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RESEARCH PAPER

Multifrequency bioelectrical impedance analysis may represent a reproducible and practical tool to assess skeletal muscle mass in euvolemic acutely ill hospitalized geriatric patients

Walther M. W. H. Sipers[1,2,3] · Jesper Dorge[1] · Jos M. G. A. Schols[2] · Lex B. Verdijk[3] · Luc J. C. van Loon[3]

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Key summary points

Aim To study the reproducibility of skeletal muscle mass assessment using multifrequency bio-impedance analysis in acutely ill hospitalized geriatric patients.

Findings Mean coefficient of variation of the three skeletal muscle mass measurements was 4.9% with excellent test–retest reliability. However, non-euvolemic patients showed a significantly larger variation and significantly lower test–retest reliability when compared to the euvolemic patients in this pilot study.

Message Multifrequency bio-impedance analysis seems a reliable method to assess skeletal muscle mass during the first week of hospitalization in geriatric patients, however, clinicians should be aware that in patients with over- or dehydration measurements may better take place after hydration status is normalized.

Abstract

Purpose Geriatric patients with low skeletal muscle mass (SMM) and strength have a poor clinical outcome following acute illness. Consequently, it is recommended to assess SMM and strength in patients admitted to the acute care geriatric ward. Bio-impedance analysis (BIA) is a practical tool to assess SMM in hospitalized patients. However, the reproducibility of this assessment may be compromised due to changing clinical conditions. The objective was to study the reproducibility of SMM assessment using multifrequency BIA (mf-BIA) in acutely ill geriatric patients.

Methods A total of 47 geriatric patients (age: 83 ± 7 years; $n = 31$ female) admitted to the acute geriatric ward participated in this pilot study. SMM was assessed on three occasions within the first week of hospital admission using the Maltron Bioscan-920-II.

Results Total skeletal SMM averaged 21.4 ± 5.7, 20.7 ± 5.4, and 20.8 ± 5.1 kg assessed at 2 ± 1, 3 ± 1 and 5 ± 2 days after hospital admission, respectively. Coefficient of variation (COV) of the three SMM measurements was 4.9 ± 4.5% with an intraclass correlation coefficient (ICC) of 0.976 (CI 95%: 0.961–0.986; $P < 0.001$). Hydration status affected the reproducibility of the measurement, with non-euvolemic patients ($n = 16$) showing a significantly higher COV (7.6 ± 5.9% vs 3.5 ± 2.9%; $P < 0.01$) and a lower ICC (0.983 vs 0.913; $P < 0.001$) when compared to the euvolemic patients ($n = 31$).

Conclusion Mf-BIA seems a highly reproducible and reliable method to assess SMM throughout the first week of hospitalization in geriatric patients. However, since abnormal hydration status may compromise reliability of the measurement, assessment of SMM using mf-BIA may better be performed when euvolemic status has been established.

Keywords Bio-impedance · Sarcopenia · Hydration · Aging · Hospitalization

✉ Walther M. W. H. Sipers
w.sipers@zuyderland.nl

✉ Luc J. C. van Loon
l.vanloon@maastrichtuniversity.nl

[1] Department of Geriatric Medicine, Zuyderland Medical Centre, Sittard-Geleen, The Netherlands

[2] Department of Health Services Research, CAPHRI, Maastricht University, Maastricht, The Netherlands

[3] Department of Human Biology, NUTRIM School of Nutrition and Translational Research in Metabolism, Maastricht University, Maastricht, The Netherlands

Introduction

Skeletal muscle mass and strength are strong prognostic factors for the functional decline, morbidity, and mortality of older patients [1–4]. Low skeletal muscle mass and poor physical performance are highly prevalent in hospitalized geriatric patients [5–8]. Clinical outcome following acute illness is generally poor in these geriatric patients with low skeletal muscle mass and strength [5, 9–11]. Consequently, it is recommended to assess skeletal muscle mass and strength in patients admitted to the acute care geriatric ward [12, 13].

