RIGINAL CLINICAL RESEARCH

Evaluation of the Ability of Point-of-Care Ultrasonography to Follow-Up the Changes in Resting Energy Expenditure in Critically Ill Patients

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Abstract

Background: We aimed to evaluate the accuracy of an ultrasound-derived equation for estimating the changes in resting energy expenditure (REE) in critically ill patients over 5 days using indirect calorimetry as the reference.

Methods: Critically ill, mechanically ventilated patients were included in the study. REE was measured using indirect calorimetry (measured REE) and estimated using point-of-care ultrasound (calculated REE) through an equation which included the muscle layer thickness (MLT), echocardiography-derived cardiac output (CO), and gender [the equation: calculated REE= (206 + 173.5 × CO (L/min) + 137 × MLT (cm) −230 × (women=1, men=0)]. Correlation between the absolute values of calculated and measured REE as well as the changes in both measurements after 5 days (Δ REE). Bland-Altman analysis for the mean bias and agreement between the calculated and measured REE and Δ REE was also performed.

Results: Sixty patients were available for the final analysis. There was no significant correlation between the Δ calculated REE and Δ measured REE (r-0.09, 95% confidence interval: -0.17 to 0.34). The mean bias between the Δ calculated REE and Δ measured REE was -8 ±239 kcal/day. There was a positive significant correlation between the absolute values of measured and calculated REE (r=0.44, 95% confidence interval: 0.28 to 0.57). The mean bias between the calculated and measured REE was -541±457 kcal/day.

Conclusion: There is a moderate correlation and poor agreement between ultrasound-derived and calorimetry-based REE. However, there was a low bias between the two methods in detecting the changes REE in a five-days interval.

Keywords: Cardiac output; critically ill; indirect calorimetry; resting energy expenditure; ultrasound.

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Introduction

Proper nutritional plan is an essential requirement in management of critically ill patients. Both malnutrition and overfeeding are associated with poor outcomes.[1, 2] Therefore, estimation of the caloric needs would allow matching the caloric intake with the actual requirements. Resting energy expenditure (REE) stands for 75%–100% of the total energy expenditure in critically ill patients. The reference route for measurement of REE in critically ill patients is the indirect calorimetry,[3] which measures the oxygen consumption and carbon dioxide production and estimate the REE using the Weir equation.[4] The other alternatives for the indirect calorimetry, which is commonly unavailable in many units, are predictive equations; however, the accuracy of the current predictive equations does not exceed 65% compared to the indirect calorimetry.[5]

The in-accuracy of the predictive equations might be due to is the lack of many determinants for REE such as the lean body mass and cardiac output (CO).[5, 6] In a previous study, a novel equation had been introduced for estimating of the REE using ultrasound-derived variables which represent the lean body mass and the CO. In the reported equation, musculoskeletal ultrasound was used for estimating muscle thickness and lean body mass[7] and transthoracic echocardiography was used for measurement of the CO.[8] The estimation equation of Mukhtar et al. explained 80% of the changes in the REE and was closer to the indirect calorimetry compared to the predictive equations. However, the ability of the equation to follow up the changes in the REE over time needs further research. The aim of this study is to evaluate the accuracy of the ultrasound-derived predictive equation for estimating REE in following up the change in the REE in critically ill patients over time.

Materials And Methods

Ethical considerations

The study was conducted after the approval of the Ethics Committee of the Faculty of Medicine, Cairo University, Egypt (10/11/2020). Written informed consents were obtained from the patients’ surrogates after being informed of the study goals and methods. The information of each participant was kept confidential.

Study design and setting

This prospective cohort study was conducted at Cairo University Hospital, Egypt, between December 2020 and June 2022.

