Energy expenditure in mechanically ventilated patients: The weight of body weight!

GRAF, Séverine, et al.

Abstract

Optimal nutritional care for intensive care unit (ICU) patients requires precise determination of energy expenditure (EE) to avoid deleterious under- or overfeeding. The reference method, indirect calorimetry (IC), is rarely accessible and inconstantly feasible. Various equations for predicting EE based on body weight (BW) are available. This study aims at determining the best prediction strategy unless IC is available.

Reference


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Energy expenditure in mechanically ventilated patients: The weight of body weight!

Séverine Graf a, b, Claude Pichard a, Laurence Genton a, Taku Oshima a, Claudia Paula Heidegger b, *

a Clinical Nutrition Unit, Geneva University Hospitals, Switzerland
b Division of Intensive Care, Geneva University Hospitals, Switzerland

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SUMMARY

Background & aims: Optimal nutritional care for intensive care unit (ICU) patients requires precise determination of energy expenditure (EE) to avoid deleterious under- or overfeeding. The reference method, indirect calorimetry (IC), is rarely accessible and inconstantly feasible. Various equations for predicting EE based on body weight (BW) are available. This study aims at determining the best prediction strategy unless IC is available.

Methods: Mechanically ventilated patients staying >72 h in the ICU were included, except those with contraindications for IC measurements. IC and BW measurements were routinely performed. EE was predicted by the ESPEN formula and other predictive equations using BW (i.e. anamnestic (AN), measured (MES), adjusted for cumulated water balance (ADJ), calculated for a body mass index (BMI) of 22.5). Comparisons were made using Pearson correlation and Bland & Altman plots.

Results: 85 patients (57 ± 19 y, 61 men, SAPS II 43 ± 16) were included. Correlations between IC and predicted EE using the ESPEN formula with different BW (BWAN, BWME, BWADJ, and BWBMI22.5) were 0.44, 0.40, 0.36, and 0.47, respectively. Bland & Altman plots showed wide and inconsistent variations. Predictive equations including body temperature and minute ventilation showed the best correlations, but when using various BWs, differences in predicted EE were observed.

Conclusion: No EE predictive equation, regardless of the BW used, gives statistically identical results to IC. If IC cannot be performed, predictive equations including minute ventilation and body temperature should be preferred. BW has a significant impact on estimated EE and the use of measured BWMES or BWBMI22.5 is associated with the best EE prediction.

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Ethical committee number: CE-14-070.

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1. Introduction

Optimal nutritional care for intensive care unit (ICU) patients requires precise determination of the energy expenditure (EE) to avoid under- or over-feeding, both being deleterious [1,2]. Although indirect calorimetry (IC) is considered the reference method to determine EE, it is rarely available and suffers from some limitations in its feasibility. Various equations for predicting EE based on body weight (BW) have been proposed. This study aims at determining the best EE prediction strategy when IC is not available.

EE can be determined by three methods in ICU patients. Firstly EE can be computed from pulmonary artery catheter measurements, using the Fick equation; however this method is highly invasive as it requires a right heart catheter. Secondly EE can also be measured by IC, which is the recommended method [3,4]. However, IC requires a trained staff, an expensive and validated calorimeter for accurate measurements [5,6] and is contraindicated in a number of clinical situations in the critically ill patient (e.g. air leaks in the circuit, ventilation with inspired fraction of oxygen (FiO2) > 60%, end-expiratory pressure (PEEP) > 9 cm H2O, gas...
exchange therapy or inhaled nitrogen gas). Only about 70% of the critically ill ICU patients can be measured by this method [7]. Finally, EE can be estimated by using predictive equations. Of note is that most of these equations were developed for healthy people. For ICU patients, a number of correction factors have been suggested taking account of different stress levels, type of treatments, and body compositions such as severe obesity or extreme leanness (i.e. sex, age, height, weight, body temperature, minute ventilation, pathology, severity of disease…). All predictive equations include patients’ body weight (BW). However, the use of BW in ICU patients is highly controversial because it largely varies according to fluid retention and edema related to the inflammation process and resuscitation therapies [8].

This quality of care study is part of a global effort to improve and harmonize our clinical practices. It aims at identifying the best EE prediction strategy, with regard to the choice of the BW and of the predictive equation, when IC is not available.

2. Materials and methods

2.1. Patients

Patients mechanically ventilated, staying ≥72 h in the ICU were included. Due to our infection control policy, patients with respiratory multi-drug resistant bacteria were excluded as well as those with unstable pH, FiO2 > 60%, PEEP > 9 cm H2O, and pulmonary fistula.

