TECHNIQUE

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Clinical validation of the Deltatrac monitoring system in mechanically ventilated patients

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Abstract *Objective:* To evaluate a monitor of pulmonary gas exchange (Deltatrac, Datex) in a clinical setting.
Design: After in vitro evaluation, comparison over 2 min between $\dot{V}O_2$ and $\dot{V}CO_2$ values measured by the Deltatrac and the Douglas bag technique. Comparisons were also achieved over 8 h periods between the Deltatrac and a system using a mass-spectrometer.
Setting: Polyvalent intensive care unit (ICU 15 beds) in a 1200 bed general hospital.
Patients: Comparison with the Douglas bag technique in 10 patients undergoing controlled ventilation. Comparison with the mass-spectrometer system in 25 other patients undergoing controlled or pressure support ventilation.

Measurements and results: Compared to the results obtained by the Douglas bag technique, the bias (± 2 SD) for $\dot{V}O_2$ and $\dot{V}CO_2$ was -3.5 ± 26.6 and 6.1 ± 12.7 ml·min^{-1}, respectively. By comparison with the mass-spectrometer system, the bias for $\dot{V}O_2$ and RQ was -5.8 ± 16.0 ml·min^{-1} and 0.018 ± 0.048, respectively. No drift between the two systems was observed over time.
Conclusions: The Deltatrac appears suitable for $\dot{V}O_2$ and $\dot{V}CO_2$ measurements in ventilated patients and equivalent to a mass-spectrometer system for long term measurements.

Key words Indirect calorimetry · Oxygen consumption

Introduction

With the recent development of commercially available metabolic monitors there has been an increasing interest in measuring oxygen uptake ($\dot{V}O_2$) and carbon dioxide pulmonary elimination ($\dot{V}CO_2$) in critically ill patients requiring mechanical ventilation. Among these systems is the Deltatrac Metabolic Monitor (Datex Instrumentation, Helsinki, Finland). The evaluation of this system has been thoroughly established in studies performed in vitro [1–4]. However, as claimed by Weissman et al. [1] "in vivo testing is needed to determine its performance in the clinical environment". Indeed, mechanical ventilation in the clinical setting is associated with specific conditions

of gas temperature, humidity and pressure which may interfere with measurements of $\dot{V}O_2$ and $\dot{V}CO_2$. In addition, continuous recordings of $\dot{V}O_2$, $\dot{V}CO_2$ and respiratory quotient (RQ) for the purpose of nutritional assessment must be carried out over a long period of time to correctly evaluate energy expenditure and substrate utilization in patients [5].

The objective of the present study was to perform a complete evaluation of the Deltatrac system. Therefore, this system was first tested in vitro and then evaluated in vivo, in mechanically ventilated patients, in a two-fold manner: by comparison over 2 min periods with results given by the Douglas bag technique and, by comparison, over 8 h periods with results given by a mass-spectrometer system.

Materials and methods

Instrumentation

The Deltatrac Metabolic Monitor is an open system indirect calorimetry device which measures $\dot{V}O_2$ and $\dot{V}CO_2$ in both mechanically ventilated and spontaneously breathing patients. The salient features of the Deltatrac are a fast differential paramagnetic O_2 sensor to measure a differential signal between inspired and expired gases and a gas dilution system to measure flow [3]. The constant flow generator was periodically checked according to the manufacturer's recommendations and corrected if necessary.

The mass-spectrometer system (Mass spectrometer Perkin Elmer MGA 1100, Zenith Z200 microcomputer, Glenview, USA) especially designed to be used in mechanically ventilated patients can be briefly described as follows: gas samples were drawn from the Y piece of the patient's breathing circuit to the mass spectrometer, and analysed for inspired O_2 concentration and CO_2 waveform recognition. The latter analysis allowed rejection of artifactual cycles, e.g. coughing. Expired gas was then sampled from the outlet of a mixing chamber for measurement of mixed expired O_2 and CO_2 concentrations. The duration of the entire analysis was about 3 min. Expired flow was measured by a pneumotachometer (Gould Godart BV, Bilthoven, The Netherlands). All signals were recorded by the computer, which was programmed to compute the physiological variables. A thorough description and validation has been given elsewhere [6]. In the present study, all measurements performed simultaneously by the two instruments were carried out by connecting the Deltatrac to the outlet of the mass-spectrometer system.

