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Different body fluid volumes measured by single- and multi-frequency bioelectrical impedance analyzers in overweight/obese renal patients*

Różnice w pomiarach objętości płynowych ciała mierzone przy pomocy analizatorów bioimpedancji jedno- i wielo-częstotliwościowych u pacjentów z nadwagą/otyłością i niewydolnością nerek

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

Mariusz Kusztal[1, A, C, D, E, F, G], Przemysław Dzierżek[1, B, D], Tomasz Gołębiowski[1, D, F], Wacław Weyde[1,2, A, D], Marian Klinger[1, D, F]

[1] Department of Nephrology and Transplantation Medicine, Wroclaw Medical University, Wroclaw, Poland
[2] Faculty of Dentistry, Wroclaw Medical University, Wroclaw, Poland

Summary

Introduction: Bioelectrical impedance analysis (BIA) is an affordable, non-invasive and fast alternative method to assess body composition. The purpose of this study was to compare two different tetrapolar BIA devices for estimating body fluid volumes and body cell mass (BCM) in a clinical setting among patients with kidney failure.

Methods: All double measurements were performed by multi-frequency (MF) and single-frequency (SF) BIA analyzers: a Body Composition Monitor (Fresenius Medical Care, Germany) and BIA-101 (Akern, Italy), respectively. All procedures were conducted according to the manufacturers' instructions (dedicated electrodes, measurement sites, positions, etc). Total body water (TBW), extracellular water (ECW), intracellular water (ICW) and BCM were compared. The study included 39 chronic kidney disease patients (stage III-V) with a mean age of 45.8 ± 8 years (21 men and 18 women) who had a wide range of BMI [17-34 kg/m^2 (mean 26.6 ±5)].

Results: A comparison of results from patients with BMI <25 vs ≥25 revealed a significant discrepancy in measurements between the two BIA devices. Namely, in the group with BMI <25 (n=16) acceptable correlations were obtained in TBW (r 0.99; p<0.01), ICW (0.92; p<0.01), BCM (0.68; p<0.01), and ECW (0.96 p<0.05), but those with BMI ≥25 (n=23) showed a discrepancy (lower correlations) in TBW (r 0.82; p<0.05), ICW (0.78; p<0.05), BCM (0.52; p<0.05), and ECW (0.76; p<0.01).

Conclusions: Since estimates of TBW, ICW and BCM by the present BIA devices do not differ in patients with BMI <25, they might be interchangeable. This does not hold true for overweight/obese renal patients.

Key words: **bioimpedance • chronic kidney disease • obesity • single-frequency • multi-frequency**

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Author's address: Mariusz Kusztal MD, PhD, Department of Nephrology and Transplantation Medicine, Borowska 213, 50-556 Wroclaw, Poland; e-mail: mariok@tlen.pl

Abbreviations: **BCM** – body cell mass, **BIA** – bioelectrical impedance analysis, **ECW** – extracellular water, **HD** – hemodialysis, **ICW** – intracellular water, **MF** – multi-frequency, **SF** – single-frequency, **TBW** – total body water.

Introduction

A crucial target of hemodialysis (HD) is to achieve the so-called dry weight. However, the best way to assess fluid status and dry weight is still unclear. Dry weight is currently determined in most dialysis units on a clinical basis. The most promising method of assessing dry weight that has emerged in recent years is bioelectrical impedance analysis (BIA), a non-invasive and fast method. This method estimates body composition, including total body water (TBW), extracellular water (ECW), and intracellular water (ICW), by measuring the body's resistance (R) and reactance (Xc) to electrical current. This method has been validated in healthy subjects and various patient populations by isotope dilution and other body composition techniques [2,5,7,9]. The procedure is safe, simple, and relatively inexpensive. There are two types of BIA: single-frequency (SF) BIA, which involves the application of a single 50 kHz frequency current, and multifrequency (MF) BIA, which uses multifrequency currents (ranging from 5 to 1000 kHz). Although the former is more widely used because of the simpler and less expensive device, the latter can make a more accurate distinction between ECW and ICW. Comparative studies in various populations suggested that the two systems provided different results for the body compartments and the methods were not fully interchangeable due to the high inter-method variability and utilized equations [3,6].

