International Journal of Body Composition Research 2013 Vol. 11 No. 3 & 4: 67–76. © Smith-Gordon ISSN 1479-456X

Submitted 1 September 2013 accepted 15 November 2013

Generation of normal ranges for measures of body composition in adults based on bioelectrical impedance analysis using the seca mBCA

S Peine[1], S Knabe[1], I Carrero[1], M Brundert[1], J Wilhelm[1], A Ewert[1], U Denzer[1], B Jensen[2] and P Lilburn[2]

[1]Institute for Transfusion Medicine, Centre for Diagnostics, University Medical Centre Hamburg-Eppendorf, Germany; [2]seca gmbh & co. kg, Hamburg, Germany.

Background/objectives: A validated body composition analyzer using eight-electrode segmental multi-frequency bioelectrical impedance analysis (BIA) enables a fast and accurate measurement of body compartments. For interpretation of measurement results normal ranges are needed.
Methods: In a cross-sectional study, reference values for phase angle (PA), bioelectrical impedance vector analysis (BIVA), the body composition chart (BCC), skeletal muscle mass (SMM), total body water (TBW), extracellular water (ECW) and fat mass (FM) were generated stratified according to gender, age and BMI using the seca mBCA 514/515.
Results: 1050 healthy blood donors (532 men and 518 women, BMI 18.2 - 42.6 kg/m^2) were examined before blood donation. When compared with data from the German National Nutrition Survey II, the recruited population is a representative sample. Reference percentiles (p5%, p50% and p95%) were generated for all parameters.
Conclusion: The developed reference percentiles can be used for diagnostic purposes and to monitor outcomes of treatments in patients.

Keywords: body composition analysis, bioelectrical impedance analysis, normal ranges, fat mass, total body water, extracellular water, skeletal muscle mass, phase angle, bioelectrical impedance vector analysis, body composition chart

Introduction

BIA has long been used in clinical settings as well as for research purposes. 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 the prognosis of patients [1-3].

The seca medical Body Composition Analyzer 514/515 (seca gmbh & co. kg, Hamburg) is a medical device that has been validated against respective gold standard reference methods in a multiethnic population [4]. To determine normal ranges of outcome parameters it is necessary to collect data from a healthy population.

The aim of this study was to establish a reference data base to generate normal ranges for phase angle (PA), bioelectrical impedance vector analysis (BIVA), the body composition chart (BCC), skeletal muscle mass (SMM), total body water (TBW), extracellular water (ECW) and fat mass (FM) by measuring a representative population of healthy subjects using bioelectrical impedance with the seca medical Body Composition Analyzer 514/515.

Subjects and methods

A total of 1.050 subjects (532 men and 518 women) aged 18-65 years were recruited at the blood transfusion service of the Institute for Transfusion Medicine at the University Medical Centre Hamburg-Eppendorf, Germany. All adult blood donors under the age of 65 years were generally eligible for the study. Blood donors were recruited throughout the complete opening hours of the donation service by student personnel.

Subjects were included in the study if they qualified as blood donors according to the German guidelines

Address for correspondence: Sven Peine, Transfusion Medicine, Centre for Diagnostics, University Medical Centre Hamburg-Eppendorf, Martinistraße 52, 20246 Hamburg, Germany.
Tel: +49 40 7410 54871
Email: s.peine@uke.de

for blood donors ('Hämotherapie-Richtlinien §§ 12 a and 18 TFG', chapter 2.1.4 'Untersuchung zur Eignung als Spender und zur Feststellung der Spendetauglichkeit'). This inclusion criterion was defined as 'healthy' in the clinical investigation plan and approved by to the responsible Ethical Committee (Ethikkommission der Ärztekammer Hamburg). All BIA measurements had to be performed before blood donation to avoid fluid shifts. The following exclusion criteria were applied: acute and chronic diseases, amputation of limbs, electrical implant as cardiac pacemaker, insulin pumps, artificial joints, metallic implants (except tooth implants, pregnancy or breastfeeding period, subjects who cannot provide an informed consent form by themselves, subjects who might be dependent from the sponsor or the investigation site, extensive tattoos at arms or legs. Ankle edema were excluded by inspection. All subjects provided their fully informed and written consent before participation.

Anthropometrics

Body height was obtained with the stadiometer seca 231 to the nearest mm with an accuracy of ± 5 mm. Waist circumference was measured by means of a non-stretchable measurement tape (seca 201).

Bioelectrical impedance analysis

BIA measurements were taken with the seca mBCA. Impedance was measured 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. All 19 frequencies were used for verification purposes by means of the Cole-Cole-Plot. For the calculation of all normal range values frequencies at 5 kHz and 50 kHz were used. In addition, the measurement was done segmentally 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 (PA) were measured 19 x 7 = 133 times (19 above-mentioned frequencies x 7 above-mentioned body segments) for each subject.

Statistics for the development of normal ranges

Data analyses were performed using R software, version 3.0.1 (R Foundation, Vienna, Austria). In order to determine the reference values of PA at 50kHz a normal distribution of the data was verified by using a normal quantile plot. The percentiles of PA were calculated by using the mean value of the right and left body side and the standard deviation for both genders.

Tolerance ellipses of bivariate Z-Scores (RXc-score graph) for BIVA were calculated according to Antonio Piccoli from the University of Padova, Italy [5]. For Z transformation the mean value and the standard deviation of the resistance (R) and reactance (Xc) divided by the height (ht) of the patient were calculated.

