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VALIDATION OF COSMED'S FitMate™ IN MEASURING EXERCISE METABOLISM

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*The purpose of this study was to assess the validity of the FitMate™ metabolic system (Cosmed, Rome, Italy) in measuring oxygen consumption during graded exercise. The FitMate™ is a new, small (20 × 24 cm) metabolic analyzer designed for measurement of oxygen consumption during rest and exercise. Subjects included 40 healthy adults (*N *= 20 males,* N *= 20 females) ranging in age from 18 to 37 kg/m*^{2} *(mean ± SD age, 22.5 ± 3.6 years) and body mass index (BMI) from 18.3 to 32.5 kg/m*^{2} *(23.2 ± 3.3 years). One-minute FitMate™ and Douglas bag measurements were made during steady state conditions at the end of each 3-minute stage of the Bruce treadmill graded exercise test, and subjects continued until they could not attain steady state exercise during a stage. Oxygen consumption difference scores (Douglas bag minus FitMate™ measurements) did not differ between males and females, so data were combined and analyzed for the entire group. During the first three stages, mean oxygen consumption did not differ significantly between the Douglas bag and FitMate™ systems (26.5 ± 1.1 and 26.7 ± 1.3 ml·kg*$^{-1}$*·min*$^{-1}$*, respectively,* P *= 0.140) with a mean absolute difference of 0.23 ± 0.91 ml·kg*$^{-1}$*·min*$^{-1}$ *or 14.2 ± 67.5 ml·min*$^{-1}$*. In conclusion, the FitMate™ metabolic system accurately measures oxygen consumption during graded treadmill exercise when compared with the Douglas bag system in male and female adults.*

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INTRODUCTION

One of the most common measurements made by exercise science professionals is oxygen consumption during both rest and exercise. Oxygen consumption during exercise can be measured using human calorimeters, closed-circuit indirect calorimetery equipment, and open-circuit indirect calorimetry equipment such as Douglas bags, gas analyzers, whole body respiratory chambers, and computerized metabolic carts (Macfarlane 2001; Meyer, Davison, and Kindermann 2005). These methods are costly, cumbersome to conduct, and require highly skilled technicians, making them impractical for most clinical and community settings. Studies show that automated metabolic systems often vary when compared with one another or with the Douglas bag system (Carter and Jeukendrup 2002; Rietjens et al. 2001; Foss and Hallen 2005; Miles, Cox, and Verde 1994; Gore et al. 2003; Bassett et al. 2001).

During the past 40 years, various portable metabolic devices have been developed to facilitate oxygen consumption measurements in nonlaboratory settings. Validation studies have been published for several of these devices, including the K4b2 from Cosmed (Duffield, Dawson, and Pinnington 2004; Eisenmann et al. 2003; McLaughlin et al. 2001; McNaughton et al. 2005; Pinnington et al. 2001), K2 from Cosmed (Crandall, Taylor, and Raven 1993; Lucia et al. 1993), VO2000 from Medical Graphics (Crouter et al. 2006; Wahrlich et al. 2006) and its predecessor Aerosport TEEM 100 and KB1-C from Aerosport Inc. (King et al. 1999), VmaxST from Sensor Medics (Brehm, Harlaar, and Groepenhof 2004), and MetaMax II from CORTEX Biophysik (Larsson et al. 2004). Although these portable metabolic devices are accurate, they still pose problems when considering cost and ease of use.

A small, hand-held, and easy-to-use metabolic system, the BodyGem/MedGem (HealtheTech, Golden, CO), was developed for accurate measurement of resting oxygen consumption and energy expenditure (Nieman, Trone, and Austin 2003; Nieman et al. 2005; Stewart, Goody, and Branson, 2005; St-Onge et al. 2004). The BodyGem/MedGem, however, was not designed for measurement of oxygen consumption during exercise. The FitMate™ from Cosmed Inc. (Rome, Italy) is a small, easy-to-use, inexpensive, and accurate metabolic analyzer that is designed for metabolic measurements during graded exercise. Previously, we validated the use of the FitMate™ in measuring resting oxygen consumption and energy expenditure (Nieman et al. 2006). The FitMate™ utilizes new sampling technology through the use of a representative small sample of the expired volume in a miniaturized dynamic mixing chamber. The FitMate™ uses a turbine flowmeter for measuring ventilation and a galvanic fuel cell oxygen sensor for analyzing fraction of expired oxygen.

The FitMate™ does not have a CO2 analyzer and relies on a software paradigm that ramps the respiratory exchange ratio (RER) between 0.8 and 1.2 based on the increase in heart rate.

