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**S. Petros**
**L. Engelmann**

# Validity of an abbreviated indirect calorimetry protocol for measurement of resting energy expenditure in mechanically ventilated and spontaneously breathing critically ill patients

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S. Petros (✉) · L. Engelmann
Universität Leipzig, Medizinische Klinik I,
Abteilung für Intensivmedizin,
Philipp-Rosenthal-Strasse 27a,
04103 Leipzig, Germany
E-mail: pets@medizin.uni-leipzig.de
Phone: +49-0341-9712706
Fax: +49-0341-2615456

**Abstract** *Objective*: To test a short indirect calorimetry protocol with five stable 1-min readings (5-min steady state) against the commonly used protocol of 30 1-min readings (30-min steady state) in critically ill patients with various modes of ventilation.
*Design:* A prospective clinical study.
*Setting:* A medical ICU of a university hospital.
*Subjects:* Forty-six mechanically ventilated patients (group A and B), and 16 spontaneously breathing patients (group C).
*Intervention:* Indirect calorimetry with the Deltatrac II MBM-200 Metabolic Monitor.
*Results:* Mechanically ventilated patients were classified into group A (controlled) and B (assisted) depending on the ventilation mode. All patients in group A, but only 48.8 % of those in group B, received some form of analgosedation, and the doses were significantly higher in group A. The 30-min steady state test was 100.0 %, 83.7 %, and 75.0 % successful in group A, B, and C, respectively. The corresponding rate for the 5-min steady state test was 100.0 %, 81.4 %, and 100.0 %, respectively. The coefficient of determination ($r^2$) for resting energy expenditure between the two protocols ranged between 0.972 and 0.994. The time required to collect the 5-min steady state data was 5.5 ± 1.1, 9.9 ± 5.7, and 6.5 ± 3.3 min for group A, B, and C, respectively.
*Conclusion:* Indirect calorimetry with 5-min steady state test correlated very well with the 30-min steady state test in both mechanically ventilated and spontaneously breathing patients. The time required varies depending on the mode of ventilation, and it is influenced by the level of sedation in mechanically ventilated patients. The abbreviated protocol may be more acceptable to spontaneously breathing patients.

**Keywords** Indirect calorimetry · Mechanical ventilation · Critical illness · Intensive care · Steady state · Abbreviated protocol

## Introduction

Variation in the metabolic state is a common finding in critically ill patients [1, 2, 3, 4, 5] and predictive equations are not accurate enough [6, 7, 8, 9, 10, 11, 12, 13, 14]. Therefore, frequent measurements of energy expenditure may be necessary to avoid over- and underfeeding and their consequences [7, 15]. Measuring respiratory gas exchange with indirect calorimetry [16, 17, 18] is a useful tool. However, there are limitations to its widespread implementation, since the device is relatively expensive and the methodology lengthy for routine use. The test protocols for resting energy expenditure (REE) in mechanically ventilated patients are not standardised, although a period of 20–30 min has been commonly used. Adding the time the patient should be left undisturbed and that required for preparation [19, 20], the whole procedure may last over 60 min, which may hamper routine patient care. An abbreviated protocol may thus be an alternative. Previous authors have already shown this possibility for total energy expenditure [6] and REE [21], although their data were not clearly predefined. A recent study [22] reported that five stable 1-min readings (5-min steady state) have a very good correlation with the 30 1-min readings (30-min steady state) in sedated, mechanically ventilated patients. However, this has not been validated for different modes of ventilation. The aim of this study was to test the validity of an indirect calorimetry protocol with 5-min steady state test compared to the more standard 30-min steady state test in critically ill patients with various modes of ventilation. Factors, such as sedation, neuromuscular relaxation, and organ dysfunction states, that may influence the test were also considered.

## Materials and methods

The study included critically ill patients admitted to the Medical ICU of the University of Leipzig, Germany. Patients ventilated with an inspiratory oxygen fraction ($FIO_2$) > 0.6 or positive end-expiratory pressure (PEEP) > 10 $cmH_2O$, with chest tubes, or with gross inconsistencies in their vital signs were excluded. The Servo 300 ventilator (Siemens-Elema, Solna, Sweden) was used and a test for air leaks was conducted adapting a procedure already described [23]. The metabolic monitor was connected to an in vitro system consisting of a test lung ventilated by the same ventilator type used on the patient. Breathing frequency, tidal volume, and $FIO_2$ were adjusted. Since no oxygen was consumed or carbon dioxide added to this system, oxygen consumption ($VO_2$) and carbon dioxide production ($VCO_2$) was zero. Leaks within the ventilator circuit of the individual patient were ruled out using volume-controlled mode of ventilation with a predefined tidal volume and frequency. Patients were left undisturbed for at least 30 min and ventilator parameters unchanged for 60–90 min before starting with and during the calorimetry [20]. The cuff pressure of the tracheal tube was controlled and, if need be, adjusted before the test. Mechanically ventilated patients were usually sedated with midazolam in combination with ketamine or fentanyl or alone. Propofol was administered instead of midazolam in only three patients. The neuromuscular relaxant pancuronium was used as deemed necessary. The decision on the use of these drugs was made by physicians not involved in this study. Mechanically ventilated patients were tested in either controlled or assisted or in both modes of ventilation, with at least 24 h elapsing between the tests in the last case. The data were then classified into group A (controlled) and B (assisted) according to the ventilation mode.

