Clinical Nutrition (2003) **22(2)**: 167–174
© 2003 Elsevier Science Ltd. All rights reserved.
doi:10.1054/clnu.2002.0617

Available online at www.sciencedirect.com
SCIENCE DIRECT®

ORIGINAL ARTICLE

Improved assessment of body cell mass by segmental bioimpedance analysis in malnourished subjects and acromegaly

M. PIRLICH,*T. SCHÜTZ,* J. OCKENGA,* H. BIERING,* H. GERL,* B. SCHMIDT,* S. ERTL,† M. PLAUTH,‡ H. LOCHS*

**Medizinische Klinik und Poliklinik, Abteilung Gastroenterologie, Universitätsklinikum Charité, Humboldt-Universität zu Berlin, Germany, †Abteilung für Nuklearmedizin, Helios Klinikum Buch, Berlin, Germany, ‡Abteilung Innere Medizin, Klinikum Dessau, Germany (Correspondence to: MP, Medizinische Klinik und Poliklinik, Universitätsklinikum Charité, Humboldt-Universität zu Berlin, 10098 Berlin, Germany)*

Abstract—Background: Estimation of body cell mass (BCM) has been regarded valuable for the assessement of malnutrition.

Aim: To investigate the value of segmental bioelectrical impedance analysis (BIA) for BCM estimation in malnourished subjects and acromegaly.

Methods: Nineteen controls and 63 patients with either reduced (liver cirrhosis without and with ascites, Cushing's disease) or increased BCM (acromegaly) were included. Whole-body and segmental BIA (separately measuring arm, trunk, leg) at 50 kHz was compared with BCM measured by total-body potassium. Multiple regression analysis was used to develop specific equations for BCM in each subgroup.

Results: Compared to whole-body BIA equations, the inclusion of arm resistance improved the specific equation in cirrhotic patients without ascites and in Cushing's disease resulting in excellent prediction of BCM ($R^2 = 0.93$ and 0.92, respectively; both $P < 0.001$). In acromegaly, inclusion of resistance and reactance of the trunk best described BCM ($R^2 = 0.94$, $P < 0.001$). In controls and in cirrhotic patients with ascites, segmental impedance parameters did not improve BCM prediction (best values obtained by whole-body measurements: $R^2 = 0.88$ and 0.60; $P < 0.001$ and < 0.003, respectively).

Conclusion: Segmental BIA improves the assessment of BCM in malnourished patients and acromegaly, but not in patients with severe fluid overload. © 2003 Elsevier Science Ltd. All rights reserved.

Key words: body cell mass; total-body potassium; segmental bioelectrical impedance; malnutrition; acromegaly

Introduction

Protein malnutrition is a prognostically ominous finding in several chronic diseases and its assessment is critical in the clinical evaluation and management of these patients (1–6). Estimation of body cell mass (BCM) has been regarded most meaningful among all body compartments for the assessment of malnutrition, especially since BCM comprises the metabolically active and protein-rich intracellular tissue (7). Precise estimates of BCM can be obtained by isotope dilution or the total-body potassium approach, but these methods are expensive and not generally available for clinical use. For clinical research purposes, bioelectrical impedance analysis (BIA) has been used as a non-invasive and inexpensive bedside tool to estimate BCM (4, 6, 8–11).

BIA prediction equations for BCM usually include the impedance index (height^2/resistance) which is strongly correlated with total-body water and fat-free mass, and/or the reactance (X_c) which is dependent on the capacitant effect of cell membranes and tissue interfaces (12). X_c has also been found to be inversely correlated with extracellular fluid volumes (13). Other approaches include the phase angle ($\varphi = \arctan X_c/R$) (14), which is thought to be an indicator of extra- and intracellular fluid distribution (15), or multiple frequency impedance measurements (11). However, the value of BIA equations to estimate BCM has been questioned in diseases with loss of BCM (6). In addition, the validity of whole-body BIA appears also to be limited in patients with general or compartmentalized fluid retention such as ascites (16, 17) or in adiposity (18). Therefore, segmental impedance measurements (separately measuring impedance of the limbs and trunk) have been suggested for more precise estimates of body fat, fat-free mass, or fluid compartments (15, 19–22).

The theoretical background for this approach is based on the fact that the human body is not an isotropic

conductor with uniform length and cross-sectional area as it is assumed for whole-body BIA. In fact, it has been shown that most of the measured whole-body impedance arises from a small fraction of the total body volume, i.e. the limbs, while the trunk contributes only 9% of total resistance and >50% of body weight (23). To our knowledge, no attempts have been made to evaluate the potential value of segmental BIA for the assessment of body cell mass.

This tempted us to hypothesize, that in patients with malnutrition and fluid retention or in patients with changes of the body geometry (i.e. excess trunkal body fat) segmental impedance measurements might be advantageous to the whole-body approach in estimating BCM.

