Original article

# Comparative assessment of skeletal muscle mass using computerized tomography and bioelectrical impedance analysis in critically ill patients

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## ARTICLE INFO

## SUMMARY

*Background:* We compared the evaluation of skeletal muscle mass (SMM) using the computed tomography (CT) and bioelectrical impedance analysis (BIA) methods in critically ill patients. We also evaluated whether BIA can be applied for measuring SM with high accuracy to critically ill patients.
*Methods:* We included 135 critically ill surgical patients (83 men and 52 women, mean age: 59.3 years) who got the BIA and abdominal CT scan both within 7 days during the intensive care unit (ICU) stay. With CT scan, skeletal muscle area (SMA) measured from the L3 spine level image was used for calculation of the whole body skeletal muscle volume and mass (kg). Body composition data from BIA were obtained using touch-type electrodes and 50 kHz current. Subgroup analyses for SMM were performed according to the sex, SMA, and edema status of the patients with Pearson correlation or regression analysis et al.
*Results:* SMM from CT and BIA showed a good correlation ($p < 0.0001$) to sex, SMA, and edema in the subgroup analysis. A stronger correlation was noted between SMM from CT and BIA in male patients or mild edema group than for the other groups. SMM from BIA showed greater values than that from CT (mean difference, 3.35 kg) in all groups, except the normal SMA (higher than 170 cm$^2$ in men, and 110 cm$^2$ in women) group. Male patients and mild edema group showed more SMM as evaluated by BIA when compared to the other groups.
*Conclusion:* SMM measure by BIA in critically ill patients showed high correlation with SMM calculation by CT scan and had greater values than SMM from CT scan.
*Trial registration:* Ajou University Hospital Institutional Review Board DEV-DE4-15-115, Registered Jan 1 2015.

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## 1. Background

Patients admitted to the intensive care unit (ICU) exhibit a dramatic change in their body composition during their hospitalization periods such as loss of lean body mass. In particular, the decrease in the amount and strength of skeletal muscle mass (SMM) in critically ill patients is a known risk factor for mortality, owing to its negative correlation with the length of hospital stay.

Rapid wasting of SMM in critically ill patients is observed during the first 2—3 weeks of hospitalization [1,2]. Muscle mass is known as a strong independent predictor for morbidity and mortality, physical functioning, and quality of life [3—5]. Therefore, various techniques have been attempted to assess the muscle mass, including bioelectrical impedance analysis (BIA), computed tomography (CT), dual energy X-ray absorptiometry (DEXA), magnetic resonance imaging (MRI), mid-upper arm muscle circumference (MUAMC), and ultrasound (US).

BIA is an easy-to-use, noninvasive, portable, quick, and inexpensive method for measuring body composition [6]. It is based on the relation between the volume of a conductor and its electrical resistance [7], and indirectly estimates body composition by

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sending a low electrical current into the body [8,9]. As the body's electrical conductivity depends on its composition (fat and water content), the total body water (TBW), including the intra- and extracellular water distribution (ICW and ECW, respectively) can be estimated. Experimental results also enable the calculation of fat mass (FM), fat-free mass (FFM), and cell or muscle mass (e.g., SMM) by using a regression equation based on the measurements obtained. Moreover, it is possible to determine the water content and muscle mass for specific body parts such as the arms, legs, and trunk [10]. However, BIA can have a limitation in the ICU because many critically ill patients have edematous status from fluid overload and this edema can interfere with the body composition results.

Although some studies have previously evaluated SMM using CT and BIA independently and compared the results of these two methods in critically ill patients [10–14], some of them have been performed in specific severe pathological states such as pre-transplant patients or those with rheumatic diseases.

The aim of this study was to compare SMM evaluation by the CT and BIA methods in general critically ill surgical patients. In addition, we also evaluated whether BIA can be applied to critically ill patients with a high accuracy of measuring SMM in pathological conditions, including low SMM levels or severe edema.

## 2. Methods

### 2.1. Patients

This study was conducted, at the surgical ICU of Ajou University Hospital, Suwon, Korea throughout 2015. We enrolled patients aged over 18 years who had BIA and CT data collected within seven days of stay in the ICU. A total of 135 critically ill surgical patients (83 men and 52 women, mean age $59.3 \pm 14.4$ years, age range: 23–90 years) were enrolled in this study (Table 1). Pregnant or brain-dead patients were excluded.

BIA was performed for all patients regardless of whether they were in dieting or fasting states; had limb edema, anasarca, sepsis, or shock; or were undergoing renal replacement therapy. For the CT, we included CT scans of the abdomen and pelvis, liver or pancreas dynamic CT, and aorta CT (which shows the third lumbar vertebrae (L3 spine)). The mean difference time between the BIA and CT evaluation was $2.3 \pm 3.7$ days.

