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Original Article

Comparative Characteristics of Some Methods for Estimating Energy Expenditure in Critically Ill Mechanically Ventilated Patients

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Abstract

Aim: To compare the energy expenditure (EE) assessed by ventilator-derived carbon dioxide production (EE–VCO_2-ventilator) and the energy expenditure calculated from six predictive equations with the gold standard energy expenditure measured with indirect calorimetry (IC) in mechanically ventilated patients.

Materials and methods: This is a prospective, non-randomized, one-month study which included six mechanically ventilated patients with FiO_2 <60% and PEEP <10 mbar. Thirty-minute measurements were taken using a Cosmed Q-NRG+ metabolic monitor. The average ventilator-derived VCO_2 from the Drager Evita Infinity V500 respirator ($V'CO_2$, ml/min) was calculated for the same period. The IC-measured EE (MEE-IC) was compared with EE–VCO_2-ventilator by a formula proposed in ESPEN (8.19×VCO_2) and with six predictive equations.

Results: Mean MEE-IC was 1650±365 kcal. Mean measured EE–VCO_2-ventilator was 1669±340 kcal. A statistically nonsignificant difference was found between the two measurements (p=0.84, correlation coefficient 0.98). Of the predictive equations we compared, the best correlation to the reference method was the Penn State 3 with mean EE of 1679±356 (p=0.81, correlation coefficient of 0.78).

Conclusions: In critically ill mechanically ventilated patients, the assessment of EE based on a ventilator-derived VCO_2 is an alternative to IC and is more accurate than most predictive equations.

Keywords

calories, energy metabolism, indirect calorimetry, predictive equations

INTRODUCTION

Nutritional support is an integral part of intensive care. In practice, caloric needs are estimated using both measured energy expenditure (MEE) and a fixed sum of calories based on predictive equations.[1-4] Energy expenditure (EE) during the stay in the ICU is known to be dynamic, influenced by body temperature[5], nutritional support[6], presence of sepsis[7], level of sedation[8], and physiotherapy[9]. The only measurement of EE using techniques such as indirect calorimetry (IC) can accurately estimate the energy requirements of critically ill patients (CIP).[10] Measurement of EE contributes to the prevention of overfeeding during the early phase of intensive care and underfeeding during the late phase, both of which are associated with increased mortality.[11-13]

EE can be accurately calculated with IC which measures oxygen consumption (VO_2) and carbon dioxide production (VCO_2) from the respiratory mixture.[14,15] EE can then be calculated using Weir's abbreviated formula[16]:

EE kcal/day =
$3.941 \times VO_2$ (L/min) + $1.11 \times VCO_2$ (L/min)$\times 1440$

Although IC is the reference method for EE assessment[17], metabolic monitoring is often unavailable, implementation of IC is time- and resource-consuming, and even in a prospective clinical trial study, IC is performed effectively in only 40% of patients[18]. Therefore, daily assessment of EE by IC is difficult to implement but may be important, as EE is known to vary significantly over time because of changes in metabolic rate.[19-21]

In CIPs, the EE calculated by predictive equations shows a significant difference from MEE measured by IC.[22] More than 200 predictive equations have been developed, and there is no consensus on which of them should be used in routine practice. It is best to use specific equations in patients like the reference population from which the equation was derived. Equations that only consider static variables such as height, age, weight, and gender and do not account for metabolic changes are proverbially inaccurate in estimating the caloric needs of critically ill patients. If equations are to be used to calculate the EE in critically ill patients, the Penn State University equations are the best choice because they include some dynamic parameters, such as body temperature and minute ventilation.[23,24]

An alternative method is the assessment of EE based on ventilator-derived VCO_2. Modern mechanical ventilators can measure VCO_2 continuously, making the method practical and allowing long-term monitoring.[25-27] Since the respirator cannot measure VO_2, the Weir's equation is adjusted using a respiratory quotient (RQ) to calculate EE as follows:

EE kcal/day = $(3.941 \times VCO_2/RQ + 1.11 \times VCO_2) \times 1440$

To date, several studies have examined the EE–VCO_2-ventilator with mixed results.[25-27,31-33]

AIM

The aim of the present study was to compare the EE–VCO_2-ventilator in mechanically ventilated patients calculated by the formula ($8.19 \times VCO_2$)[2,25], as well as EE from six predictive equations with a reference method MEE-IC.