As the measurement of $\dot{V}O_2$ requires a stable inspiratory fraction of oxygen (FIO_2) [7], we examined the oxygen fraction delivered by different ventilators: Servo C (Siemens, Solna, Sweden), Drager Evita (Dräger, Lübeck, Germany), Cesar (CFPO, Paris, France) and Bennett 7200 (Bennett Puritan, Carlsbad, CA). This was achieved by using the mass-spectrometer connected to the Y piece of a mechanically ventilated patient. The four ventilators were alternatively used on the controlled mode. As shown in Fig. 1, only the Servo C equipped with an additional inspiratory mixing chamber [7] delivered a stable FIO_2 throughout the inspiratory time and over successive cycles. Therefore, subsequent in vitro and in vivo studies were carried out using this type of ventilator.

In vitro study

We used the method described by Damask [8]. The gas sensors of the Deltatrac and the mass-spectrometer were first calibrated using the same high precision gas ($CO_2 = 7.94\%$ in O_2, CFPO, Paris, France). Then, the RQ obtained by burning methanol in a lung model (true value = 0.667) was simultaneously measured by the Deltatrac and the mass spectrometer system. The measurements were carried out at an FIO_2 of 0.21. Fifteen values were obtained. Finally, simulated $\dot{V}O_2$ and $\dot{V}CO_2$ were achieved by injecting into the ventilated lung model a gas mixture from a cylinder (69% nitrogen in carbon dioxide) by means of a Krohne flowmeter. The gas mixture was administered at different low rates to simulate different values of $\dot{V}O_2$ and $\dot{V}CO_2$. Each value was simultaneously measured by the two systems over 30 min.

Clinical studies

Two sets of data were obtained in 35 clinically stable patients who were mechanically ventilated with FIO_2 lower than 0.5. In 10
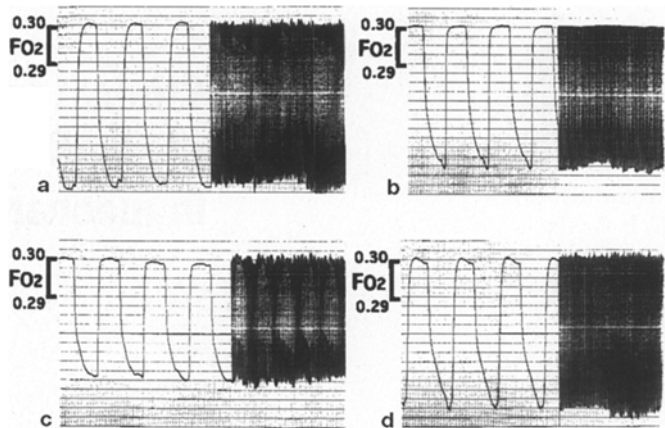

Fig. 1a–d Recordings of FIO_2 measured at the Y piece of a ventilated patient by a mass-spectrometer. Two speeds of recording were used: $15\ mm \cdot s^{-1}$ and $15\ mm \cdot min^{-1}$. Four ventilators were alternately used: a Cesar Taema (**a**), a Servo C (**b**), a Drager Evita (**c**), and a Bennett 7200 (**d**)

patients, undergoing controlled ventilation, results given by the Deltatrac system were compared on 28 occasions to the results given by the Douglas bag technique, according to the following protocol. $\dot{V}O_2$ and $\dot{V}CO_2$ were recorded during 2 min by the Deltatrac, then the expiratory outlet was connected to a Douglas bag for a 2 min collection period. The bag volume was measured by a Tissot gasometer. In 25 other patients ventilated on the controlled mode ($n = 15$) or the pressure support mode ($n = 10$), $\dot{V}O_2$, $\dot{V}CO_2$ and RQ were simultaneously measured by the Deltatrac and the mass-spectrometer system for 8 consecutive hours.

Statistical method

All results are expressed as mean ± SE unless otherwise stated. Comparisons between the two measurement systems were carried out using the Bland and Altman method [9]. Finally, during the 8 h study, the differences between $\dot{V}O_2$ and RQ values measured by the Deltatrac and the mass spectrometer system were examined as a function of time by one way analysis of variance.

Results

In vitro study

RQ of burning methanol was found to be 0.658 ± 0.002 for the Deltatrac and 0.673 ± 0.001 for the mass spectrometer system (true value 0.667), providing a relative precision of 1.3% and 0.9%, respectively. Figure 2 shows that simulated $\dot{V}O_2$ and $\dot{V}CO_2$ values measured by the two systems were in close agreement.