This study was performed after obtaining the approval of the Institutional Review Board (IRB) of Ajou University Hospital. Informed consent was obtained from all patients or their next of kin prior to their inclusion in this study.

### 2.2. Assessment of SMM from CT scan

Cross-sectional areas (in $cm^2$) of the skeletal muscle, intermuscular adipose tissue (IMAT), subcutaneous adipose tissue (SAT), and visceral adipose tissue (VAT) were quantified using 2 consecutive axial images at the L3. The psoas; erector spinae; quadratus lumborum; transverse abdominal, internal, and external obliques; and rectus abdominis were included for quantification of skeletal muscle tissues. All image analyses were performed using a dedicated workstation (Aquarius 3D Workstation, TeraRecon, San Mateo, CA, USA) by one radiologist. We used the Hounsfield unit threshold defined at −29 to 150 for skeletal muscle [15], −150 to 50 for VAT [16] and −190 to −30 for both SAT and IMAT [15] for quantification of specific tissues.

**Table 1**
Patients' clinical and physical characteristics.

| Characteristics | Class | Total (135 patients) Number (%) | Mean ± SD |
|---|---|---|---|
| Age (years) | | | 59.3 ± 14.4 |
| Height (cm) | | | 165.3 ± 10 |
| Weight (kg) | | | 67.6 ± 15.5 |
| BMI (kg/m$^2$) | | | 24.7 ± 4.8 |
| Patient Category | | | |
| | Abdominal surgery (malignancy) | 31(23) | |
| | Abdominal surgery (benign) | 13(10) | |
| | Open heart surgery | 24(18) | |
| | Orthopedic surgery | 18(13) | |
| | Lung surgery | 16(12) | |
| | Liver transplantation | 14(10) | |
| | Aortic problem | 13(10) | |
| | Others | 6(4) | |
| APACHE II score | | | 16.4 ± 7.3 |
| Length of stay in ICU (days) | | | 16.4 ± 20.2 |
| SMA (cm$^2$) | Low[a] | 94 (70) | 116.1 ± 30.4 |
| | Normal[b] | 41 (30) | 170.4 ± 35.5 |
| SMV (L) | Low[a] | 94 (70) | 21.4 ± 5.1 |
| | Normal[b] | 41 (30) | 30.4 ± 5.9 |
| SMM (kg) | Low[a] | 94 (70) | 22.7 ± 5.4 |
| | Normal[b] | 41 (30) | 32.6 ± 6.2 |
| BIA data | | | |
| - ICW (liters) | | | 23.7 ± 5.6 |
| - ECW (liters) | | | 16.4 ± 4 |
| - TBW (liters) | | | 40.1 ± 9.3 |
| - Edema (ECW/TBW) | Mild (<0.420) | 98 (73) | 0.400 ± 0.019 |
| | Severe (≥ 0.420) | 37 (27) | 0.430 ± 0.011 |
| - FM (kg) | | | 13.5 ± 8.4 |
| - FFM (kg) | | | 54.1 ± 12.5 |

(BMI) Body Mass Index; (APACHE II) Acute Physiology and Chronic Health Evaluation II; (ICU) Intensive Care Unit; (SMA) Skeletal Muscle Area; (SMV) Skeletal Muscle Volume; (SMM) Skeletal Muscle Mass; (ICW) Intracellular Water; (ECW) Extracellular Water; (TBW) Total Body Water; (FM) Fat Mass; (FFM) Fat-Free Mass.
[a] Low: Male <170 cm$^2$, Female < 110 cm$^2$ in skeletal muscle area (cm$^2$).
[b] Normal: Male ≥ 170 cm$^2$, Female ≥ 110 cm$^2$ in skeletal muscle area (cm$^2$).

Skeletal muscle area (SMA) was measured from the L3 level CT. Patients with an SMA lower than 170 cm$^2$ in men, and lower than 110 cm$^2$ in women, were considered as having low SMA levels. Otherwise, patients were considered having a normal level of SMA. We measured SMA using Shen et al.'s regression equation for skeletal muscle volume [17]. Shen et al. described estimation of SMM from cross-sectional areas between the 2 CT images: skeletal muscle volume $= 0.166 \times$ [SMA greater than 5 cm higher than L4 to L5 (cm$^2$)] $+ 2.142$ (R2 $= 0.855$). Since mass is measured by multiplying the volume to density, SMM is calculated by multiplying skeletal muscle volume to 1.06 kg/liter, which is the density of mammalian skeletal muscle tissue.

All CT examinations were performed using 16- or 64-detector-row CT scanner (Brilliance; Philips Medical Systems, Cleveland, Ohio). CT image parameters included contrast-enhanced or unenhanced, 120 kVp, and approximately 290 mAs with automatic tube current modulation, 5-mm slice thickness reconstruction without gap.