To prove this hypothesis, we studied body composition using whole-body and segmental BIA in comparison to total body potassium counting as the reference method in healthy controls and in disease states which are known to be associated with either reduced (liver cirrhosis, Cushing's disease) or increased BCM (acromegaly).

Patients and methods

Patients and Controls

Nineteen healthy controls and a total of 63 consecutive patients with different diseases, potentially associated with changes of body composition were studied. Patient subgroups were as follows: liver cirrhosis without ascites ($n=17$), liver cirrhosis with ascites ($n=16$), untreated Cushing's syndrome ($n=12$), and untreated acromegaly ($n=18$). Patients with malignancies, clinically apparent infection, malabsorption, and hyperthyroidism were excluded. Diagnosis of cirrhosis was confirmed by histology, and the presence or absence of ascites was evaluated by ultrasound. Only those cirrhotic patients who had none or significant ascites were included in the study. Diagnosis of Cushing's syndrome was based on elevated urinary cortisol excretion, and abnormal plasma cortisol response in the dexamethasone suppression test. Acromegaly was diagnosed by elevated IGF1-levels and abnormal plasma growth hormone response in the glucose suppression test.

The study protocol was approved by the Ethics Committee of the Universitätsklinikum Charité, and informed consent was obtained for each subject.

Body composition analysis

Total body potassium counting

Total-body potassium content (TBK) has been considered to be an accurate reflection of BCM because >97% of all the potassium in the body is intracellular (24). TBK was determined by measuring the amount of the naturally occurring radioisotope ^{40}K using a shielded-room whole-body counter (Nuclear Enterprises Ltd., Edinburgh, UK) working with four NaI(TI) detectors (Berthold, Wildbad, Germany) as described previously (25). The coefficient of variation for repeated measurements was ≤2%. In addition, measured total-body potassium was compared with expected normal values as calculated by the following predictor equations (4): TBK = 35.76 H − 4.51 age − 2483 (male); TBK = 35.76 height − 4.51 age − 3211 (female). BCM was then calculated according to Moore (7): BCM_{TBK} = TBK 0.00833.

BIA

BIA was performed by the tetrapolar contact electrode approach using an impedance analyzer applying an alternating electric current of 800 μA at 50 kHz frequency (BIA 2000-M, Data Input GmbH, Frankfurt/Main, Germany). For whole-body impedance measurements, two pairs of current-introducing and voltage-sensing electrodes were attached to the dorsum of hand and foot of the dominant side of the body (26).

In addition, segmental impedance measurements were performed for the arm, leg and trunk using the method of Rallison (20) which is a modification of the approach suggested by Baumgartner (15). For the arm measurement, one pair of electrodes was attached on the standard locations on the hand and wrist and the other pair on the acromial process of the shoulder (receiving electrode) with the second electrode placed 5 cm superior in the midaxillary line (source electrode). For measurement of the trunk, the receiving electrode was placed on the acromial process as described above, and the source electrode was attached 5 cm distally over the deltoid muscle. The second pair of electrodes was placed on the midaxillary line of the hip with the receiving electrode located on the iliac crest and the source electrode located 5 cm distally towards the thigh. For measurement of the leg, one pair of electrodes was attached on standard locations on the foot and ankle. The other pair of electrodes was placed on the midaxillary line of the hip with the receiving electrode placed on the iliac crest and the source electrode placed 5 cm superior.

Resistance (R), reactance (X_c), and the phase angle (φ) were measured. All impedance measurements were taken after a 4-h fast, with the patient supine for at least 30 min before measurement, the arms relaxed at the sides but not touching the body, and thighs separated.

The coefficient of variation for repeated R and X_c measurements at 50 kHz was determined in four healthy controls, and in four patients of each disease group. The coefficient of variation for R and X_c were <1 and <2% in controls, and <1.6 and <3% in patients.

One established standard equation based on whole-body 50 kHz monofrequency BIA for BCM estimation was applied to the study population which has been developed by Kotler and co-workers in HIV-infected

and healthy subjects using TBK measurements as reference method (9). In this equation, parallely transformed reactance and body height and weight were used, and an exponential rather than linear relation to TBK was introduced with specific coefficients for male and female subjects:

$$\text{BCM (males)} = 0.00833\,(0.76\,[59.06\,(H^{1.6}/(X_c + R^2/X_c)^{0.5}] + 18.52\,W - 386.66),$$

$$\text{BCM (females)} = 0.00833\,(0.96\,[1.3\,(H^{2.07}/(X_c + R^2/X_c)^{0.36}] + 5.79\,W - 30.51).$$

In addition, in controls and in each patient group we developed two different population-specific BIA equations using multiple regression analysis. The first equation was based solely on whole-body BIA measurements. The second equation was based on segmental or segmental + whole-body BIA values. The selection of parameters for multiple regression analysis was based on published predictive models, and on the results obtained by linear correlation and by stepwise regression analysis. The following parameters were analysed: H, H^2, W, whole body/segmental resistance or resistance corrected by H or H^2, whole body/segmental reactance or phase angle, and logarithmic transformed reactance or phase angle.