Eligibility criteria

The study included critically ill, mechanically ventilated patient, aged > 18 years. Exclusion criteria included patient's surrogate's refusal to participate in the study, major endocrine dysfunction, hypothermia, body temperature above 39°C, mean arterial pressure < 65 mmHg despite full vasopressor and fluid support, poor visualization of the heart, fraction of inspired oxygen > 60%, positive end-expiratory pressure > 14 cmH2O, and air leakage from chest tubes. Patients were included in the study when they have an expected length of stay > 4 days. Patients who were extubated or dead before this interval were excluded for not having the required 2 measurements.

Procedures and interventions

All participants were mechanically ventilated using assisted-controlled mode and the following monitors were applied: electrocardiogram, pulse oximeter, invasive- and non-invasive arterial blood pressure monitors. The patients were sedated according to the discretion of the attending intensivist to achieve Richmond Agitation and Sedation Scale (RASS)[9] in a range between −3 and −1.

Nutritional plan

All patients received early enteral feeding unless contraindicated. The caloric intake was adjusted according to the indirect calorimetry while the protein intake was adjusted at 1.5 gm/kg/day. The total volume of enteral fluids was 30 mL/kg/day. Patients who were not able to tolerate enteral feeding received intravenous crystalloids (Ringer acetate and glucose 5%) at a rate of 30 mL/kg/day for the first 3 days. If enteral feeding was not tolerated 3 days after admission, patients received partial parental nutrition in form of glucose 10%, amino acids and electrolyte supplementation until day 7 with the same previously mentioned nutritional targets.

Ultrasound evaluation of arm and thigh

Ultrasound examination for muscle layer thickness (MLT) was performed with the patient positioned supine with extended arms and legs. The muscles were scanned in axial and longitudinal planes at standardized anatomical points: 1) MLT arm: was assessed over the biceps muscle while keeping patient's elbow extended and forearm supinated. The muscle thickness was measured midway between the tip of the acromion and the tip of the olecranon; 2) MLT thigh: was assessed at the mid-point between the anterior superior iliac spine and the upper pole of the patella. The ultrasound transducer was applied perpendicular to the skin in a non-compressing technique. Each muscle was scanned twice, and the average measurement was calculated for each anatomical point. The MLT measurements at the biceps and the thighs were summed to calculate the bone-free lean body mass.

Cardiac output measurement

Trans-thoracic echocardiography was performed by an experienced physician. With the patient positioned supine, the subaortic velocity time integral (VTI) was measured using a phased array probe at the pulsed-wave Doppler mode. The sample cursor was settled immediately proximal to the aortic valve in the apical five-chamber view. The left ventricular outflow tract diameter was measured at the left parasternal long-axis view. The left ventricular outflow diameter (LVOT) was calculated as the distance between the inflection points near the base of the aortic valve cusps. Based on the assumption that the LVOT had a circular cross section, the LVOT area was calculated from the LVOT diameter using the following equation:

$$\pi \text{ X } \left(\text{LVOT}\,\frac{\text{diameter}}{2}\right)^2 = \left(\text{LVOT}\,\frac{\text{diameter}}{2}\right)^2 \text{ X } 0.785.$$

The stroke volume was calculated as the product of the VTI and the LVOT diameter. All ultrasound measurements were done using a GE Vivid E9 echocardiographer.

Measurement and calculation of the REE

REE was obtained two times over a five-day interval. The changes in the REE values (ΔREE_C, ΔREE_H, and ΔREE_U) were calculated as the difference between the baseline values and those obtained after 5 days. REE was calculated using two methods:

A) Using indirect calorimetry (measured REE)

The patient was placed in the supine position with fixed ventilator settings, feeding rates, drug infusions and without any circuit disconnection, unless urgent, for 60 minutes before measurement.[10] The REE was measured using a General Electric ventilator (Engstrom Carestation and Carescape R860, GE Health care, USA) via a M-COVXTM metabolic module, and using standard techniques to obtain the calorimetric measurements. REE was calculated by using the modified weir equation: REE = [VO2 (3.941) + VCO2 (1.11)] 1440 kcal/day. Respiratory quotient was calculated as the ratio of CO_2 production over oxygen consumption (Respiratory quotient = VCO2 /VO2).[6] The respiratory quotient was used to assess reliability of displayed value of REE. Normal respiratory quotient should range between 0.69 and 0.98 and All values of REE with respiratory quotient outside this range were discarded.

