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Comparison of oxygen consumption calculated by Fick's principle (using a central venous catheter) and measured by indirect calorimetry

Chiaki Inadomi[1,2], Yoshiaki Terao[1], Kazunori Yamashita[1], Makoto Fukusaki[1], Masafumi Takada[1], and Koji Sumikawa[2]

[1] Department of Anesthesia, Nagasaki Rosai Hospital, Sasebo, Japan
[2] Division of Anesthesiology, Department of Translational Medical Science, Nagasaki University School of Medicine, 1-7-1 Sakamoto, Nagasaki 852-8501, Japan

Abstract
We investigated the clinical usefulness of the Fick method using central venous oxygen saturation (Scv_{O_2}) and cardiac output (CO) measured by pulse dye densitometry (PDD) for monitoring oxygen consumption ($\dot{V}_{O_2}$). This prospective clinical study was performed in 28 mechanically ventilated postoperative patients after major abdominal surgery. $\dot{V}_{O_2}$ was determined by two methods, i.e., the Fick method and indirect calorimetry. The Fick method was employed using CO measured by PDD and Scv_{O_2} obtained from a central venous catheter (CVC). $\dot{V}_{O_2}$ measured by indirect calorimetry was averaged for 15 min. Fifty-six sets of measurements were performed. $\dot{V}_{O_2}$ values determined by the Fick method were significantly lower than those measured by indirect calorimetry (110 ± 29 vs $148 \pm 28\,ml \cdot min^{-1} \cdot m^{-2}$; $P < 0.01$). Bland and Altman analysis showed that the mean bias and precision were $33\,ml \cdot min^{-1} \cdot m^{-2}$ and $32\,ml \cdot min^{-1} \cdot m^{-2}$, respectively. The correlation between the two measurements of $\dot{V}_{O_2}$ was weak ($r^2 = 0.145$; $P = 0.0038$), indicating that the Fick method using PDD and Scv_{O_2} is not clinically acceptable for the monitoring of $\dot{V}_{O_2}$.

Key words Oxygen consumption · Fick method · Indirect calorimetry · Central venous oxygen saturation

Introduction

The measurement of oxygen consumption ($\dot{V}_{O_2}$) in critically ill patients is important for the assessment of therapeutic management. Some previous studies have compared indirect calorimetry and the Fick method for the measurement of $\dot{V}_{O_2}$ [1–4]. Samples obtained with a pulmonary artery catheter (PAC) were used to calculate $\dot{V}_{O_2}$ by the Fick method, whereas some studies suggested the possibility of direct complications using a PAC [5–8]. It was also reported that there was a higher rate of pulmonary embolism in a group with a PAC compared with a group undergoing standard therapies including the use of a central venous catheter (CVC) [8].

Reinhart et al. [9] suggested that central venous oxygen saturation (Scv_{O_2}) with a CVC was clinically interchangeable with the mixed venous oxygen saturation (Sv_{O_2}) obtained with a PAC. CVCs are more frequently and easily available in all clinical settings compared with PACs. Although indirect calorimetry is a precise method to determine $\dot{V}_{O_2}$, portable metabolic carts are not routinely available for all postoperative patients because of the high cost.

We assessed the clinical usefulness and equivalence of $\dot{V}_{O_2}$ determined by the Fick method (using a combination of Scv_{O_2} with CVC and pulse dye densitometry [PDD]) in comparison with indirect calorimetry in mechanically ventilated postoperative patients.