The Ethical Committee of the Geneva University Hospital approved this study. They waived the need for a written consent because the study was part of a continuous quality of care improvement in our ICU, and because the study did not generate any additional risks for the patient as the measurements are routinely performed in our ICU.

2.2. Methods

The clinical data were prospectively collected from our electronic medical records. These data included gender, body temperature, details of mechanical ventilation (type of ventilator, spontaneous or controlled ventilation, minute ventilation, etc), laboratory data, treatments received the day of IC measurement (morphine, sedatives etc.), anthropometric data (height, anamnestic BW, age), ICU admission diagnosis and severity scores (APACHE II and SAPS II) during the first 48 h after ICU admission and at the time of the IC measurement.

❖ Anthropometric data and predictive equations

Anamnestic body weight (BWAN) was obtained from the electronic medical file or from the family members. Actual body weight (BWMESS) was measured using the built-in bed scale. Adjusted body weight (BWADJ) was determined by correcting the measured body weight (BWMESS) according to the cumulative fluid balance calculated from the ICU admission to the day of the IC measurement. Ideal BW (IBW) was calculated for a reference body mass index (BMI) at 22.5 kg/m2 (IBW22.5), and at 25 kg/m2 (IBW25) or calculated from the ICU admission to the day of the IC measurement. Ideal BW was calculated using the Metropolitan Life Insurance tables (IBWMLI), the Lorentz equation (IBWLO) (height (cm)/C0) and the Broca equation (IBWBRO) (height (cm)/C21). We then used the following equations to calculate EE with the different BWs listed above: ESPEN formula [9], Harris–Benedict, Black et al. [10], Faisy et al. [7], Frankenfield et al. [11], Brandi et al. [12], Ireton-Jones et al. [13], Penn State et al. [14] and Swinamer et al. [15] (web Appendix Table 4).

❖ Indirect Calorimetry

IC was performed using the Deltatrac II® (Datex, Finland) as previously described [5]. Each measurement was done by trained professionals for at least 25 min. Data of the first 5 min were discarded. Patients were measured in standardized conditions [16] and on-going feeding was not interrupted.

2.3. Statistical analysis

Data are presented as mean ± standard deviation (SD), or median and range, as appropriate. Parametric analyses were used after confirming the normal data distribution using Skewness and Kurtosis tests.

We compared the different BWs by one-way ANOVA followed, in case of significance, by a Bonferroni post-hoc test. T-tests were used to assess the differences of mean EE obtained from IC measurements with binary variables such as gender, fever, surgical versus medical patients, fed versus fasting patients, and spontaneous versus controlled ventilation modes.

We correlated the predictive equations with different BWs and IC by Pearson’s correlation tests. The distribution of patients with predicted EE below 90% of measured EE by IC (underestimation), between 90 and 110% (acceptable), and over 110% (overestimation) were calculated in percentage. These percentages were considered as a measure of the precision of the predictive strategies. Bland & Altman plots were performed to determine the variability between the IC data (considered as the reference) and the predictive equations with the various BWs. Mean differences with limits of agreement (±2 SD) were recorded as the reflection of the accuracy.

STATA version 13.0 (StataCorp, Texas, USA) was used for the analyses and the level of significance was set at 0.05.

3. Results

Eighty-five patients were included (Table 1 and web Appendix Fig. 1), of which 26 patients were on controlled and 59 on spontaneous ventilation. The different BWs are presented in Table 1 and show significant differences with measured BW (p < 0.001) (web Appendix Table 1). The influence of the different BWs used in the EE predictive equations is significant for the Black equation (p = 0.0001), the Brandi equation (p = 0.0017), the ESPEN formula (p < 0.0001), the Frankenfield equation (p = 0.0018), the Harris–Benedict equation (p < 0.0001) and the Penn State equation (p = 0.0001), but has no impact for the Ireton-Jones equation (p = 0.7744), the Faisy equation (p = 0.0950) and the Swinamer equation (p = 0.7900).

Measured EE was obtained by IC performed on the median of the 4th day after admission (range 1–15). No statistical difference was observed between the results of medical and surgical patients (p = 0.6935), fed and fasting patients (p = 0.3967), and spontaneous and controlled ventilation (p = 0.1126). On the contrary, gender and temperature ≥37 °C were associated with significant difference in EEs (p = 0.0004 and 0.0051, respectively). Calculated EEs with predictive equations differed from EE measured by IC (Table 2; more details on web Appendix Table 2). Best Pearson correlations with measured EE are observed with results from the Frankenfield or the Penn State predictive equations, whereas the ESPEN formula, whatever the BW selected, presented poor correlation (0.36).