Statistical analysis

All data are given as mean ± SD. Multiple comparison between controls and patient groups was performed by ANOVA and subsequent least-significant difference procedure test. In tables, only significant differences between controls and patient groups are indicated, but differences between patient groups were excluded for better readability. Spearman's correlation coefficient was calculated for testing the relationship between different quantities in a bivariate regression model. Stepwise and multiple regression analysis was used to develop predictive equations for BCM in controls and each patient group separately.

Results

Clinical characteristics and total-body potassium counting

Age and gender distribution as well as body height were not different between controls and patient groups (Table 1). Body weight was significantly higher in patients with acromegaly.

In healthy controls, mean total-body potassium was not different from predicted values, whereas in LC without and in LC with ascites and in Cushing patients mean total-body potassium was significantly lower than predicted (−17%−34.5% and −18.7%, respectively) and also significantly lower than in healthy controls, indicating a loss of BCM in these patient groups (Table 1, Fig. 1). In contrast, in patients with acromegaly measured total-body potassium was significantly higher than the predicted values (Table 1).

Whole-body and segmental impedance data

The results of whole-body and segmental impedance measurements are given in Table 2. Whole-body resistance of patients with acromegaly was significantly lower than in controls, but no differences were found between controls and the other patient subgroups. In contrast, whole-body reactance and phase angle were significantly lower in LC without and with ascites as well as in acromegaly when compared with controls, but in Cushing patients whole-body reactance was not different. Segmental data of controls and of all patient subgroups demonstrated that the trunk resistance and reactance were unproportionally low compared with data obtained by arm and leg measurements. In patients with acromegaly, all segmental resistance, reactance and phase angle values were lower than in controls.

Table 1 Clinical data and total-body potassium measurements of the study population

	Controls (n = 19)	LC without ascites (n = 17)	LC with ascites (n = 16)	Cushing's disease (n = 12)	Acromegaly (n = 18)
Age (years)	47.1 ± 7.3	53.7 ± 12.4	53.4 ± 7.7	42.2 ± 13.4	50.4 ± 12.6
Gender (f/m)	5/14	7/10	4/12	7/5	6/12
Weight (kg)	71.1 ± 8.3	74.7 ± 22.1	69.2 ± 11.4	84.1 ± 16.2	91.4 ± 16.5**
Height (cm)	174.5 ± 8.4	170.0 ± 6.5	168.8 ± 6.8	172.1 ± 11.9	175.1 ± 11.1
BMI (kg/m)	25.1 ± 4.6	24.8 ± 6.8	24.3 ± 3.8	28.5 ± 3.1	29.6 ± 4.2**
Lower limb oedema (±)	0/19	8/9	10/6	11/1	3/15
Total-body potassium					
TBK_m (g)	127.2 ± 24.4	98.7 ± 32.6**	78.9 ± 15.5***	95.2 ± 24.6**	142.2 ± 38.0
TBK_p (g)	130.9 ± 21.8	117.7 ± 22.2†	122.4 ± 20.3†	117.8 ± 31.2†	129.5 ± 28.9†
TBK_m (% of predicted)	97.7 ± 14.0	83.0 ± 18.0**	65.5 ± 14.9***	81.3 ± 12.6**	109.3 ± 12.9*
Body cell mass (kg)	27.1 ± 5.1	21.0 ± 6.9**	16.8 ± 3.3***	20.3 ± 5.2**	30.2 ± 8.0

Values are given as mean ± SD.
LC, liver cirrhosis; TBK_m, measured total body potassium; TBK_p, predicted total body potassium calculated according to McMillan (4); TBK_m (% of predicted), calculated as (TBK_m/TBK_p) 100.
*$P<0.05$; **$P<0.01$; ***$P<0.001$ controls vs patient group;$^{\dagger}P<0.01$ measured vs predicted potassium.

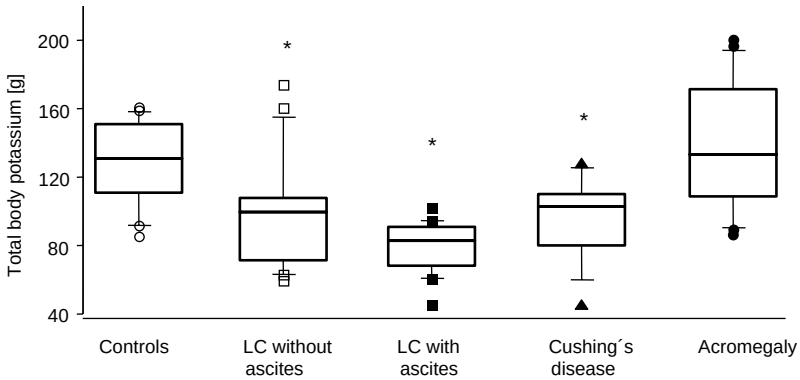

Fig. 1 Results of total-body potassium counting in controls ($n = 19$), cirrhotic patients without ascites ($n = 17$), cirrhotic patients with ascites ($n = 16$), Cushing's disease ($n = 12$), and acromegaly ($n = 18$). Box plots with horizontal bars indicating median values, boxes indicating the 25th and 75th centiles, error bars indicating the 10th and 90th centiles, and symbols indicating values outside the 10th and 90th centiles. $P<0.01$, patients vs controls.