Clinical study

There was also good agreement between $\dot{V}O_2$ and $\dot{V}CO_2$ values measured over 2 min periods by the Deltatrac and

Fig. 2 Differences of simulated V̇O₂ and V̇CO₂ measured by the Deltatrac and the mass-spectrometer system plotted against their mean values. Each point is the mean of the values recorded for 15 minutes. The *solid line* indicates the mean average of the differences and the *dotted lines* are drawn at a 2 SD distance. The bias±SE for V̇O₂ and V̇CO₂ was 2.3 ± 1.5 ml·min^{-1} and 3.9 ± 1.3 ml·min^{-1}, respectively

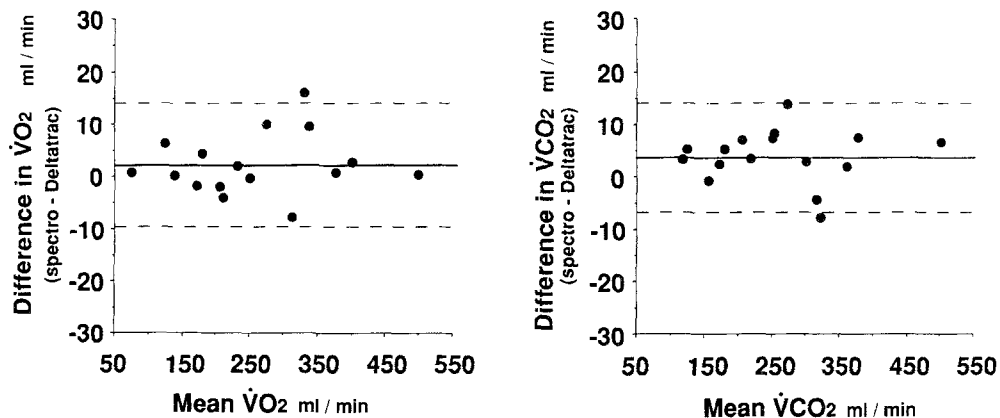**Fig. 3** Differences of V̇O₂ and V̇CO₂ measured by the Douglas bag technique and the Deltatrac plotted against their mean values. *Solid line* and *dotted lines* have the same meaning as in Fig. 2. The bias±SE for V̇O₂ and V̇CO₂ was -3.5 ± 2.5 ml·min^{-1} and 6.1 ± 1.2 ml·min^{-1}, respectively
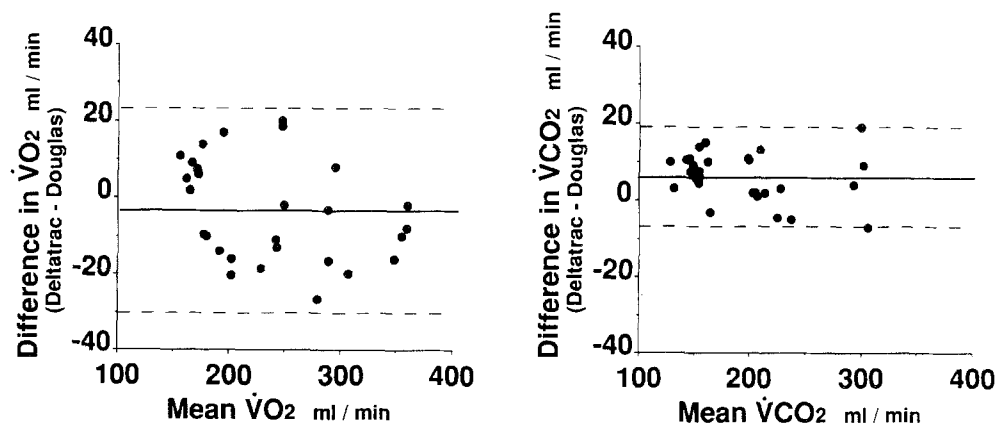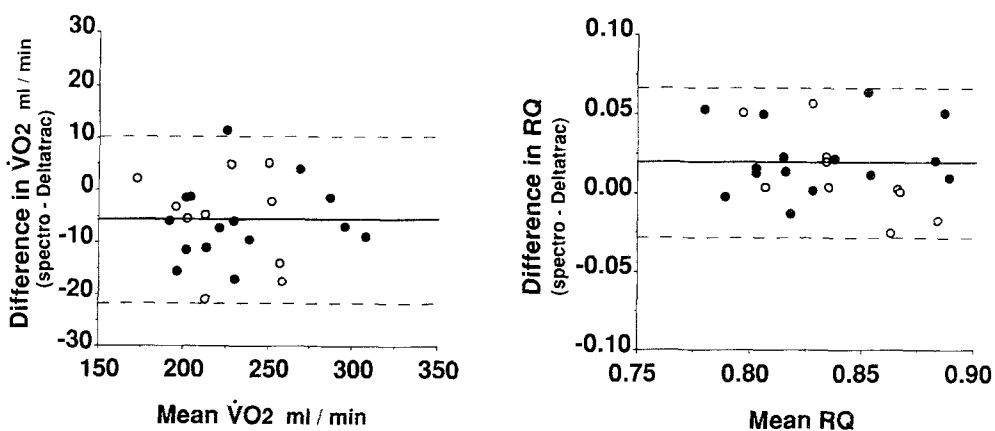