The purpose of this study was to compare two different tetrapolar bioimpedance (BIA) devices for estimating body fluid volumes and body cell mass (BCM) in a clinical setting among patients with kidney failure.

Patients and methods

Patients

The cross-sectional study encompassed 39 patients with chronic kidney disease (stage III-V; eGFR range 50-8 ml/min/1.73m^2) and with various etiologies, including 9 patients on hemodialysis maintenance from one academic center. Mean age of patients was 45.8 ± 8 years (21 men and 18 women), and they had a wide range of BMI: 17-34 (mean 26.6 ±5) kg/m^2. Pregnant women and patients with pacemakers or metallic implants and limb amputation were excluded. All patients were in a clinically stable condition, with no signs or symptoms of generalized infection or congestive heart failure. The patients have signed informed consent, and the study was approved by the Bioethical Committee at Wroclaw Medical University.

Bioimpedance measurement

Whole-body bioimpedance measurements were conducted according to the manufacturers' instructions by the same operator. Before the study was performed, BIA analyzers underwent calibration and validation in a manufacturer/distributor service center. Each subject was kept in a supine position for at least 10 min before the first measurement to allow for equilibration of fluid shifts. In hemodialyzed patients (n=9) the measurements were taken on a non-dialysis day.

All double measurements (consecutive) were performed by multi-frequency (MF) and single-frequency (SF) BIA analyzers, a Body Composition Monitor (Fresenius Medical Care, Germany) and BIA-101 (Akern, Italy), respectively. The technique involves attaching electrodes (single use dedicated by the manufacturer) to the patient's hand (non-fistula hand in dialysis patients) and ipsilateral ankle, with the patient in a supine position. The SF device offers measurement at 0.8 mA, at only one frequency (50 kHz). However, the MF apparatus measures reactance and resistance at 0.8 mA, in 50 different frequencies, with a range of 1200 kHz.

The average of 4 pairs in each R and Xc at 50 KHz was used to calculate the final R and Xc when the SF device was used. When the MF device was applied, attention was paid to data quality displayed on the apparatus and only measurements reaching >95% of quality were recorded and analyzed.

Parameters and statistics

Age, height, weight and blood pressure were documented in all patients. Total body water (TBW), extracellular water (ECW), intracellular water (ICW) and BCM (body cell mass) were recorded for statistical analysis since these are the only parameters which are universally available in both SF and MF devices, and are available in every BIA monitor on the European market.

Continuous data were expressed as mean ± standard deviation. For univariate comparisons, Student's t-test and the Mann-Whitney U-test were used. The correlation between SF and MF methods was measured using Pearson's coefficients. An intra-class correlation analysis, which varied between 0 (no agreement) and 1 (total agreement), allowed us to examine the variability between the two measurement methods [1]. A *P*-value <0.05 was considered statistically significant.

Results

Overall, the comparison of mean values of bioimpedance parameters between the two methods (SF vs MF) indicated that measurements of ICW and BCM were similar (19 vs 18.7; p=ns; and 24.8 vs 20.7 kg; p=ns), but TBW and ECW were not. The SF device gives higher mean estimates of TBW and ECW when compared to the MF device (Table 1). TBW showed relatively high correlations between both methods, with intra-class and Pearson's coefficients reaching 0.91 and 0.96, respectively. Pearson's coefficients for ECW and ICW were high (r=0.9) with an acceptable intra-class coefficient (0.72-0.68). BCM was found as a BIA parameter with moderate correlations between the two devices (Table 1).

Table 1. Comparison of mean bioimpedance parameters between single- and multi-frequency methods

BIA device \ parameter	TBW [L] Mean ± SD	ECW [L] Mean ± SD	ICW [L] Mean ± SD	BCM [kg] Mean ± SD
Single frequency (SF)	41 ±11	22 ±6.4	19 ±6.4	24.8 ±8.8
Multi frequency (MF)	35.8 ±9.4	17.2 ±4.8	18.7 ±5.1	20.7 ±11.1
P-value (SF vs MF)	p=0.04	p=0.01	p=0.87	p=0.08
Relative diffrence (%)	12.6	21.8	1.6	16.5
Pearson's coefficient	0.96	0.90	0.91	0.62
ICC	0.91	0.72	0.68	0.42

Bioimpedance (BIA) parameters: total body water (TBW), extracellular water (ECW), intracellular water (ICW), body cell mass (BCM); intra-class correlation coefficient (ICC); The Pearson's coefficients were statistically significant (P< 001) in all analyzed parameters.