### 2.3. BIA evaluation

Body composition was measured using a portable BIA device for segmental BIA (InBody S10®, InBody Corp., Seoul, South Korea), using 50 kHz alternating current. The InBody S10 body composition analyzer is designed for patients over 3 years of age who are immobile or amputees, with touch-type or adhesive-type electrodes, and which produces results within 2 min. Skeletal muscle mass is calculated from the equation, muscle mass amount from 4 limbs (2 arms and 2 legs)/0.75 because muscle mass from 4 limbs are 75% of whole body muscle mass and 25% belongs to the rest of muscles in the human body [18].

After a patient's admission to the ICU, the measurements were performed twice weekly (Monday and Thursday). BIA measurements were performed while patients were lying on the bed with their arms and legs spread out. Because it is usually difficult to apply touch-type electrodes due to intravascular lines or dressing bandages covering catheter lines, adhesive-type electrodes were used for ICU patients. Overall, eight adhesive electrodes were attached: one on the most distal part of the third metacarpal bone of each hand, one on each wrist, one on the most distal part of the second metatarsal bone of each foot, and one on the central part of each ankle.

Physical information of patients such as age, height, and weight which were measured by scale in the ICU bed was needed to be input manually. Investigators checked out improper patient postures or attachment of the electrodes to prevent causing any measurement errors. After assessment, body composition data were gathered and analyzed. extracellular water (ECW) ratios (ECW/total body water [TBW]) were classified into two categories: mild edema if the ratio was <0.420 and severe edema if the ratio was ≥0.420.

### 2.4. Statistical analysis

Descriptive statistics were presented as means ± standard deviations (mean ± SD). Regression analysis and Pearson's correlation coefficient were used to investigate relationships between male and female, patients who have low or normal SMA, and patients who have mild or severe edema. The level of agreement between the two methods was assessed by the Bland–Altman analysis. The Kolmogorov–Smirnov goodness of fit test was used to verify the normal distribution for key parameters. Those parameters were compared using the Wilcoxon rank-sum test or Wilcoxon signed-rank test when appropriate. Significance was considered as $p < 0.05$ for all data analysis. All the statistical analyses were performed using SAS University Edition (SAS Institute Inc., Cary, NC, USA).

## 3. Results

A total of 135 patients had both CT and BIA measurement, and their characteristics are summarized in Table 1.

We compared SMM from CT and BIA according to the patient's sex, SMA, and edema status. Generally, SMM from BIA was greater than SMM from CT (Fig. 1). SMM of female patients were less than male patients ($p < 0.001$ from both CT and BIA). SMM from CT in the normal level SMA was surely greater than low level SMA ($p < 0.001$), and SMM from BIA also showed the same trend with a high significance ($p < 0.001$). The mild edema group (ECW/
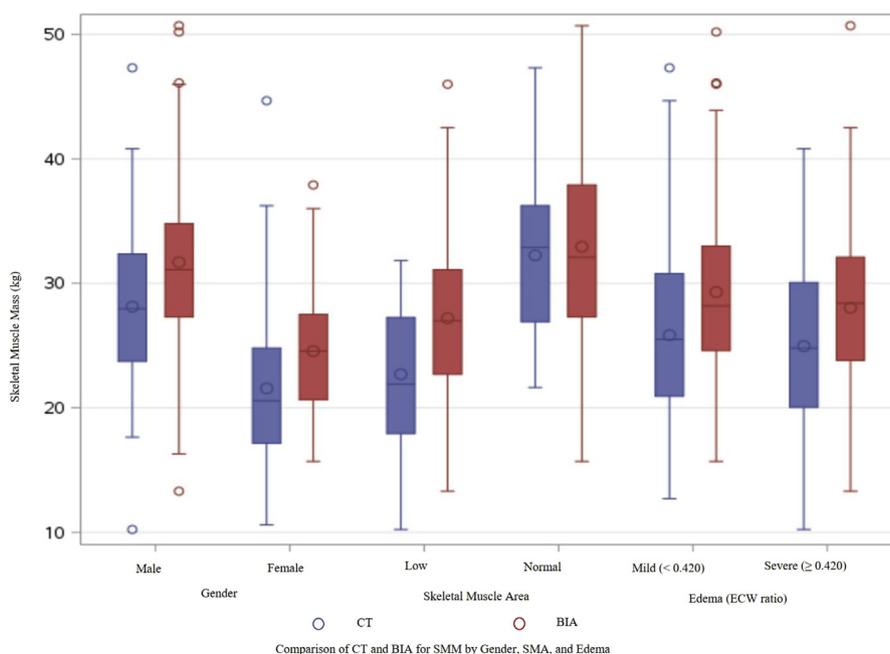


**Fig. 1.** Boxplots of skeletal muscle mass between CT and BIA according to the patients' sex, skeletal muscle area, and edema subgroups.