The occurrence of underestimation of EE when calculated, compared to the measured EE is least frequent with the Penn State equation using measured BW, whereas overestimation of EE is the least frequent with the Frankenfield equation using the ideal BW calculated for a BMI at 22.5 kg/m² (Fig. 1, web Appendix Table 3).
Table 1
Patients’ anthropometric and clinical characteristics at calorimetry measurement.

<table>
<thead>
<tr>
<th></th>
<th>All (n = 85)</th>
<th>Men (n = 61)</th>
<th>Women (n = 24)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>57 ± 19</td>
<td>56 ± 20</td>
<td>60 ± 16</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.71 ± 0.09</td>
<td>1.75 ± 0.07</td>
<td>1.62 ± 0.07</td>
</tr>
<tr>
<td>BWAN</td>
<td>76.1 ± 14.8</td>
<td>78.9 ± 12.7</td>
<td>69.0 ± 17.4</td>
</tr>
<tr>
<td>BWAN2.25</td>
<td>66.1 ± 7.1</td>
<td>68.9 ± 5.8</td>
<td>59.1 ± 4.6</td>
</tr>
<tr>
<td>BWADJ</td>
<td>79.5 ± 15.3</td>
<td>82.3 ± 14.7</td>
<td>72.2 ± 14.9</td>
</tr>
<tr>
<td>BWAV</td>
<td>75.9 ± 15.5</td>
<td>78.7 ± 14.5</td>
<td>68.8 ± 16.2</td>
</tr>
<tr>
<td>BMI with BWMES</td>
<td>27.1 ± 4.9</td>
<td>27.0 ± 4.8</td>
<td>27.5 ± 5.2</td>
</tr>
<tr>
<td>BMI with BWADJ</td>
<td>25.9 ± 4.9</td>
<td>25.8 ± 4.6</td>
<td>26.2 ± 5.7</td>
</tr>
<tr>
<td>SAPS II (point)</td>
<td>43 ± 16</td>
<td>44 ± 16</td>
<td>40 ± 17</td>
</tr>
<tr>
<td>APACHE II (point)</td>
<td>23 ± 6</td>
<td>23 ± 6</td>
<td>22 ± 7</td>
</tr>
<tr>
<td>Inspired fraction of oxygen (%)</td>
<td>28 ± 7</td>
<td>27 ± 6</td>
<td>29 ± 8</td>
</tr>
<tr>
<td>PEEP (cm H2O)</td>
<td>6 ± 1</td>
<td>6 ± 1</td>
<td>6 ± 1</td>
</tr>
<tr>
<td>Minute ventilation (l/min)</td>
<td>9 ± 3</td>
<td>10 ± 3</td>
<td>9 ± 3</td>
</tr>
<tr>
<td>Body temperature (°C)</td>
<td>37 ± 1</td>
<td>37 ± 1</td>
<td>37 ± 1</td>
</tr>
<tr>
<td>C-reactive protein (mg/l)</td>
<td>108 ± 79</td>
<td>95 ± 85</td>
<td>119 ± 62</td>
</tr>
<tr>
<td>Heart rate (pulse)</td>
<td>83 ± 21</td>
<td>82 ± 23</td>
<td>88 ± 17</td>
</tr>
<tr>
<td>Mitral arterial pressure (mmHg)</td>
<td>85 ± 15</td>
<td>85 ± 15</td>
<td>86 ± 17</td>
</tr>
</tbody>
</table>

Data are presented in mean ± standard deviation.
BW: body weight; AN: anamnestic; MES: measured; ADJ: adjusted for cumulated water balance; SAPS II: severity score “Simplified Acute Physiology Score”; APACHE II: severity score “Acute Physiology And Chronic Health Evaluation”; PEEP: positive end-expiratory pressure.

Table 2
Comparison between indirect calorimetry and predictive equations with the most relevant body weights.