MATERIALS AND METHODS

This is a prospective, non-randomized study conducted over a period of one month. It included six mechanically ventilated patients who were hospitalized and treated in the ICU of the Clinic of Anesthesiology and Intensive Care at St George University Hospital in Plovdiv. Thirty 30-minute measurements were taken using a Cosmed Q-NRG+ metabolic monitor. Three to seven measurements per patient were performed on different days. The sample of patients was random. They were between 52 and 62 years old, two men and four women. Two patients with polytrauma, one of them with a dominant thoracic trauma, with a thoracic drain placed, but with a reported leak from mechanical ventilation of less than 8%. The remaining patients had subdural hematoma or intracerebral hemorrhage. In 8 of the measurements, the patients were conscious and evaluated by GCS, with an average score of 12 points. In the rest of the measurements, the patients were sedated and assessed according to the Ramsay sedation scale, with an average score of 3-4 points. One of the patients was connected to the ventilator with a tracheostomy cannula, the others were connected with endotracheal tubes. In 14 of the measurements, the patients were on pressure support ventilation, in the remaining measurements, they were in a combined mode - controlled plus supported ventilation, the average measured minute ventilation was 8 liters, and the average leak from mechanical ventilation was 4%. Only in three measurements did the patients receive vasopressors but continued to have mean arterial pressures greater than 65 mmHg; otherwise, all patients had stable hemodynamics. The calorimeter was calibrated according to the manufacturer's recommendations with a routine Pneumotach test before each measurement, as well as a monthly Gas Analyzer test and a Blower test. Patients' inclusion criteria were stable condition at least 30 minutes before measurement, normocapnia, ventilation with FiO_2 <60% and PEEP <10 mbar. The average CO_2 production from the Drager Evita Infinity V500 respirator ($V'CO_2$, ml/min) was tracked for the same period. The MEE-IC was compared with EE–VCO_2-ventilator calculated by this formula - $8.19 \times VCO_2$[2,25] as well as with EE from six predictive equations: the Harris-Benedict[28], the Mifflin-St. Jeor[29], the equations of Penn State University[30], from the proposed body weight formulas of ASPEN[4] 12–25 kcal/kg/d and ESPEN[2] 20–25 kcal/kg/d, 20 kcal/kg/d, and 25 kcal/kg/d were included in the comparison. The average minute ventilation for the calorimetry period as well as the highest body temperature recorded during the last 24 hours was taken to calculate the Penn State University equations. The mean EE of the different methods was calculated. The MEE by IC is the method used as a reference to which the results achieved by all other prediction methods are compared. The mean difference and the standard deviation between each of the calculation methods and the reference one were presented as ΔcEE-mEE. Student's *t*-test was applied to compare paired data. Correlations were calculated using the Pearson's test and the results were presented as *r*.

RESULTS

The average MEE–IC was 1650 kcal. The mean measured EE–VCO_2-ventilator was 1669 kcal. A statistically non-significant difference was found between the two measurements (p=0.84, r=0.98), the mean difference to the reference method and standard deviation (19±68). Of the predictive equations we compared, the lowest difference to the reference method was calculated with the Penn State 3 (30±236), mean EE of 1679 (p=0.81, r=0.78). The obtained results are presented in **Table 1**.

DISCUSSION

The present prospective study in mechanically ventilated patients confirms the concept that EE can be accurately estimated by ventilator-derived VCO_2. Moreover, it shows that this method is more accurate than most predictive equations, especially those using only static parameters. However, the Penn State 3 equation is a good choice if predictive equations are to be used because it includes variables (minute ventilation and body temperature).

The results of our study are consistent with those of Stepel et al., who, in a sufficient sample size (84 patients on mechanical ventilation, a heterogeneous group), compared MEE from a 24-h IC, EP–VCO_2-ventilator as well as EE–VCO_2 from a metabolic monitor. They found that the EE–VCO_2-ventilator was acceptably accurate and more precise than predictive equations.[25] Based on the study, ESPEN[2] in 2018 recommended that in the absence of IC, measurement of EE should be carried out by using the carbon dioxide production obtained from the ventilator according to the formula proposed by Stepel: EE = $VCO_2 \times 8.19$.[25] In another study which makes a comparison of a different method of energy expenditure in COVID-19 mechanically ventilated patients, Saseedharan et al.[31] concludes that the EE estimated by ventilator-derived carbon dioxide correlated better with IC values than the energy expenditure derived from weight-based calculations.

One of the latest studies, Linder et al.[32] published on 7 January 2023, shows that median measured resting EE was significantly higher in the critically ill (1457 kcal/d) versus the healthy cohort (1351 kcal/d), with low predictive equations accuracy rates (21% to 49%), showing again the need to be more accurate.

Rousing et al.[26] confirmed the lack of accuracy of predictive equations and indicated the use of VCO_2 as a more accurate alternative for EE estimation. The study confirms that using only VCO_2 without VO_2 is a sensitive method for determining EE. This study's shortcoming is using VCO_2 only from the calorimeter and not from the ventilator. Koekkoek et al.[27] came out with a controversial opinion: EE–VCO_2-ventilator compared to EE–IC overestimates actual energy expenditure, and predictive equations, although inaccurate, may even predict EE better compared to the VCO_2 method. In this study, in contrast to Stepel's study[25], a greater difference in reported VCO_2 from the ventilator compared with VCO_2 from the metabolic monitor was noted, which appears to be the cause of an overestimation of EE–VCO_2-ventilator versus EE–IC. In the study by Koekkoek et al.[27], the authors themselves indicated that the significant bias and low levels of accuracy in the study could be attributed to inaccuracy in VCO_2 measurement from the ventilator (calibration error, patient-ventilator desynchronization), or inaccuracy of the metabolic monitor