Table 2 Whole-body and segmental impedance data

	Controls ($n = 19$)	LC without ascites ($n = 17$)	LC with ascites ($n = 16$)	Cushing's disease ($n = 12$)	Acromegaly ($n = 18$)
Resistance (Ω)					
Whole body	500.7±81.9	526.4±137.9	556.0±158.3	548.0±77.7	400.3±54.9*
Arm	229.5±42.6	276.2±72.4*	331.8±83.7**	264.4±56.0	181.3±31.7*
Leg	261.3±40.0	236.8±73.7	209.7±79.5*	267.8±52.1	208.7±25.5*
Trunk	77.7±15.9	62.0±15.9**	50.1±10.8**	74.6±10.7	46.2±7.3**
Reactance (Ω)					
Whole body	55.8±7.9	46.3±14.2*	38.9±11.8**	50.3±10.4	38.3±6.0**
Arm	23.8±3.6	24.4±5.9	25.4±5.8	22.8±3.5	16.1±2.7**
Leg	30.3±4.4	20.4±8.9**	11.9±6.9**	21.1±10.3**	19.8±3.9**
Trunk	12.7±1.7	7.8±2.0**	7.6±2.8**	8.3±1.7**	6.9±1.5**
Phase angle (deg)					
Whole body	6.4±0.6	5.0±1.3**	4.0±0.5**	5.2±0.8**	5.5±0.7*
Arm	6.0±0.9	5.2±1.1*	4.6±0.7**	5.2±0.8*	5.2±0.9*
Leg	6.7±0.7	4.8±1.7**	3.0±1.0**	4.2±1.7**	5.4±0.9*
Trunk	9.7±2.0	7.5±2.6*	8.7±3.1	6.4±1.4**	8.5±1.9

Values are given as mean±SD; *$P<0.05$; **$P<0.001$ controls vs patient group.

Comparison of segmental data between controls and the other patient subgroups were more complex with the only exception of phase angle of the arm and leg, which was significantly lower in all patient subgroups.

Linear correlation between TBK and body height, weight and impedance parameters

In order to estimate the potential value of height, weight and impedance measurements to predict BCM we first performed a linear correlation analysis (Table 3). In healthy controls and in all patient subgroups, body weight was significantly correlated with TBK, but R^2 values ranging from 0.285 in patients with ascites to 0.76 in cirrhotic patients without ascites indicated a large variability between patient subgroups. A similar pattern was observed for body height which explained >80% of TBK variance in Cushing's syndrome and acromegaly, but which was not correlated to TBK in cirrhotic patients with ascites.

Regarding impedance parameters, best correlations with TBK were found for segmental resistance of the trunk (controls and patients with acromegaly) or for resistance of the arm (cirrhotic patients without and with ascites, Cushing's syndrome). In all subgroups, reactance was not correlated to TBK, and correlation between phase angle and TBK was either low or not significant.

Prediction of BCM by impedance measurements using multivariate analysis

In order to analyse the predictive power of parameter combinations we performed multivariate regression analysis to develop specific equations for BCM using whole-body and/or segmental impedance data. The resulting parameter combinations which best correlated with BCM-TBK are shown in Table 4 for each subgroup separately. In addition, simple regression analysis was performed to analyse the relationship between an established standard BIA equation (Kotler) for the

Table 3 Correlation between TBK and height, weight, and impedance data derived from whole body or segmental measurements

	Controls ($n = 19$)	LC without ascites ($n = 17$)	LC with ascites ($n = 16$)	Cushing's disease ($n = 12$)	Acromegaly ($n = 18$)
H	0.251*	0.414*	0.117	0.802***	0.821***
W	0.393**	0.760***	0.285*	0.696***	0.613***
$R_{\text{whole body}}$	0.512**	0.529***	0.457**	0.154	0.402**
R_{arm}	0.519***	0.636***	0.479**	0.528*	0.462**
R_{leg}	0.443**	0.303*	0.313*	0.06	0.198
R_{trunk}	0.536***	0.108	0.197	0.032	0.464**
$X_{\text{c whole-body}}$	0.204	0.033	0.242	0.023	0.004
$X_{\text{c arm}}$	0.138	0.177	0.205	0.034	0.01
$X_{\text{c leg}}$	0.084	<0.001	0.144	0.015	0.03
$X_{\text{c trunk}}$	0.020	0.038	0.006	0.116	0.001
$\varphi_{\text{whole-body}}$	0.257*	0.336*	0.121	0.216	0.422**
φ_{arm}	0.310*	0.297*	0.07	0.494*	0.293*
φ_{leg}	0.264*	0.262*	0.004	0.042	0.347*
φ_{trunk}	0.419*	0.028	0.04	0.178	0.284*

Numbers are R^2 values; ***$P<0.001$; **$P<0.01$; *$P<0.05$; H = height, W = weight, R = resistance at 50 kHz X_c = reactance at 50 kHz, φ = phase angle at 50 kHz.