Bio-impedance analysis (BIA) is the preferred method to measure skeletal muscle mass in the acute care geriatric ward [13–15]. This is because the geriatric patient is clinically compromised and the BIA application can be done at bedside, is non-invasive, imposes no radiation exposure, and the measurement is relatively inexpensive and readily available in many hospitals [14, 16].

BIA was introduced in the 1950s to measure body composition and is based on the principle that tissues rich in water and electrolytes, e.g. the skeletal muscle mass, are less resistant to an electrical current than lipid-rich tissue [14, 17–21]. The many available BIA systems range from single to multiple frequency, employ contact or gel electrodes, and measure whole-body or segmental (upper–lower arm, upper–lower leg, and the trunk) electrical pathways [19–22]. All BIA systems measure impedance and resistance (caused by the total water across the body) and reactance (due to capacitance of cell membranes). These measurements are incorporated into automated body composition prediction equations that are population specific, usually taking into account age, gender, ethnicity, height, and weight [21, 23, 24].

To accurately assess skeletal muscle mass with BIA, it is required that the method is reproducible. To our knowledge, there is no study evaluating the reproducibility of skeletal muscle mass assessment with mf-BIA in acutely ill hospitalized geriatric patients. Reproducibility of skeletal muscle mass assessment with BIA could be severely compromised in this population for several reasons. Acute care geriatric ward patients frequently experience issues with hydration status upon hospital admission, and hydration status can subsequently change dramatically during the first week of hospitalization due to strategies to resolve hydration problems, malnutrition, progression of disease, treatment and/or recovery from acute illness. Therefore, accurate assessment of muscle mass in the geriatric patient using BIA may be compromised when applied throughout the first week of hospital admission. In the present pilot study, we therefore aimed to assess the reproducibility of skeletal muscle mass assessment using BIA in acutely hospitalized geriatric patients. Muscle mass was assessed within 2 days after hospital admission and on two more occasions throughout the first week of hospitalization in the acute care geriatric ward.

Methods

Study sample

All geriatric patients admitted to the acute geriatric ward of a Dutch general hospital were asked to participate in the study. In the 5-month period of recruitment, from October 2014 through February 2015, we intended to include as many patients as possible. The inclusion criteria were: age above 70 years and being frail according to the Fried criteria [25, 26]. Patients were excluded if they had a terminal condition (avoiding unnecessary burden for those expected to die within 2–3 weeks), an implantable cardioverter defibrillator (ICD) or if no informed consent was obtained from the patient or proxy.

Patient characteristics

Patient characteristics were retrieved from the medical and nursing files. These included sex, age, diagnosis at hospital admission, medical history, fluid management during hospitalization (e.g. diuretics or intravenous fluid), C-reactive protein (CRP) as a marker of inflammation, nutritional status, and the acute illness that led to hospital admission. Since C-reactive protein (CRP) levels higher than 100 mg/L are severely elevated and almost always a sign of severe bacterial infection, patients were classified as either higher or lower than 100 mg/L [27]. Height was estimated to the nearest cm by measuring ulna length because many patients were temporarily bedridden [28]. The frailty score was assessed according to the Fried criteria, which ranges from 0 to 5: a score of three or higher indicates frailty [25, 26]. The fifth item of the Fried criteria "low physical activity" is based on the question (obtained from patient or caregiver): *are you at least 5 days a week during 30 min a day physically active like walking or biking?* Test is positive if this physical activity is not achieved [25]. Body weight was measured on a sitting weight scale (SECA, Model 959).

A number of scales were used to evaluate patient status. The Katz ADL-6 was used as a validated instrument for screening daily living activities (ADL) [29]. Scores range from 0 (totally independent) to 6 (completely dependent) [29].The cumulative illness rating scale (CIRS) was used to calculate the number and severity of chronic illnesses of the patients' comorbid diseases. The score ranges from 0, which corresponds to the absence of disorders, to a maximum of 56 [30]. Malnutrition was measured using the Short Nutritional

Assessment Questionnaire (SNAQ), which is a validated screening instrument for malnutrition. Scores range from 0 to 5; a score of three or higher indicates that the patient is malnourished [31].