B) Using point-of-care ultrasound (Calculated REE)

The REE was calculated using the ultrasound (Mukhtar et al. equation): 206 + 173.5 × CO (L/min) + 137 × MLT (cm) −230 × (women=1, men=0).[7]

Study outcomes

The primary outcome was correlation between Δ measured REE, and Δ calculated REE. Secondary outcomes included correlation between measured, and calculated REE. Bias and agreement between Δ measured REE, and Δ calculated REE. Bias and agreement between measured and calculated REE. Other data: age, gender, weight, height, cause of ICU admission, cause of mechanical ventilation, severity scores, and the presence of severe sepsis or septic shock at the time of data collection.

Sample size

MedCalc Software version 14 (MedCalc Sofware bvba, Ostend, Belgium) was used for sample size calculation. The sample size was calculated to detect a correlation coefficient of 0.5 between ΔREE_C, and ΔREE_U. The number of paired measurements to have a study power of 90% and an alpha error of 0.05 will be 37 patients which was increased to 40 patients to compensate for any dropouts.

Statistical analysis

Normality of the data was checked using Shapiro-Wilk test. Data were presented as either medians (interquartile ranges), means (standard deviations), and frequencies (%) as appropriate. The correlation between calculated and measured REE values was assessed using the Spearman rank correlation test or Pearson correlation test according to data normality. Bland-Altman method was used for detection of the mean bias and the 95% limits of agreement between calculated and measured REE values. The statistical significance was set at $P < 0.05$. The data analyses were performed using statistical software programs Statistical package for social science (SPSS) software, version 21 for Microsoft Windows (SPSS inc., Chicago, iL, USA), and MedCalc Software version 14 (MedCalc Sofware bvba, Ostend, Belgium).

Results

Demographic data and baseline clinical characteristics of the patients are shown in Table 1. Sixty-seven patients were screened for eligibility, seven patients were excluded for not fulfilling the inclusion criteria (four patients were excluded due to poor echo window and three patients were excluded for having systolic blood pressure < 90 mmHg despite the vasopressors). Sixty patients were included and were available for the final analysis (Figure 1).

There was a positive significant correlation between the absolute values of measured and calculated REE (r=0.44, 95% confidence interval: 0.28 to 0.57) (Figure 2). The mean bias between the calculated and measured REE was -541±457 kcal/day (Figure 3).

There was no significant correlation between the Δ calculated REE and Δ measured REE (r-0.09, 95% confidence interval: -0.17 to 0.34) (Figure 4).

The mean bias between the Δ calculated REE and Δ measured REE was -8 ±239 kcal/day (Figure 5).

Table 1. Demographic data and baseline clinical characteristics

Variable	Mean ± SD, median (quartiles), or frequency (%)
Age (years)	50 (40, 60)
Male (%)	25 (42%)
Weight (kg)	80 (70, 90)
Body mass index (kg.m^{-2})	27 ± 5
Primary cause of ICU admission	
Disturbed conscious level	16 (27%)
Post-emergency laparotomy	15 (25%)
Sepsis, septic shock	10 (17%)
Trauma	8 (13%)
Respiratory failure	7 (12%)
Acute kidney injury	4 (7%)
APACHE II score	16 (10, 21)
RASS score	-2 (-4, -2)
Baseline cardiac output (L/min)	7.8 ± 2.3
Baseline average MLT (cm)	6.7 (5.9, 6.9)

SD: standard deviation, APACHE II score: Acute Physiology and Chronic Health Evaluation II score, MLT: muscle layer thickness, RASS: Richmond Agitation and Sedation Scale