**Table 2**
Linear regression and correlation coefficient of SMM from CT scan and BIA in subgroup analysis.

| Group | Subgroup | Patients (N = 135) | Regression | | | Correlation | |
|---|---|---|---|---|---|---|---|
| | | | Slope | Intercept | R-squared | Correlation coefficient | p-value |
| Sex | Male | 83 | 0.7529 | 10.5189 | 0.4241 | 0.6513 | <0.0001 |
| | Female | 52 | 0.4214 | 15.4771 | 0.3416 | 0.5844 | <0.0001 |
| SMA | Low[a] | 94 | 0.7413 | 10.3839 | 0.4197 | 0.6479 | <0.0001 |
| | Normal[b] | 41 | 0.8436 | 5.7334 | 0.4194 | 0.6476 | <0.0001 |
| Edema | Mild | 98 | 0.7726 | 9.3297 | 0.5383 | 0.7337 | <0.0001 |
| | Severe | 37 | 0.5711 | 13.7815 | 0.376 | 0.6132 | <0.0001 |

[a] Male (62), female (32).
[b] Male (21), female (20).

TBW < 0.420) and severe edema group (ECW/TBW ≥ 0.420) did not show a difference in SMM (p = 0.593 from CT, p = 0.485 from BIA).

Table 2 shows the result from correlation coefficients and slope of linear regression equations of SMM comparisons. SMM from CT and BIA in three subgroups, sex, SMA, and edema parameters, showed significantly high correlations with p < 0.0001 (Fig. 2). SMM from the male group (r = 0.651) or from patients who have mild edema (r = 0.734) turned out to have stronger correlations between CT and BIA than the female group (r = 0.584) or patients with severe edema (r = 0.613) (Table 2). On the other hand, SMM comparison in the SMA subgroup seemed not to have such a difference whether SMA is low (r = 0.648) or normal (r = 0.648).

The Bland—Altman analysis of comparison between the difference and mean of CT and BIA for SMM with regards to sex, SMA, and edema is illustrated in Fig. 3. It shows a mean bias of −3.35 ± 5.59 kg, meaning that the BIA method overestimated SMM than CT by 3.35 kg. Even though the mean difference of SMM is −3.35 and the 95% confidence interval of the mean difference is −4.3 to −2.5, which means that there is a significant difference between CT and BIA, both methods were in agreement according to the limits of agreement. There were negative relationships between the difference of SMM from CT and BIA and average of SMM from both methods in male patients, patients with low or normal SMA, or patients with mild edema, whereas that in female patients or patients with severe edema had a positive relationship. This means that, as SMM increases, SMM from BIA becomes greater than SMM from CT in male patients or patients with mild edema. The SMA did not affect the difference of SMM from both methods according to the increase of SMM.

Figure 4 shows boxplots of differences in SMM from CT and BIA in sex, SMA, and edema subgroups in total. There were no statistical differences in SMM from CT and BIA in sex or edema groups (p = 0.866 and 0.758, respectively), which means SMM from CT and BIA showed the same trend regardless of sex or edema status. However, patients with low SMA showed less SMM from CT than SMM from BIA, compared to patients with normal SMA (p = 0.0006, Table 3). Moreover, Wilcoxon's test for comparisons of SMM difference between CT and BIA in sex, SMA, and edema subgroups determined that there was no difference in SMM between CT and BIA methods for patient with normal SMA (p = 0.479, Table 3, Fig. 1). Conclusively, SMM from BIA were greater than SMM from CT, and the exceptional group was the normal SMA group.

## 4. Discussion

Measuring SMM *in vivo* is accomplished by many different muscle mass measurement methods [19]. CT and MRI are considered as most preferred tools for estimating fat and SMM from patients since it is a highly accurate technique that can separate fat from other soft tissues [20]. However, these measurements have disadvantages of high cost and limited availability. Additionally,

fluid retention which can result in the overestimation of SMM in critically ill patients was one of risks of preventing accurate measurement, as all these techniques assume a normal state of hydration [21]. Mid-upper arm muscle area (MUAMA) is one of the measurements of body composition by principal anthropometric measurement. MUAMA is derived from MUAMC which can be calculated by mid-upper arm circumference (MUAC) and triceps skinfold (TSF). The two principal anthropometry measures are obtained two times at the midpoint of the nondominant upper arm using a tape measure (MUAC) and at the same point using a John Bull skinfold caliper (TSF) [22]. MUAMA is frequently used in clinical practice but has a disadvantage of less accuracy because of a high inter-rater variability [23]. DEXA is a widely used method to measure body composition at the molecular level. It is a quick, noninvasive, and safe method to assess body composition, such as BIA, and has an important advantage of estimating appendicular skeletal muscle (ASM) mass by measuring the appendicular lean soft tissue in the arms and legs [24,25]. However, DEXA has a limitation as its hardware and software programs differ among manufacturers, which leads to residual calibration errors between different machines [26]. Ultrasound (US) is clinically used to quantify tissue thickness, and is a simple, portable, and safe technique. Bazzocchi et al. [27] revealed that US has a higher correlation in fat tissue detection compared with CT or MRI. However, measuring muscle mass by US tends to create errors by muscle compressibility, selection of reliable site, or resting and hydration status of patients [28].