Body composition measurement

The Maltron BioScan 920-II, a multifrequency bioelectrical impedance analysis (mf-BIA) device, was used to measure skeletal muscle mass (SMM). The Maltron Bioscan 920-II has been validated for the assessment of body composition and muscle mass at the whole-body level as well as segmental muscle mass in healthy older people [32, 33]. The Maltron BioScan 920-II has an eight-point electrode system, which separately measures impedance of the patient's trunk, arms and legs at four different frequencies (5 kHz, 50 kHz, 100 kHz and 200 kHz) for each body segment. The Maltron BioScan 920-II calculates SMM according to the device-specific calculation called the Maltron calculation [33]. BIA was performed with patients only wearing their pyjamas, and electrodes were placed on foot, ankle, knee, hip, hand, wrist, elbow and shoulder [8] (http://www.maltronint.com/). Three repeated measurements were performed for each patient, all on the same moment of the day (either in the morning or in the afternoon); within 2 days after hospital admission, and on two more occasions throughout the first week of hospitalization in the acute care geriatric ward, and at least 1 day apart. Since we aimed to assess reliability of the SMM assessment per se, and we were unable to accurately assess height in bedridden patients, only true SMM values are presented, rather than 'adjusted' values such as SMM Index (SMMI).

Clinical judgement of hydration status

No single 'gold standard' marker of hydration status exists [34, 35]. In clinical practice, parameters like skin turgor, axillary dryness, dry mucous membranes in combination with blood biochemistry including plasma osmolality, electrolytes, and blood urea nitrogen-to-creatinine ratio (BUN:Cr) represent a criterion method of identifying dehydration or overhydration [36]. In our study, the assessment of hydration status (normal, dehydrated or overhydrated) was based on signs and symptoms of dehydration (poor skin turgor, axillary dryness, dry mucous membranes of mouth and tongue or orthostatic blood pressure) or signs and symptoms of overhydration (presence of edema, signs of decompensated heart failure, including chest X-ray, if present) in combination with BUN:Cr ratio and potassium level. This clinical judgement of hydration status was done by an experienced ward resident at hospital admission and during the daily rounds during the first week of hospital stay.

Statistics

Data were analysed using SPSS Statistics version 23 (IBM Corp., Armonk, NY, USA). Due to the practical/clinical setting of this study, we intended to include as many patients as possible throughout the 5-month study period, without performing pre-set sample size calculations. Patients' characteristics are described by mean ± SD and range for continuous variables (after checking for normality) and by frequencies and percentages for the categorical variables. The variability between the different measurements of the absolute skeletal muscle mass (SMM) was determined by calculating the coefficient of variation (COV). Repeated measures ANOVA test was used to determine systematic differences in SMM between the three occasions of measurement, since SMM was normally distributed based on Kolmogorov–Smirnov testing. To determine test–retest reliability between the three measurements during the first week of hospitalization, Intraclass correlation coefficients (ICC) for absolute agreement and average measures were calculated, including 95% confidence intervals (95% CI).

To determine the influence of the hydration status (based on clinical judgment) and time effect on repeated BIA measurement of SMM, an additional repeated measures ANOVA was performed with hydration status added as group factor. Furthermore, Mann–Whitney *U* test was performed to compare COV values between patients with a normal hydration status and patients categorized as dehydrated or overhydrated. Moreover, ICC and 95% CI values were calculated for euvolemic and non-euvolemic patients separately.