Data presented as mean standard deviation, median (quartiles), and frequency (%)

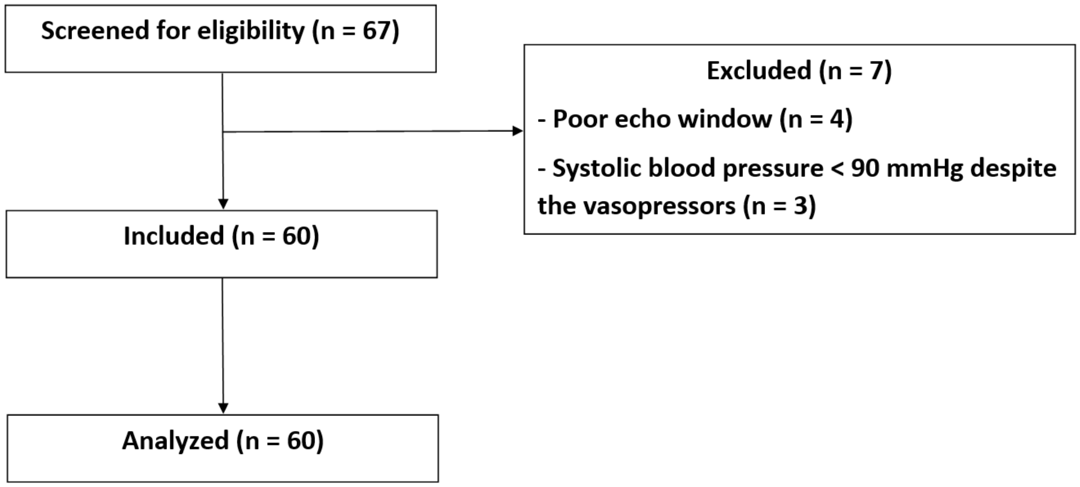

Figure 1. Patients' enrolment.

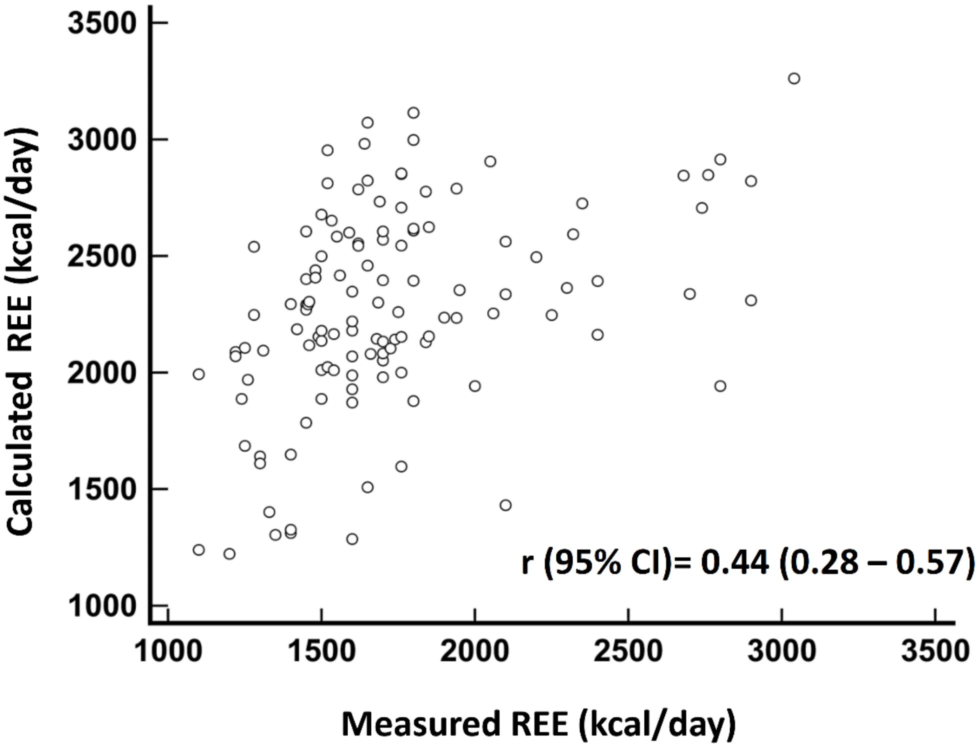

Figure 2. Scatter plot for the absolute REE values.

