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GUEST EDITORIAL

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Bioimpedance analysis in patients with chronic kidney disease

INTRODUCTION

In recent years the use of bioimpedance analysis (BIA) for assessment of fluid status as well as body composition as a mean to assess nutritional status in CKD has increased. The interest in the method is due to the associations between fluid overload and cardiovascular disease, and between fluid overload and malnutrition, both of which contribute to an increased risk of morbidity and mortality (Hur et al., 2013; Onofriescu et al., 2014). Moreover, BIA devices are suitable for clinical use, since they are portable, easy to use and, with a median to low price. However, the results can be difficult to interpret and integrate into routine clinical care, and although impedance measurements can contribute to an increased understanding of the patient's fluid balance, the results should be used with caution and in combination with other physiological parameters and clinical assessments (de Ruiter et al., 2020; Scotland et al., 2018). The aim of this editorial is to contribute to increased awareness of the benefits and limitations of using bioimpedance in patients with CKD with or without dialysis, and contribute to improving the measurement quality, facilitating interpretations, and highlighting possible sources of error.

BASIS OF BIOIMPEDANCE IN PATIENTS WITH CHRONIC KIDNEY DISEASE

BIA can be defined as the resistance measured by a weak alternating current when conducted through biological tissue. The conductivity differs between different tissues, which makes it possible to estimate body composition and fluid balance. BIA equipment measures impedance, which includes the *reactance* (capacitive impedance in cell membranes and other structures) and *resistance* (resistance due to extracellular [ECW] and intracellular water [ICW]). These variables can be measured with good precision and reproducibility between different devices (Kyle et al., 2004).

However, it is of fundamental importance to understand the limitations of BIA technology to avoid unrealistic expectations of measurement accuracy and precision (Ward, 2019). Deriving body composition information from impedance data includes estimated and assumed parameters and the use of population-averaged factors, such as body shape. Although it is plausible that prediction equations could be improved by including more individual-level information (e.g., the use of plasma sodium to improve estimations of tissue resistivity (Mitsides et al., 2020; Schneditz et al., 2023) this would have huge implications for the ease of use and applicability of the technology.

Variations in agreement between different impedance techniques and devices as well as with reference methods for measuring body composition can largely be attributed to the choice of method and device-specific software (Kyle, 2004; Kyle et al., 2004; Sheean et al., 2020). Also, each manufacturer of BIA equipment designs its own software for analysis and description of measurement results; this makes direct comparisons between different devices uncertain, and it would be difficult to give universal advice on how to use bioimpedance in day-to-day clinical management of patients with CKD. Therefore, although many of the guiding principles in this paper can be translatable to various devices, we will hence forward primarily be referring to the Body Composition Monitor (BCM®; Bad Homburg) a device which has been validated in patients with CKD (Davies et al., 2017; Marcelli et al., 2015; Wabel et al., 2009).

Different types of bioimpedance equipment

All bioimpedance devices are not created equal and a lack of appreciation of the fundamental differences can lead to significant problems. Three of the most important aspects are illustrated in Figure 1 and summarised here:

Measured frequencies

Impedance measurements at a *single frequency*, usually 50 kHz, have limited ability to distinguish intracellular and extracellular water (ICW and ECW) and are not recommended for abnormal hydration, such as in kidney failure. Measurement of impedance at *multiple frequencies* (MF-BIA) allows assessment of fat-free mass (FFM), total body water (TBW) and ICW and ECW, respectively. *Bioimpedance spectroscopy* (BIS) measures impedance at multiple frequencies (5–1000 kHz) and reports the results based on mathematical models and equations specifically developed for the assessment of TBW, ECW, ICW and FFM (Kyle, 2004; Kyle et al., 2004).