Finally, repeated measures ANOVA was also performed to study the influence of presence of fluid management (applying intravenous fluid or diuretics vs no fluid correction) and presence of low or high inflammation (low systemic inflammation with CRP < 100 mg/L vs high systemic inflammation with CRP > 99 mg/L) on mf-BIA measurement of SMM during hospitalization. Furthermore, COV and ICC values were also calculated and compared between these groups.

Results

Patients

In a 4-month period, 122 older patients were admitted to the acute geriatric ward and asked to participate. Thirteen patients or proxies refused to participate and another 26 were excluded because primary admission was on a different hospital ward. Of the remaining 83 patients, 36 were excluded from the present analysis, because of missing one or more BIA measurements due to early hospital

discharge. Mean ± SD age of the remaining 47 patients was 83 ± 7 years and 66% ($n = 31$) were female. All patients were frail with a mean Fried score of 4.1 ± 0.7. Forty-two percent of the patients were malnourished, with SNAQ scores of three or higher. Forty-two percent were highly ADL dependent, with a Katz ADL-6 score of five or six. The mean CIRS score was 20.0 ± 5.5. All participating geriatric patients had at least five medical diagnoses/problems at hospital admission. The most frequent diagnoses at hospital admission were pneumonia ($n = 21$), delirium ($n = 15$), dehydration ($n = 11$), urinary tract infection ($n = 8$), anaemia ($n = 7$), vertebral fracture ($n = 6$), decompensated heart failure ($n = 5$), falls ($n = 6$), medication intoxication ($n = 4$), septic shock ($n = 2$), and others ($n = 12$). The first mf-BIA measurement was performed at 2 ± 1 days after hospital admission and the second and third measurements were performed at, respectively, 3 ± 1 and 5 ± 2 days after hospital admission. Based on clinical judgement, $n = 31$ patients were euvolemic and $n = 16$ patients were either over- or dehydrated. See Table 1 for a summary of patients' characteristics separated for hydration status. CRP was lower and handgrip strength was greater in euvolemic vs non-euvolemic patients.

Skeletal muscle mass

Mean absolute SMM was 21.4 ± 5.7 kg at the first, 20.7 ± 5.4 kg at the second, and 20.8 ± 5.1 kg at the third measurement. No systematic differences in mean SMM were observed between the first, second and third day of measurement with mf-BIA during the first week after hospital admission ($P = 0.129$). The mean COV calculated over the three mf-BIA measurements of SMM was 4.9 ± 4.5%. Similar findings were observed for the first and second measurement, the first and third measurement and the second and third measurement separately (Table 2).

Test–retest reliability for the three mf-BIA measurements of SMM was shown to be high with an ICC of 0.976 (95% CI: 0.961–0.986; $P < 0.001$). Also for ICC, similar findings were observed when separate analyses were performed for the first and second measurement, the first and third measurement and the second and third measurement (Table 3). In ten patients all the BIA measurements took place in the afternoon and the results for COV and ICC did not differ from the patients measured early in the morning (*data not shown*).

Table 1 Patients' characteristics ($n = 47$) categorized based on clinical judgement of hydration status as euvolemic ($n = 31$) and abnormal ($n = 16$)

	Euvolemic hydration status	Abnormal hydration status
Number of patients	31	16
Age (years)	83.4 ± 5.5	83.7 ± 8.6
Female (n, %)	19 (61)	4 (25)
Weight (kg)	74.2 ± 14.4	64.8 ± 18.5
CRP (mg/L)	67.6 ± 65.6	136.4 ± 110.8*
HGS Jamar (kg)	15.7 ± 8.0	10.8 ± 6.5*
Fried score	4.0 ± 0.7	4.3 ± 0.7
SNAQ	2.2 ± 1.8	2.4 ± 1.9
Katz ADL-6	3.8 ± 2.0	3.4 ± 2.9

CRP C-reactive protein, *HGS Jamar* handgrip strength measured with Jamar dynamometer, *SNAQ* Short Nutritional Assessment Questionnaire, *Katz ADL-6* activities of daily living

