Validity of COSMED’s Quark CPET Mixing Chamber System in Evaluating Energy Metabolism During Aerobic Exercise in Healthy Male Adults

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This study validated the accuracy of COSMED’s Quark cardiopulmonary exercise testing (CPET) metabolic mixing chamber system in measuring metabolic factors during maximal, graded exercise testing. Subjects included 32 physically active men between the ages of 18 and 34 years. During the first test session, subjects were measured for maximal oxygen consumption twice (15 min separation) with the CPET and Douglas bag systems (random order). During the second test session, subjects exercised through four stages of the Bruce treadmill protocol with measurement by the CPET and Douglas bag systems (random order) during steady state at the end of each 3-minute stage. Statistical analysis using a 2 (systems) x 5 (time) repeated measures ANOVA showed that the pattern of change in VO₂, VCO₂, VE, FeO₂, FeCO₂, and RER did not differ significantly between CPET and Douglas bag systems. This validation study indicates that the CPET mixing chamber system provides valid metabolic measurements that compare closely with the Douglas bag system during aerobic exercise.

KEYWORDS oxygen consumption, carbon dioxide production, Bruce treadmill test, ventilation, respiratory exchange ratio
INTRODUCTION

The classical Douglas bag system (Douglas, 1911) remains the gold standard for gas exchange measurement, but this cumbersome methodology has been replaced by automated metabolic gas analysis systems. Most human performance laboratories use automated metabolic gas analysis systems (i.e., metabolic carts) to measure oxygen consumption, carbon dioxide production, and minute ventilation during graded exercise testing to evaluate aerobic fitness (Macfarlane, 2001; Meyer, Davison, & Kindermann, 2005). Metabolic carts provide a wealth of data and are available in many different shapes and sizes (Hodges, Brodie, & Bromley, 2005). The validity of different metabolic carts is not well investigated, and available data suggest considerable variance between systems or when compared with the Douglas bag system (Bassett et al., 2001; Carter & Jeukendrup, 2002; Eisenmann, Brisko, Shadrick, & Welsh, 2003; Foss & Hallén, 2005; Gore, Clark, Shipp, VanDerPloeg, & Withers, 2003; Lee, Bassett, Thompson, & Fitzhugh, 2011; Macfarlane, 2001; McNaughton, Sherman, Roberts, & Bentley, 2005; Miles, Cox, & Verde, 1994; Nieman et al., 2007).

Some metabolic carts provide breath-by-breath metabolic data, but this degree of sophistication can be frustrating when the cart malfunctions, and it is seldom needed in human performance laboratory testing and research programs. Various companies and laboratories are returning to metabolic carts with mixing chamber systems to improve control of testing procedures and reduce the volume of measurement data (Crouter, Antczak, Hudak, DellaValle, & Haas, 2006; Foss & Hallén, 2005). COSMED (Rome, Italy) manufactures cardiopulmonary diagnostic equipment, including the Quark Cardio Pulmonary Exercise Testing (CPET) system that now includes an option of using a 7-liter mixing chamber. The purpose of this study was to assess the validity of the CPET mixing chamber system when compared with the Douglas bag system in measuring oxygen consumption, carbon dioxide production, and minute ventilation in young male adults during graded exercise on a treadmill.

METHODS

Subjects

Subjects included 32 healthy males between the ages of 18 and 34 years. Other inclusion criteria included a history of aerobic exercise (≥3 sessions/week, ≥30 minutes or more per session) to ensure that subjects could exercise through four complete stages of the Bruce treadmill protocol. The research design and methods were approved by the university’s Internal Review Board prior to initiation of the study. Subjects voluntarily gave informed consent.
Research Design