The Z Transformation is performed by the following formulas:

$$Z\left(\frac{R}{ht}\right)=\frac{\frac{R}{ht}-mean\left(\frac{R}{ht}\right)}{SD\left(\frac{R}{ht}\right)} \quad \text{and} \quad Z\left(\frac{Xc}{ht}\right)=\frac{\frac{Xc}{ht}-mean\left(\frac{Xc}{ht}\right)}{SD\left(\frac{Xc}{ht}\right)}$$

For the BCC, FM and fat free mass (FFM) were divided by height squared (ht^2) to generate the two indices fat mass index (FMI, kg/m^2) and fat free mass index (FFMI, kg/m^2). For these indices, the mean value and the standard deviation are calculated for Z transformation. The tolerance ellipses were calculated analogous to the BIVA ellipses.

For determination of normal values for FM the FMI was correlated with the Body Mass Index (BMI). The function resulting from this correlation allows to calculate the corresponding FMI cut-offs from the BMI cut-offs used by the World Health Organization (WHO).

TBW and ECW were related to body weight considering a fixed density of 0.99371 kg/ l. The resulting values were then correlated with 1/BMI. The function resulting from this correlation was used to calculate the mean value for the respective variable, which resembles the 50th percentile. Percentiles 5%, 50% and 95% were calculated from the standard error of estimation (SEE) from this regression.

For skeletal muscle mass (SMM) normal ranges were developed for every segment (right arm, left arm, torso, right leg, left leg) as well as for the complete body. Mean values and standard deviations were calculated after normalizing all values by ht^2. This normalisation by ht^2 allows a height independent interpretation of SMM. Percentiles 5% and 95% are used for classifying the upper and lower normal ranges. Since SMM divided by ht^2 was not normally distributed, a Box-Cox transformation according to formula (1) in Cole and Green (1992) [7] was performed to calculate the percentiles.

While PA and BIVA are calculated directly by the BIA raw data (R and Xc) all other parameters were validated against respective reference methods [4]. FM was validated against the 4-compartment model by Fuller et al. 1992 including body volume (by air displacement plethysmography), TBW (by deuterium dilution) and bone mineral content (by DXA). Deuterium dilution was used as reference for TBW, sodium bromide dilution for ECW and whole body MRI for SMM.

Results

The study examined 1.050 healthy individuals, 532 man and 518 women in the age of 18 to 65 years. BMI ranged from 18.2 to 42.6 kg/m^2, waist circumference from 63 to 126 cm. Basic characteristics of the study population stratified by gender are given in Table 1. In order to evaluate representivness of the study population the distribution of BMI was compared to characteristics of the Nationale Verzehrsstudie II (National Nutrition Survey II) which investigated a

Table 1. Descriptive characteristics (means ± SD) of the study population stratified by gender.

gender	*BMI*	*age*		*weight*		*height*		*BMI*		*waist*	
		mean±SD	*range*	*mean±SD*	*range*	*mean±SD*	*range*	*mean±SD*	*range*	*mean±SD*	*range*
	kg/m²	*y*	*y*	*kg*	*kg*	*m*	*m*	*kg/m²*	*kg/m²*	*cm*	*cm*
all	all (n=1050)	39.0 ± 13.3	18 - 65	78.1 ± 14.9	49.8 - 135.1	1.75 ± 0.10	1.44 - 2.03	25.5 ± 3.9	18.2 - 42.6	90 ± 12	63 - 126
female	all (n=518)	38.6 ± 13.4	18 - 65	69.6 ± 12.2	49.8 - 116.1	1.68 ± 0.07	1.44 - 1.84	24.7 ± 4.2	18.2 - 42.6	85 ± 11	63 - 126
male	all (n=532)	39.3 ± 13.3	18 - 65	86.4 ± 12.5	61.6 - 135.1	1.81 ± 0.07	1.61 - 2.03	26.3 ± 3.4	18.5 - 41.1	95 ± 10	64 - 126
all	<25	35.5 ± 13.0	18 - 65	68.1 ± 9.2	49.8 - 98.5	1.74 ± 0.09	1.52 - 2.01	22.5 ± 1.6	18.2 - 25.0	82 ± 7	63 - 102
female	<25	36.4 ± 13.2	18 - 65	63.0 ± 6.2	49.8 - 80.3	1.68 ± 0.06	1.52 - 1.84	22.2 ± 1.6	18.2 - 25.0	79 ± 6	63 - 100
male	<25	34.1 ± 12.5	18 - 65	76.3 ± 7.1	61.6 - 98.5	1.82 ± 0.07	1.65 - 2.01	23.0 ± 1.4	18.5 - 25.0	87 ± 6	64 - 102
all	≥25,<30	42.0 ± 12.8	18 - 65	85.1 ± 10.0	55.9 - 116.1	1.77 ± 0.10	1.45 - 2.03	27.2 ± 1.3	25.0 - 30.0	95 ± 8	64 - 116
female	≥25,<30	41.9 ± 12.6	19 - 65	76.1 ± 7.4	55.9 - 99.8	1.67 ± 0.07	1.45 - 1.83	27.2 ± 1.4	25.0 - 29.8	91 ± 7	64 - 108
male	≥25,<30	42.0 ± 12.9	18 - 65	89.5 ± 7.9	74.7 - 116.1	1.81 ± 0.07	1.64 - 2.03	27.2 ± 1.3	25.0 - 30.0	98 ± 6	79 - 116
all	≥30	44.6 ± 12.2	18 - 64	99.5 ± 13.1	72.0 - 135.1	1.73 ± 0.10	1.44 - 1.96	33.2 ± 2.8	30.0 - 42.6	108 ± 9	85 - 126
female	≥30	44.1 ± 13.1	19 - 64	92.2 ± 11.2	72.0 - 116.1	1.66 ± 0.07	1.44 - 1.79	33.5 ± 3.2	30.1 - 42.6	104 ± 9	85 - 126
male	≥30	45.2 ± 11.4	18 - 64	106.2 ± 11.1	77.9 - 135.1	1.80 ± 0.07	1.61 - 1.96	32.9 ± 2.3	30.0 - 41.1	111 ± 8	92 - 126

