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Indirect Calorimetry: From Expired CO_2 Production, Inspired O_2 Consumption to Energy Equivalent

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Abstract

This paper emphasizes the methodology of data collection of indirect calorimetry, including establishment of steady state conditions and the standards in which the values are presented. It also aims to describe in details the calculations of VO2, VCO2, Resting Energy Expenditure (REE) and Respiratory Quotient (RQ). The trial is registered with ClinicalTrials.gov number NCT02072694.

Keywords: Indirect calorimetry; Energy expenditure; Oxygen consumption; Calibration; Respiration; Metabolism

Introduction

The indirect calorimetry can be understood as a non-invasive measurement of energy produced by the organism through quantifying the volumes of consumed oxygen and produced carbon dioxide (V_{o2} and V_{co2}, respectively) by the oxidation of substrates [1].

The calorimeters commercially available calculate V_{o2} and V_{co2} through equations using concentrations of O_2 and CO_2 concentrations in the inhaled air (FIO_2 and $FICO_2$) and exhaled air (FEO_2 and $FECO_2$), respectively, and the inhaled (VI) and exhaled (VE) lung volumes of air per minute [2,3].

While the software acquired with the calorimeter provides all results, understanding how the calculations from which the values of V_{o2}, V_{co2} and Resting Energy Expenditure (REE) are obtained could be challenging even for experts in this field. Therefore, this report shows how the data provided by the calorimeter could be used to compute those values, since the establishment of steady state conditions, once seldom papers clearly demonstrate it.

Materials and Methods

Subject

A 34 years-old healthy female volunteer, BMI 18.7 kg/m^2, underwent an indirect calorimetry test. The subject was a participant of a study approved by the ethical review board of Ribeirão Preto Medical School of São Paulo University, which is registered with ClinicalTrials.gov number NCT02072694.

Experimental design

According to the manufacturer recommendations, the calorimeter Quark RMR® (Cosmed, Rome, Italy) was turned on 45 minutes before calibration [4] in 3 steps: 1) Ambient air; 2) standard mixture composed of CO_2, O_2 and N_2 in the concentrations of 5%, 16% and 79%, respectively and 3) Validation of the bidirectional digital turbine flowmeter, performed using a certified 3 L calibration syringe [5]. The IC test was performed as suggested by Compher et al. [6] and Suen et al. [7], with canopy, being the flow rate regularly adjusted to maintain a constant $FECO_2$ through all the time.

Before the acquisition of data, the participant was asked to remain quiet, awake, with a regular respiratory pattern, avoiding yawning, coughing, speaking and sighing. After emptying of the bladder, her height and weight were measured; the volunteer layed down on supine position with her head elevated 30 degrees, extended limbs and opened eyes in a silent room at 23°C [7].

The indirect calorimetry test lasted approximately 15 minutes, in which was assured that all recommendations were followed.

Establishment of steady state conditions and data analysis

Initially, the obtained data was exported from Cosmed 10.0a software to a spreadsheet of Microsoft Excel 2007® and the first 5 minutes were not taken into account. In the graphic plotted with the variations of V_{o2} and V_{co2} along the remaining 10 minutes, a 5-minute period with steady state conditions was chosen. In this interval, the coefficients of variation of the observed V_{o2} and V_{co2} were respectively 4.8 and 4.7 [5] (Figure 1). The mean values of VE, FEO_2 and $FECO_2$ were calculated and used in the equations to obtain the V_{o2}, V_{co2}, REE and RQ. The volume of VE was provided by the calorimeter in L/min BTPS, which means the volume of a gas at body temperature (37°C), ambient pressure and saturated with water vapor at the subject's body temperature [8].

