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Short Communication

Existing equations to estimate lean body mass are not accurate in the critically ill: Results of a multicenter observational study

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SUMMARY

Background & aims: Lean body mass (LBM), quantified using computed tomography (CT), is a significant predictor of clinical outcomes in the critically ill. While CT analysis is precise and accurate in measuring body composition, it may not be practical or readily accessible to all patients in the intensive care unit (ICU). Here, we assessed the agreement between LBM measured by CT and four previously developed equations that predict LBM using variables (i.e. age, sex, weight, height) commonly recorded in the ICU.
Methods: LBM was calculated in 327 critically ill adults using CT scans, taken at ICU admission, and 4 predictive equations (E1–4) that were derived from non-critically adults since there are no ICU-specific equations. Agreement was assessed using paired *t*-tests, Pearson's correlation coefficients and Bland–Altman plots.
Results: Median LBM calculated by CT was 45 kg (IQR 37–53 kg) and was significantly different ($p < 0.001$) from E1 (52.5 kg; IQR: 42–61 kg), E2 (55 kg; IQR 45–64 kg), E3 (55 kg; IQR 44–64 kg), and E4 (54 kg; IQR 49–61 kg). Pearson correlation coefficients suggested moderate correlation ($r = 0.739$, 0.756, 0.732, and 0.680, $p < 0.001$, respectively). Each of the equations overestimated LBM (error ranged from 7.5 to 9.9 kg), compared with LBM calculated by CT, suggesting insufficient agreement.
Conclusions: Our data indicates a large bias is present between the calculation of LBM by CT imaging and the predictive equations that have been compared here. This underscores the need for future research toward the development of ICU-specific equations that reliably estimate LBM in a practical and cost-effective manner.

1. Introduction

Loss of lean body mass (LBM) and skeletal muscle is a defining characteristic of malnutrition [1]. A high proportion of patients admitted to ICU exhibit some degree of malnutrition, with 63–71% having lower than what is to be considered normal muscle mass at the time of admission [2,3]. Those with low muscularity exhibit higher in-hospital mortality, increased ICU and hospital length of stays (LOS), decreased ventilator-free days and are more likely to be discharged to a nursing home [2,3]. However, to enable a more precise nutrition prescription and to determine the effectiveness of any targeted nutrition interventions on preservation of muscle mass in the critically ill, access to a universally practical, reliable, and cost-effective method to accurately estimate skeletal muscle and/or LBM at the bedside is required. Unfortunately, no such tool currently exists. Furthermore, as our understanding of protein requirements for the critically ill continues to evolve, it is plausible that nutrition therapies could be dosed based on lean body mass versus the more traditional methods of weight and BMI.

Several modalities can be used to measure lean body and/or skeletal muscle mass, including dual-energy X-ray absorptiometry (DXA), computed tomography (CT), ultrasound (US) imaging, and

Abbreviations: BIA, bioelectrical impedance analysis; CT, computed tomography; DXA, dual-energy X-ray absorptiometry; L3, 3rd lumbar vertebra; LBM, lean body mass; US, ultrasound.

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bioelectrical impedance analysis (BIA) [4]. DXA and CT are precise methods of assessing LBM and skeletal muscle mass, respectively, however neither are practical, widely accessible, nor cost-effective modalities that can be utilized at the bedside. In clinical populations, such as the critically ill, that tend to experience abnormal fluid shifts, BIA is not considered to be an accurate method of assessing body composition [5]. US is an emerging portable tool used to measure body composition in the ICU; however, validation and reliability studies are currently underway to assess its effectiveness for LBM measures and estimations. While weight and BMI are crude measures of body composition, these variables, in addition to height, age, and sex are easily obtained and universally accessible. To our knowledge, four predictive equations [6–9] exist that allow for the estimation of LBM using only such variables, however all were derived from non-acutely ill, community dwelling populations and may not acceptably predict LBM in critically ill populations (Table 1). Thus, the aim of this study was to assess the agreement between LBM as measured by CT, a highly precise method of quantifying LBM, and each of these four equations in a critically ill population.