Patients, materials, and methods

This study was approved by the Institutional Ethics Committee, and informed written consent was obtained from each patient. We studied 28 patients (18 men and 10 women) who required mechanical ventilation overnight postoperatively. The study's inclusion criteria were as follows: (a) elective major abdominal surgery; (b) American Society of Anesthesiologists physical status I to III; and (c) age more than 20 years. The exclusion criteria were: (a) fractional inspired oxygen (FI_{O_2}) more than 0.6; (b) air leaks from the endotracheal tube; and (c) renal failure. Each patient had a CVC (Microneedle Seldinger kit, double-lumen catheter, 0.4 ml in the proximal lumen (17 G) and 0.6 ml in the distal lumen (14 G); Argyle; Nippon Sherwood Medical Industries, Tokyo, Japan) inserted via the right subclavian vein for

Address correspondence to: C. Inadomi
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the measurement of central venous pressure and for receiving total parenteral nutrition. The CVC position was confirmed by a chest radiograph.

All patients were transported from the operating room to the intensive care unit (ICU). They were intubated and received intravenous buprenorphine at a rate of $0.625\,\mu g \cdot kg^{-1} \cdot h^{-1}$ continuously [10]. Intravenous midazolam was also administered after their admission to the ICU, and was adjusted every 2h to achieve the desired depth of sedation, i.e., 3–5 on the Ramsay sedation scale. Patients were ventilated by synchronous intermittent mandatory ventilation or continuous positive airway pressure. All patients received conventional intensive care therapy according to clinical requirements.

Indocyanine green (ICG) was injected into a peripheral vein, and the cardiac output (CO) and cardiac index (CI) were determined by PDD (DDG-Analyzer; Nihon-Kohden, Tokyo, Japan). The sensor was attached to the patient's nose. Obtained values were averaged from three consecutive ICG administrations. Values for arterial oxygen saturation (Sa_{O_2}), Scv_{O_2}, arterial oxygen tension (Pa_{O_2}), central venous oxygen tension (Pcv_{O_2}), and hemoglobin concentration (Hb), obtained by blood gas analysis (ABL520; Radiometer, Copenhagen, Denmark), were used to calculate $\dot{V}_{O_2}$ by the Fick method, using the following equation:

$$\dot{V}_{O_2} = CI \times \{[Hb \times 1.39 \times (Sa_{O_2} - Scv_{O_2})] + 0.0031 \times (Pa_{O_2} - Pcv_{O_2})\} \times 10$$

We obtained the blood sample from a proximal port of the CVC.

$\dot{V}_{O_2}$ was measured by indirect calorimetry (Puritan-Bennett 7250 Metabolic Monitor, Puritan-Bennett, Carlsbad, CA, USA), which had been integrated with a 7200 Puritan-Bennett ventilator. A 45-min warmup period was observed before each monitoring session, followed by sensor calibration with a known gas mixture consisting of 5% carbon dioxide and 95% oxygen. Metabolic parameters were calculated by the metabolic monitor. $\dot{V}_{O_2}$ measured by the 7250 Metabolic Monitor was averaged for 15 min.

Simultaneous measurements of $\dot{V}_{O_2}$ by the Fick method and by indirect calorimetry were made 1–2h after the patients' admission to the ICU when the hemodynamic state, respiratory state, and body temperature were stable. Second measurements were performed the next morning. Thus, a total of 56 sets of measurements were performed in the 28 patients.

The Wilcoxon test was performed to analyze the differences between methods. Concordance between the two methods was determined by means of bias (mean difference between the two methods) and precision (SD of the mean difference between the two methods), using Bland and Altman analysis [11]. Linear regression plots were used to examine the relationship. We considered $P < 0.05$ to be significant. Sample size was determined on the basis of a previous work [3], which indicated that, with 28 patients, there was a power of 80% to detect a 75% difference in $\dot{V}_{O_2}$ between the two methods at a significance level of 5%.