<table>
<thead>
<tr>
<th></th>
<th>Pearson correlation</th>
<th>Mean ± DS</th>
<th>Meanb</th>
<th>Limits of agreement (±2 SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indirect calorimetry</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESPEN*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BWAN</td>
<td>0.44</td>
<td>2181 ± 490</td>
<td>−271</td>
<td>(−1272; 229)</td>
</tr>
<tr>
<td>BWAN*</td>
<td>0.40</td>
<td>2178 ± 516</td>
<td>−265</td>
<td>(−1339; 271)</td>
</tr>
<tr>
<td>BWADJ</td>
<td>0.36</td>
<td>2281 ± 518</td>
<td>−368</td>
<td>(−1477; 186)</td>
</tr>
<tr>
<td>BWRES</td>
<td>0.47</td>
<td>1895 ± 309</td>
<td>15</td>
<td>(−812; 428)</td>
</tr>
<tr>
<td>Frankenfield*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BWAN</td>
<td>0.71</td>
<td>1780 ± 316</td>
<td>130</td>
<td>(−518; 777)</td>
</tr>
<tr>
<td>BWADJ</td>
<td>0.70</td>
<td>1802 ± 312</td>
<td>111</td>
<td>(−549; 770)</td>
</tr>
<tr>
<td>BWRES</td>
<td>0.70</td>
<td>1824 ± 307</td>
<td>88</td>
<td>(−572; 740)</td>
</tr>
<tr>
<td>Faisy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BWAN</td>
<td>0.63</td>
<td>1951 ± 276</td>
<td>−42</td>
<td>(−753; 670)</td>
</tr>
<tr>
<td>BWADJ</td>
<td>0.63</td>
<td>1954 ± 268</td>
<td>−42</td>
<td>(−746; 714)</td>
</tr>
<tr>
<td>BWRES</td>
<td>0.62</td>
<td>1962 ± 263</td>
<td>−70</td>
<td>(−785; 699)</td>
</tr>
<tr>
<td>BWRES2.25*</td>
<td>0.63</td>
<td>1871 ± 244</td>
<td>38</td>
<td>(−675; 752)</td>
</tr>
<tr>
<td>Penn State*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BWAN</td>
<td>0.70</td>
<td>1871 ± 363</td>
<td>38</td>
<td>(−619; 695)</td>
</tr>
<tr>
<td>BWADJ</td>
<td>0.69</td>
<td>1899 ± 361</td>
<td>14</td>
<td>(−658; 350)</td>
</tr>
<tr>
<td>BWRES</td>
<td>0.69</td>
<td>1927 ± 355</td>
<td>−15</td>
<td>(−687; 322)</td>
</tr>
<tr>
<td>BWRES2.25*</td>
<td>0.72</td>
<td>1738 ± 310</td>
<td>171</td>
<td>(−464; 807)</td>
</tr>
</tbody>
</table>

*ANOVA p-value < 0.05.
*Bonferroni post-hoc p-value < 0.05.
bMean differences.

The plot distribution shows no tendency for systematic over- or underfeeding when using the different predictive equations. Similar results are found when using the Penn State equation with the measured BW.

Finally, none of the equations are accurate enough to replace IC as their variability (±2 SD) is clinically significant (±652 kcal using Frankenfield equation with ideal BW for a BMI at 22.5) (Fig. 2).

4. Discussion

This study shows for the first time that the choice of the BW used in predictive equations has a significant impact on the evaluation of the EE in ICU patients (web Appendix Table 1). It also reconfirms that no predictive equation accurately matches the EE measured by IC.

4.1. Body weight measurement is inaccurate

Irten-Jones et al. [17] suggested that the measured BW is more suitable for use in EE predictive equations compared to the ideal...
BW obtained from the Metropolitan life Insurance Company standards. Cutts et al. [8] reported that adjusted BW is preferable to BW obtained from the Metropolitan life Insurance Company standards. Cutts et al. [8] reported that adjusted BW is preferable to BW obtained from the Metropolitan life Insurance Company standards. Cutts et al. [8] reported that adjusted BW is preferable to BW obtained from the Metropolitan life Insurance Company standards.

Our results are consistent with those of others studies demonstrating that EE predictive equations poorly predict EE measured by IC [18–20]. This observation is at least partly due to the inaccuracy of BW determination/evaluation. First, the so-called actual BW is often estimated or anamnestic, which can create major errors. Second, measured BW can be a poor indicator of the metabolic requirements in the presence of fluid retention related to metabolic stress, kidney or heart failures, fluid administration or diuretics administration [8]. However, it seems less worse when BW is estimated. Third, the BW poorly reflects the metabolically active lean body mass (i.e. mostly muscle mass) which deeply influences EE [21]. Indeed, even with the same BW, a sarcopenic obese elderly patient typically features a reduced lean body mass and low EE, whereas a young athletic patient would have a minimal fat body mass, and a high EE. As the metabolically active lean body mass is the major determinant of the resting EE, the development of predictive formulas including this factor in replacement of body weight seems a reasonable approach. However measurements of lean body mass are difficult in the critical care settings, mainly because of the technical limits of the different methods [22]. The gold standard for measuring body composition is dual-energy X-ray absorptiometry (DXA). However, DXA requires complex equipment and trained manpower and cannot be performed at the bedside for routine use in all ICU patients. Bioelectrical impedance analysis (BIA) allows to measure body composition but results are strongly influenced by fluid and electrolytic imbalances frequently observed in the critically ill patients (edema, ascites, renal failure, etc.), making the measurements unreliable. Muscle sonography is a promising alternative to assess muscle mass, and may become useful in the near future [23]. Measurements of lean body mass derived from routine CT-Scan obtained at the level of the third lumbar vertebra (L3), allows to calculate the total skeletal muscles area at this body level, but does not measure whole body composition, and it’s capacity to predict the total body lean mass remains to be proven. Finally, BW does not take into account the impact on EE of preexisting metabolism alterations [24] as well as metabolic alterations secondary to the injury response [25].