Table 4 Prediction models based on whole-body or segmental BIA measurements to estimate BCM-TBK

	Equation	R^2	P	SEE
Controls	$0.534\ H/R_{\text{whole-body}} + 0.233 X_{\text{c whole-body}} - 19.25$, (1)*	0.875	<0.0001	1.95
	$1.752\ \varphi_{\text{trunk}} + 0.267 W - 10.12$. (2)**	0.865	<0.0001	2.02
	Kotler*	0.856	<0.0001	2.03
LC without ascites	$0.174\ H/R_{\text{whole-body}} + 11.44 \ln \varphi_{\text{whole-body}} + 0.129 W - 17.11$ (3)*	0.913	<0.0001	2.28
	$0.102\ H/R_{\text{arm}} + 7.559 \ln \varphi_{\text{whole-body}} + 0.125\ W - 11.83$ (4)**	0.930	<0.0001	2.04
	Kotler*	0.903	<0.0001	2.25
LC with ascites	$0.148\ H/R_{\text{whole-body}} + 9.98 \ln \varphi_{\text{whole-body}} - 5.163$ (5)*	0.601	<0.003	2.24
	$-0.026\ R_{\text{arm}} + 6.93 \ln \varphi_{\text{whole-body}} + 15.892$ (6)**	0.562	<0.005	2.35
	Kotler*	0.459	<0.004	2.51
Cushing's disease	$0.172\ X_{\text{c whole-body}} + 42.353\ H - 61.287$, (7)*	0.914	<0.0001	1.71
	$-0.052 \times R_{\text{arm}} + 0.622\ X_{\text{c arm}} + 29.48\ \times H - 31.04$ (8)	0.922	<0.0001	1.60
	Kotler*	0.697	<0.001	3.03
Acromegaly	$0.373\ H/R_{\text{whole-body}} + 0.447\ X_{\text{c whole-body}} + 0.156\ W - 30.499$, (9)*	0.934	<0.0001	2.29
	$0.034\ H/R_{\text{trunk}} + 1.332\ X_{\text{c trunk}} + 0.208\ W - 21.115$ (10)**	0.943	<0.0001	2.12
	Kotler*	0.893	<0.0001	2.72

H, height (in m); W, weight; R, resistance at 50 kHz; X_c, reactance at 50 kHz; φ, phase angle at 50 kHz.
*denotes equations which only contain whole-body measurements; **denotes equations which contain segmental or segmental + whole body measurements.

estimation of BCM and BCM-TBK. The corresponding R^2-, P- and SEE-values are also shown in Table 4.

Controls

The best prediction of BCM was obtained by using the combination of whole-body resistance corrected by H^2 and whole-body reactance (Equation (1). The subject's body weight was not found to be an independent variable. The resulting R^2 value was higher than the value obtained by the equation of Kotler. Multiple regression analysis including segmental impedance measurements resulted in a formula based solely on the phase angle of the trunk and body weight (Equation (2)). The resulting BCM estimates from this equation were also significantly correlated with BCM-TBK, but with respect to SEE, there was no advantage seen to the whole-body impedance approach.

Cirrhotic patients without ascites

In these patients, the combination of resistance of the arm corrected by H^2, the logarithmic transformed phase angle of the whole body and the body weight provided the best population-specific equation (4) with excellent R^2 and SEE values of 0.93 and 2.04, respectively. When using only whole-body impedance values (Equation (3) we found a lower correlation with BCM-TBK comparable to the equation of Kotler.

Cirrhotic patients with ascites

In patients with ascites, the equation of Kotler explained less than 50% of TBK-BCM variance. This value was lower than the value obtained by linear correlation analysis using resistance of the arm alone (see Table 3). However, population-specific prediction formulae with a combination of BIA parameters were also disappointing and only slightly improved the prediction of BCM. The best equation was based on resistance of the whole body corrected by H^2 and the logarithmic-transformed phase angle of the whole body (Equation (5)). Body weight did not contribute to the predictive power of the resulting equation.

Cushing's syndrome

As described above, in patients with Cushing's disease body height was a strong predictor of TBK. It was, therefore, not unexpected that the population-specific equations included height as an independent variable. The equation based on whole-body measurements included the reactance, but the resistance of the whole body did not contribute to the predictive power (Equation (7)). However, the best prediction formula was obtained using the resistance and reactance of the arm (Equation (8)) explaining 92% of the variance of BCM-TBK. In contrast, the standard equation of Kotler explained only 69% of the variance of BCM-TBK.