Figure 1. Means and standard deviations for BMI in different age groups. Comparison between the study population(UKE) and data from the National nutrition survey (NVS). A – females; B – males.

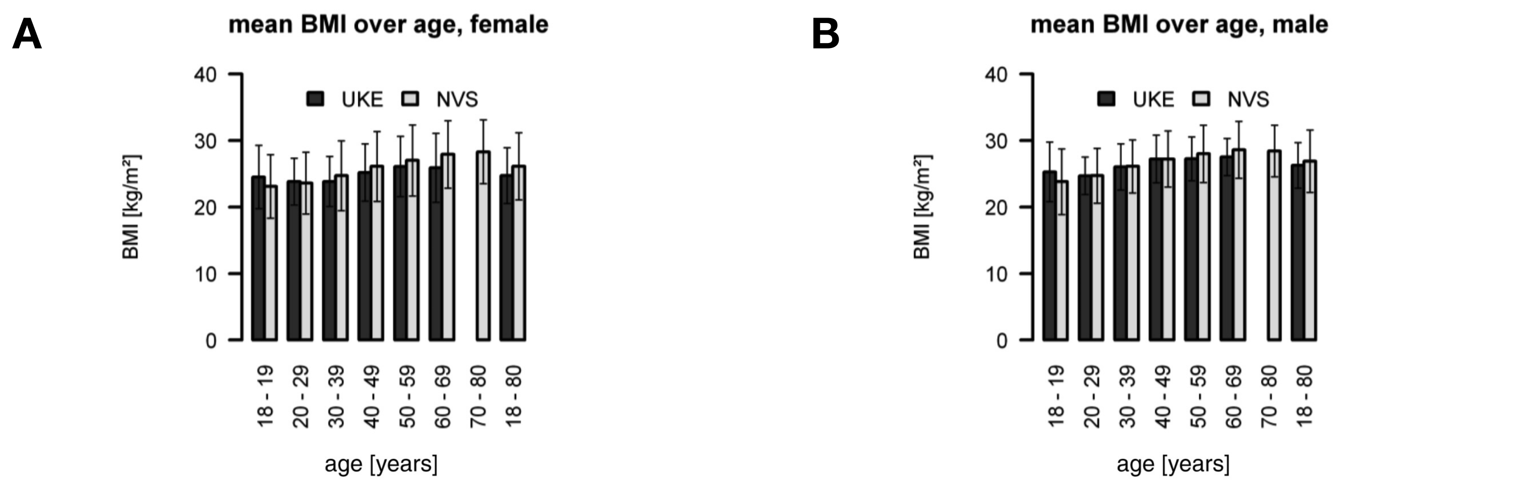

Figure 2. Phase angle normal Q-Q Plot comparing measured phase angle values to standard normal distribution for (A) female and (B) male subjects.

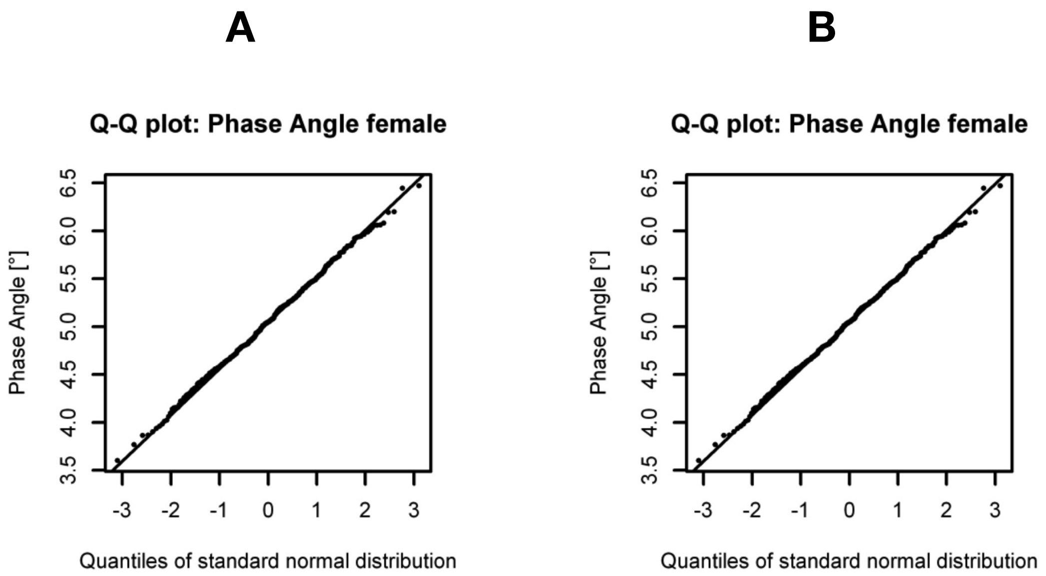

Table 2. Percentiles for phase angle (PA), resistance (R) and reactance (Xc) at 50 kHz calculated according to Piccoli et al. 2002 [5].