*Significantly different from euvolemic patients ($P < 0.05$)

Clinical hydration status and skeletal muscle mass

According to clinical judgement at the first moment of mf-BIA measurement, $n = 31$ (66%), $n = 11$ (23%) and $n = 5$ (11%) patients were categorized as euvolemic, dehydrated and overhydrated, respectively. These numbers changed to $n = 28$ (60%), $n = 11$ (23%), and $n = 8$ (17%) at the second assessment, and $n = 39$ (83%), $n = 3$ (6%), and $n = 5$ (11%) at the third assessment, respectively. No differences in mean SMM measured with mf-BIA were observed in patients with normal or abnormal hydration status between the first, second and third day of measurement (Table 4).

For euvolemic patients separately (at first measurement, $n = 31$), the mean COV of SMM calculated over all the three time points of mf-BIA measurement was 3.5 ± 2.9% (Table 4, Fig. 1). Similar findings were observed for the first and second measurement, the first and third measurement and the second and third measurement separately (Table 4). For patients that were euvolemic on all three occasions of BIA measurement ($n = 21$), the mean COV of SMM remained unchanged (Table 4). The COVs of mf-BIA measurement of SMM in patients with abnormal hydration status ($n = 16$; dehydrated or overhydrated) were significantly greater than those calculated for patients with euvolemic hydration status ($P = 0.003$) (Fig. 1). Mean COV of SMM for patients with abnormal hydration status calculated over all three time points was 7.6 ± 5.9%. Again, similar findings were observed for the first and second measurement, the first and third measurement, and the second and third measurement separately (Table 4).

In accordance with the COV data, test–retest reliability for repeated mf-BIA measurement of SMM was better in the euvolemic patients (mean ICC 0.983; 95% CI 0.964–0.992; $P < 0.001$) compared to non-euvolemic patients (mean ICC 0.913; 95% CI 0.711–0.971; $P < 0.001$). Since the point-estimate of ICC for euvolemic patients was not included in the 95% CI of the non-euvolemic patients (and vice versa), this difference was significant.