Indirect calorimetry in spontaneously breathing patients (group C) was carried out, after prior informed consent, adopting standard widely accepted protocols using a hood: overnight fasting, measurement in the morning between 7.00 a.m. and 8.00 a.m. after the subject was awake for about an hour, under room temperature, in a half-darkened room, and quiet environment with the subject lying supine. Febrile or agitated patients were excluded.

The Deltatrac II MBM-200 Metabolic Monitor (Datex-Ohmeda, Finland) was used in this study and the test was to last at least 35 min. Gas calibration was done before each measurement with a standard calibration gas supplied by the manufacturer (95 % $O_2$, 5 % $CO_2$). Values for $VO_2$, $VCO_2$, minute ventilation ($V_E$) (in mechanically ventilated patients), respiratory quotient (RQ), and energy expenditure (EE) were recorded every minute. Data for the first 5 min were routinely discarded to exclude artefacts during connecting the calorimeter to the patient. Data presentation henceforth does not include these 5 min.

The test was considered a success if there was a period of 30 consecutive minutes with a coefficient of variation ≤ 10 % for $VCO_2$ and $VO_2$. A 5-min steady state was defined as the first five consecutive stable 1-min readings with a coefficient of variation ≤ 5 % for $VCO_2$ and $VO_2$ [21, 22]. The first five and 15 1-min readings were also tested without considering a 5-min steady state phase but using the same criteria used to define a 5-min steady state test.

Data for body temperature, body weight, vital signs, the Sequential Organ Failure Assessment (SOFA) score, and dose of sedatives and neuromuscular blockers were collected during each test.

Statistical analysis was conducted using the program SPSS for Windows version 8.0 (SPSS, Chicago, Ill., USA). Student's *t* test, Fisher exact test, and linear regression analysis were used. Values are given as mean ± SD unless stated otherwise. A $p$ value of < 0.05 was considered significant.

## Results

Forty-six (28 males and 18 females) mechanically ventilated patients aged 59.7 ± 18.9 years were included in group A and B. There was a total of 86 tests with 43 tests in each group. Forty patients were tested in both controlled and assisted modes, three each in controlled or assisted mode only. The test was successful in all cases in group A and in 36/43 (83.7 %) cases in group B. In this study, only pressure-controlled and pressure support ventilation modes were considered.

The major diagnoses on the test day were: septic shock (20 in group A, six in group B), severe sepsis (18, 16), congestive heart failure (two, eight), pneumonia (two, seven), chronic obstructive lung disease (six cases in group B), and hepatic coma (one case in group A). Sepsis was diagnosed as defined by Bone et al. [24]. The SOFA score was significantly higher in group A than B [11.6 ± 4.4 vs 7.7 ± 3.5, $p = 0.001$, confidence interval (CI) 2.16–5.6]. All the patients in group A, but only 48.8 % of those in group B, received some form of analgosedation (doses in μg/kg per minute). The dose of midazolam for group A($n = 40$) was 3.0 ± 1.1 and for group B ($n = 19$) 1.7 ± 1.1 ($p < 0.001$, CI = 0.65–1.89). The doses for ketamine were 13.0 ± 7.0 ($n = 34$) and 6.3 ± 3.0 ($n = 11$), respectively ($p < 0.001$, CI = 3.67–9.8). Eight patients in group A and four in group B received fentanyl instead of ketamine. Pancuronium was administered as a bolus of 8 mg in eight patients of group A within 2 h before the test. In group B, 20/36 (55.6 %) patients in the success group but only one of the seven patients (14.3 %) in the "failure" group were sedated. Taking group A and B together, sedation had

**Table 1** Success rates (%) for indirect calorimetry at various time points

| Study group | $n$ | Five-minute steady state | First 5 1-min reading | First 15 1-min reading |
|---|---|---|---|---|
| A | 43 | 100.0 | 79.1 | 72.1 |
| B | 43 | 81.4 (97.2)[a] | 30.2 (36.1)[a] | 32.6 (38.9)[a] |
| C | 16 | 100.0 | 83.3 | 50.0 |

[a] Numbers in brackets are the rates in the subgroup with a successful 30-min steady state test ($n = 36$)

a significant influence on the success of the 30-min steady state test ($p = 0.001$).