variable	*unit*	*gender*	*BMI*	*mean ± SD*	*p5%*	*p50%*	*p95%*
phase angle	°	female	all	5.05 ± 0.47	4.28	5.05	5.82
			<25	5.00 ± 0.45	4.26	5.00	5.74
			≥25<30	5.14 ± 0.49	4.34	5.14	5.94
			≥30	5.13 ± 0.49	4.32	5.13	5.93
		male	all	5.88 ± 0.51	5.03	5.88	6.73
			<25	5.87 ± 0.49	5.06	5.87	6.69
			≥25<30	5.89 ± 0.54	5.00	5.89	6.78
			≥30	5.87 ± 0.47	5.10	5.87	6.64
R_{50kHz} / ht	Ω/cm	female	all	3.937 ± 0.400	3.278	3.937	4.596
			<25	4.072 ± 0.363	3.475	4.072	4.670
			≥25<30	3.787 ± 0.333	3.240	3.787	4.335
			≥30	3.513 ± 0.320	2.986	3.513	4.040
		male	all	3.023 ± 0.323	2.491	3.023	3.554
			<25	3.223 ± 0.297	2.735	3.223	3.711
			≥25,<30	2.946 ± 0.253	2.530	2.946	3.362
			≥30	2.693 ± 0.254	2.276	2.693	3.111
Xc_{50kHz} / ht	Ω/cm	female	all	0.348 ± 0.046	0.272	0.348	0.423
			<25	0.356 ± 0.045	0.282	0.356	0.430
			≥25<30	0.340 ± 0.042	0.271	0.340	0.410
			≥30	0.315 ± 0.042	0.246	0.315	0.384
		male	all	0.312 ± 0.045	0.237	0.312	0.386
			<25	0.332 ± 0.045	0.258	0.332	0.406
			≥25<30	0.304 ± 0.041	0.237	0.304	0.371
			≥30	0.277 ± 0.034	0.220	0.277	0.333

Figure 3. Z-transformed BIVA and BCC tolerance ellipses; A – BIVA vector analysis for female subjects displaying tolerance ellipses representing 50%, 75% and 95% reference value percentiles in RXc graph; B – BIVA vector analysis for male subjects displaying tolerance ellipses representing 50%, 75% and 95% reference value percentiles in RXc graph; C – BCC for female subjects displaying tolerance ellipses representing 50%, 75% and 95% reference value percentiles in FFMI-FMI graph; D – BCC for male subjects displaying tolerance ellipses representing 50%, 75% and 95% reference value percentiles in FFMI FMI graph.