Sub-analysis with respect to body mass index (BMI) showed various internal consistency of BIA measurement between both BIA devices. Renal patients were divided into two groups with BMI <25 vs ≥25 kg/m^2. Namely, in the group with BMI <25 (n=16) the highest (almost absolute) correlations were obtained in TBW (r=0.99) and relatively high in ECW (r=0.96), ICW (r=0.92), and BCM (r=0.68), as displayed in Figure 1. Different results were obtained in the group with BMI ≥25 (n=23), indicating a relatively high measurement discrepancy in TBW (r=0.83), ECW (r=0.76), ICW (r=0.78), and BCM (r=0.52), between SF and MF devices (Figure 1).

In those patients with BMI ≥25, the SF device gives significantly higher mean estimates of TBW (45.9 vs 40.1; p=0.03), ECW (24 vs 19.2; p<0.01) and BCM (28.7 vs 23; p=0.05) than the MF device.

Discussion

The choice of which bioelectrical impedance device should be used in renal patients with or without diuresis has caused controversy. The main question we asked in this clinical cross-sectional study was to what extent single- and multi-frequency bioelectrical impedance devices were interchangeable in renal patients.

The measurements and calculations of total body water, extracellular water and intracellular water provided by SF and MF devices have a high level of agreement (Pearson's coefficient ≥0.9). The intra-class correlation coefficient (0.9) for TBW suggests that both methods are interchangeable. Indeed, the measurements for TBW, EBW and BCM showed variability and bias from a statistical point of view (relative differences >12%, and/or P<0.05). We observed that the SF device yields higher values than the MF device for all compartments analyzed. Taking into account all statistical analyses, the best correlation between the two methods occurred in ICW (mean variability 1.6%; intraclass correlation coefficient 0.68; Pearson's coefficient 0.91), which is acceptable.

In fact, the precise estimation of ECW is crucial in hemodialysis patients since this parameter, alone or in combination with other BIA measurements, indicates fluid volume (overload) prescribed for a dialysis session. In many dialysis centers using BIA devices, a patient is considered to be hyperhydrated if relative fluid overload exceeds 15% of extracellular water [4].

Recently published data suggest that in comparison to bioimpedance-based evaluation, clinical judgment overestimates volume overload in obese patients, which leads to the delivery of high ultrafiltration volumes and to volume contraction at the end of a dialysis session in this group of patients [7]. Thus, when bioimpedance measurements are conducted in overweight/obese patients, the device used should be reliable and equivalent to the others.