Acromegaly

Patients with acromegaly represented the only group in which resistance and reactance of the trunk (together with body weight) provided the best parameter combination explaining 94% of BCM-TBK variance. Regarding the Kotler equation, we found also a highly significant correlation but a higher SEE value.

Discussion

The purpose of this study was to evaluate the value of segmental application of monofrequency BIA in comparison to the conventional whole-body approach to estimate BCM in normal and in malnourished subjects. The selection of different patient subgroups permitted us to study BIA under conditions with a wide range of BCM values and distinct changes of body composition and geometry. Liver cirrhosis frequently is associated with protein-energy malnutrition and fluid retention (10, 16, 27, 28). Cushing's syndrome is characterized by markedly increased trunkal fat mass and loss of muscle mass (29), and in acromegaly an increase of the BCM is expected (30, 31). In our population, these expected changes of BCM were plausibly reflected by TBK measurements as the reference method: Patients with liver cirrhosis and Cushing's disease had a significantly reduced BCM. The observed loss of BCM was most impressive in cirrhotic patients with ascites (−34.5% of predicted values). In contrast, in patients with acromegaly we found an increased TBK when compared with predicted values.

The results of BIA measurements in our study clearly demonstrated the superiority of population-specific to standard BIA equations in estimating BCM in all patient groups and even in healthy subjects. This finding further illustrates the limitations of BIA when standard equations well validated in one population are applied to another population or different disease states (6, 8, 9).

In healthy controls, we found no advantage of the segmental BIA approach compared with whole-body measurements, but it is remarkable that a very simple equation solely based on phase angle of the trunk and body weight almost reached the precision of the whole-body impedance equation for BCM estimation. Therefore, the segmental approach could be useful in otherwise healthy patients with lymph oedema of the extremities or limb amputation.

In contrast, in cirrhotic patients without ascites, in Cushing's disease and in acromegaly inclusion of segmental impedance data improved the predictive power of the final BIA equation indicated by higher R^2 values and lower SEE values. In cirrhotic patients without ascites and in Cushing's disease, the arm resistance better reflected BCM than whole-body resistance. In both patient groups we observed a significant loss of BCM, which is predominantly related to a loss of skeletal muscle mass, especially of the limbs. Thus, one could expect that resistance of the leg is equal or even better in predicting BCM, because the legs represent a much larger portion of BCM than the arms. However, we could not find any improvement by inclusion of leg data, and we observed a markedly lower correlation between leg resistance and TBK than between arm resistance and TBK. An explanation of this finding may be the presence of lower limb oedema observed in a relevant number of patients without ascites and in patients with Cushing's disease (Table 1), especially since none of the patients had oedema of the upper extremities.

A negative influence of fluid overload on BIA precision to estimate total-body water (16, 17) or fat-free mass (32) has been previously described in patients with cirrhosis, especially in those patients with ascites. In accordance with these studies, we found in patients with ascites that even the best specific equation explained only 60% of BCM-TBK variance. In these patients, the linear correlation between body height, weight, resistance and reactance, and TBK was lower than in all other subgroups studied (Table 3), and—contrary to our initial hypothesis—inclusion of segmental impedance data did not improve the predictive power of the final equation.

It is tempting to speculate that in patients with moderate fluid overload, which can be expected in cirrhotic patients without ascites (16) and in patients with adiposity (33), changes of the electrical conductivity of the lean body tissue might be less marked in the arms than in the legs. In these patients, BIA appears to be reliable to assess BCM, especially when arm resistance measurements are included. However, in patients with severe fluid overload such as patients with ascites, interindividual differences of lean tissue hydration are probably too high to develop an uniform equation to precisely assess BCM.

Since body fat is an electrical isolator the increase in trunkal body fat might influence whole-body resistance measurements in patients with Cushing's disease as it was reported in a previous study in obese subjects (18). This might explain the rather poor correlation between

the values obtained by a standard BIA equation and the excellent correlation with a low SEE value obtained by a specific equation based on resistance and reactance of the arm.

In acromegaly, best description of BCM-TBK was obtained by using resistance and reactance of the trunk. In these patients, potential sources of error for the BIA method may be the markedly increased bone masses of the limbs together with changes in skin thickness and skin hydration possibly influencing the extension of the electrical current. This might explain the advantage of trunk measurements to whole-body or limb measurements observed in our study.

In a more general view, the large differences observed between normal and malnourished patients demonstrated that the relationships between impedance or biologic parameters and TBK are complex and almost not predictable. For example, linear correlation analysis demonstrated that body height or weight were weak predictors of TBK in healthy subjects, and whole-body or segmental resistance values alone or corrected by H^2 much better described the variance of TBK. In contrast, in Cushing's disease body height was the best predictor of TBK and resistance of the whole body was not correlated with TBK. This situation became more complex when various parameters were included in multiple regression analysis. Parameters which were not linearly correlated with TBK became independent and significant predictors of BCM, and, thus, were included in the final model. For example, in healthy controls or in Cushing's disease the reactance of the whole-body was not correlated with TBK but significantly improved the predictive power of the final specific BCM equation.