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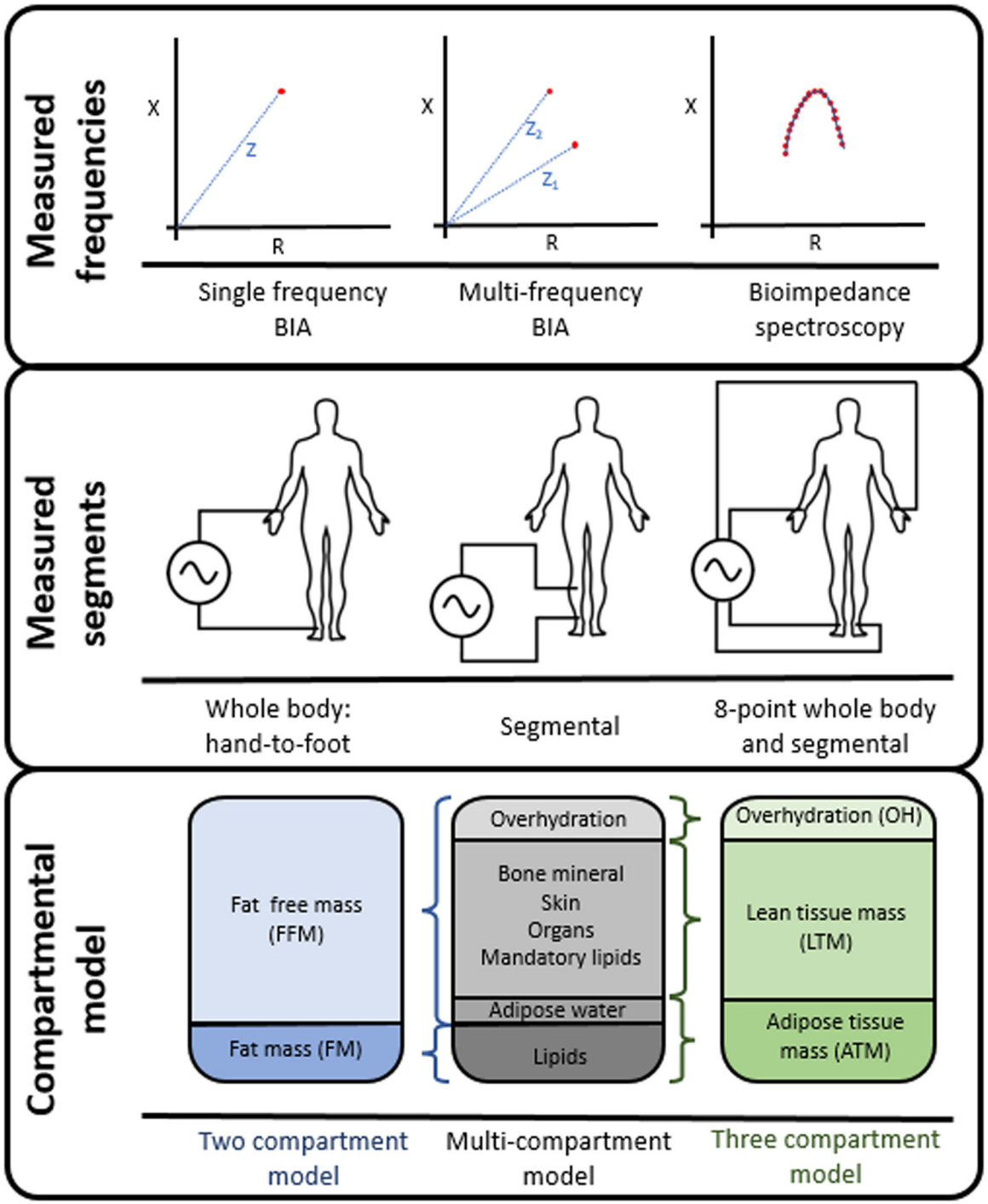

FIGURE 1 Important aspects of bioimpedance devices that can lead to significant differences in a particular device's validity and measurement uncertainty in a given population. BIA, bioimpedance analysis; R, resistance; X, reactance; Z, impedance.

Measured body segments

Bioimpedance treats the body as five segments: arms, legs and trunk. The *hand-to-foot* approach makes measurements on one side of the body and projects the processed results across the whole body. *8-point devices* can make hand-to-foot measurements on both sides of the body as well as being able to isolate individual segmental information (i.e., arms, legs and trunk). *Segmental BIA* measures in a defined part of the body, such as the calf, which allows more precise anatomical information to be used in analysis but may not represent whole body composition.