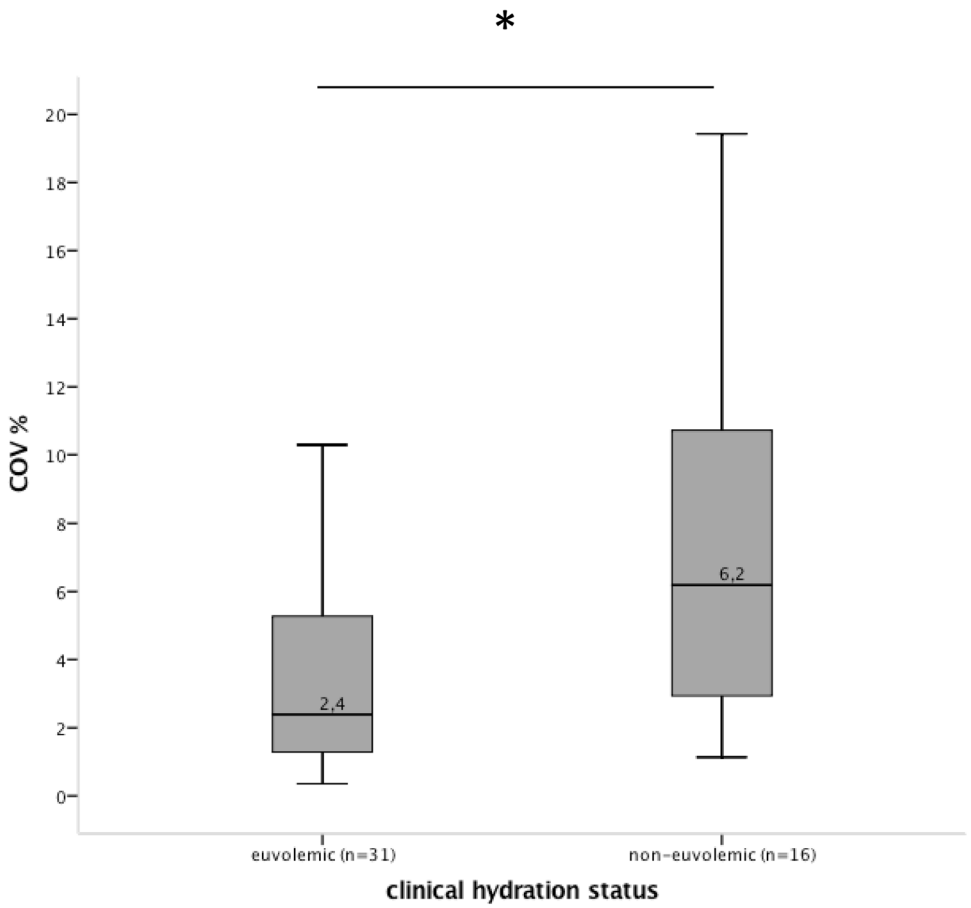

Fig. 1 Coefficient of variation (COV) repeated mf-BIA measurement of skeletal muscle mass on three different days during the first week after hospitalization in the acutely ill geriatric patients categorized as euvolemic ($n=31$) and dehydrated or overhydrated ($n=16$) at first measurement. Horizontal lines indicate median, boxes indicate 25 and 75 percentile and bars indicate minimal and maximal values. Asterisk significant difference based on Mann–Whitney U test ($P=0.003$)

Table 2 Covariance of repeated mf-BIA measurement of skeletal muscle mass on three different days in the first week after hospitalization in acutely ill geriatric patients ($n=47$)

Time point	1-2	1-3	2-3	1-2-3
Mean SMM, kg	21.1	21.1	20.8	21.0
SD SMM	5.5	5.3	5.2	5.3
Mean COV, %	4.8	4.4	3.8	4.9
SD COV	5.2	5.2	4.5	4.5

mf-BIA multifrequency bio-impedance analysis, *SMM* absolute skeletal muscle mass, *COV* coefficient of variation, *SD* standard deviation

Table 3 Intraclass Correlation Coefficients (ICC) of repeated mf-BIA measurement of skeletal muscle mass on three different days in the first week after hospitalization in acutely ill geriatric patients ($n=47$)

Time point	ICC*	95% CI	P value
1-2	0.960	0.925–0.978	$<0.001^{\#}$
2-3	0.976	0.957–0.987	$<0.001^{\#}$
1-3	0.959	0.926–0.977	$<0.001^{\#}$
1-2-3	**0.976**	**0.961–0.986**	$\mathbf{<0.001^{\#}}$

mf-BIA multifrequency bio-impedance analysis, *SMM* absolute skeletal muscle mass

*Two mixed model with absolute agreement definition

#Significantly high ICC between repeated mf-BIA measurements of skeletal muscle mass ($P < 0.05$)

Fluid management, inflammation and skeletal muscle mass

Seventy-two percent of the patients received intravenous fluid or loop diuretics prior to the first mf-BIA assessment. Prior to the second and third measurements, this was substantially less (34% and 39%, respectively). Mean SMM measured with mf-BIA did not change significantly over the three different days in the patients who did ($n=34$) or did not receive fluid management prior the first measurement ($n=13$). Upon the first mf-BIA measurement, mean CRP was 91 ± 82 mg/L (range 1–377 mg/L) with a median CRP value of 58 mg/L. A plasma CRP < 100 mg/L was categorized as a low level of systemic inflammation ($n=31$), a CRP > 99 mg/L was categorized as a high level of systemic inflammation ($n=16$). No changes in SMM were observed over the three measurement days for both these groups.

No differences were observed for SMM, COV, or ICC of repeated SMM assessment between patients with or without intravenous fluid therapy or loop diuretics, nor between patients with a high level of systemic inflammation compared to those with a low level of systemic inflammation.