Fig. 4 Differences of V̇O₂ and RQ measured by the mass-spectrometer and the Deltatrac plotted against mean values. ● controlled mode. ○ pressure support. Measurements were made over periods of 8 consecutive hours. *Solid line* and *dotted lines* have the same meaning as in Fig. 2. The mean differences for V̇O₂ and RQ were -5.8 ± 1.6 ml·min and 0.018 ± 0.005 respectively


by the Douglas bag (Fig. 3), and between V̇O₂ and RQ values measured over 8 h periods by the Deltatrac and the mass spectrometer system (Fig. 4). The mean differences in RQ and V̇O₂ values between the two systems were found to be not significantly different from zero. For the 8 h testing, we found the difference between values measured by the two systems to be independent of the ventilatory mode (Fig. 4) and of the duration of the recording (Fig. 5).

Discussion

For both clinical and research purposes, the measurements of pulmonary gas exchange in mechanically ventilated patients are of great interest. However, accuracy of these measurements is of primary importance when these values are used to compute substrate oxidation rates. For example, a variation of 0.03 in RQ value corresponds to

Fig. 5 Differences of $\dot{V}O_2$ and RQ measured by the mass-spectrometer system and the Deltatrac during each hour of the 8 consecutive hour periods
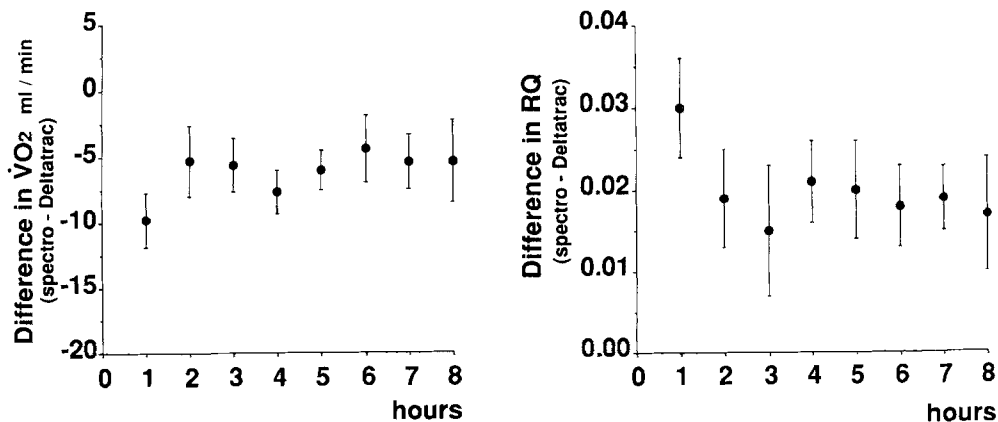
a 10% variation in lipid oxidation rate or in glucose oxidation rate according to the tables published by Lusk [10]. Therefore, any device designed to be used for nutritional studies needs to be carefully tested. Assessing the performance of a gas exchange monitor requires both in vitro and in vivo evaluations. In the present study, these evaluations were carried out using a Servo C ventilator equipped with an additional mixing chamber. Other new generation ventilators which were tested were found to provide an insufficiently stable FIO_2. Indeed, these ventilators have no bellows in the inspiratory circuit, and the FIO_2 which they deliver is the result of the proportion of flow passing through oxygen and air gas valves during the inspiratory time. This explains why FIO_2 may vary up to 0.5% from one cycle to another. Although not clinically relevant, such slight variations may be of importance for the calculation of $\dot{V}O_2$ [6]. The effect of such FIO_2 fluctuations, which seem randomly distributed over the time, is an increase in the variability of $\dot{V}O_2$ and thus RQ determination [7]. This might preclude detecting moderate changes in pulmonary gas exchange. Therefore, special attention should be paid to avoid FIO_2 fluctuations. This can be done by inserting a mixing chamber upstream of the ventilator bellows. In new generation ventilators, which do not include bellows, a similar mixing system placed upstream of the high pressure gas alimentation is also conceivable.