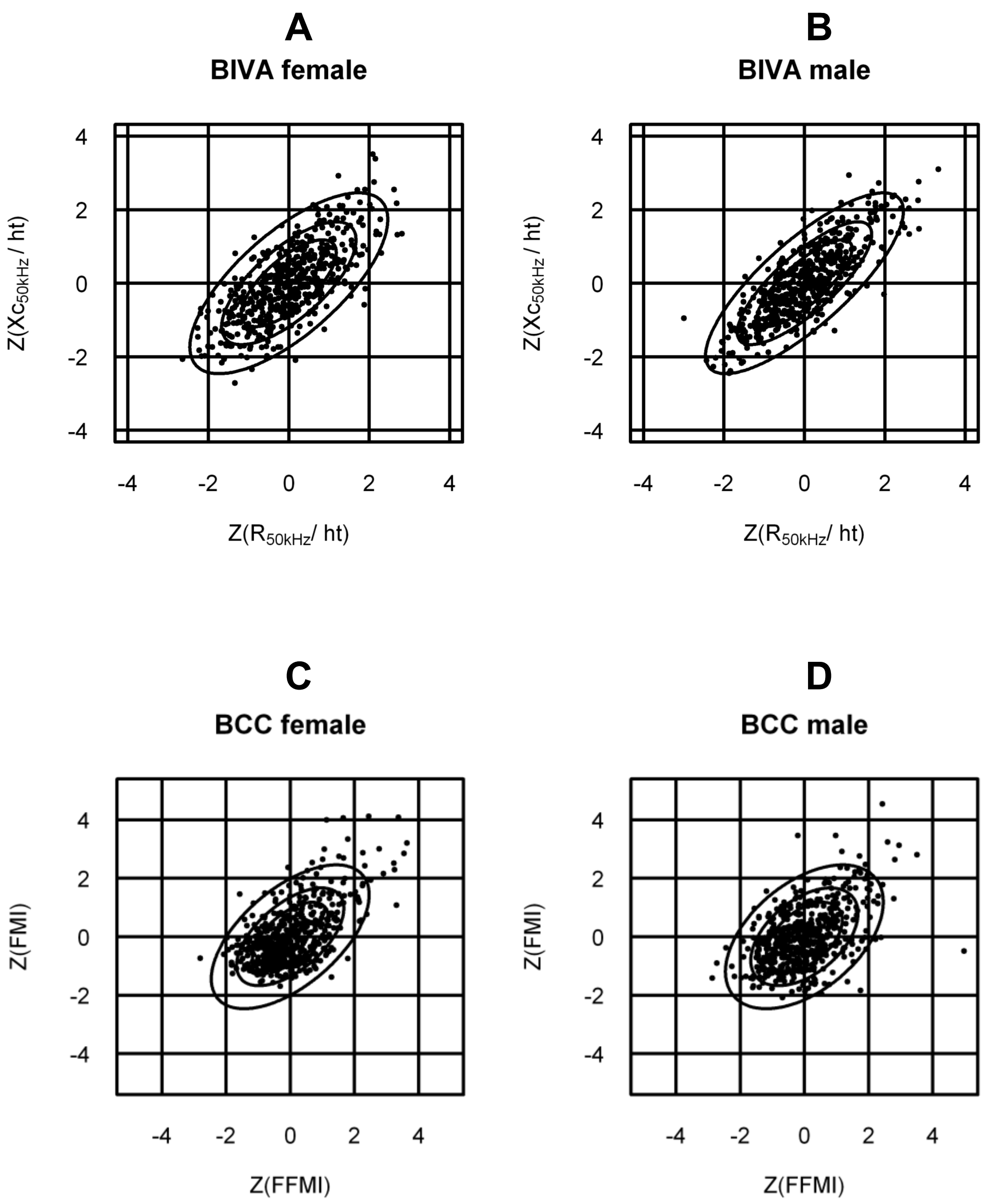

Table 3. FMI and FFMI percentiles for BCC tolerance ellipse calculation according to Piccoli et. al. 2002 [5].

variable	*unit*	*gender*	*BMI*	*mean ± SD*	*p5%*	*p50%*	*p95%*
FFMI	kg/m²	female	all	16.27 ± 1.36	14.04	16.27	18.49
			<25	15.63 ± 0.92	14.11	15.63	17.14
			≥25,<30	16.88 ± 0.93	15.35	16.88	18.41
			≥30	18.48 ± 1.27	16.39	18.48	20.57
		male	all	19.83 ± 1.47	17.42	19.83	22.24
			<25	18.81 ± 1.03	17.11	18.81	20.51
			≥25,<30	20.08 ± 1.03	18.40	20.08	21.77
			≥30	22.09 ± 1.24	20.05	22.09	24.12
FMI	kg/m²	female	all	8.46 ± 3.24	3.13	8.46	13.78
			<25	6.55 ± 1.39	4.27	6.55	8.84
			≥25,<30	10.30 ± 1.34	8.09	10.30	12.50
			≥30	15.04 ± 2.65	10.68	15.04	19.41
		male	all	6.42 ± 2.49	2.33	6.42	10.51
			<25	4.23 ± 1.22	2.21	4.23	6.24
			≥25,<30	7.08 ± 1.28	4.97	7.08	9.19
			≥30	10.79 ± 1.99	7.52	10.79	14.06

total of 20.000 subjects [6]. Figure 1 shows that mean BMI ranges were nearly identical for all listed age ranges. The standard deviation was higher for all age groups in the Nationale Verzehrsstudie II.

The normal distribution of PA values can be verified according to the quantile-quantile plots for male and female subjects shown in Figure 2. Mean values for PA in Table 2 show significantly higher PA values in men when compared to women.

BIVA results reveal a normal distribution with only a small cluster of measurements with a combined high Z(R50kHz/ ht) and Z(Xc50kHz/ ht) for women and men (Figure 3). The percentiles for the gender specific resistances are listed in Table 2.

The BCC shows a normal distribution for females as well as for males with only a small cluster of measuring points with a combined high FMI and FFMI for both genders (Figure 3). Table 3 provides an overview of FMI and FFMI percentiles for men and women.

Because there was a close correlation between FMI and BMI (Figure 4) the cut-off points for FMI (calculated from WHO BMI cut-offs by linear regression) allow an interpretation of a subject's individual fat mass.

Due to the good correlation of TBW divided by weight (%TBW) to 1/BMI and ECW divided by weight (%ECW) to 1/ BMI, the percentiles for %TBW and %ECW were calculated from this regression and plotted vs BMI (Figure 5).

The normal values for SMM/ht² show that men have significantly higher muscle mass than women in all body segments (Table 4).

Discussion

Reference values were developed for all parameters of body composition derived from BIA. These can be used to evaluate individual measurement results compared to a healthy population.

The BCC is based on the principle of the Hattori-Chart introduced by Komei Hattori from the Ibaraki University, Japan [1991], plotting FMI over FFMI and illustrating the wide variability in fatness for a given BMI. The visual presentation of the chart may help to practically better assess changes in body composition during weight management over time. It may help to detect hidden obesity or sarcopenic obesity with only one data set. The original approach by Hattori was also used by Yves Schutz from the University in Lausanne, Switzerland [9] who generated and established FMI and FFMI percentiles in a Swiss population to determine age and gender specific normal ranges. The work by Schutz was the basis for the BCC used in the seca mBCA. The limitations of the BCC lay in the overestimation of muscle mass in patients with fluid overloads as these only contribute to the FFM and thus FFMI. In these cases other calculated results may help to explain this overestimation.