Compartmental models

Classical body composition analysis involved *multicompartmental models* which are simplified to a *2-compartment model* in the vast

majority of bioimpedance devices. This approach, however, leads to the FFM compartment incorporating fluid overload/fluid deficit in states of fluid imbalance, leading to over/underestimation of nutritional markers. This is of particular importance in patients with kidney failure and led to the development of a *three-compartment model* used in the BCM; the degree of hydration in fat mass (FM) and FFM is defined, and adipose tissue mass (ATM), lean tissue mass (LTM) and overhydration (OH) are estimated. It should be noted that LTM just like FFM, includes minerals from the skeleton.

PRACTICAL HANDLING

As kidney failure progresses from early stages through to end-stage kidney failure, body composition is increasingly affected, including fluid retention and loss of muscle mass. Unless bioimpedance results deviate significantly from reference values, a single measurement provides limited information, but repeated measurements over time provide the most valuable information. If the measurement conditions deviate from the normal, it is especially important to have a structured and uniform methodology. Carefully conducted measurements, performed over time, probably reflect actual changes in body composition (Kyle, 2004; Kyle et al., 2004; van der Sande et al., 2020). When conducting impedance measurements, pay attention to the recommendations in Table 1.

Recommended routines for bioimpedance measurements in the clinic

Haemodialysis (HD)

Whole-body bioimpedance measurements are dependent on the distribution of fluid between body segments, which differs when moving from standing to prone position and is affected by ultrafiltration during HD. The BCM validation is based on values in individuals with stable fluid distribution and supine position so measurements should preferably be performed before the dialysis session. It has been argued that for assessment of nutritional status, measurements are made after the dialysis session, as fluid overload may affect the body composition, but this is only applicable for devices that use a 2-compartment model which cannot distinguish fluid overload from FFM (see Figure 1) and not the case for the BCM. If the measurement is performed after dialysis, a minimum of 30 min should pass between the end of dialysis and the start of impedance measurement as the electrolyte and water balance is unstable after dialysis treatment (Ikizler et al., 2020; Keane et al., 2017). To enable comparison of recurrent measurements, it is of outmost importance that each measurement is performed in the same way, and with a consistent method for assessing weight and height. The weight entered to the device should always be the actual weight, according to the scale. For recurrent measurements, the electrodes should be

TABLE 1 Summary of recommendations for clinical bioimpedance measurement, when using the BCM®.

Before measurement

- Do not perform BIA measurement in patients with a central venous catheter (CVC) when connected to a dialysis treatment device.
- Do not perform BIA measurement in pregnant women as there is a lack of knowledge about how to interpret the values.
- For individuals with pacemakers or implantable defibrillators, see the respective device manual.
- Metal objects such as watches, and bracelets should be removed from limbs in the measurement path.
- Allow the patient to rest in measurement position at least 5 min before the measurement. The ideal measurement position is completely supine. However, if resting in supine position is uncomfortable, the legs should still be raised but having the trunk in a semi-recumbent position is acceptable.
- Make sure arms and legs are slightly separated.

Body weight

- Body weight should be measured with light clothing, without shoes, to the nearest ±0.1 kg on a calibrated scale.
- In PD, the estimated volume of PD fluid in the abdomen should be subtracted from body weight.

Body length

- For the measurement results, correctly measured body length is more important than the entered body weight
- Body length should be measured without shoes.
- For recurrent measurements,it is important that the same length is entered into the device.
- Body length can be measured in a supine position, via arm span, arm length or knee height (Nestlé Nutrition Institute, 2004).
- If the original body length is available—that is, before the body length has decreased due to for example, osteoporosis, vertebral compressions or as in natural aging—this length can be used.