In overall, each tool for muscularity measurement has limitations and Buckinx et al. indicated that there is no gold standard method to measure muscle mass [29]. Considering all advantages and disadvantages, BIA has been at present the mostly used technique to assess body composition. Recently, researchers attempted to assess SMM using BIA and compared its results to that of CT or other techniques. Hosono et al. [11] analyzed and compared variability among BIA, CT, and MRI in patients with rheumatic disease receiving glucocorticoid therapy, and concluded that CT and MRI were more accurate than BIA in assessing SMM loss following glucocorticoid treatment. Similarly, Itoh et al. [12] assessed SMM by CT and a stronger correlation was found between CT and muscle strength and physical performance in liver-related hospital cases. Kuchnia et al. [13] on evaluating whether BIA values, phase angle and impedance, could be used to assess low muscularity and predict clinical outcomes, found that low phase angle and high impedance values were significantly associated with low muscle cross-sectional area. Thus, these two BIA parameters could be successfully used to predict low CT-derived muscle cross-sectional area.

Our study aimed to compare SMM from CT and BIA and assess the usefulness of BIA for SMM assessment in critically ill patients. In our study, SMM from CT and BIA showed a high correlation (p < 0.0001) regardless of patients' sex, muscle mass, or edema
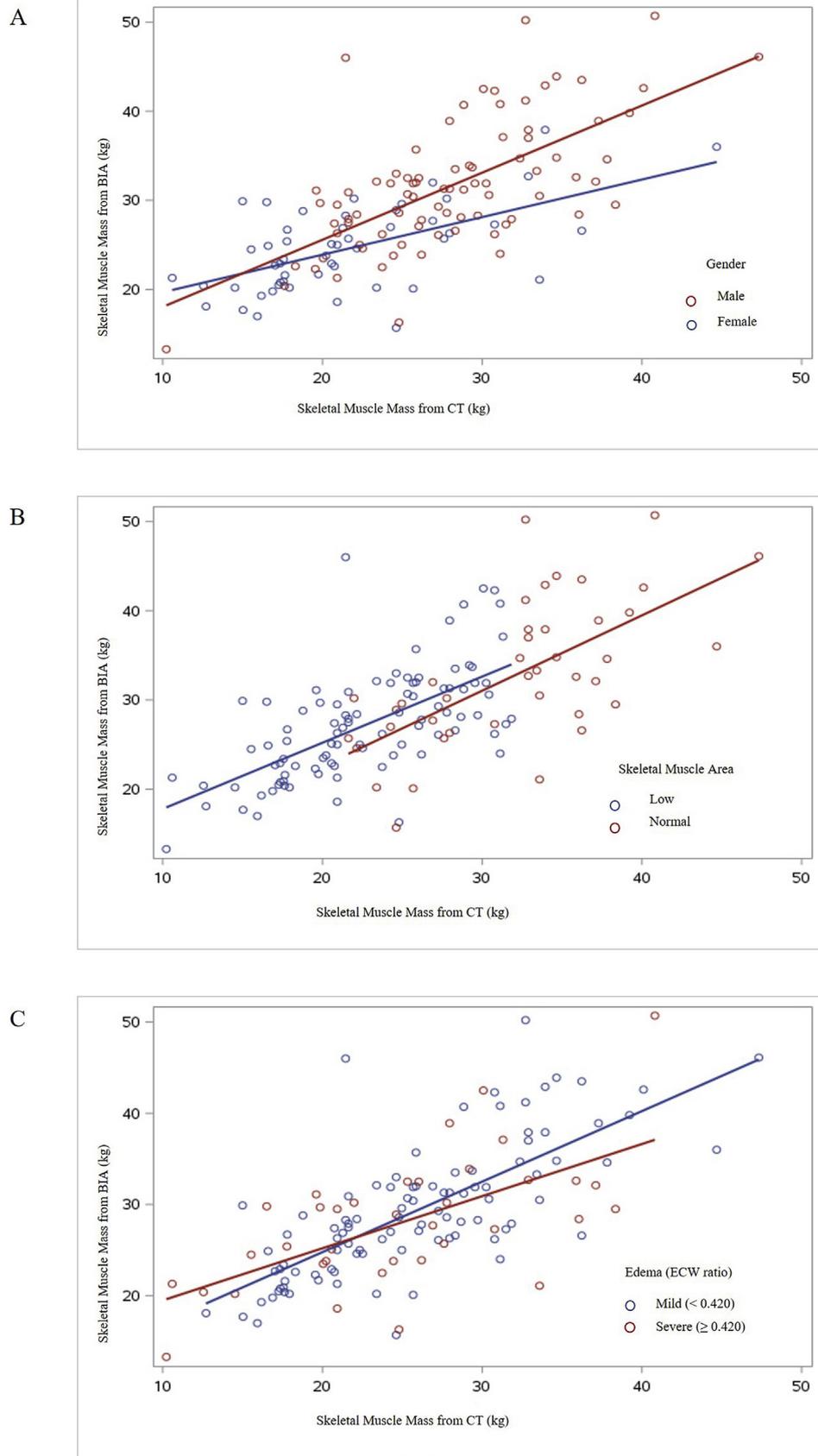
**Fig. 2.** Correlation between skeletal muscle mass measured by CT and BIA based on patients' (A) sex, (B) skeletal muscle area, and (C) edema subgroups.
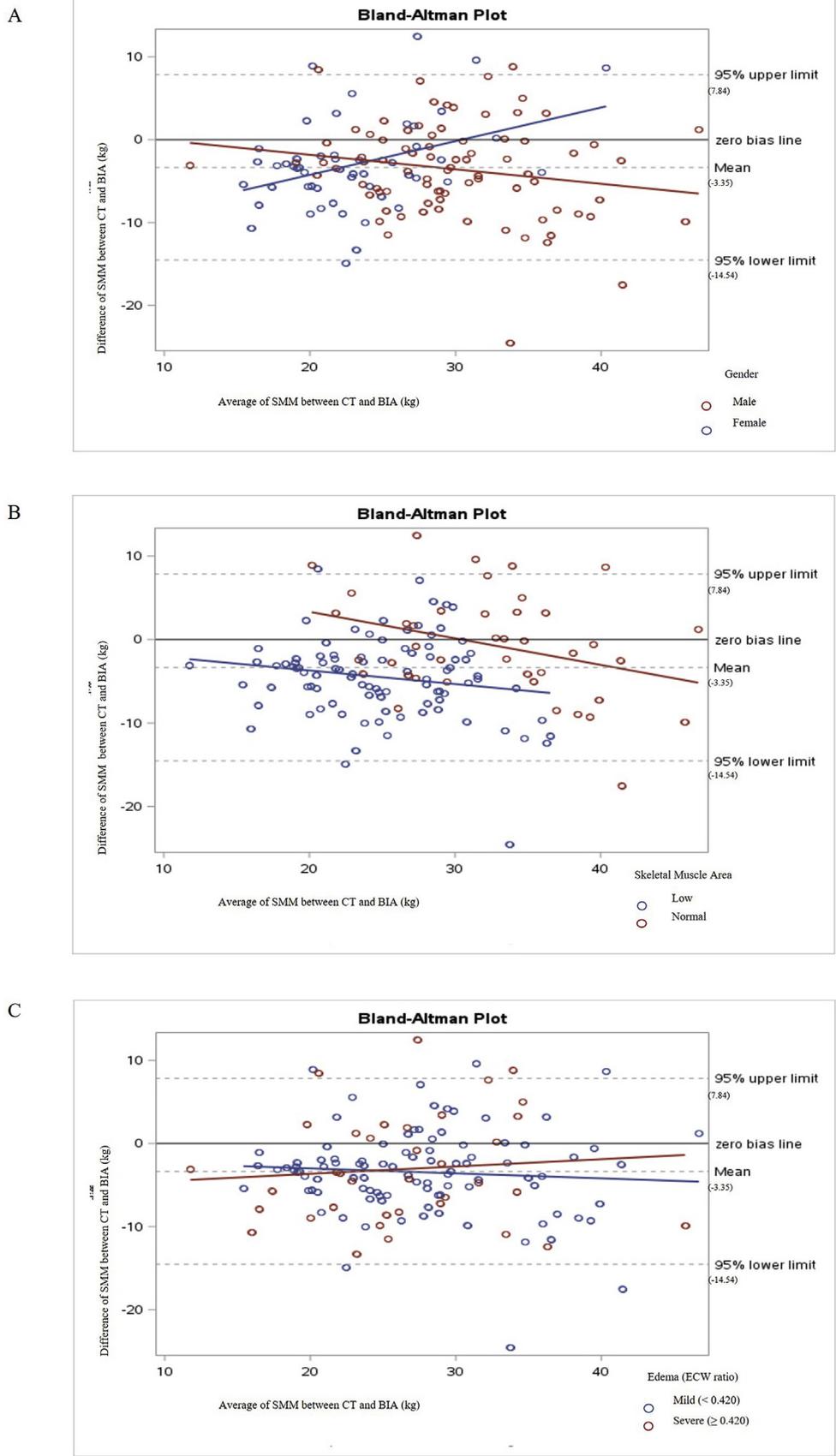
**Fig. 3.** Bland–Altman plots of agreement assess skeletal muscle mass between CT and BIA based on patients' (A) sex, (B) skeletal muscle area, and (C) edema subgroups.
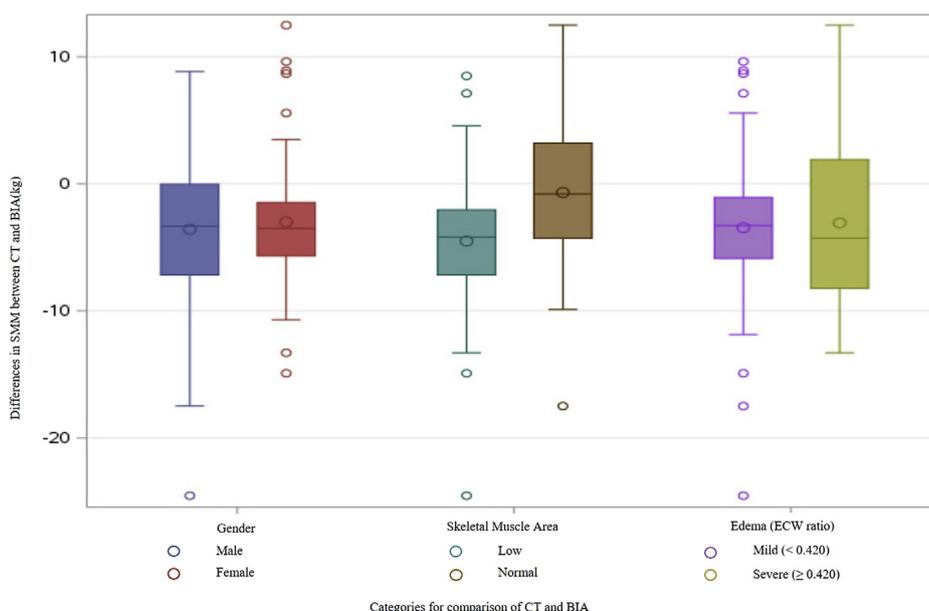
**Fig. 4.** Boxplots of differences in skeletal muscle mass between CT and BIA to the patients' sex, SMA, and edema subgroups and their subcategories.