Validation studies have not yet been conducted to test whether the unique features of the FitMate™ allow for accurate measurement of oxygen consumption during graded exercise. Therefore, the purpose of this study was to assess the validity of the FitMate™ metabolic system when compared with the Douglas bag system in measuring oxygen consumption and ventilation in male and female adults during graded exercise on a treadmill.

METHODS

Subjects

Subjects included 20 men and 20 women between the ages of 18 and 37 years. Subjects came to the Appalachian State University (ASU) Human Performance Lab between 3:30 and 5:30 p.m. for one test session. Prior to the treadmill test, a screening questionnaire was used to determine health and disease status, followed by measurement of height and weight, and an orientation to the testing procedures. Testing procedures were approved by the university's internal review board prior to initiation of the study. Subjects voluntarily gave informed consent.

Research Design

The Bruce treadmill graded exercise test was used with 1-minute measurements made by the Cosmed FitMate™ and the Douglas bag systems during steady state after exercising for 3 minutes during each treadmill stage. Prior to starting the treadmill test, subjects were fitted with a facemask that was used for all metabolic measurements. After exercising for 3 minutes in a treadmill stage, 1-minute measurements were first made with the FitMate™ followed by removal of the FitMate™ turbine flow meter and sampling line, and then attachment to the face mask of a two-way Hans-Rudolph valve (Hans-Rudolph Inc., Kansas City, MO) and hose for a 1 minute collection of expired air in a Douglas bag. The first stage of the Bruce treadmill test was set at 1.7 mph and 10% grade (easy), the second stage at 2.5 mph and 12% grade (light exertion), the third stage at 3.4 mph and 14% grade (brisk uphill walk, moderate exertion for most), the fourth stage at 4.0 mph and 16% grade (uphill jog, hard exertion for most), and the fifth stage at 4.5 mph and 18% grade. Subjects continued until they could attain steady state exercise (or the ability to hold the pace without tiring) during a stage.

Douglas Bag Testing Procedures

Douglas bag collections of expired gases were made for 1 minute using a facemask connected to a Hans-Rudolph two-way valve (Hans-Rudolph Inc., Kansas City, MO). Expired gas fractions 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 two-point method with outside air and medical grade primary standard gases containing 16.0% O_2 and 4.0% CO_2 (Matheson Tri-Gas, Parsippany, NJ). Expired gas volumes were measured using a Rayfield RAM 9200 air flowmeter (Waitsfield, VT) calibrated against a Tissot spirometer.

FitMate™ Testing

The FitMate™ is a new, small (20 × 24 cm) metabolic analyzer designed for the measurement of oxygen consumption and energy expenditure during rest and exercise (Cosmed, Rome, Italy). It uses a turbine flowmeter for measuring ventilation and a galvanic fuel cell oxygen sensor for analyzing the fraction of expired oxygen, and it incorporates a patented sampling technology that allows FitMate™ performance to be comparable with the performance of a metabolic cart with a standard mixing chamber. The FitMate™ uses a representative small sample of expired volume in a dynamic mixing chamber to analyze fractions of expired oxygen (FeO_2). The FitMate™ system has an automatic recalibration system using room air, recalibrating periodically during the test without any interruptions. This is possible because there is no CO_2 analyzer, and the O_2 sensor is intrinsically linear (a single-point calibration ensures accuracy in the entire range of measurements). Without CO_2 data, VO_2 is calculated intrinsically with the use of the equation$VO_2 = (FiO_2*IV - FeO_2*EV)*RF*STPD$, where RF = respiratory frequency, IV = inspired volume, EV = expired volume, FiO_2 = fraction of inspired O_2, and FeO_2 = fraction of expired O_2. Inspired volume is calculated using the Haldane correction, $IV = (100 + R*(FeO_2 - 20.93) - Fe0_2)*EV/79.04$, where R = respiratory exchange ratio. R is estimated by ramping values linearly between 0.8 and 1.2 in accordance with the increase in heart rate during exercise. Sensors measure temperature and barometric pressure for use in internal calculations.

Statistical Analysis

FitMate™ and Douglas bag oxygen consumption and metabolic measurements were compared using paired *t* tests with difference scores computed between methods (Douglas bag – FitMate™). Statistical significance was set at the $p \leq 0.05$ level, and values were expressed as mean ± SD.

RESULTS

Forty subjects (20 males and 20 females) completed all phases of the study. Subject characteristics are reported in Table 1, with data summarized for age, stature, body mass, and BMI (kg/m^2). For all subjects combined, age ranged from 18 to 37 years, and BMI from 18.3 to 32.5 kg/m^2.