Electrodes and cables

- The application of the electrodes is important for the quality of the measurement and should therefore be done carefully.
- The electrodes should be in place for at least 5 min before measurement.
- Selection and placement of electrodes should be done according to the manufacturer's recommendations for the specific device
- Clean the skin with alcohol and allow to dry before applying the electrodes.
- If necessary, shave for good connection between skin and electrode.
- The electrodes must not be applied to damaged skin or rashes.
- Unused electrodes must be stored in resealable packaging to prevent drying of the gel in the contact point.
- The electrode connection cables must not come into direct contact with any central venous catheter.

(Continues)

TABLE 1 (Continued)

- The cables must run freely, not be twisted or rolled up, nor touch the ground, metal objects, electrical equipment including mobile phones or another person.

During the measurement

- The patient should not move during the measurement
- Before defibrillation, disconnect BIA device.
- Several repeated measurements provide more reliable information.

Recommendations for research and special circumstances

- In the hours before measurement no large meal should be ingested, nor should intense physical activity be performed.
- The bladder should be emptied.
- Amputation: There are guideline values for correction of measured values (see Fresenius Medical Care manual) but also suggestions for alternative electrode placement with measurement from hand to hand in amputation (which does not require correction of the values) (Keane & Lindley, 2015).
- Metal implants in the arm or leg can affect the measurement results. If possible, choose measurement path that does not cross any implants.

placed on the same side of the body. Where possible, do not place the electrodes on the side of the body with an arteriovenous dialysis fistula and do not perform impedance measurement when the patient is connected to a dialysis device.

Peritoneal dialysis (PD)

Ideally, the impedance measurement should be performed without PD fluid in the abdomen. However, according to the literature, the measurement results are probably not much affected by fluid in the abdomen. If measuring with dialysis fluid in the abdomen, the estimated dialysis fluid volume should be subtracted from the body weight before the body weight is entered into the bioimpedance device. If the body weight is not adjusted for the dialysis fluid in the abdomen, this volume will mainly be reported as fat (Schwaiger et al., 2020).

CKD stages 3–5

Follow the instructions in recommended routines for bioimpedance measurements in the clinic, see Table 1. If applicable, follow local routines.

Sources of error and data quality

The BCM is, as are most technical devices, susceptible to artefacts that can cause significant error and is not very good at identifying them. Hence, it is important to be aware of possible precision and measurement errors. A medical body weight scale has a measurement error of 0.1%–0.2%. If different (possibly uncalibrated) scales are used the error is just above 1%—that is, about 0.5–1.0 kg. The "electrical" measurement error of an impedance measurement amounts to 1%–2%. As the result of a measurement includes both weight and electrical data, and that the biological day-to-day variation in the body's water content is calculated to be about 1 L, a rough estimate of the measurement error can amount to 1%–3%, ~1.7 L. The conclusion from this is that differences in repeated measurements that are less than 2–3 kg are uncertain at the individual level (Kyle, 2004; Kyle et al., 2004; Wabel et al., 2009). Repeated measurements of OH indicate that the precision is approximately ±1.0–1.5 L (Chamney et al., 2007; Keane et al., 2017). Several repeated measurements provide more reliable information. On a group level, prediction errors for TBW, ICW and ECW are in the range of 3%–8% (Kyle, 2004; Seoane et al., 2015). Furthermore, measurements that are not performed in a standardized way (see Table 1) and in patients with artificial joint implants or amputated extremities decrease accuracy and can give difficult-to-interpret results (Keane et al., 2017).

MEASUREMENT PARAMETERS

An impedance measurement generates a multitude of data. Impedance devices of various manufactures may report fluid balance and body composition output in different ways. For assessment of fluid status and nutritional status with bioimpedance, the variables in Tables 2 and 3 are commonly used:

FACTORS AFFECTING THE MEASUREMENT RESULTS

Age

In older ages (>70 years) muscle mass, bone tissue, organ weight and ICW decrease (i.e., sarcopenia). However, the FM increases while the amount of water is the same. This means that ECW is increased and the reference value for ECW/ICW is slightly higher, around 0.9–1.0 (Bruce et al., 1980). This means that OH estimated will generally increase with age. The BCM however adjusts OH for age.

Body mass index (BMI)

The bioimpedance technology has not been validated in patients with BMI <16 or >34 kg/m^2. Therefore, the results may be difficult to interpret, especially the hydration status. However, changes in FFM and FM will probably be reflected over time (Keane et al., 2016; Kyle et al., 2004).