CI: confidence interval, r: Spearman correlation coefficient, REE: resting energy expenditure

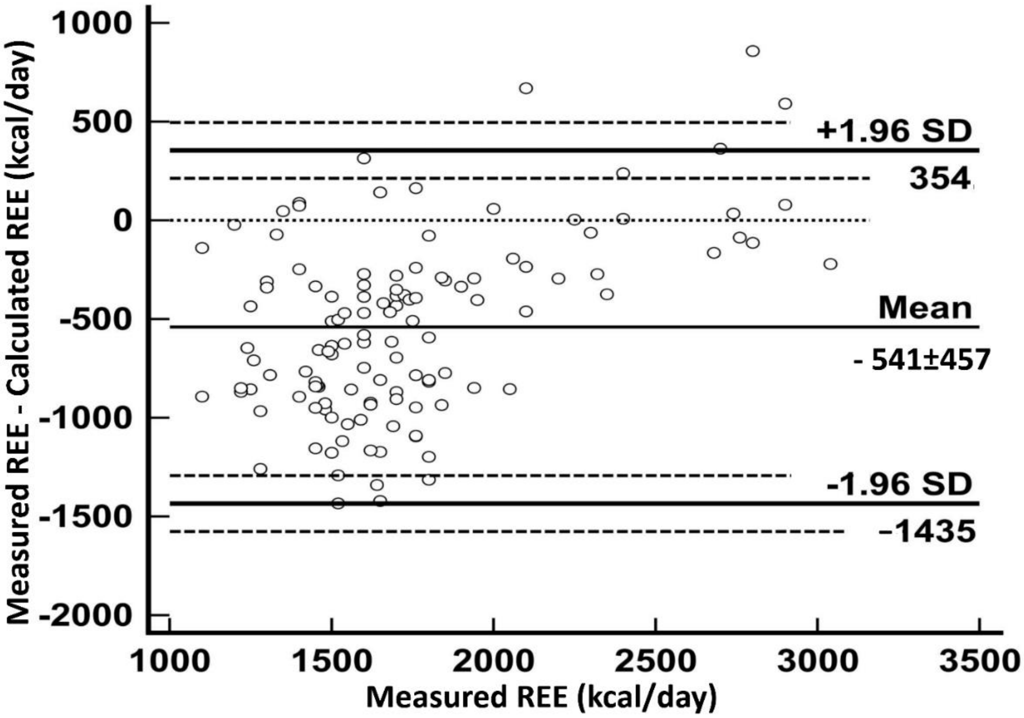

Figure 3. Bland-Altman plot for the absolute REE values

The horizontal solid lines represent the mean and the 95% limits of agreement, and the dashed horizontal line represent the 95% confidence interval of the limit of agreement. REE: resting energy expenditure