Results

The mean values for age, height, weight, and body surface area in the 28 patients were: 69 ± 11 years (range, 50–81 years), 158 ± 12cm (range, 136–176cm), 56 ± 12kg (range, 32–78kg), and 1.6 ± 0.2 m^2 (range 1.1–1.9 m^2), respectively. Nine patients underwent pancreatoduodenectomy; 4, total gastrectomy; 2, low anterior resection; and 13, other operative procedures. A total of 56 simultaneous measurements were performed. $\dot{V}_{O_2}$ determined by indirect calorimetry was significantly higher than that determined by the Fick method (142 ± 28 $ml \cdot min^{-1} \cdot m^{-2}$ vs 110 ± 29 $ml \cdot min^{-1} \cdot m^{-2}$; $P < 0.01$). The correlation between the two measurements of $\dot{V}_{O_2}$ was weak ($r^2 = 0.145$; $P = 0.0038$; Fig. 1). Bland and Altman plots showed the mean bias (33 $ml \cdot min^{-1} \cdot m^{-2}$), upper precision (65 $ml \cdot min^{-1} \cdot m^{-2}$), and lower precision (1 $ml \cdot min^{-1} \cdot m^{-2}$; Fig. 2). The upper limit of agreement was 97 $ml \cdot min^{-1} \cdot m^{-2}$ and the lower limit of agreement was −31 $ml \cdot min^{-1} \cdot m^{-2}$.

Discussion

To monitor $\dot{V}_{O_2}$ in the ICU, the Fick method is a standard formula for calculating $\dot{V}_{O_2}$, but PAC insertion is required. Some previous reports indicated the complications and high cost of PAC [5–8]. Although indirect calorimetry is a more accurate method for the measurement of $\dot{V}_{O_2}$, it is not routinely available. Thus, convenient, safe, and relatively inexpensive methods to determine $\dot{V}_{O_2}$ are needed for postoperative patients. Rivers et al. [12] demonstrated that early goal-directed therapy using Scv_{O_2} provided benefits with respect to the outcome in patients with severe sepsis and those with septic shock. Continuous Scv_{O_2} monitoring with CVC has become commercially available in recent years. Because Reinhart et al. [9] reported that Scv_{O_2} was clinically interchangeable with Sv_{O_2}, we compared $\dot{V}_{O_2}$ determined by the Fick method (using a PDD and CVC without a PAC) with $\dot{V}_{O_2}$ determined by indirect calorimetry in this study.

The results showed that $\dot{V}_{O_2}$ determined by the Fick method using a PDD and CVC underestimated the $\dot{V}_{O_2}$ measured by indirect calorimetry. Because Bland and Altman plots showed that the bias and precision of our data were too wide and the correlation between the two