TABLE 2 Examples of variables for assessment of fluid status with bioimpedance.

Variable	Definition	Normal range	What it can indicate	Important limitations
TBW	The total volume of water in the body.	Dependent on body composition (hence on age and gender) but roughly 50%–60% of body weight	TBW is the sum of ECW and ICW.	Very dependent on body composition
ICW	The total volume of intracellular water in the body.	Roughly two-thirds of TBW	A decrease in ICW may reflect a decrease in muscle mass.	If body cell mass has increased (according to Fresenius Medical Care BCM device), ICW should also have increased, as the amount of water is proportional to the muscle mass.
ECW	The extracellular water is composed of the interstitial water, the plasma volume and the transcellular water.	Roughly a third of TBW	Increased ECW (absolute or relative) may indicate fluid overload.	Very dependent on body composition
ECW/ICW or ECW/TBW	Extracellular to intracellular water or extracellular to total body water ratios. Both are commonly used but effectively give the same information	Normal ECW/ICW ratio is approximately 0.7 (range 0.6–0.9). It increases with age to 0.9–1.2 at age 70 For normal ECW/TBW this translates to around 0.35–0.40 (Bruce et al., 1980; Chamney et al., 2007).	Increased ratios can be due to fluid overload or low lean tissue mass, malnutrition, and obesity.	It is not possible to distinguish changes in the variables from fluid imbalance or body composition changes, for details see 'Factors that affect measurement results' below.
The following measurement variables are specific to the BCM device				
OH	Overhydration is defined as the difference between an individual's weight with normal ECW (the normally hydrated weight -NHW) and the actual weight. It can be positive (fluid overload) or negative (fluid deficit).	By definition, should be zero for euvolemic individuals. In healthy controls the 10th–90th percentiles of ±1.1 L which will indicate normovolemia (Moissl et al., 2006; Passauer et al., 2010).	This is the only variable directly measuring altered fluid status and not confounded by body composition. However, awareness of limitations is important, and measurements should be combined with clinical assessment (Stenberg et al., 2020).	Interindividual variation is notable, though repeatability in an individual is good. Concerns remain at extremes of body composition, malnutrition, and in inflammatory states.
OH/ECW	Measured OH normalized to % of ECW	HD patients with OH/ECW >15% were associated with higher mortality (Wizemann et al., 2009)	Normalising OH to ECW can help to make comparisons between individuals	ECW is strongly linked to nutritional state which could introduce confounding.

Abbreviations: ECW, extracellular water; ICW, intracellular water; OH, overhydration; TBW, total body water.

TABLE 3 Examples of variables for assessment of nutritional status with bioimpedance.