Results

Calculating V_{co2}

From the steady state interval, the means found were: VE=26.59 L/min (BTPS); FEO_2=19.92%; $FECO_2$=0.83%. The means of FIO_2 and $FICO_2$ were 20.89% and 0.08%, respectively. The value of VI was obtained using Haldane's transformation [2]. The calculations are described below:

$VI=(FEN_2 xVE)/FIN_2$

$FEN_2=1-FEO_2-FECO_2$

$FEN_2=1-0.1992-0.0083 \rightarrow FEN_2=0.7925$

$FIN_2=1-FIO_2-FICO_2$

$FIN_2=1-0.2089-0.0008 \rightarrow FIN_2=0.7903$

$VI=(FEN_2 xVE)/FIN_2$

$VI=(0.7925x26.59)/0.7903 \rightarrow VI=26.66$ L/min

$V_{co2}=(VExFECO_2)-(VIxFICO_2)$

$V_{co2}=(26.59x0.0083)-(26.66x0.0008)$(x1000 to convert to mL/min)

V_{co2}(BTPS)=199.37 L/min

The V_{co2}, adjusted to Standard Temperature, Pressure and Ambience Dryness (STPD), which was 0.7681 (provided by the calorimeter) is:

$V_{co2}=199.37$ x $0.7681 \rightarrow V_{co2}$ (STPD) = 153.13 mL/min

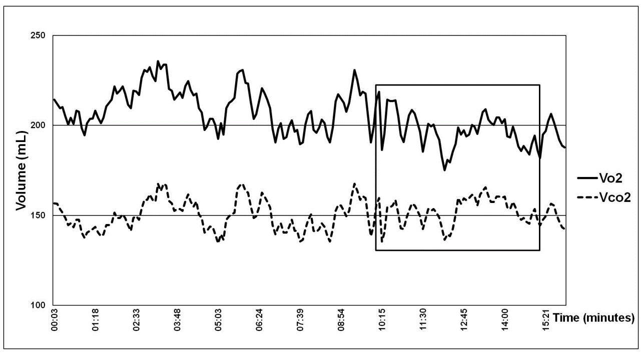

Figure 1: Measurements of V_{O2} (solid line) and V_{CO2} (dashed line) expressed in mL in a 15 minutes period test. The square highlights the 5-minute period with coefficients of variation of V_{O2} and V_{CO2} ≤ 10%, which was chosen as the steady state interval.

Calculating V_{o2}

To calculate the V_{o2}, an equation from Haldane's transformation was employed [2], as follow:

$V_{o2}=((1-FEO_2-FECO_2)/(1-FIO_2))x(FIO_2-FEO_2)xVE$

$V_{o2}=(0.7925/0.7918)x(0.2089-0.1992)x26.59$

V_{o2}(BTPS)=258.15 mL/min

Adjusting to STPD: $V_{o2}=258.15x0.7681$

V_{o2}(STPD)=198.28 mL/min

Calculating both REE and RQ

The Weir equation [9] was used to compute the REE

$REE=((3.941xVo_2)+(1.11xV_{co2}))x1.44$

$REE=((3.941x198.28)+(1.11x153.14))x1.44 \rightarrow REE=1370$ kcal/day

The RQ is obtained by the ratio V_{co2}/V_{o2}

$RQ=153.14/198.28 \rightarrow RQ=0,8$

Discussion

The indirect calorimetry has been used as a research and clinical practice tool [10]. Usually, the software provided with the available calorimeters processes the collected data and summarizes it in reports or spreadsheets containing the values of REE, V_{o2}, V_{co2}, RQ and others.

Nevertheless, sometimes the researcher wishes to understand how this software computes the aforementioned values. Once, in the literature, there are discrepancies among the equations used [9,11], some difficulties arise at this point. Moreover, researchers must attempt to not only describe the values given by the calorimeter software, but also to report the methods to obtain it in order to assure the quality of collected data. Therefore, it is important to disclose all equations used, how steady state conditions were established; the standard of the values (BTPS or STPD) and under which conditions the test was executed.

The value of VE given by the calorimeter and the VI, in this case, calculated through Haldane's transformation are expressed in BTPS. However, the values of V_{o2} and V_{co2} are usually expressed in STPD, which is the volume of a gas under standard conditions of temperature (0°C), barometric pressure (760 mmHg) and humidity (partial pressure of water, 0 mmHg) [8]. Therefore, it is necessary to adjust the V_{o2} and V_{co2} to STPD.

Because detailed reports about the calculations related to indirect calorimetry are commonly not found, this paper illustrates all the steps involved, since the arrangements for test execution, the establishment of a steady state interval, the calculations of the values of the V_{o2}, V_{co2}, REE and RQ. In addition, it emphasizes the adjustment of values to STPD.

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