Table 4 Covariance of repeated mf-BIA measurement of SMM on three different days in the first week after hospitalization in acutely ill geriatric patients categorized as euvolemic at the first measurement day ($n=31$), euvolemic on all three measurement days ($n=21$) and dehydrated or overhydrated at the first measurement day ($n=16$)

Time point	Initial euvolemic ($n=31$)				Euvolemic at 3 time points ($n=21$)				Initial dehydrated or overhydrated ($n=16$)			
	1-2	1-3	2-3	1-2-3	1-2	1-3	2-3	1-2-3	1-2	1-3	2-3	1-2-3
Mean SMM, kg	21.7	21.6	21.6	**21.6**	21.6	21.1	21.1	**21.3**	19.9	20.1	19.3	**19.7**
SD SMM	5.5	5.4	5.3	**5.4**	5.9	5.7	5.5	**5.7**	5.3	5.1	4.7	**5.0**
Mean COV, %	3.3	3.1	3.2	**3.5**	3.4	3.4	3.0	**3.4**	7.7	6.8	5.0	**7.6**
SD COV	3.0	3.4	3.2	**2.9**	3.1	3.5	3.1	**2.8**	7.2	7.1	6.3	**5.9**

mf-BIA multifrequency bio-impedance analysis, *SMM* absolute skeletal muscle mass, *COV* coefficient of variation, *SD* standard deviation

Discussion

In the present pilot study, we observed an overall reproducibility (COV) of 4.9% and test–retest reliability (ICC) of 0.976 for three repeated measurements of SMM using mf-BIA in the first week after hospitalization in acutely ill geriatric patients. For patients classified as having a normal hydration status based on clinical judgement, repeated mf-BIA measurement of SMM showed lower variation and, thus, better reproducibility compared to the patients with an abnormal hydration status.

Low SMM and strength in geriatric patients admitted to the acute care geriatric ward is of prognostic significance [10, 11, 37]. Therefore, measuring SMM is relevant in the acute care geriatric ward. BIA represents a relatively cheap, non-invasive, and easily accessible tool to assess SMM in these patients. However, there is little information about the reproducibility of the assessment of SMM using BIA in this patient group. We assessed SMM using mf-BIA in geriatric patients within 2 days of admission at the geriatric ward, with repeated measurements performed 1 and 3 days later. No systematic changes in SMM were observed over the three measurements. Previous work in healthy, older individuals has reported very good reproducibility of repeated BIA measurements, with a COV of 1.8% for muscle mass assessment ($n=24$, 61 ± 4 years) (38). To our knowledge there are no studies addressing the reproducibility of repeated mf-BIA measurements of SMM in acutely ill hospitalized geriatric patients. Our findings show a COV of 4.9% for mf-BIA based muscle mass assessments calculated for three repeated measurements within the first week of hospitalization in acutely ill geriatric patients. Despite acceptable reproducibility (i.e. COV < 5%), the COV for repeated measurements tends to be higher in this geriatric patient group when compared with healthy (older) individuals. Indeed, obvious differences between study populations likely affect the test–retest reliability of the BIA measurement. We recruited acutely ill hospitalized geriatric patients with a high mean age of 83 years, a variety of diseases and co-morbidity, and measurements over a time period of changing (clinical) conditions and a variety of induced medical therapies like applying antibiotics, steroids, opioids, antipsychotics, nutritional support, bladder catheters, etc. For example, in patients admitted to the acute geriatric ward, hydration status is often hampered. Indeed, 34% of the patients were not normally hydrated, with dehydration present in 11 patients and overhydration present in 5 patients. When separately calculating the reproducibility in both the dehydrated or overhydrated patients ($n=16$), we observed a substantially higher COV of 7.6% compared to a COV of 3.5% in patients with a normal hydration status ($n=31$). In accordance, the ICC for three repeated measurements was very high for the entire patient group (ICC: 0.976), but hydration status strongly affected the reliability. A much higher ICC and, thus, better reproducibility was observed for the patients with normal (ICC: 0.983) when compared with abnormal hydration status (ICC: 0.913). Notably, a COV of 7.6% could translate into a ~ 1.6 kg error margin for SMM assessment in this population of geriatric patients, which we propose is unsatisfactory in terms of reliable SMM assessment. Although it may seem contradictory to the findings on hydration status, we observed no differences for reliability between patients that did or did not receive intravenous fluid or loop diuretics. This is likely explained by the fact that in clinical practice, some euvolemic patients actually receive (chronic) loop diuretics to prevent exacerbation of their heart failure, whereas some non-euvolemic patients did not receive intravenous fluid administration because they were able to drink and compensate for dehydration themselves. Altogether, our findings clearly underline that caution should primarily be taken when using BIA to assess skeletal muscle mass in patients with abnormal hydration status.