Variable	Definition	Normal range	What it can indicate	Important limitations
FFM (kg)	Fat-free mass is the nonfat part of the body and calculated as body weight minus fat mass. FFM consists of muscles, organs and bones and usually amounts to 70%–80% of the body weight.	The proportion of FFM to the total body weight varies depending on gender, age, physical activity and morbidity (such as CKD).	Change in FFM due to illness and aging is a risk marker of malnutrition and of vital importance for diagnosis and follow-up of nutritional status.	The majority of bioimpedance devices assume euvolemia when assessing FFM and fluid overload will falsely be considered as lean tissue
FM (kg)	Fat mass is calculated as body weight minus FFM. In Fresenius BCM device the fat mass is stated as FAT (kg).	In normal-weight people FM amounts to approximately 10%–25% of the body mass in men and 20%–35% in women (Gallagher et al., 2000)	Loss of FM indicates low or insufficient energy intake and is therefore a good risk marker of malnutrition.	BIS devices are not precise enough to measure clinically important differences in FM over a short time
FFMI (kg/m^2)	FFM normalized to body height squared (FFM/height^2)	Men 17–20 kg/m^2, Women 15–17 g/m^2. The result can be categorized as low, normal, or high FFMI (Cederholm et al., 2019; Kyle et al., 2003).	Low FFMI indicate low muscle mass and possibly sarcopenia or malnutrition.	Used as proxy for but is not analogous to muscle mass. Can falsely be inflated by fluid overload
FMI (kg/m^2)	FM normalized to body height squared (FM/height^2)	Men 2–8 g/m^2, Women 4–12 g/m^2. The result can be categorized as low, normal, or high FMI (Kyle et al., 2003).	Low FMI indicates low body energy stores and limited reserves for future energy deficits. High FMI indicates obesity.	
BMI (kg/m^2)	Body weight normalized to body height squared (weight/height^2)	18.5–25.0 g/m^2 and 18.5–23.0 g/m^2 in Asian population (WHO Expert Consultation, 2004).	Low BMI indicates sarcopenia or malnutrition and high BMI indicates obesity.	Is not a good indicator in disease states with altered body composition or fluid status
The following measurement variables are specific to the BCM device				
LTM (kg)	Lean tissue mass, describes the body mass (i.e., proteins in muscles and organs, minerals in the skeleton and water) minus adipose tissue mass (ATM) and the possible excess, extracellular water.	Clinically analogous to the FFM, though is independent of excess fluid/fluid deficit. As with FFM, normal range is dependent on many other variables	Change in LTM due to illness and aging is a risk marker of malnutrition and of vital importance for diagnosis and follow-up of nutritional status.	Used as proxy for but is not analogous to muscle mass.
ATM (kg)	Adipose tissue mass, that is, fat mass including protein and water in the adipose tissue (approximately 10%).	Describes adiposity free from the effect of excess fluid/fluid deficit. As with FFM, normal range is dependent on many other variables	Clinically analogous to fat mass (FM)	See fat mass (FM)
LTI (kg/m^2)	Lean tissue index LTM (kg)/length (m^2).	Reference values are age and gender-dependent and are based on measurements made on 1000 healthy people aged 18–75 years (Wabel, 2009). In the BCM individual values are compared to reference ranges as: ↑ or ↓ or = signs.	Low LTI indicates low muscle mass and possibly sarcopenia or malnutrition	Used as proxy for but is not analogous to muscle mass index. Cut-off points for different populations are limited.

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TABLE 3 (Continued)

Variable	Definition	Normal range	What it can indicate	Important limitations
FTI (kg/m^2)	Fat tissue index, that is, ATM (kg)/length (m^2).	Reference values are age and gender-dependent and are based on measurements made on 1000 healthy people aged 18–75years (Wabel, 2009). In the BCM individual values are compared to reference ranges as: ↑ or ↓or = signs.	Clinically analogous to FMI.	Cut-off points for different populations are limited.
BCM (kg)	Body cell mass can be roughly calculated by dividing the ICW by 0.7. It is calculated by subtracting ECW and estimated bone mass from FFM.		According to Fresenius' definition, body cell mass represents the cellular, metabolically active body mass.	Less intuitive and commonly used term than ICW, which it is directly linked, for clinical practice.

Abbreviations: ATM, adipose tissue mass; BCM, body cell mass; BMI, body mass index; FFM, fat-free mass; FFMI, fat-free mass index; FM, fat mass; FMI, fat mass index; FTI, fat tissue index; LTI, lean tissue index; LTM, lean tissue mass.

Fever

In case of fever or hypothermia, tissue resistances changes, which affects the measurement result.

Ethnicity

Ethnicity can affect the measurement results. Variations are due to differences in body proportions (length of arms, legs and torso). It is generally recommended that BIA equations are adapted to ethnicity. In practice, this may not be possible, as this variable is not electable in many BIA devices. Differences in measurement results between people of different ethnicities are assumed to be systematic, and on an individual level, repeated measurements under the same conditions probably reflect actual changes in hydration status and body composition (Kyle et al., 2004).

Sex

Body composition differs between men and women (see measurement variables above), as women (on a group level) have a smaller proportion of muscle in relation to body weight, and thus lower FFM as well as a higher proportion of FM. The BCM however accounts for sex differences.

