An Accurate Indirect Calorimetry for Measuring Resting Energy Expenditure or Basal Metabolic Rate

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Abstract. This paper presents a newly developed indirect calorimetry system for measuring resting energy expenditure (REE) or basal metabolic rate (BMR). The system consists of ventilated hood, gas analysis module, calibration gas, operation and display module, trolley etc. It is low operator dependency and comfortable for test subjects. Experiments with carbon dioxide and nitrogen infusion technology was conducted to test the accuracy of the indirect calorimetry. Measured values were highly correlated (r >0.99, p <0001) with simulated values and the differences were small (1.37% for VO₂ and 1.85% for VCO₂). The newly developed indirect calorimetry system may potentially act as an accurate tool in the assessment of REE or BMR.

Introduction

Determination of resting energy expenditure (REE) or basal metabolic rate (BMR) is important in clinical nutrition practice because it is a basic component of nutritional assessment and nutritional support [1]. Indirect calorimetry devices have been developed to measure REE or BMR and used in intensive care unit (ICU) and department of clinical nutrition in the past decades [2,3]. However, they have not been widespread in China until now, especially in small-scale hospitals and public health institutions, due to time-consuming of the measurements and the need for professional operators.

In this study, a low operator dependency indirect calorimetry system (IIM-IC-100) was developed and presented. The indirect calorimetry system is able to determine metabolic status by providing a quiet and comfortable environment for patients. The accuracy of the newly developed indirect calorimetry was assessed in vitro in this study.

Development of the Indirect Calorimetry

The IIM-IC-100 is an open circuit device that uses a gas dilution technique to measure gas exchange variables [4]. It consists of ventilated hood, gas analysis module, calibration gas, operation and display module and trolley etc. (Figure 1). Gas exhaled from subjects are mixed with atmosphere and then pumped into gas analysis module, where the mixed gas is analyzed by flow measuring, sampling, drying, and component analysis.

Specifically, flow rate is measured by bi-direction differential pressure preVent™ pneumotach. Oxygen content of mixed gas was measured by using zirconia sensor (range 0–100%) and carbon dioxide was measured by using non-dispersive infrared carbon dioxide analyzer (range 0–10%). The response times of the two gas concentration sensor are short (< 110 and 100 ms, respectively), which provided condition for rapid and real-time analysis of metabolic parameters. Oxygen uptake (VO₂) and carbon dioxide output (VCO₂) can be derived from the real-time flow rate and component of mixed gas and displayed for each breath. REE or BMR is then calculated using modified Weir equation [5]. Metabolic parameters can also be calculated and displayed minutes by minutes.
According to the short-time steady state in the indirect calorimetry technique, coefficient of variation (CV) of VO2 and VCO2 is determined in five consecutive 1-min intervals. The degree of stability that defined as complement of CV is shown to operators. In order to be easy to operate, metabolic test can be stopped manually or automatically when a settable minimum degree of stability achieved. REE or BMR is automatically derived from the last five continuous minutes. The calibration procedure of the calorimeter consists of two different content gas calibration, and it can be automatically executed by one-touch operation.

**Experimental to Test Accuracy**

**Experimental Design**

As shown in Figure 2, a carbon dioxide and nitrogen infusion method was employed to simulate oxygen consumption and carbon dioxide production. A gas mixture of nominal composition 21% CO2 and balance N2 was selected. The standard gas was able to be infused in an adjustable and steady flow rate by gas decompression valve, constant pressure valve and steady flow valve. The
infusion flow rate can be measured accurately by a mass flow sensor (FS4003, Siargo, Santa Clara, USA). Simulated VO2 and VCO2 gas exchange rate can be ascertained as computational formula described previously [6].

In this study, the infusion rates were set at different levels randomly between 700 and 1500 SCCM. During each infusion, infusion flow rate was recorded and simulated VO2 and VCO2 were calculated accordingly. Measured values of VCO2 and VO2 were allowed to reach a steady state plateau before the evaluation was carried out over a minimum of ten minute period. Before each test, the IIM-IC-100 indirect calorimetry was calibrated.

**Statistical Analysis**

Pearson’s correlation coefficients (r) were used to analyze relationships between the simulated VO2, VCO2 and measured VO2, VCO2. Differences between simulated values and measured values were examined using paired t-tests. Bland-Altman analysis was also used to assess mean differences and degree of general agreements as expressed by the limits of agreement (LoA). The LoA was defined as the mean ± 2SD. For all analyses, p<0.05 was considered significant.

**Experimental Results and Considerations**

There were high and significant correlations between simulated and measured values for both VO2(r=0.999, p<0001) and VCO2(r=0.998, p<0.001) as shown in Figure 3. Although paired t-test showed that there were significant differences between simulated and measured values for both VO2 and VCO2, the differences were so small that they lacked clinical significance. Bland-Altman plots further revealed a small mean difference of 2.67 mL/min (1.37%) and 3.62 mL/min (1.85%) with LoA of -1.14 to 6.48 mL/min (-0.59% to 3.37%) and -0.87 to 8.11 mL/min (-0.44% to 4.14%) for VO2 and VCO2, respectively (Figure 4).

![Figure 3. Correlations between simulated and measured VO2 and VCO2.](image)

![Figure 4. Bland-Altman plots show mean differences and limits of agreement of simulated and measured values.](image)

Deltatrac Metabolic Monitor has been considered as the “gold standard” indirect calorimetry device. It has been used as criterion measure when validating other indirect calorimetry devices [7,8]. During in vitro studies of Phang, P.T et al, the Deltatrac Metabolic Monitor was found to deviate from known simulated constant values for VO2 and VCO2 by <2% [9]. In this study, the IIM-IC-100 was found to have similar accuracy with that of Deltatrac Metabolic Monitor. It may be
potentially act as an accurate tool in the measurement of REE or BMR. Further study is needed to inform its performance by comparing with Deltatrac Metabolic Monitor.

Conclusion
This paper presents a newly developed indirect calorimetry (IIM-IC-100) and preliminary examines the accuracy of it. This study suggested that it may act as an accurate indirect calorimetry device for measuring REE or BMR. Further research is necessary to validate the accuracy and repeatability of IIM-IC-100 by clinical experiment.

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References