**Table 3**
Test of difference of SMM between CT and BIA for sex, SMA, and edema.

| Variable | Wilcoxon's test | |
|---|---|---|
| | | **Rank-sum** |
| Sex | Male vs female | 0.8656 |
| SMA | Low vs normal | 0.0006 |
| Edema | Mild vs severe | 0.7583 |
| | | **Signed-rank** |
| Male | CT vs BIA | <0.001 |
| Female | CT vs BIA | <0.001 |
| Low SMA | CT vs BIA | <0.001 |
| Normal SMA | CT vs BIA | 0.479 |
| Mild edema | CT vs BIA | <0.001 |
| Severe edema | CT vs BIA | 0.007 |

status. Because of the muscle difference in male and female patients, we did a subgroup analysis based on the patients' sex. Both male and female patients showed a good correlation of SMM from CT and BIA, and generally SMM from BIA was greater than SMM from CT. However, as muscle mass increases, male patients showed a tendency of greater SMM from BIA than from CT, whereas female patients showed greater SMM from BIA than from BIA.

Low SMA means low SMM and indicated a weak muscle group. We assumed that muscle mass difference might affect the result of SMM from CT and BIA. In the low level SMA group, SMM from BIA seemed to be greater than SMM from CT, whereas no statistical difference was noted between the two methods in the normal SMA group.

Regarding edema status, muscle mass can be overestimated due to muscle swelling, and this overestimation would be similar in CT and BIA. Critically ill patients often show severe edema from vascular tone release or massive fluid resuscitation. Therefore, edema could be a major limitation of muscle mass assessment in ICU patients. We evaluated the SMM features according to the edema status using the ECW/TBW parameter from BIA. In subgroup analysis of edema status, SMM from CT and BIA showed the same tendency, a good correlation between the two methods, and higher SMM values from CT than BIA. Interestingly, SMM from CT or BIA in both mild and severe edema groups did not show any difference (CT: $p = 0.593$, BIA: $p = 0.485$). This result could be attributed to the compensation of muscle loss in patients with severe edema and the

over-measurement of muscle mass in more moderate edemas. A small sample size also could be a causative factor of getting indifference between mild and severe edema groups. If having enough large sample sizes to satisfy normality, the test results might be different.