It is obvious that this complex interrelationship between biologic parameters, impedance measurements and TBK cannot be described by general or uniform algorithms (8). Thus, despite convincing theories and models on the electrical behaviour of different human tissues (12, 13, 15, 19) the application of BIA on body composition analysis still requires empirical evaluation in different clincal situations.

On the other hand, the residuals between methods depend not only on the validity of BIA but also on the validity of the criterion method. To our knowledge, there are no data regarding the validity of TBK to estimate BCM in Cushing's syndrome or acromegaly. However, the possible influence of electrolyte disorders on the cellular potassium content has been investigated in patients with liver cirrhosis. The intracellular potassium has found to be normal even in patients with ascites or under diuretic treatment (34–36), and the clinical significance of TBK losses has been demonstrated in patients with different causes of protein malnutrition (1, 4, 5). Therefore, TBK can be considered as an adequate criterion method for BCM estimation in malnourished patients.

Although the number of subjects investigated was too small for cross-validation studies or to consider sex-specific analysis, our data allow some important conclusions: in patients with large alterations of the body's geometry or hydration status (i.e. patients with ascites, hypercortisolism or acromegaly), application of standard BIA equations is not appropriate to assess BCM.

Inclusion of segmental impedance parameters (i.e. of the arm or trunk) should be considered for the development of specific BCM equations in patients with reduced BCM and in acromegaly. However, in patients with severe fluid overload segmental BIA measurements can probably not improve the precision of BCM estimation.

In conclusion, the segmental BIA measurement of the arm or the trunk may be a promising and simple approach for improved assessment of BCM in the majority of patients with reduced BCM and in acromegaly.

Acknowledgements

Dr M. Pirlich was supported by the Else Kröner-Fresenius-Stiftung, Bad Homburg, Germany. We would like to thank Mrs Christa Efler (Abteilung für Nuklearmedizin, Klinikum Buch, Germany) for technical assistance in performing total body potassium measurements, and Prof. Manfred James Müller, Institut für Humanernährung und Lebensmittelkunde, Christian-Albrechts-Universität zu Kiel, for critical discussions of the manuscript.

References

1. Kotler D P, Tierney A R, Wang J, Pierson R N. Magnitude of body-cell-mass depletion and the timing of death from wasting in AIDS. Am J Clin Nutr 1989; 50: 444–447
2. McCullough A J, Mullen K D, Kalhan S C. Body cell mass and leucine metabolism in cirrhosis. Gastroenterology 1992; 102: 1325–1333
3. McMillan D C, Preston T, Watson W S et al. Relationship between weight loss, reduction of body cell mass and inflammatory response in patients with cancer. Br J Surg 1994; 81: 1011–1014
4. Suttmann U, Ockenga J, Selberg O, Hoogestraat L, Deicher H, Muller M J. Incidence and prognostic value of malnutrition and wasting in human immunodeficiency virus-infected outpatients. J Acquir Immune Defic Syndr Hum Retrovirol 1995; 8: 239–246
5. Selberg O, Böttcher J, Pirlich M, Henkel E, Manns M P, Müller M J. Clinical significance and correlates of whole body potassium status in patients with liver cirrhosis. Hepatol Res 1999; 16: 36–48
6. Schwenk A, Eschner W, Kremer G, Ward L C. Assessment of intracellular water by whole body bioelectrical impedance and total body potassium in HIV-positive patients. Clin Nutr 2000; 19: 109–113
7. Moore F D, Boyden C M. Body cell mass and limits of hydration: their relation to estimated skeletal weight. Ann NY Acad Sci 1963 110: 62–71
8. NIH conference. Bioelectrical impedance analysis in body composition measurement: National Institute of Health Technology Assessment Conference Statement. Am J Clin Nutr 1996; 64(suppl): 524S–532S
9. Kotler DP, Burastero S, Wang J, Pierson RN. Prediction of body cell mass, fat-free mass, and total body water with bioelectrical impedance analysis: effects of race, sex, and disease. Am J Clin Nutr 1996; 64(Suppl): 489–497
10. Pirlich M, Schütz T, Spachos T et al. Bioelectrical impedance analysis is a useful bedside technique to assess malnutrition in cirrhotic patients with and without ascites. Hepatology 2000; 32: 1208–1215