Normal values for TBW and ECW are innovative and may allow evaluating normal hydration. Until today no official normal ranges are available for body water. The literature generally lists percentage body water (%BW) ranges for men and women. In summary men generally have more %BW than women, obesity contributes to lower relative body water values and increasing age contributes to continuously decreasing values [10, 11, 12]. The biggest effect on %BW in adults can be explained by the BMI which could be shown in this study (Figure 5).

Fluid overloads mainly accumulate in the extracellular space [13] which is why mainly ECW/TBW and ICW/ECW are used to assess fluid status [14, 15]. This approach has limitations though for example directly after dialysis treatment as extracellular fluid is slowly refilled during the inter-dialytic period [16]. A measurement directly after treatment – when the patient is still available for a BIA measurement – thus is not able to give an appropriate answer, whereas using

Figure 4. Regression of FMI vs. BMI for female (A) and male subjects (B); Fat mass vs. height for female (C) and male subjects (D) including BMI cut-off lines converted to FMI values by means of FMI vs BMI regression.

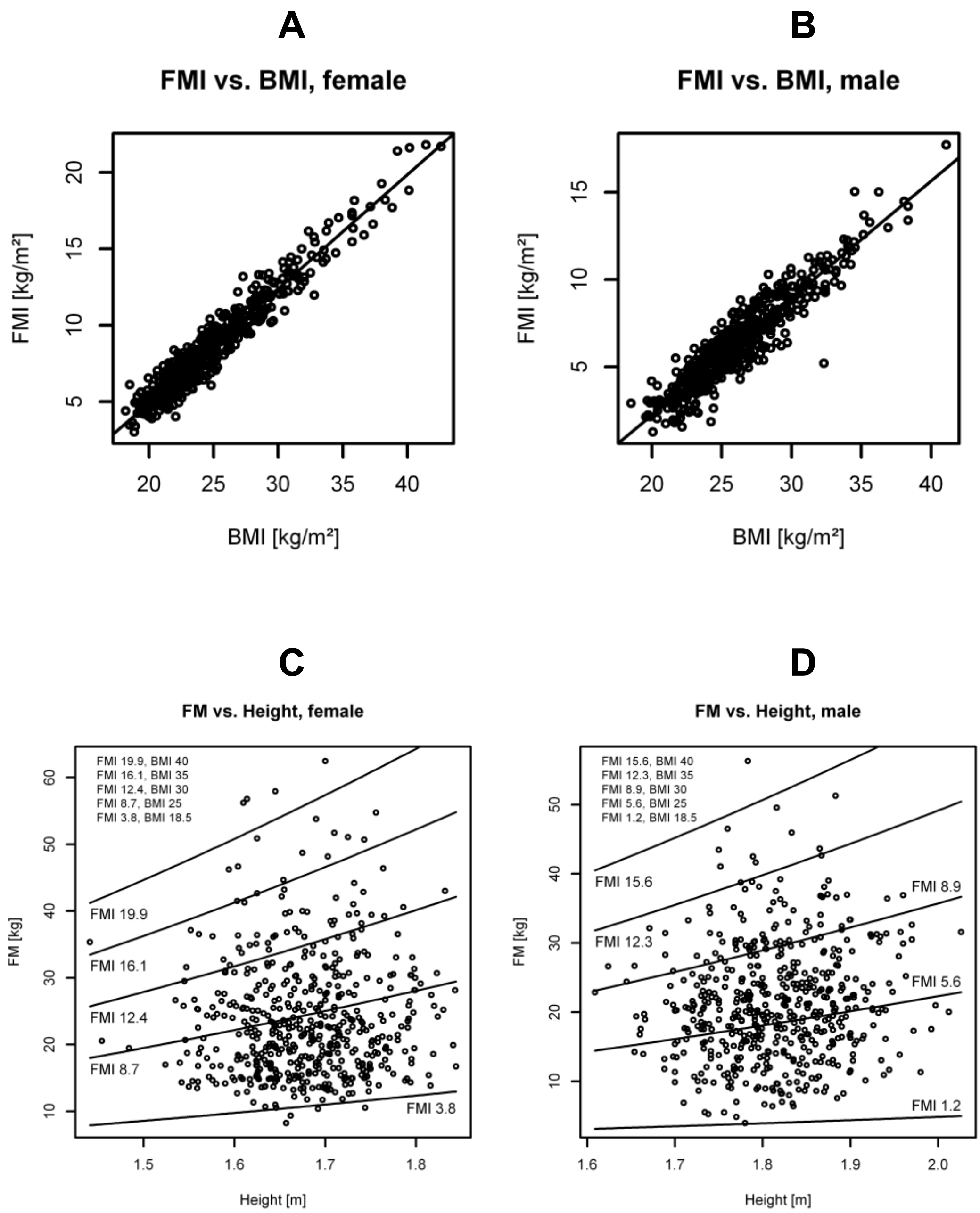

Figure 5. Percentiles for %TBW and %ECW stratified by BMI and gender. %TBW vs. 1/BMI regression for (A) female and (B) for male subjects; %ECW vs. 1/BMI regression (C) for female and (D) for male subjects; Percentile curves calculated from 1/BMI regression for (E) %TBW in female subjects, (F) %TBW in male subjects, (G) %ECW in female subjects and (H) for %ECW in male subjects.