Each subject came to the Human Performance Lab on two occasions, 1 week apart. During the first test session, subjects were measured for maximal oxygen consumption twice (15 minutes separation), once with the COSMED Quark CPET mixing chamber system (CPET), and also with the Douglas bag system, in random order, using the Bruce treadmill protocol (Bruce, Kusumi, & Hosmer, 1973). During the second test session, subjects exercised through four stages of the Bruce treadmill exercise protocol with 30- to 60-second measurements by the CPET and Douglas bag systems in random order during steady state at the end of each 3-minute stage. Sixty-second measurements were made at the end of stages one and two (when minute ventilation was relatively low), with 30-second measurements made during stages three and four. The treadmill speed and grade for each stage of the Bruce treadmill protocol were as follows: (1) 1.7 mph/10% (easy); (2) 2.5 mph/12% (light exertion); (3) 3.4 mph/14% (brisk uphill walk; moderate exertion for most); and (4) 4.0 mph/16% (uphill jog; hard exertion for most). The primary outcome measures were heart rate, oxygen consumption, carbon dioxide production, minute ventilation, fractions of expired air as oxygen and carbon dioxide, and the respiratory exchange ratio.

Douglas Bag Testing Procedures

Subjects were fitted with head gear and a rubber mouthpiece connected to a two-way nonrebreathing valve (Hans-Rudolph Inc., Kansas City, MO). The breathing valve was connected via a plastic hose to a three-way Hans Rudolf stopcock and meteorological balloon. Expired gas fractions in the balloons were analyzed using an Applied Electrochemistry S-3A oxygen analyzer and an Applied Electrochemistry CD-3A carbon dioxide analyzer (AEI Technologies, Applied Electrochemistry, Pittsburgh, PA). The analyzers were calibrated using a 2-point method with room air and medical grade primary standard gases containing 16.0% oxygen and 4.0% carbon dioxide (Matheson Tri-Gas, Parsippany, NJ) before each treadmill test. Expired gas volumes were measured using a 120 liter Tissot spirometer (Warren E. Collins, Braintree, MA), with corrections made for air removed for gas fraction analysis.

COSMED CPET Testing

CPET measurements were made with subjects wearing head gear attached to a rubber mouthpiece, turbine flow meter, two-way nonrebreathing valve (Hans-Rudolph Inc., Kansas City, MO), plastic hose for transfer of expired air to a 7-liter mixing chamber, and a sampling line connected from the mixing chamber to CPET gas analyzers. The CPET paramagnetic oxygen analyzer had a range of 0% to 25% for analysis of fraction of air as oxygen, and the
nondispersive infrared sensor (NDIR) carbon dioxide analyzer had a range of 0% to 10% for analysis of fraction of air as carbon dioxide. The bidirectional digital turbine had an accuracy of ±2%, with a range of 0.08 to 20 L/second for flow rate measurement, and 0 to 300 L/minute for minute ventilation measurement during performance testing. The 7-liter mixing chamber allowed metabolic assessment through a full range of low to high minute ventilation rates during exercise testing. COSMED’s Quark CPET underwent factory validation using a metabolic calibrator capable of delivering cyclic air flows of known tidal volume, frequency, and gas makeup (Gore, Catcheside, French, Bennett, & Laforgia, 1997).

Statistical Analysis

Data are expressed as mean ± standard deviation (SD). COSMED CPET and Douglas bag oxygen consumption and metabolic measurements were compared using 2 (systems) x 5 (time) repeated measures ANOVA for data collected during the end of each of four Bruce treadmill stages and maximum exercise. If the interaction statistic was significant at P<0.05, paired t tests were computed between systems at each time point, with statistical significance set at P<0.01 after Bonferroni adjustment. Figures 1 and 2 provide scatterplot data for oxygen consumption and minute ventilation, with linear regression used to compare lines of best fit and identity. The standard error

FIGURE 1 Oxygen consumption (VO$_2$ ml·kg$^{-1}$·min$^{-1}$) scatterplot data comparing CPET and Douglas bag systems during each stage of the Bruce treadmill protocol, and maximal levels (interaction statistic, P = 0.185).
of estimate (SEE) was calculated using this equation: $SD_{Douglas\ bag} \sqrt{1 - r^2}$.

Figure 3 is a Bland-Altman plot, with difference scores for oxygen consumption between Douglas bag and CPET systems plotted against mean values for both systems (Bland & Altman, 1987). A regression line of differences was calculated to help detect a proportional difference.