Malnutrition

Nutritional status affects fluid status. Malnourished patients have a decreased ICW volume resulting in a higher ECW/ICW ratio with variations between 0.8 and 1.19, depending on the degree of malnutrition (Chamney et al., 2007). This will generally overestimate OH in malnourished patients, by as much as +6 L in severe cases (Chamney et al., 2007). It is not known why the ratio rises in malnutrition, but a common hypothesis is that it is due to changed conditions in the active transport of ions across cell membranes. Attempts to correct OH, as measured by impedance, in a malnourished patient may cause hypovolemia. An assessment of nutritional status should always supplement the bioimpedance measurement, especially in patients at risk of developing malnutrition.

Hypoalbuminemia

A possible and important condition to consider when removing excess body fluid is hypoalbuminemia, or hypoalbuminemia *in combination* with inflammation, which may contribute to hypoalbuminemia, see below. This type of fluid overload may not be associated with increased plasma volume. Thus, attempts to normalize ECW/TBW through increased ultrafiltration may lead to hypovolemia and loss of residual kidney function.

Inflammation

Inflammation causes increased vascular permeability, which causes albumin and fluid to diffuse from the vascular space to the extracellular space which makes it difficult to assess fluid status. OH in a patient with acute inflammation should not necessarily be completely remedied by increased ultrafiltration as this may pose a risk of severe hypovolemia.

Obesity

A high proportion of FM influences the ECW/ICW ratio because this ratio differs greatly between lean tissue (1:2) and adipose tissue (3:1). This may increase the uncertainties of OH at extremes of body fatness (Bellafronte et al., 2018; Chamney et al., 2007).

INTERPRETATION OF MEASUREMENT AND CLINICAL IMPLICATIONS

Fluid balance

Fluid overload increases the risk of mortality in patients treated with dialysis (Tabinor et al., 2018; Wizemann et al., 2009). However, OH as measured with bioimpedance, does not only correspond to fluid overload in the form of increased plasma volume that should be removed by ultrafiltration. In patients with pronounced fluid overload and concomitant loss of muscle mass, bioimpedance technology does not differentiate between extravascular ECW and plasma ECW. In these patients, there is a risk that reduction of body weight, based on ECW estimation with impedance measurements, will lead to intravascular fluid depletion which may accelerate loss of residual kidney function and lead to complications, such as seizures, hypotension, patient discomfort, and increased risk of coagulation in grafts and fistulas (Davies & Davenport, 2014; Tabinor & Davies, 2018; van der Sande et al., 2020).

Although bioimpedance measurements can contribute to an increased understanding of the patient's fluid status, the results should be interpreted with caution and in combination with other physiological parameters and clinical assessment. The use of clinical decision aids such as the Recova® tool (Stenberg et al., 2020)—which takes a number of patient-related factors into account—may facilitate systematic clinical assessment of fluid status, early recognition of fluid alterations, and incorporation of bioimpedance into target weight management.

Nutrition status

Assessment of nutritional status can be done with the help of measurements of body composition. Below are two models for assessment; the first is based on the generally accepted nomenclature for body composition (FFM and FM), and the second model is based on Fresenius Medical Care's model for body composition (LTM and ATM).

Nutrition status assessment using FFMI and FMI

Low FFMI in combination with normal FMI indicates sarcopenia, that is, low muscle mass, (and low muscle strength) see Table 2 (Cruz-Jentoft et al., 2019). Sarcopenia secondary to kidney failure can be caused by loss of protein mass due to the catabolic effect of the dialysis procedure and/or inadequate intake of protein (sometimes in combination with insufficient energy intake) via food and/or low physical activity (Sabatino et al., 2021). Low FMI and FFMI indicates malnutrition, that is, the patient has insufficient intake of both energy and protein, possibly exacerbated by low physical activity (Cederholm et al., 2017). Low FFMI in combination with high FMI indicates sarcopenic obesity, that is, low muscle mass and/or low muscle strength with simultaneous high body fat (Donini et al., 2022). Sarcopenic obesity and malnutrition are strong risk factors for morbidity and mortality (Sabatino et al., 2021; Wilkinson et al., 2022).

