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

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 analgesedation, 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 (r²) 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 (FI\textsubscript{O\textsubscript{2}}) > 0.6 or positive end-expiratory pressure (PEEP) > 10 cmH\textsubscript{2}O, 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 used on the patient. Breathing frequency, tidal volume, and FIO\textsubscript{2} were adjusted. Since no oxygen was consumed or carbon dioxide added to this system, oxygen consumption (VO\textsubscript{2}) and carbon dioxide production (VCO\textsubscript{2}) were 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 Deltrac II MM-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\textsubscript{2}, 5% CO\textsubscript{2}). Values for VO\textsubscript{2}, VCO\textsubscript{2}, minute ventilation (V\textsubscript{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\textsubscript{2} and VO\textsubscript{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\textsubscript{2} and VO\textsubscript{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 analgesedation (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