In accordance with clinical practice, assessment of hydration status in the present study was based on clinical judgment, taking both physical and laboratory parameters into account. Categorizing hydration status based on clinical judgement was partly subjective and could be a limitation of our study; however, there is no gold standard for assessing

hydration status and judgement was performed by experienced clinicians in the current study. The first measurement of SMM with BIA took place between day one and day three of hospital stay, a period during which changes in hydration status can take place and may impact reproducibility of the measurements. However, no differences in mean SMM measured with mf-BIA were observed in patients with normal or abnormal hydration status between the first, second, and third measurement. Because measurement of SMM with BIA was in some patients ($n = 10$) performed in the afternoon and not in the early morning influence of food and drinks could have impacted reproducibility of the measurement. However, measurements were always performed at the same time of day for each individual patient, and no differences in mean COV and ICC of SMM measurement with mf-BIA were observed between patients with measurements performed in the early morning vs afternoon. As a final limitation, in this pilot study the number of non-euvolemic patients ($n = 16$) was relatively low. Although we were able to detect relevant differences between euvolemic and non-euvolemic patients, our findings need to be confirmed in additional studies with larger study samples. As with the current work, it would be preferred to do that within a clinical environment. As such, if the results of this study can be confirmed in larger studies it provides easily translatable, relevant clinical insight and provides clinicians information on the usefulness of mf-BIA measurement as well as with its limitations due to the influence of the patients' hydration status. Indeed, the strength of the present study is that it was performed in a real life setting in an acute care geriatric ward with the objective of studying the reproducibility of SMM with mf-BIA during hospitalization.

In this study, we show that bio-impedance measurement of SMM seems a practical, reproducible method with a high test–retest reliability in the geriatric patient admitted to the acute care geriatric ward. However, when patients are dehydrated or overhydrated, reliability of bio-impedance measurements may be compromised. Therefore, we propose that muscle mass assessment during the first week after hospitalization may better take place when the patient is clinically euvolemic. For non-euvolemic patients, we propose that it is likely better to perform mf-BIA based muscle mass assessment after correction of dehydration or overhydration through regular fluid management.

In conclusion, multiple frequency bio-impedance analysis seems a highly reproducible and reliable method to assess skeletal muscle mass throughout the first week of hospitalization in patients admitted to the acute care geriatric ward. However, since abnormal hydration status may compromise reliability of the measurement, assessment of muscle mass using bio-impedance may better be performed when euvolemic status has been established.

Author contributions WS, JD, LL, JS, and LV were involved in the design of the study. WS and JD managed the study and performed the patient inclusion and measurements. WS, LL and LV performed the statistical analysis. WS, LL, JS and LV drafted the manuscript. All the authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Ethics statement This study complied with the guidelines set out in the Declaration of Helsinki and was approved by the Ethics Committee of Sittard-Heerlen, the Netherlands (14-N-168; NTR 4928).

Informed consent All patients gave their written informed consent prior to enrolment.

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