### 4.2. ICU-specific equations perform better

The Frankenfield equation [10] with the ideal BW for a BMI at 22.5 kg/m² and the Penn State equation [13] with the measured BW, show the best correlation with the measured EE. However, the relative risks of under- or overestimation of EE should be taken into account when using these two equations.

The worst results were obtained with the ESPEN formula using the measured BW (mean difference −368 ± 555 kcal) as shown in Table 2 and web Appendix Table 2. A fixed amount of calories per kg of BW, is recommended by the ESPEN Society for ICU patients (i.e. 20–25 kcal/kg acute phase, 25–30 kcal/kg/d later on) [4]. Although this concept is pragmatic, it is probably too simple to fit for a highly heterogenous population of ICU patients as previously suggested [26]. Compared to other equations, the Faisy [7], Frankenfield [11] and Penn State [14] take into account specific criteria such as minute ventilation or body temperature. In spite of this characteristics, their accuracy compared to IC remains limited probably because of other factors influencing EE such as medications, treatments and significant EE variations occurring during the course of the critical illness [27–29].

In absence of IC, our results suggest that the use of measured BW or adjusted BW for cumulated water balance is an acceptable option when used in conjunction with ICU patient specific EE predictive equations (i.e. Frankenfield [10], Penn State [13]), although this method is associated with overestimation of EE in nearly 20% of cases. The use of ideal BW based on the body height is the easiest method, independent of any fluid overload, but does not take into account the variations related with the metabolic disturbances or the lean body mass mentioned above, and therefore leads to the largest errors of EE prediction. This method is associated with a high risk of underestimation of EE even when used with ICU-specific EE predictive equation.

### 4.3. Future developments

As the IC is the recommended method to know precisely EE, an on-going international initiative to develop a new IC is supported by the European Society of Clinical Nutrition (ESPEN) and the European Society of Intensive Care Medicine (ESICM) [2]. This device has been conceived to be accurate, affordable and without the actual limitations of clinical use. The clinical tests are currently performed and the availability of the device is expected for 2016.
4.4. Study limitations

This prospective unblinded study has a number of limitations such as the great heterogeneity of the ICU patient population and its metabolic variations during the different phases of critical illness which impact on the results of EE measurements. Indeed, timing of IC measurements was made according to our routine measurements of EE and probably does not reflect the changes of EE during the rest of the day in the ICU. Also, our study population may not reflect all ICU patients as patients with contraindications to IC, representing about 30% of all ICU patients, were not included and so didn’t take part in the comparisons of predictive equations with various BWs and IC. In spite of these limitations, we believe that our findings remain clinically relevant for most of the ICU patients.

5. Conclusion

No predictive equation of EE, regardless of the BW used, gives statistically identical results to IC. If IC cannot be performed, EE predictive equations which include body temperature and minute ventilation should be preferred. BW has a significant impact on estimated EE, the use of measured BW or the ideal BW for BMI at 22.5 is associated with the best EE estimation.

Conflict of interest

Financial support came from the APSI-ICU quality funds of the Geneva University Hospital. All authors declare that they have no conflict of interest, except Claude Pichard who has received grants from the European Society of Clinical Nutrition (ESPEN) and the European Society of Intensive Care Medicine (ESCIIM) to lead an international initiative to develop a new IC.

Statement of authorship

Séverine Graf conceived the study, participated in its design, recruited patients, collected, analyzed and interpreted the data, and drafted the manuscript. Claudia-Paula Heidegger participated in the study design, obtained funding and drafted the manuscript. Laurence Genton participated in the interpretation of the data and drafted the manuscript. Taku Oshima participated in the collection and interpretation of the data and drafted the manuscript. Claudia Pichard participated in the study design, interpretation of the data, and drafted the manuscript.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.clnu.2015.11.007.

References