Using the in vitro validation method proposed by Damask, we have confirmed in the present study that the Deltatrac system, as well as our mass spectrometer system, provide accurate measurements of $\dot{V}O_2$ and $\dot{V}CO_2$ under laboratory conditions. This in vitro validation was a pre-requisite for the main part of the present study which consisted of an evaluation of the Deltatrac system under clinical conditions.

Clinical evaluation of the Deltatrac has been limited to only one study in mechanically ventilated patients [3]. In this study, $\dot{V}O_2$ values measured by the Deltatrac were found to be closely related to $\dot{V}O_2$ values as calculated by the Fick principle. However, this method of assessment

carries certain limitations. Firstly, the Fick method is limited by intermittent data availability. Secondly, it usually does not measure $\dot{V}CO_2$. Thirdly, when using the Fick principle to calculate $\dot{V}O_2$, oxygen consumption by the pulmonary tissues is assumed to be negligible. This is likely not the case in mechanically ventilated patients with infected lungs [11]. For the short-term evaluation of the Deltatrac, we therefore used the Douglas bag technique, which may be considered as the reference method for 1–3 min measurements of $\dot{V}O_2$ and $\dot{V}CO_2$ [15]. It must be pointed out that during the $\dot{V}O_2$ and $\dot{V}CO_2$ data acquisitions by the Deltatrac monitor, it was not possible to measure $\dot{V}O_2$ and $\dot{V}CO_2$ by the Douglas bag method, due to the specific dilution technique used by the Deltatrac for the measurement of expired flow [1]. Values given by the Douglas bag method were thus compared to those given by the Deltatrac during the 2 min preceding gas collection. Pulmonary gas exchange is a short-term fluctuating process, even in clinically stable patients. Therefore, this lack of strict synchronous acquisition of data may explain that $\dot{V}O_2$ and $\dot{V}CO_2$ differences between the two methods were more variable than previously observed during in vitro evaluation. However, as illustrated in Fig. 3, the bias was negligible and the intervals of agreement were within acceptable limits.

The Deltatrac monitor permits minute-by-minute recording of $\dot{V}O_2$ and $\dot{V}CO_2$ over a long period of time during mechanical ventilation. As no reference method exists in this field, we assessed the performance of the Deltatrac by comparison with results obtained over 8 consecutive hours by a mass spectrometer system. The problems related to variations of gas temperature, humidity and airway pressure, and those related to possible artifactual respiratory cycles are solved differently in the two systems. For example, in the Deltatrac, the effects of humidity are eliminated by a special Nafion tubing (Perma Pure Products, Kent, UK) which equalizes the humidity of sampled gas to the level of ambient air in all sampling lines. Then, the measured partial pressures of gas are transformed into fractional concentrations by taking ac-

count of the measured atmospheric pressure and of the partial pressure of water vapor at the temperature of the gas analyser. In the mass spectrometer system, all the analog outputs of measured partial pressures of the gas mixture are multiplied by a same factor in such a manner that the sum of the output is equal to 1. So, the results are obtained in fractional concentrations and dry conditions provided that all the gases of the mixture are measured except the water vapor. Our findings demonstrated no systematic drift of $\dot{V}O_2$ and $\dot{V}CO_2$ provided by the Deltatrac by comparison with the values given by the mass spectrometer system over an 8 h period. This indi-

cates a good stability of O_2 and CO_2 sensors of the Deltatrac monitor over time and that the two methods used to overcome the difficulties arising from temperature, humidity and airway pressure did not introduce any systematic bias.

In conclusion, the results of the present study have confirmed that, in clinical conditions, the Deltatrac monitor can measure $\dot{V}O_2$ and $\dot{V}CO_2$ with an acceptable level of accuracy. In addition, its performances for long-term continuous measurements of pulmonary gas exchanges appear equivalent to those of the mass-spectrometer system.

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