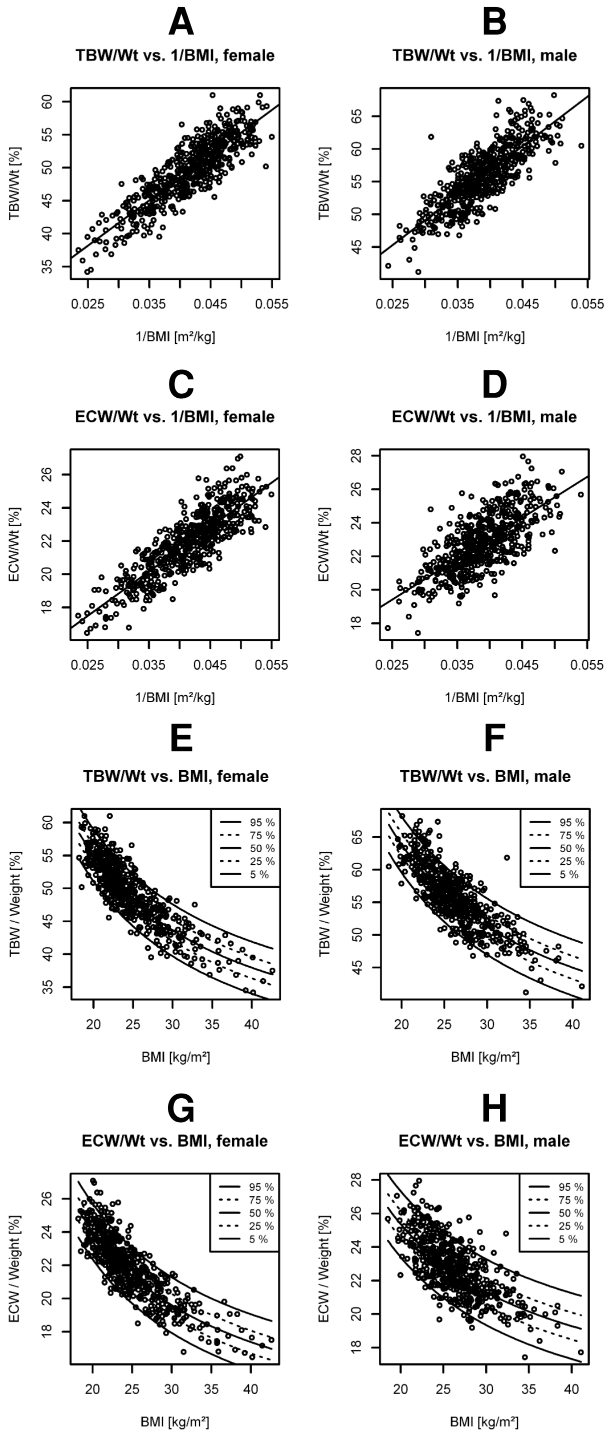

Table 4. Gender specific mean values and standard deviations for skeletal muscle mass (SMM) normalized by ht².

variable	*unit*	*gender*	*BMI*	*mean ± SD*	*p5%*	*p50%*	*p95%*
SMM right arm	kg	female	all	0.449 ± 0.053	0.370	0.449	0.544
			<25	0.436 ± 0.046	0.367	0.436	0.519
			≥25,<30	0.462 ± 0.054	0.382	0.462	0.558
			≥30	0.490 ± 0.061	0.399	0.490	0.598
		male	all	0.631 ± 0.070	0.528	0.631	0.756
			<25	0.593 ± 0.057	0.509	0.593	0.694
			≥25,<30	0.645 ± 0.063	0.552	0.645	0.758
			≥30	0.696 ± 0.066	0.598	0.696	0.813
SMM left arm	kg	female	all	0.427 ± 0.053	0.349	0.427	0.523
			<25	0.416 ± 0.047	0.347	0.416	0.499
			≥25,<30	0.439 ± 0.054	0.359	0.439	0.536
			≥30	0.466 ± 0.063	0.373	0.466	0.578
		male	all	0.607 ± 0.068	0.505	0.607	0.729
			<25	0.571 ± 0.056	0.488	0.571	0.672
			≥25,<30	0.618 ± 0.060	0.529	0.618	0.726
			≥30	0.671 ± 0.072	0.564	0.671	0.801
SMM right leg	kg	female	all	1.713 ± 0.202	1.414	1.713	2.074
			<25	1.624 ± 0.142	1.413	1.624	1.878
			≥25,<30	1.797 ± 0.152	1.571	1.797	2.069
			≥30	2.024 ± 0.198	1.730	2.024	2.379
		male	all	2.033 ± 0.204	1.730	2.033	2.398
			<25	1.902 ± 0.137	1.699	1.902	2.146
			≥25,<30	2.063 ± 0.157	1.831	2.063	2.343
			≥30	2.334 ± 0.197	2.042	2.334	2.687
SMM left leg	kg	female	all	1.702 ± 0.201	1.404	1.702	2.062
			<25	1.614 ± 0.143	1.402	1.614	1.870
			≥25,<30	1.786 ± 0.147	1.568	1.786	2.049
			≥30	2.009 ± 0.206	1.704	2.009	2.378
		male	all	2.016 ± 0.205	1.712	2.016	2.383
			<25	1.887 ± 0.139	1.680	1.887	2.136
			≥25,<30	2.046 ± 0.163	1.805	2.046	2.337
			≥30	2.313 ± 0.190	2.031	2.313	2.652
SMM trunk	kg	female	all	3.21 ± 0.40	2.61	3.21	3.93
			<25	3.02 ± 0.29	2.60	3.02	3.54
			≥25,<30	3.41 ± 0.28	2.99	3.41	3.91
			≥30	3.83 ± 0.38	3.28	3.83	4.50
		male	all	4.52 ± 0.38	3.95	4.52	5.20
			<25	4.25 ± 0.29	3.82	4.25	4.76
			≥25,<30	4.60 ± 0.27	4.19	4.60	5.09
			≥30	5.05 ± 0.33	4.55	5.05	5.64
SMM total body	kg	female	all	7.50 ± 0.82	6.28	7.50	8.97
			<25	7.11 ± 0.56	6.29	7.11	8.11
			≥25,<30	7.89 ± 0.58	7.02	7.89	8.93
			≥30	8.82 ± 0.76	7.70	8.82	10.18
		male	all	9.80 ± 0.83	8.57	9.80	11.29
			<25	9.20 ± 0.55	8.38	9.20	10.19
			≥25,<30	9.97 ± 0.59	9.10	9.97	11.02
			≥30	11.06 ± 0.72	9.99	11.06	12.35