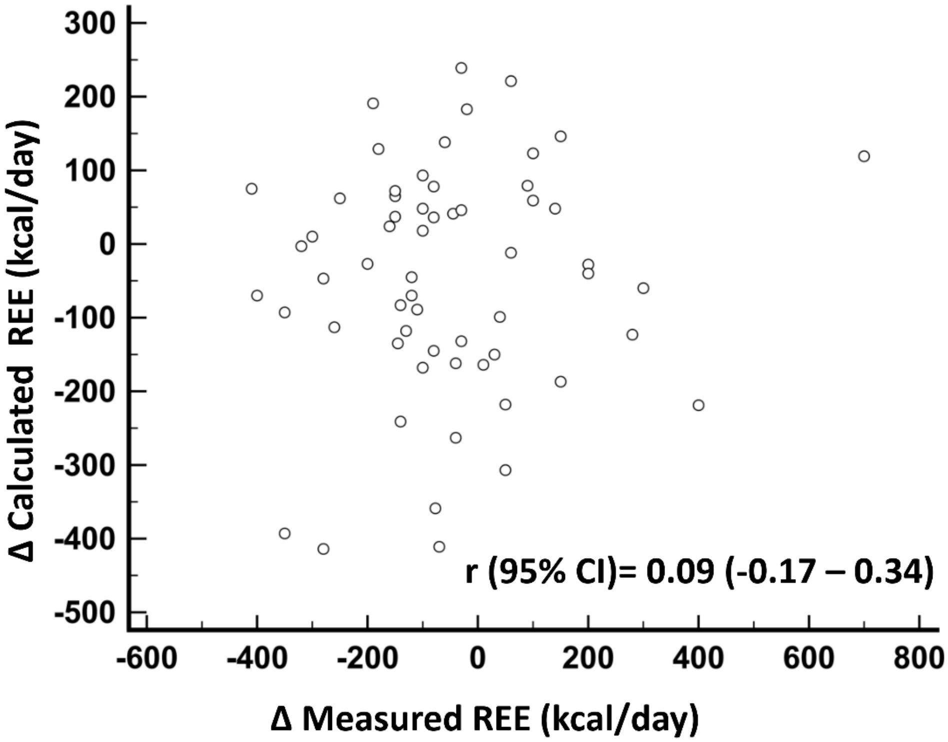

Figure 4. Scatter plot for the trending REE values

CI: confidence interval, r: Spearman correlation coefficient, REE: resting energy expenditure.