11. Paton N I, Elia M, Jennings G, Ward L C, Griffin G E. Bioelectrical impedance analysis in human immunodeficiency virus-infected patients: comparison of single frequency with multifrequency, spectroscopy, and other novel approaches. Nutrition 1998; 14: 658–666
12. Kushner R F. Bioelectrical impedance analysis: a review of principles and applications. J Am Coll Nutr 1992; 11: 199–209
13. Lukaski H C, Bolonchuk W W. Estimation of body fluid volumes using tetrapolar bioelectrical impedance measurements. Aviat Space Environ Med 1988; 59: 1163–1169
14. Lautz H U, Selberg O, Körber J, Bürger M, Müller MJ. Protein–calorie malnutrition in liver cirrhosis. Clin Investigator 1992; 70: 478–486
15. Baumgartner R N, Chumlea W C, Roche A F. Bioelectrical impedance phase angle and body composition. Am J Clin Nutr 1988; 48: 16–23
16. McCullough A J, Mullen K D, Kalhan S C. Measurement of total body and extracellular water in cirrhotic patients with and without ascites. Hepatology 1991; 14: 1102–1111
17. Zillikens M C, van den Berg J W O, Wilson J H, Swart G R. Whole-body and segmental bioelectrical-impedance analysis in patients with cirrhosis of the liver: changes after treatment of ascites. Am J Clin Nutr 1992; 55: 621–625
18. Fulcher G R, Farrer M, Walker M, Rodham D, Clayton B, Alberti K M. A comparison of measurements of lean body mass derived by bioelectrical impedance analysis, skinfold thickness and total body potassium. A study in obese and non-obese normal subjects. Scand J Clin Lab Invest 1991; 51: 245–253
19. Chumlea W C, Guo S S, Cockram D B, Siervogel R. Mechanical and physiologic modifiers and bioelectrical impedance spectrum determinations of body composition. Am J Clin Nutr 1996; 64 (Suppl): 413S–422S
20. Schloerb P R, Forster J, Delcore R, Kindscher J D. Bioelectrical impedance in the clinical evaluation of liver disease. Am J Clin Nutr 1996; 64(suppl): 510S–514S
21. Scheltinga M R, Jacobs D O, Kimbrough T D, Wilmore D W. Identifiying body fluid distribution by measuring electrical impedance. J Trauma 1992; 33: 665–670
22. Rallison L R, Kushner R F, Penn D, Schoeller D A. Errors in estimating peritoneal fluid by bioelectrical impedance analysis and total body electrical conductivity. J Am Coll Nutr 1993; 12: 66–72
23. Foster K R, Lukaski H C. Whole-body impedance—what does it measure? Am J Clin Nutr 1996; 64(Suppl): 388S–396S
24. Pierson R N Jr, Lin D H Y, Phillips R A. Total-body potassium in health: effects of age, sex, height, and fat. Am J Physiol 1974; 226: 206–212
25. Ertl S, Tautz M, Deckart H, Mischke W. Physical characterization and clinical use of the reconstructed whole-body counter in the Nuclear Medical Clinic of Berlin–Buch. Radiobiol Radiother 1979; 20: 448–458
26. Kushner R F, Schoeller D A. Estimation of total body water by bioelectrical impedance analysis. Am J Clin Nutr 1986; 44: 417–424
27. Müller M J. Malnutrition in cirrhosis. J Hepatol 1995; 23(Suppl): 31–35
28. Ockenga J, Bischoff S C, Tillmann H L et al. Elevated bound leptin correlates with energy expenditure in cirrhotics. Gastroenterology 2000; 119: 1656–1662
29. Wajchenberg B L, Bosco A, Marone M M et al. Estimation of body fat and lean tissue distribution by dual energy X-ray absorptiometry and abdominal body fat evaluation by computed tomography in Cushing's disease. J Clin Endocrinol Metab 1995; 80: 2791–2984
30. Bengtsson B-A, Brummer R-J, Edén S, Bosaeus I. Body compostion in acromegaly. Clin Endocrinol 1989; 30: 121–130
31. Brummer R-J M, Lönn L, Kvist H, Grangard U, Bengtsson B-A. Adipose tissue and muscle volume determination by computed tomography in acromegaly, before and 1 year after adenomectomy. Eur J Clin Invest 1993; 23: 199–205
32. Prijatmoko D W I, Strauss B J G, Lambert J R et al. Early detection of protein depletion in alcoholic cirrhosis: role of body composition analysis. Gastroenterology 1993; 105: 1839–1845
33. Waki M, Kral J G, Mazariegos M, Wang J, Pierson R N Jr, Heymsfield S P. Relative expansion of extracellular fluid in obese vs. nonobese women. Am J Physiol 1991; 261: E199–E203
34. Mas A, Bosch, Piera C, Arroyo V, Setoain J, Rodes J. Intracellular and exchangeable potassium in cirrhosis. Evidence against the occurence of potassium depletion in cirrhosis with ascites. Dig Dis Sci 1981; 26: 723–727
35. Sewell R B, Poston L, Wilkinson S P, Cranfield L, Williams R. Abnormalities in the leukocyte sodium pump in advanced cirrhosis. Gastroenterology 1981; 81: 676–680
36. Vitale G C, Neill G D, Fenwick M K, Stewart W W, Cuschieri A. Body composition in the cirrhotic patient with ascites: assessment of total exhangeable sodium and potassium with simultaneous serum electrolyte determination. Am J Surg 1985; 51: 675–681

Submission date: 19 March 2002 *Accepted:* 4 October 2002