Group C included 16 spontaneously breathing patients (six with sepsis, five with pneumonia, two with severe pulmonary hypertension, one each with alcoholic hepatitis, Child C liver cirrhosis, and congestive heart failure), seven males and nine females, aged 50.9 ± 15.8 years, with a SOFA score of 3.8 ± 3.1. The 30-min steady state indirect calorimetry was successfully completed in 12 patients (75.0%). The test had to be stopped in two patients after 15 min and in another two patients after 25 min because they felt it to be too warm or generally uncomfortable under the hood.

Table 1 shows the success rates of the 5-min steady state and the first five and 15 1-min readings. Data for the first five and 15 1-min readings without consideration of a 5-min steady state phase were not reliable enough to be recommended for routine use. Therefore, further analysis was limited to the 5- and 30-min steady state readings.

Among those patients with an unsuccessful 30-min steady state test, 5-min steady state readings could be obtained in only one of the seven “failures” in group B but in all of those in group C.

There was a highly significant correlation between the 5-min and 30-min steady state data (Fig. 1, Table 2). The time required to collect the 30-min steady state data was 30.0, 30.4 ± 1.3, and 30.5 ± 1.4 min for group A, B, and C, respectively. The corresponding time for the 5-min steady state test was 5.5 ± 1.1 (range 5–10), 9.9 ± 5.7 (5–24), and 6.5 ± 3.3 min (5–16), respectively. In group A, there was no significant difference between those who received pancuronium and those who did not (5.5 ± 1.06 vs 5.5 ± 1.12 min, $p = 0.92$).

Analysing all mechanically ventilated patients together, there was a significant but weak negative linear correlation between the time needed to complete the 5-min steady state test on the one side and the dose of midazolam ($r^2 = 0.123$, $p = 0.007$), the SOFA score ($r^2 = 0.128$, $p = 0.001$), or both ($r^2 = 0.209$, $p = 0.002$) on the other side.