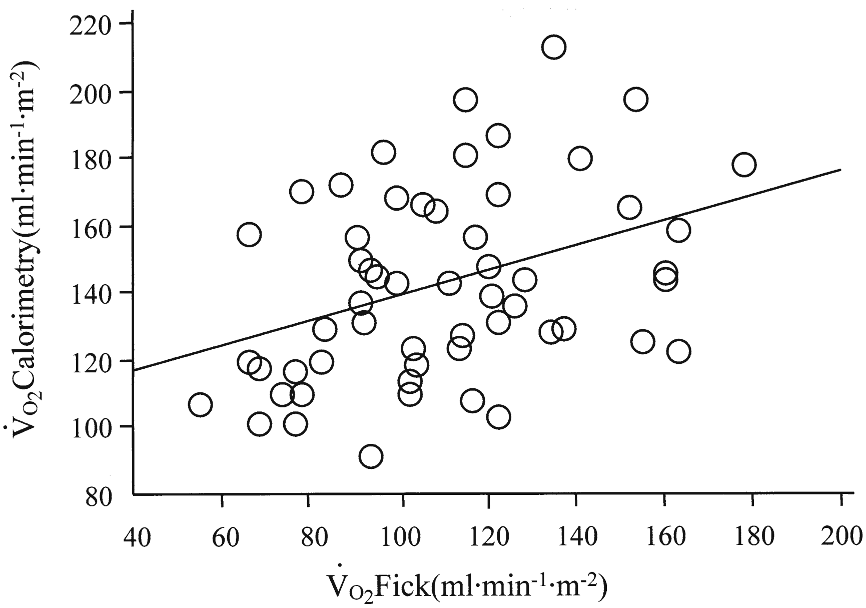

Fig. 1. Correlation coefficient between measurements of oxygen consumption ($\dot{V}_{O_2}$) by the Fick method ($\dot{V}_{O_2}Fick$) and by indirect calorimetry ($\dot{V}_{O_2}Calorimetry$). $r^2 = 0.145$; $P = 0.0038$. Equation of the regression line: $\dot{V}_{O_2}$Calorimetry = 0.37 × $\dot{V}_{O_2}$Fick + 101.92

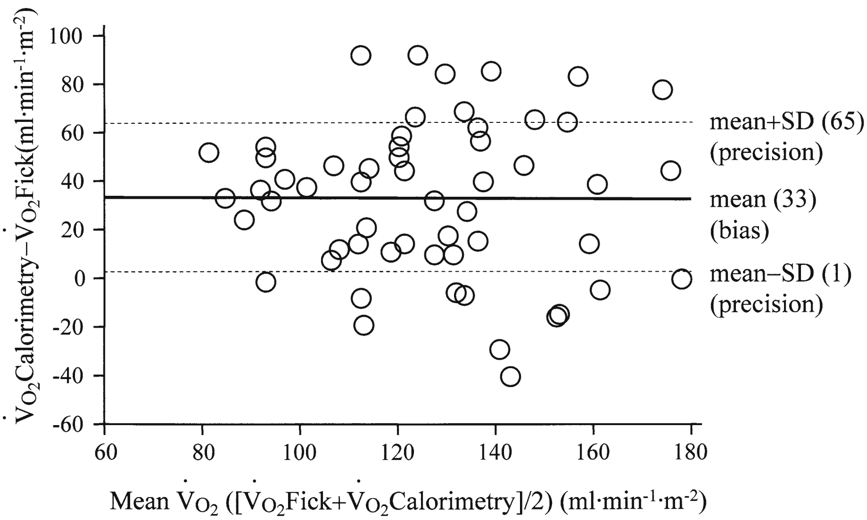

Fig. 2. Bland and Altman analysis of $\dot{V}_{O_2}$ measurements by the Fick method ($\dot{V}_{O_2}Fick$) and by indirect calorimetry ($\dot{V}_{O_2}Calorimetry$). The *solid line* shows the bias and *dotted lines* show the upper and lower precision values

measurements of $\dot{V}_{O_2}$ was too weak, our method is not clinically acceptable for monitoring $\dot{V}_{O_2}$.

Some possible explanations of this difference between the two measurements can be advanced, as follows.

(1) $\dot{V}_{O_2}$ obtained by indirect calorimetry was reported to be 8% to 27% higher than that obtained by the Fick method, using a PAC [3]. Numerous arterial and venous anastomoses exist between the bronchial and pulmonary circulations. The Fick method does not include pulmonary oxygen consumption [13].

(2) Reinhart et al. [9] reported that, although Scv_{O_2} was clinically interchangeable with Sv_{O_2}, Sv_{O_2} was estimated to be 5% to 18% lower than Scv_{O_2}.

(3) Bremer et al. [14] reported that a comparison between CO obtained by PDD and by thermodilution showed good agreement in the normal to high CO range. However, Hofer et al. [15] reported that PDD could not be recommended as a substitute for the use of PAC in the routine monitoring of CO after cardiac surgery, because there was a systematic bias using PDD compared with the thermodilution technique using a PAC. Moreover, Bremer et al. [14] mentioned that the accuracy of CO could be affected by inconstant venous blood flow in the peripheral circulation. We injected ICG via a peripheral line, according to the manufacturer's recommendations.

In conclusion, the results of the present study show that the Fick method, using PDD and Scv_{O_2}, is not clinically acceptable for the monitoring of $\dot{V}_{O_2}$.

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