Xc50/h sd [Ω /cm]	0.0458	0.0014
	r	0.706	0.021
	a95	3.2125	
	b95	1.3341	
	a75	2.1819	
	b75	0.9061	
	a50	1.5418	
	b50	0.6403	
male	R50/h mean [Ω /cm]	3.0267	0.014
	R50/h sd [Ω /cm]	0.3253	0.0099
	Xc50/h mean [Ω /cm]	0.3116	0.002
	Xc50/h sd [Ω /cm]	0.0453	0.0014
	r	0.789	0.015
	a95	3.2975	
	b95	1.1053	
	a75	2.2398	
	b75	0.7507	

a&b, semi-axes; R, resistance; Xc, reactance; r, radius; h, height; sd, standard deviation

For verification of these results, the BIVA vectors of the measurements were plotted using the calculated values for the Z-transformation and the tolerance ellipses.

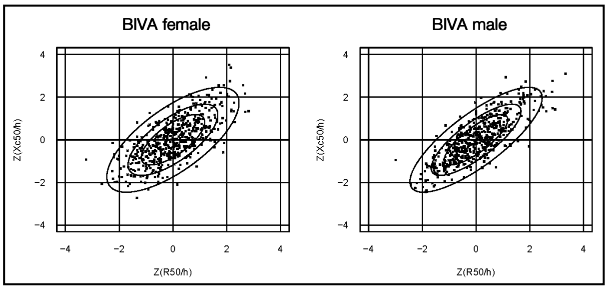

Figure 2 Z-transformed BIVA vector values imaged in tolerance ellipses

BCC

The results for the BCC were calculated analogue to the BIVA using FMI and FFMI instead of R and Xc.

Table 4 BIVA calculation according to Piccoli et. al

gender	variable	value	uncertainty
female	FMI mean [kg/m²]	8.4663	0.1424
	FMI sd [kg/m²]	3.2350	0.1008
	FFMI mean [kg/m²]	16.2809	0.0606
	FFMI sd [kg/m²]	1.3756	0.0429
	r	0.584	0.028
	a95	3.0961	
	b95	1.5855	
	a75	2.1029	
	b75	1.0769	
	a50	1.4860	
	b50	0.7609	
male	FMI mean [kg/m²]	6.4163	0.1071
	FMI sd [kg/m²]	2.4843	0.0758
	FFMI mean [kg/m²]	19.8164	0.0634
	FFMI sd [kg/m²]	1.4696	0.0448
	r	0.484	0.032
	a95	2.9962	
	b95	1.7657	
	a75	2.0351	
	b75	1.1994	
	a50	1.4381	
	b50	0.8475	

a&b, semi-axes; FMI, fat mass index; FFMI, fat free mass index; r, radius; h, height; sd, standard deviation

Analogous to the BIVA vectors, the BCC vectors of the measurements were plotted using the calculated values for the Z-transformation and the tolerance ellipses.

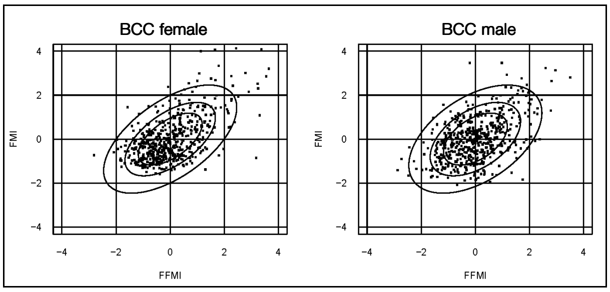

Figure 3 Z-transformed BIVA vector values imaged in tolerance ellipses

The reference values for the percentage of the fat mass were calculated from the BMI. The level for underweight is 18.5 kg/m², the level for overweight is 25 kg/m². Using a linear regression with 1/BMI and age, these values were adopted to the fat mass in accordance to Gallagher, "Healthy percentage body fat ranges: an approach for developing guidelines based on body mass index", Am J Clin Nutr 2000; 72:694-701.
In accordance with this regression, the fat percentage was calculated for the BMI values 18.5 kg/m² and 25 kg/m² for ages of 30, 50 and 70 years.

Table 5 calculation of fat percentage based on regression values

sex	age [years]	BMI [kg/m²]	fat mass [%]	fat mass from Gallagher [%]
female	30	18.5	20.6	21
female	30	25.0	33.5	33
female	50	18.5	22.9	23
female	50	25.0	35.9	35
female	70	18.5	25.3	25
female	70	25.0	38.2	38
male	30	18.5	7.3	8
male	30	25.0	21.7	21
male	50	18.5	8.9	11
male	50	25.0	23.3	23
male	70	18.5	10.5	13
male	70	25.0	24.9	25

BMI, Body Mass Index

Conclusion

The study population corresponds with the average European adult population. Thus, the normal ranges generated for φ, BIVA and BCC are ideal interpretation factors for determining a patient's overall health status. On top of that, the generated normal ranges are precisely correlated to the device's measuring technique which ensures medical precise measuring results.