the TBW normal range approach in combination with BIVA may better assess this.

Conflict of interest – BJ and PL are employees of seca gmbh & co. kg, Hamburg, Germany. The remaining authors declare no conflict of interest.

Acknowledgements – The research funding for this study was provided by seca gmbh & co. kg, Hamburg, Germany.

References

1. Kyle UG, Bosaeus I, De Lorenzo AD, Deurenberg P, Elia M, Gómez JM, Heitmann BL, Kent-Smith L, Melchior JC, Pirlich M, Scharfetter H, Schols AMWJ, Pichard C. Bioelectrical impedance analysis – part I: review of principles and methods. Clin Nutr. 2004; 23: 1226–1243. doi: 10.1016/j.clnu.2004.06.004.
2. Kyle UG, Bosaeus I, De Lorenzo AD, Deurenberg P, Elia M, Gómez JM, Heitmann BL, Kent-Smith L, Melchior JC, Pirlich M, Scharfetter H, Schols AMWJ, Pichard C. Bioelectrical impedance analysis-part II: utilization in clinical practice. Clin Nutr. 2004; 23: 1430–1453. doi: 10.1016/j.clnu.2004.09.012.
3. Barbosa-Silva MC, Barros AJ. Bioelectrical impedance analysis in clinical practice: a new perspective on its use beyond body composition equations. Curr Opin Clin Nutr Metab Care. 2005; 8: 311–317.
4. Bosy-Westphal A, Schautz B, Later W. Kehayias JJ, Gallagher D, Müller MJ. What makes a BIA equation unique? Validity of eight-electrode multifrequency BIA to estimate body composition in a healthy adult population. Eur J Clin Nutr 2013; 67: 14-21; doi: 10.1038/ejcn.2012.160.
5. Piccoli A, Pastori G: BIVA software. Department of Medical and Surgical Sciences, University of Padova, Padova, Italy, 2002 (available at Email: apiccoli@unipd.it).
6. Nationale Verzehrsstudie II, Part 1, Veröffentlichung des Bundesministeriums für Ernährung, Landwirtschaft und Verbraucherschutz (Publication of the German Federal Ministry of Nutrition, Agriculture and Consumer Protection), 2008.
7. Cole T J, Green P J: Smoothing reference centile curves: The LMS method and penalized likelihood. Statistics in medicine 1992; 11: 1305-1319.
8. Hattori K. Body Composition and Lean Body Mass Index for Japanese College Students. J. Anthrop. Soc. Nippon 1991; 99(2): 141-148, ISSN:0003-5505.
9. Schutz Y, Kyle UUG, Pichard C. Fat-free mass index and fat mass index percentiles in Caucasians aged 18 – 98 y. International Journal of Obesity 2002; 26: 953 – 960. doi: 10.1038=sj.ijo.0802037.
10. Guyton, Arthur C. Textbook of Medical Physiology (5th ed.) 1976; Philadelphia: W.B. Saunders. p. 424.
11. Guyton, Arthur C. Textbook of Medical Physiology (8th ed.) 1991: Philadelphia: W.B. Saunders. p.274.
12. Schoeller DA. Hydrometry. In: Heymsfield SB, Lohmann TG, Wang Z, Going SB, editors. Human Body Composition. 2 ed. Champaign, IL: Human Kinetics; 2005; p.35.
13. Oe B, De Fijter CW, Geers TB, Vos PF, de Vries PM. Hemodialysis (HD) versus peritoneal dialysis (PD): latent overhydration in PD patients? Int J Artif Organs 2002; 25: 838–43.
14. Domoto DT, Weindel ME. Bioimpedance analysis of fluid compartments in female CAPD patients. Adv Perit Dial 1998; 14: 220–2.
15. Plum J, Schoenicke G, Kleophas W, Kulas W, Steffens F, Azem A, et al. Comparison of body fluid distribution between chronic haemodialysis and peritoneal dialysis patients as assessed by biophysical and biochemical methods. Nephrol Dial Transplant 2001; 16: 2378–85.
16. Jain AK, Lindsay RM. Intra and extra cellular fluid shifts during the inter dialytic period in conventional and daily hemodialysis patients. ASAIO J. 2008 Jan-Feb; 54(1): 100-3. doi: 10.1097/MAT.0b013e318162c404.