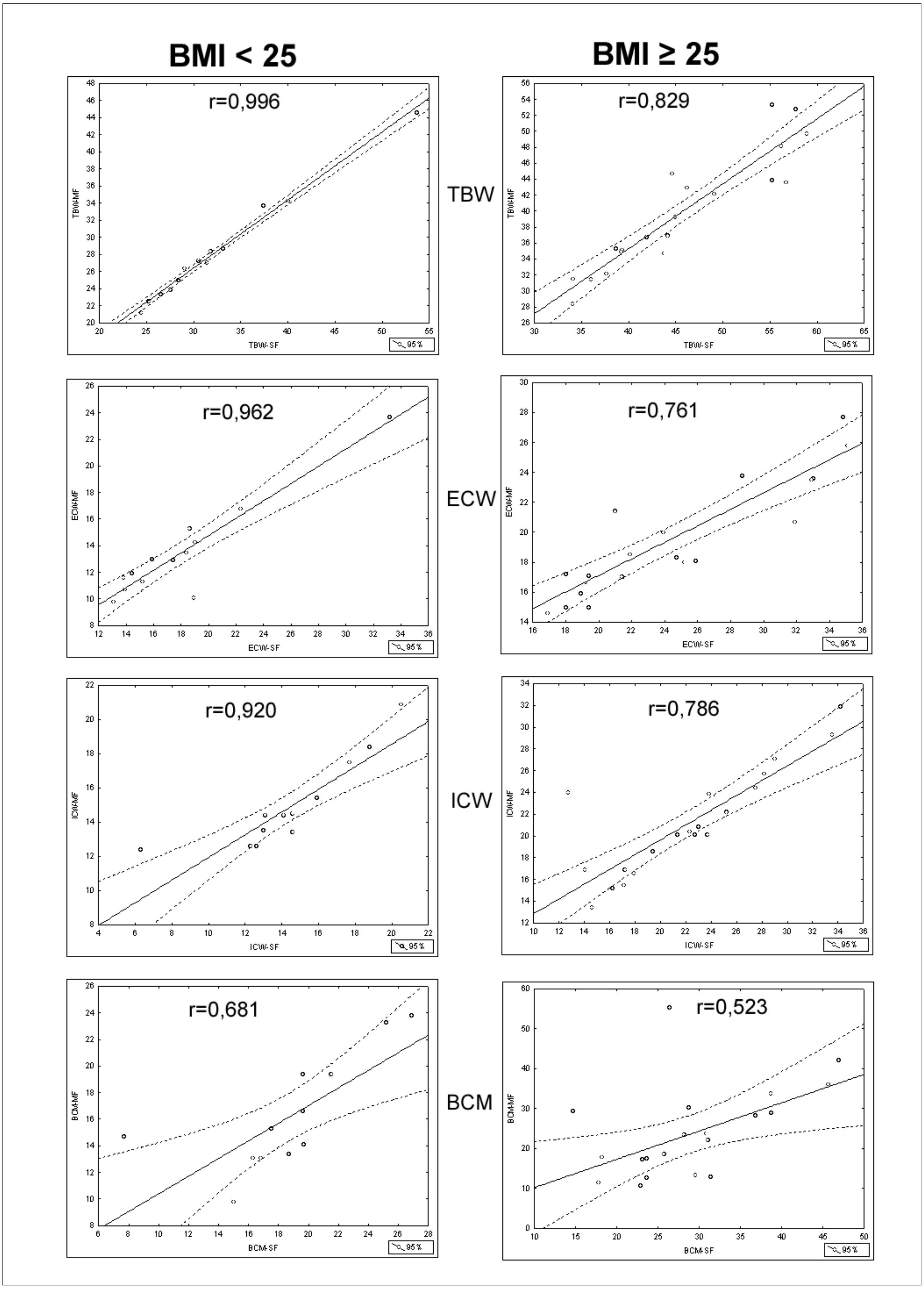

Fig. 1. Correlations of TBW, ECW, ICW, BCM between SF and MF in subgroups: BMI<25 (n=16) and BMI≥25 (n=23)

In a similar study conducted among a hemodialyzed population, the MF and SF systems provided comparable readings for bioelectrical parameters, although variation in the quantification of volume and body mass was explained by different equations used for calculation. Unfortunately, BMI was not considered as a modifying factor of significant variation, and the authors of the mentioned study stated that the criteria used by both systems to define hydration state achieved an acceptable level of equivalence [8].

Analysis in subgroups with respect to BMI revealed different concordance between both methods of BIA measurement. Since estimates of TBW, ECW and ICW by both SF and MF BIA devices do not differ in patients with BMI <25, they might be interchangeable (Pearson's coefficient r>0.9 for TBW, ECW, ICW). This does not hold true for overweight/obese renal patients (BMI ≥25 kg/m^2), since correlation coefficients were markedly lower (0.78-0.83). BCM was found in the study as the BIA parameter with the lowest correlations (intra-class as well as Pearson's) between both devices, especially in obese patients, which produced significant bias in BIA measurements.

One solution for diminishing the bias could be proximalization of electrode placement in obese patients. Yamada et al. reported in healthy individuals that proximal electrode placement improves the estimation of body composition in obese and lean elderly patients during segmental bioelectrical impedance analysis [10].

Practical applications: Because both BIA devices could over/under-estimate BCM in obese patients, an effort to reduce the bias (new equations or repositioning of electrodes) with a comparison to the gold standard (isotope distribution or DEXA) should be undertaken in a larger population of renal patients. We can conclude that the two systems (SF and MF) make very similar measurements of bioelectrical parameters (TBW, ECW, ICW) in non-obese renal patients.

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