Although CT scans has been typically used to measure body composition in critically ill patients, it has major limitations such as it requires patients to move to the inspection place and be exposed to contrast media, it is time consuming, and has a high cost. Additionally, the method requires radiologists to calculate SMA. There might be a measuring error by inspector or lack of accuracy on calibration of SMA from a single CT image. Moreover, SMA from patients with edema, usually staying in the ICU, may be abnormally measured by CT.

Compared to CT, BIA is not an impeccable technique to measure body composition. The validity and accuracy of estimated values by BIA have been debated for a long time. Nonetheless, BIA is currently used and studied with greater availability for critically ill patients. Lee et al. [10] used BIA as a marker of predicting severity scores in clinically ill patients. They showed that impedance, reactance, and phase angle which are determined by BIA were significant to predict mortality of patients and have a stronger predicting power than severity scoring systems commonly used in the ICU. Another group studied the use of BIA in assessing the nutritional status of critically ill patients and showed that phase angle and ECW ratio (ECW/TBW) may play an important role in assessing nutritional status and significant prognostic factor in the care of critically ill patients [14]. Also, there were some researchers studied for feasibility of BIA as measuring muscle mass in ICU patients [30] and how BIA can be used as a tool to measure of proportion of fatty and muscle tissues in patients who had muscle atrophy [31]. More studies regarding to availability of BIA in assessing body component accurately and evaluation of BIA compared with other methods may be required for further research.

This study had some limitations. First, this study was performed retrospectively with a small sample size in a single institution, which meant that there was lack of availability and variability for data collection. It also contributed to a lack of normal distribution on patient data, and thus, nonparametric statistical methods were required to detect the differences. Second, BIA was not performed

on the same day as CT scan. Although we selected patients who had BIA performed within 7 days from their CT scans, the mean discrepancy of 2.3 days between the two studies could have induced big alternations in the critically ill patients including muscle changes. Third, we did not include the patients' nutritional status and relationship between SMA or SMM and patients' malnutrition. However, we performed comparison of SMM from CT and BIA with a subgroup analysis of sex, muscle amount, and edema parameters. These subgroup analyses help to understand the SMM features of BIA compared to CT and increase the reliability of SMM assessment with BIA in critically ill patients.

Moreover, in terms of measuring muscularity in body, BIA has limitations comparing with other image techniques such as CT, MRI, and US. From what Hosono et al. [11] found on their study, we knew that accuracy of measuring SMM with CT and MRI were higher, or better, rather than measuring by BIA. Notwithstanding the advantage on accuracy level, they have limitations with regards to high costs and radiation exposure [32]. When comparing US with BIA, US has great information on muscle quality with different measurements, while BIA only has phase angle [33]. This could be a limit for BIA if qualification of muscles were needed.

## 5. Conclusion

The accuracy of BIA was high and comparable to that of CT scan in detecting low SMA from critically ill patients without edema. Moreover, it is simple, portable, and safe and has a low cost and short time required. Furthermore, it can figure out existence of edema right after the measurement. Therefore, BIA can be used to measure and analyze SMM in critically ill patients.

### Ethics approval and consent to participate

This study was performed after obtaining the approval of the Institutional Review Board (IRB) of Ajou University Hospital. Informed consent was obtained from all patients or their next of kin prior to their inclusion in this study.

### Authors' contributions

Dongha Kim – Formal analysis, writing-original draft, validation, visualization,
Joo Sung Sun – Data curation, software
Yeon Hee Lee, Ji Hyun Lee – Data curation, resources
Jeong Hong – Supervision
Jae-Myeong Lee – Conceptualization, data curation, funding acquisition, investigation, methodology, project administration, writing-review & editing

### Conflicts of interest

None.

### Abbreviations

| | |
|---|---|
| SMM | skeletal muscle mass |
| CT | computed tomography |
| BIA | bioelectrical impedance analysis |
| SMA | skeletal muscle area |
| ICU | intensive care unit |
| DEXA | dual energy X-ray absorptiometry |
| MRI | magnetic resonance imaging |
| MUAMC | mid-upper arm muscle circumference |
| MUAMA | mid-upper arm muscle area |
| MUAC | mid-upper arm circumference |
| TSF | triceps skinfold |
| US | ultrasound |
| TBW | total body water |
| ECW | extracellular water |
| ICW | intracellular water |
| FFM | fat-free mass |
| FM | fat mass |
| L3 spine | the third lumbar vertebrae |
| SD | standard deviations |
| ASM | appendicular skeletal muscle |

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