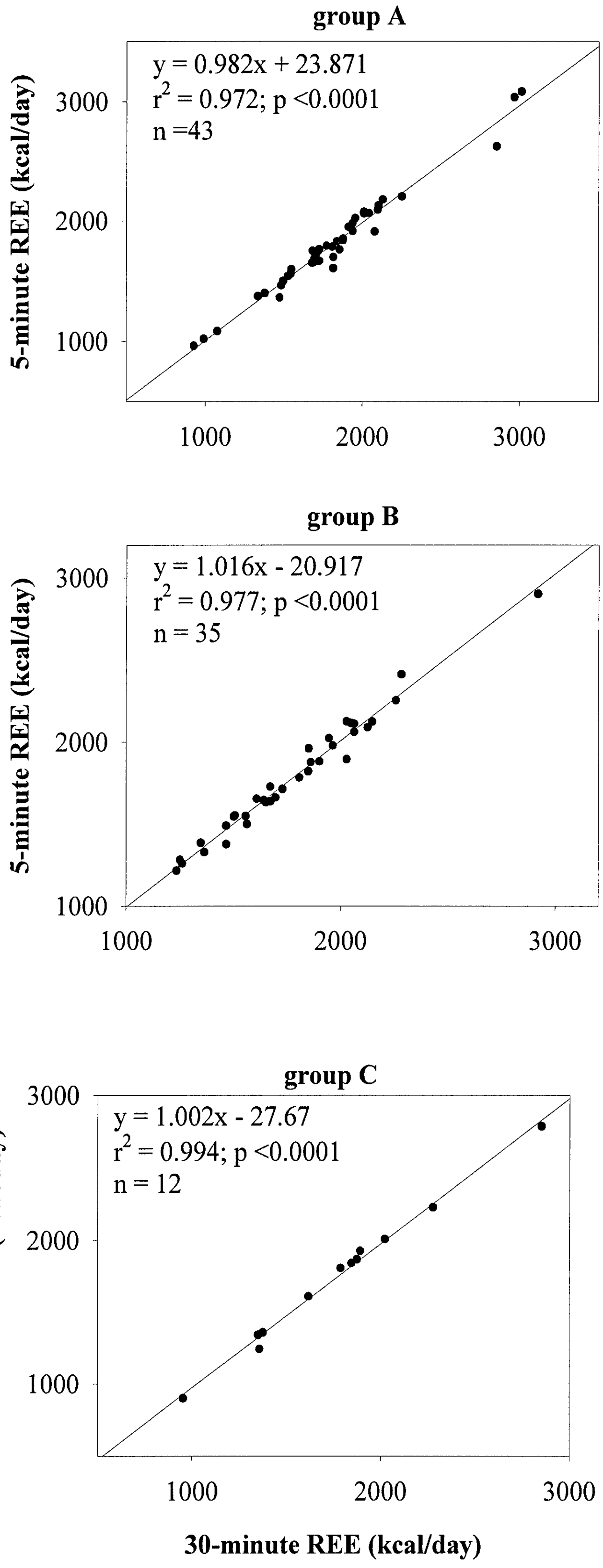

**Fig. 1** Relationship between 5-min and 30-min steady state indirect calorimetric tests for resting energy expenditure (REE)

**Table 2** Indirect calorimetry data for 30- and 5-min steady state readings ($VO_2$ and $VCO_2$ in ml/min; values for all three variables are mean ± standard error of the mean)

| Group | Variable | 30-min steady state test | 5-min steady state test | $r^2$ | $p$ |
|---|---|---|---|---|---|
| A | $VO_2$ | 262.8 ± 9.4 | 261.1 ± 9.3 | 0.968 | < 0.0001 |
|  | $VCO_2$ | 228.8 ± 8.1 | 229.9 ± 8.4 | 0.979 | < 0.0001 |
|  | RQ | 0.875 ± 0.012 | 0.884 ± 0.013 | 0.935 | < 0.0001 |
| B | $VO_2$ | 258.0 ± 8.8 | 258.7 ± 9.0 | 0.979 | < 0.0001 |
|  | $VCO_2$ | 220.6 ± 6.8 | 223.1 ± 7.1 | 0.967 | < 0.0001 |
|  | RQ | 0.861 ± 0.012 | 0.868 ± 0.012 | 0.940 | < 0.0001 |
| C | $VO_2$ | 266.7 ± 22.8 | 264.2 ± 22.7 | 0.995 | < 0.0001 |
|  | $VCO_2$ | 207.5 ± 15.3 | 206.2 ± 15.2 | 0.991 | < 0.0001 |
|  | RQ | 0.795 ± 0.03 | 0.800 ± 0.038 | 0.970 | < 0.0001 |

## Discussion

Tailoring the nutritional need of the critically ill patient is an important aspect in the day-to-day management. Although it has not yet been proven whether morbidity and outcome could be improved by frequent adjustments of caloric needs using indirect calorimetry, under- or overfeeding should be avoided. Frankenfield et al. [22] have reported that an abbreviated protocol using five consecutive stable 1-min readings was as reliable as the commonly used 30-min steady state test for REE in sedated, mechanically ventilated patients. However, it has not been reported whether it applies for different ventilation modes. In this study, we have shown that a 5-min steady state indirect calorimetry could be successfully conducted in critically ill patients with different modes of ventilation. Sedation influenced the success and the time required in mechanically ventilated patients. In patients on controlled mode (usually well-sedated), a short period was enough, while those on assisted mode (usually less sedated or not sedated) often moved their extremities for various reasons, their breathing was not regular or they coughed, resulting in the need for a longer period. The degree of organ dysfunction also seemed to have a similar effect as sedatives. Measurements simply limited to the first 5 or 15 min without considering a steady state had a high coefficient of variation so that they were not satisfactory for routine use.

To our knowledge, how to conduct indirect calorimetry in spontaneously breathing critically ill patients has not been discussed in the literature. In our study, most of the patients in this group were suffering from pulmonary dysfunction. Remaining quiet for about 30 min with the calorimetry hood over the face may be uncomfortable for them, so that the standard used on healthy subjects is not applicable in every case. In our study, 25 % of these patients did not tolerate the standard procedure. Therefore, an abbreviated test protocol may be a promising alternative.

Adding the mean+1 SD to the 5 min routinely discarded at the start, a test period of about 12 min in a controlled mode, 21 min in an assisted mode, and 15 min in spontaneously breathing patients would be enough for a successful abbreviated protocol in the majority of cases. In clinical practice, the trend display on the screen of the metabolic monitor is a useful guide and the required time may, of course, deviate in individual cases.

In conclusion, the abbreviated indirect calorimetry protocol allows an efficient use of manpower, time, and technique in ICU patients with different modes of ventilation without any significant loss of data quality. It would be more acceptable to spontaneously breathing patients.

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