RESULTS

A total of 32 male subjects (aged 23.0 ± 4.3 years, body mass of 77.8 ± 10.4 kg, and body height of 1.78 ± 0.06 m) completed all phases of the study.

The patterns of change in oxygen consumption, carbon dioxide production, fraction of expired air as oxygen and carbon dioxide, heart rate, and respiratory exchange ratio (RER) did not differ significantly between the CPET and Douglas bag systems throughout the four stages and maximal levels of the Bruce treadmill tests (Table 1). Figures 1 and 2 depict oxygen consumption ($VO_2\ ml\cdot kg^{-1}\ min^{-1}$) and minute ventilation (L·min$^{-1}$) scatterplot data comparing CPET and Douglas bag systems during each stage of the Bruce treadmill test, and maximal levels. Interaction statistics indicated no difference in these measurements between systems ($P = 0.185$ and
FIGURE 3 The Bland-Altman plot shows the difference scores between Douglas bag and CPET systems across the entire range of oxygen consumption values (mean of two systems, ml·min$^{-1}$), with the solid lines representing ±2 SD. The mean difference between systems was $-23.6 \pm 176.3$, and the linear trend of the data was nonsignificant ($r = -0.038$).

In a separate analysis of maximal metabolic data, no significant differences were found between CPET and Douglas bag systems for VO$_{2\text{max}}$ ($P = 0.680$), VE$_{\text{max}}$ ($P = 0.310$), RER$_{\text{max}}$ ($P = 0.194$), FeO$_{2\text{max}}$ ($P = 0.138$), and FeCO$_{2\text{max}}$ ($P = 0.475$).

DISCUSSION

The purpose of this study was to validate the accuracy of the CPET mixing chamber system in measuring energy metabolism when compared with the Douglas bag system. The data from 32 young, physically active, male adults
<table>
<thead>
<tr>
<th></th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
<th>Stage 4</th>
<th>Max</th>
<th>Interaction P value</th>
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<tbody>
<tr>
<td><strong>VO₂ (ml·min⁻¹)</strong></td>
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<tr>
<td>Douglas bag</td>
<td>1291 ± 224</td>
<td>1821 ± 264</td>
<td>2723 ± 401</td>
<td>3782 ± 438</td>
<td>4038 ± 435</td>
<td>0.205</td>
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<tr>
<td>CPET</td>
<td>1290 ± 213</td>
<td>1865 ± 268</td>
<td>2773 ± 388</td>
<td>3791 ± 467</td>
<td>4053 ± 521</td>
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<tr>
<td><strong>VCO₂ (ml·min⁻¹)</strong></td>
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<tr>
<td>Douglas bag</td>
<td>1075 ± 202</td>
<td>1597 ± 239</td>
<td>2643 ± 418</td>
<td>4092 ± 698</td>
<td>4749 ± 590</td>
<td>0.499</td>
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<tr>
<td>CPET</td>
<td>1075 ± 200</td>
<td>1652 ± 265</td>
<td>2697 ± 449</td>
<td>4122 ± 675</td>
<td>4682 ± 610</td>
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<td><strong>FeO₂ (%)</strong></td>
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<tr>
<td>Douglas bag</td>
<td>16.0 ± 0.5</td>
<td>15.9 ± 0.5</td>
<td>16.1 ± 0.5</td>
<td>16.8 ± 0.7</td>
<td>17.1 ± 0.5</td>
<td>0.891</td>
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<tr>
<td>CPET</td>
<td>16.1 ± 0.5</td>
<td>15.8 ± 0.5</td>
<td>16.1 ± 0.4</td>
<td>16.8 ± 0.6</td>
<td>17.0 ± 0.5</td>
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<td><strong>FeCO₂ (%)</strong></td>
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<tr>
<td>Douglas bag</td>
<td>4.31 ± 0.45</td>
<td>4.61 ± 0.43</td>
<td>4.71 ± 0.39</td>
<td>4.43 ± 0.54</td>
<td>4.36 ± 0.57</td>
<td>0.848</td>
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<tr>
<td>CPET</td>
<td>4.18 ± 0.40</td>
<td>4.61 ± 0.36</td>
<td>4.71 ± 0.32</td>
<td>4.45 ± 0.52</td>
<td>4.42 ± 0.54</td>
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<td><strong>RER</strong></td>
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<tr>
<td>Douglas bag</td>
<td>0.83 ± 0.05</td>
<td>0.88 ± 0.05</td>
<td>0.97 ± 0.08</td>
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<tr>
<td>CPET</td>
<td>0.83 ± 0.06</td>
<td>0.88 ± 0.05</td>
<td>0.97 ± 0.06</td>
<td>1.09 ± 0.08</td>
<td>1.16 ± 0.06</td>
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<tr>
<td><strong>Heart rate (beats·min⁻¹)</strong></td>
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<tr>
<td>Douglas bag</td>
<td>104 ± 18</td>
<td>123 ± 16</td>
<td>157 ± 19</td>
<td>182 ± 16</td>
<td>189 ± 11</td>
<td>0.105</td>
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<tr>
<td>CPET</td>
<td>104 ± 16</td>
<td>124 ± 16</td>
<td>157 ± 20</td>
<td>182 ± 16</td>
<td>191 ± 11</td>
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VO₂ = volume of oxygen consumed; VCO₂ = volume of carbon dioxide produced; FeO₂ = fraction of expired oxygen; FeCO₂ = fraction of expired carbon dioxide; RER = respiratory exchange ratio; Stage number = Bruce treadmill protocol.
validate the accuracy of the CPET mixing chamber system in measuring submaximal and maximal oxygen consumption, carbon dioxide production, and minute ventilation.