Note that calculations of FFM based on measurements made before HD are difficult to interpret if OH are not accounted for. Fat-free mass adjusted for OH can be calculated as $FFM_{OHadj.}$ = body weight–FM–OH. Use cut-off values in combination with routine clinical assessment.

Nutrition status assessment with LTI and FTI

The basis for evaluating nutritional status using LTI and FTI are measurements of more than 1000 healthy people (Wabel, 2009. In an international cohort study by Marcelli and colleagues, impedance measurements were performed on more than 37,000 dialysis patients with the aim of investigating the relationship between LTI, FTI and survival. The results of the measurements showed that the mortality was lowest in patients with LTI and FTI within the reference values for individuals with corresponding age and sex, while the mortality was significantly higher in individuals with low LTI and FTI values (i.e., <10th percentile). Patients with LTI between 15 and 20 kg/m^2 and FTI between 4 and 15 kg/m^2 had the best survival (Marcelli et al., 2015). Unlike FFMI, LTI measured before HD are valid as the compartment is independent of OH.

CONCLUSION

Epidemiological studies clearly demonstrate the association between BIS measurements and important outcomes for HD patients at the population level. However, results from clinical trials suggest that the incorporation of BIS into routine clinical management is challenging. Unless results from BIS measurements deviate significantly from reference values, a single measurement provides limited information. Carefully conducted measurements, however, performed over time, probably reflect actual changes in fluid status and body composition. If the measurement conditions deviate from the normal, it is

especially important to have a structured and uniform methodology for follow up and, if possible, perform repeated measurements or use a reference method, for example, dual-energy X-ray absorptiometry. We believe that by better understanding of the fundamental differences between bioimpedance devices, principles of measurement and incorporation of the results with clinical assessment as part of decision support tools may better support use of BIS at the individual level.

KEYWORDS

bioimpedance, body composition, chronic kidney disease, fluid management, heamodialysis, malnutrition, nutritional status, peritoneal dialysis

AUTHOR CONTRIBUTIONS

The members of the SWEBIS network agree to the submission of the manuscript to the Journal of Renal Care. All authors fulfil the ICMJE requirements for authorship and contributed to the manuscript. Sintra Eyre and Jenny Stenberg were principal project leaders and responsible for the main drafting of the manuscript, with special contributions, design and coordination made by Ola Wallengren and David Keane. All the other authors (Carla M. Avesani, Ingvar Bosaeus, Naomi Clyne, Olof Heimbürger, Ainhoa Indurain, Ann-Cathrine Johansson, Bengt Lindholm, Fernando Seoane, Mia Trondsen) made critical revisions and participated with important intellectual content, read, and approved the final manuscript.

CONFLICT OF INTEREST STATEMENT

Jenny Stenberg: Honoraria for lectures from AstraZeneca, Baxter Healthcare and Fresenius Medical Care. Ola Wallengren: Personal speakers fee from Fresenius Kabi AB for educational lectures. Carla M. Avesani: C. M. A. declares no conflict of interest with the current paper. C. M. A. received payment for lectures from Astra Zeneca, Fresenius Medical Care and Baxter healthcare and participation in Advisory board for Astra Zeneca. Olof Heimbürger: Honoraria for lectures from Baxter Healthcare, Fresenius Medical Care, Astra Zeneca, ewimed and Vifor. Ann-Cathrine Johansson: Personal speakers fee from Fresenius AB. Bengt Lindholm: Affiliated with Baxter Healthcare: Previous employment; owns stock; Baxter Novum is supported by grant from Baxter Healthcare to Karolinska Institutet. The remaining authors declare no conflict of interest.

THE SWEDISH BIOIMPEDANCE NETWORK (SWEBIS)

This guideline for the clinical use of bioimpedance in patients with CKD was developed by the Swedish Bioimpedance Network (SWEBIS), which is an interprofessional network of people interested in the clinical application of bioimpedance in patients with chronic kidney disease (CKD). The network, which was initiated in 2014, consists of dieticians (SE, CA, OW), physiotherapists (MT), nurses (JS), physicians (ACJ, IB, NC, OH, AI, BL), and engineers/physicist (DK, FS).

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