2. Materials and methods

For this study, lean body mass was estimated for 327 critically ill patients from 12 ICUs in Canada ($n = 10$) and the United States ($n = 2$) using CT (reference method) and four different predictive equations [6–9]. CT images were acquired from two studies: a prospective randomized control trial ($n = 178$ CT images) with a population of adults with ≥ 2 organ failures upon ICU admission [11], and a retrospective analysis ($n = 149$ CT images) evaluating the body composition of elderly patients admitted to a trauma ICU (Table 1) [2]. In both studies, CT images taken as part of usual care within 2 days of admission to the ICU were analyzed using sliceOmatic version 4.3 image analysis software (TomoVision, Montreal, Canada). All sites participating in these studies received ethics approval from their respective Research Ethics Boards.

2.1. Estimation of lean body mass by CT (reference method)

Skeletal muscle mass cross-sectional area (cm^2) was determined from a single slice CT scan at the 3rd lumbar vertebra (L3) (method described elsewhere [12]). Total body LBM (kg) was subsequently predicted using the following equation:

$\text{LBM (kg)} = 0.30 \times [\text{skeletal muscle at L3 using CT } (cm^2)] + 6.06$ [12]

($r = 0.94$, standard error of the estimate $= 0.72$ kg, mean absolute residual error $= 2.94 \pm 2.46$ kg).

2.2. Estimation of lean body mass by predictive equations

Lean body mass was then estimated for each patient using four separate predictive equations stated as follows:

Equation 1 (E1) (Kulkarni et al. [7]):

Males: $\text{LBM (kg)} = -15.605 - (0.032 \times \text{age (y)}) + (0.192 \times \text{height (cm)}) + (0.502 \times \text{weight (kg)})$.

Females: $\text{LBM (kg)} = -15.034 - (0.018 \times \text{age (y)}) + (0.165 \times \text{height (cm)}) + (0.409 \times \text{weight (kg)})$.

Equation 2 (E2) (Weijs et al. [8]):

$\text{LBM (kg)} = \text{weight (kg)} \times 0.01 \times (100 - [64.5\text{–}848 \times \text{height (m)}^2/\text{weight (kg)} + 0.079 \times \text{age(y)} - 16.4 \times \text{sex} + 0.05 \times \text{sex} \times \text{age (y)} + 39.0 \times \text{sex} \times \text{height (m)}^2/\text{weight (kg)}])$, where sex $= 1$ (male), sex $= 0$ (female).

Equation 3 (E3) (Janmahasatian et al. [6]):

Males: $\text{LBM (kg)} = (9.27 \times 10^3 \times \text{weight (kg)})/(6.68 \times 10^3 + 216 \times \text{BMI (kg/m}^2))$.

Females: $\text{LBM (kg)} = (9.27 \times 10^3 \times \text{weight (kg)})/(8.78 \times 10^3 + 244 \times \text{BMI (kg/m}^2))$.

Equation 4 (E4) (Hume [9]):

$\text{LBM (kg)} = 0.32810 \times \text{weight (kg)} + 0.33929 \times \text{height (cm)} - 29.5336$.

2.3. Statistical analysis

Statistical analysis was carried out using SPSS Statistics version 23 (IBM Corp., Armonk, NY, USA). Continuous data are presented as mean (standard deviation) or median (interquartile range), as appropriate, and categorical data as counts (percentages). Estimated LBM calculated by CT and each equation were compared using a paired *t*-test and the relationship between these variables assessed using Pearson's correlation coefficients. A *P*-value of <0.05 was regarded as statistically significant.

Table 1
Summary of the populations and reference methods used in the derivation of each. Predictive equation to estimate lean body mass (LBM).

	Population characteristics	Reference method
Equation 1 (E1) (Kulkarni et al. [7])	Healthy adult males and females Race: Indian n = 2200	DXA
Equation 2 (E2) (Weijs et al. [8]) The equation presented in this paper was derived from an equation developed by Gallagher et al. [10]	Healthy adult males and females Mean age ranged from 48 to 56 years Race: Caucasian and African American n = 671	4-compartments technique incorporating DXA, tritium or deuterium dilution, hydrostatic weighing
Equation 3 (E3) (Janmahasatian et al. [6]):	Healthy adult males and females 18–82 years Race: not specified n = 70	DXA
Equation 4 (E4) (Hume [9]):	Adult males and females Race: not specified n = 56 *Healthy, n = 8* *Chronic bronchitis, n = 9* *Polycythaemia vera, n = 9* *Obesity, n = 3*	Antipyrine space

Abbreviations: DXA, dual-energy X-ray absorptiometry.

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