Mixing chamber systems—in contrast to breath-by-breath systems—are attractive for use in human performance laboratories because the volume of data is reduced, troubleshooting is simplified, and complex software manipulation of the data is removed. Prior studies with other metabolic cart mixing chamber systems have reported accurate measurement of oxygen uptake and minute ventilation over a wide range of exercise workloads when compared with the Douglas bag system (Bassett et al., 2001; Crouter et al., 2006; Foss & Hallén, 2005). Two studies have validated the COSMED Fitmate™ system, which incorporates a patented sampling technology that allows Fitmate™ performance to be comparable with that of a metabolic cart equipped with a standard mixing chamber (Lee et al., 2011; Nieman et al., 2007). The Fitmate™ samples a small amount of expired volume in a dynamic mixing chamber to analyze FeO₂.

Automated gas analysis systems aim for an exact temporal alignment of flow measured with gas analysis. Systems must incorporate the response characteristics not only of the gas analyzers but also the interconnecting tubing and mixing chamber, and this was successfully accomplished by the CPET system in this study. This alignment of gas flow and gas analysis is more critical in breath-by-breath systems where errors in delay time between flow and analysis have the potential to cause substantial error in oxygen consumption measurements, especially during high breathing frequencies (Hodges, Brodie, & Bromely, 2005).

We attempted simultaneous measurement of gas exchange by the CPET mixing chamber and Douglas bag systems by connecting the meteorological balloons in series with the outlet port of the mixing chamber (Bassett et al., 2001). This setup caused a slight back pressure on the turbine device at the mouthpiece, however, leading to low CPET minute ventilation measures. We switched to random order measurement during end-of-stage steady state conditions, and this methodology provided a valid comparison of the CPET mixing chamber and Douglas bag systems. The VO₂max was measured twice on a separate day (15-minute separation), with random order measurement by the CPET and Douglas bag systems. This measurement protocol was used because of the inability of subjects to maintain maximal exertion long enough to obtain measurements from both the CPET and Douglas bag systems in a single test.

CONCLUSIONS

This study demonstrated that the CPET mixing chamber metabolic measurement system was accurate when compared with the Douglas bag system...
for the core measurements of FeO$_2$, FeCO$_2$, and minute ventilation during graded, maximal exercise.

REFERENCES