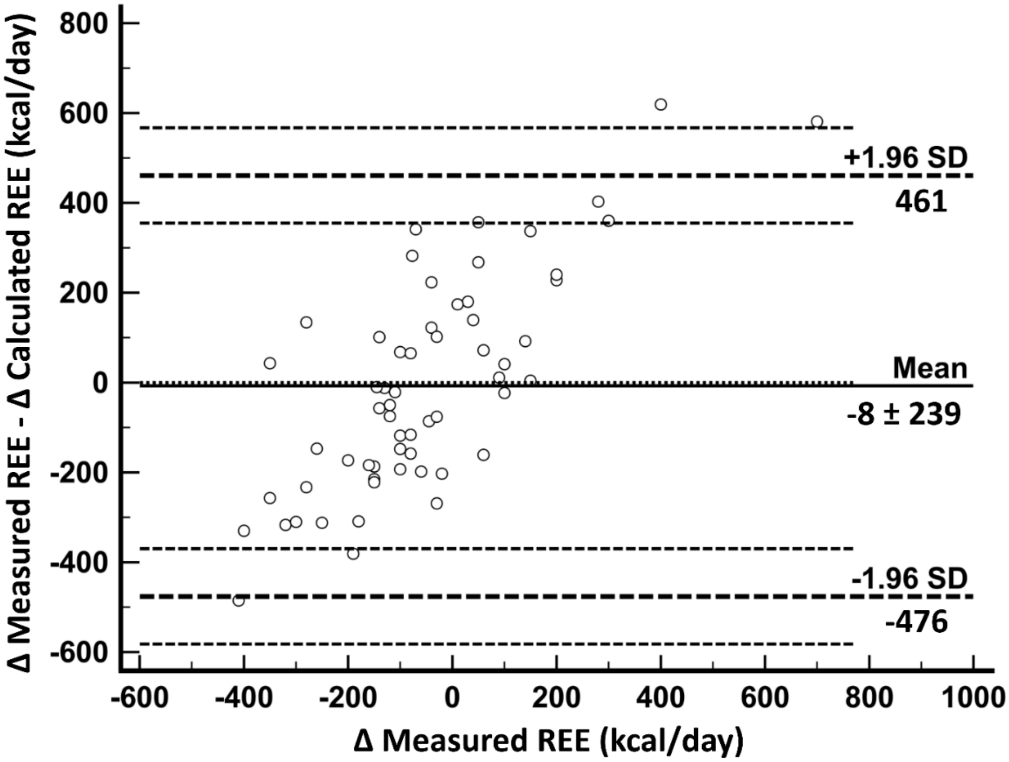

Figure 5. Bland-Altman plot for the Δ REE values

The horizontal solid lines represent the mean and the 95% limits of agreement, and the dashed horizontal line represent the 95% confidence interval of the limit of agreement. REE: resting energy expenditure

Discussion

We evaluated the accuracy of our previous equation for estimation of the REE in a cohort of surgical critically ill patients. Despite the presence of a moderate correlation between calculated and measured REE in the current study, the mean bias between the two values is relatively larger than that previously reported my Mukhtar et al. The presence of moderate correlation between the calculated- and measured REE in the current study supports the assumption that the change in REE could be detected using the ultrasound-derived equation. However, the relatively higher bias between the two methods suggests that more studies are required to validate and refine the previous equation. The difference between the current results and Mukhtar et al. results might be due to the different population as our study included lower number of septic shock patients compared to Mukhtar et al. cohort (17% vs 54%). The current study included a considerable proportion of head trauma patients while Mukhtar et al. study did not. Therefore, we believe that larger studies including separate analysis for each patient subgroup are needed to reach accurate equations for REE calculation using point-of-care ultrasound.

The trending ability of the equation was relatively better than that of the absolute values as the mean bias between Δ REE values was lower than bias between the absolute calculated- and measured REE values.

The original equation was based on a regression model which included the MLT, CO, and male gender and showed a linear relationship between the three variables and REE in critically ill patients.

Evaluation of the nutritional status of critically ill patients requires calculation of the lean body mass which can be estimated through measurement of the MLT.[13] There are several methods for estimation of the lean body mass such as predictive equations and radiological techniques. Predictive equations for the lean body mass are inaccurate.[14] Radiological techniques for estimation for MLT showed acceptable results such as computed tomography scan and musculoskeletal ultrasound with the later one being more practical in critically ill patients as it can be performed at the bedside.[15] Musculoskeletal ultrasound was able to predict the lean body mass with good accuracy using whole body dual-energy X-ray absorptiometry as reference standard.[16]

The second element in Mukhtar et al. equation is the CO. In a previous report, Floh et al. demonstrated an association between CO and REE in children undergoing cardiac surgery.[6]

The third factor in the equation is the gender. There is no definitive explanation for the higher REE in males compared to females. Higher muscle mass and lower adipose tissue within muscular layers might be responsible for this finding.[17] However, in Mukhtar et al. study, male gender remained an independent predictor for REE even after adjustment for all confounders.

Indirect calorimetry is a gold standard tool for measuring REE.[3, 18] However, indirect calorimetry is not widely used in critical care units due to lack of equipment. The commonly used equations for calculation of the REE are also not accurate. Therefore, having an easy bedside approach to estimate the REE would improve the nutritional plan of the patients. Point-of-care ultrasonography has the advantage of being non-invasive and simple in performance; furthermore, ultrasound machines are widely available nowadays in most units for being useful in several cardiac, thoracic, neurological, and vascular purposes. Our results relatively debated the accuracy of the previous equation for predicting REE using point-of-care ultrasonography. Thus, it is essential to perform larger studies in different patient subgroups for validation of the equation. We found that the ability of the equation to follow up the changes in REE is better than the absolute values.

Conclusion

There is a moderate correlation and poor agreement between ultrasound-derived and calorimetry-based REE. However, there was a low bias between the two methods in detecting the changes REE in a five-days interval.

Funding

None.

Conflict of interest

The authors declare no competing interests.

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