Table 1. Comparative characteristics of different methods for estimating energy expenditure

Measurement	Mean	Mean ΔcEE-mEE ± SD	p-value	r
VCO_2 (ml/min)				
IC	194			
Ventilator	204		0.44	0.91
Energy expenditure (kcal/d)				
IC	1650			
VCO_2-ventilator	1669	19±68	0.84	0.98
Harris-Benedict	1663	−143±68	0.12	0.72
ESPEN/ASPEN (20 kcal/kg/d)	1577	−73±279	0.41	0.65
ESPEN/ASPEN (25 kcal/kg/d)	1971	321±288	0.002	0.65
Mifflin-St. Jeor	1528	−121±204	0.23	0.83
Penn State 1	1754	104±265	0.31	0.70
Penn State 2	1593	−57±284	0.51	0.63
Penn State 3	1679	30±236	0.81	0.78

ΔcEE-mEE: the difference between measured energy expenditure by indirect calorimetry and calculated energy expenditure by predictive equations, as well as by ventilator-derived carbon dioxide production; VCO_2: the carbon dioxide production; ESPEN: European Society for Clinical Nutrition and Metabolism; ASPEN: American Society for Parenteral and Enteral Nutrition; r: correlation coefficient.

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(error during calibration, large variability (>10%) of VCO_2 and VO_2 during measurement. Another reason for the difference between the two studies was a difference in the duration of the measurements, which was 24 hours in the study by Stapel et al.[25] and 6 times per day for 10 minutes each in the study by Koekkoek et al.[27]

Briassoulis et al.[33] conclude that VCO_2-derived predicted EE cannot be recommended as an alternative to EE measured by IC in mechanically ventilated children. They stated that a new generation of user-friendly, cost-effective calorimeters incorporated into the ventilators' hardware and software is a one-way street to overcome the current limitations in reliably measuring real-time EE in an intensive care setting. To some extent, we agree with that. IC remains the gold standard method to measure EE. Maybe, this new generation of calorimeters is the future, but they are not widespread in the world, also results of measurements with them will be discussed first. So, while IC is still a time- and resource-consuming process, we need an alternative. In this study, calculated EE by predictive equations in children is not included.

A disadvantage of our study is the small number of patients, 6 patients who had a total of 30 measurements on different days, which can be a potential source of bias in the obtained results. Moreover, factors such as gender and age are not taken into consideration.

CONCLUSIONS

In critically ill patients on invasive mechanical ventilation, assessment of EE by analysis of CO_2 production by the ventilator is a reliable alternative. EE–VCO_2-ventilator is more accurate than most predictive equations. Unlike indirect calorimetry, the method is easy to apply, convenient for long-term monitoring, does not take additional time and resources, and is not associated with additional disconnection of the patient from the respiratory circuit. The results of our study coincide with those of Stapel et al. Further research is needed to determine the applicability of the method in routine practice. If, however, it is necessary to use predictive equations in mechanically ventilated patients, the Penn State 3 equation is a good choice.

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Сравнительная характеристика некоторых методов оценки энергетических затрат у больных в критическом состоянии на искусственной вентиляции лёгких

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Резюме

Цель: Сравнить энергозатраты (EE), оценённые по выработке углекислого газа аппаратом искусственной вентиляции лёгких (EE-VCO_2-вентилятор), и энергозатраты, рассчитанные по шести прогностическим уравнениям, с золотым стандартом энергозатрат, измеренным с помощью непрямой калориметрии (IC) у пациентов с искусственной вентиляцией лёгких.

Материалы и методы: Это проспективное нерандомизированное месячное исследование, в которое вошли шесть пациентов с искусственной вентиляцией лёгких с FiO_2 <60% и PEEP <10 mbar. Тридцатиминутные измерения проводились с использованием метаболического монитора Cosmed Q-NRG+. За тот же период рассчитывали среднее значение VCO_2, полученное аппаратом искусственной вентиляции лёгких от респиратора Drager Evita Infinity V500 ($V'CO_2$, ml/min). EE, измеренные IC (MEE-IC), сравнивались с EE-VCO_2-вентилятором по формуле, предложенной в ESPEN (8.19×VCO_2), и с помощью шести прогностических уравнений.

Результаты: Средний MEE-IC составил 1650±365 kcal. Среднее измеренное EE–VCO2-ИВЛ составило 1669±340 kcal. Между двумя измерениями была обнаружена статистически недостоверная разница (p=0.84, коэффициент корреляции 0.98). Из прогностических уравнений, которые мы сравнивали, наилучшей корреляцией с эталонным методом был Penn State 3 со средним EE 1679±356 (p=0.81, коэффициент корреляции 0.78).

Заключение: У критически больных пациентов, находящихся на искусственной вентиляции лёгких, оценка EE на основе VCO_2, полученного с помощью вентилятора, является альтернативой IC и более точной, чем большинство прогностических уравнений.

Ключевые слова

калории, энергетический обмен, непрямая калориметрия, прогностические уравнения