No difference was found between males and females for the primary outcome measures, and the data are presented for all subjects combined (Table 2 and Figure 1). When combining data from treadmill stages 1, 2, and 3 (N = 35 subjects), no significant differences were found between Douglas bag and FitMate™ systems for oxygen consumption (26.5 ± 1.1 and 26.7 ± 1.2 ml·kg^{-1}·min^{-1}, respectively, $P = 0.140$), with a mean difference of 0.23 ± 0.91 ml·kg^{-1}·min^{-1} (or 14.2 ± 67.5 ml·min^{-1}). Only 10 subjects completed stage 4, and oxygen consumption was slightly but significantly higher during the Douglas bag measurement, in part due to an "order effect" (see next paragraph). Figure 1 depicts scatterplot data comparing FitMate™ and Douglas bag systems during each stage of the Bruce treadmill test. The line of best fit for the entire data set was nearly identical in slope to the line of identity (dashed line).

Due to methodological issues, measurements at the end of each 3-minute treadmill stage were taken first with the FitMate™ system followed by the Douglas bag system, a process that took about 3 minutes. This measurement order effect resulted in small but significant differences in FeO_2, ventilation, and heart rate between the FitMate™ and Douglas bag systems (Table 2).

Table 2 summarizes $FeCO_2$ and RER data from the Douglas bag measurements, and respiratory rate data from the FitMate™ system. Comparisons between systems were not possible because the FitMate™ system does not have a CO_2 analyzer, and the Douglas bag system does not provide respiratory rate measurements.

Table 1. Subject Characteristics for Male (*n* = 20) and Female (*n* = 20) Subjects (mean ± SD)

Variable	Males	Females
Age (yrs)	23.5 ± 4.1	21.5 ± 2.8
Stature (m)	1.79 ± 0.05	1.63 ± 0.07
Body mass (kg)	79.7 ± 12.9	57.8 ± 7.4
Body mass index (kg/m^2)	24.9 ± 3.4	21.6 ± 2.4

Table 2. Comparison of Oxygen Consumption (VO_2), Ventilation, and Other Metabolic Values Between the FitMate and Douglas Bag Methods During Steady State Exercise for the First Three Stages of the Bruce Treadmill Test (mean ± SD)

	Stage 1 (*N* = 40)	Stage 2 (*N* = 40)	Stage 3 (*N* = 35)	Stage 4 (*N* = 10)
VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)				
Douglas bag	17.3 ± 1.0	25.4 ± 1.3	36.8 ± 1.9	52.4 ± 2.3
FitMate	17.8 ± 1.2**	25.7 ± 1.6	36.7 ± 2.0	50.7 ± 2.8**
FeO_2 (%)				
Douglas bag	15.9 ± 0.5	15.8 ± 0.6	16.2 ± 0.7	16.4 ± 0.5
FitMate	15.2 ± 0.5**	15.4 ± 0.5**	15.8 ± 0.6**	16.0 ± 0.4**
Ventilation ($l \cdot min^{-1}$)				
Douglas bag	30.7 ± 7.1	45.0 ± 10.2	70.4 ± 14.5	117 ± 20
FitMate	28.6 ± 6.0**	43.6 ± 10.1	67.5 ± 14.1**	105 ± 13**
Heart rate ($beats \cdot min^{-1}$)				
Douglas bag	110 ± 15	137 ± 20	168 ± 21	181 ± 12
FitMate	105 ± 14**	132 ± 21**	162 ± 21**	177 ± 12**
$FeCO_2$ (%)				
Douglas bag	4.32 ± 0.45	4.69 ± 0.51	4.69 ± 0.59	4.64 ± 0.51
RER				
Douglas bag	0.81 ± 0.05	0.88 ± 0.05	0.97 ± 0.06	1.03 ± 0.06
RR ($breaths \cdot min^{-1}$)				
FitMate	22.9 ± 4.7	27.6 ± 5.3	34.3 ± 7.3	39.6 ± 6.3

VO_2 = volume of oxygen consumed; FeO2 = fraction of expired oxygen; FeCO2 = fraction of expired carbon dioxide; RER = respiratory exchange ratio; RR = respiratory rate.

*P value < 0.05; **P value < 0.01 when comparing FitMate and Douglas bag systems.

DISCUSSION

The purpose of this study was to compare the Douglas bag system with the FitMate™, a small, portable metabolic device used to measure oxygen consumption during both rest and exercise. The data from a group of 40 young male and female adults indicated that the FitMate™ gave accurate oxygen consumption measurements when compared with the Douglas bag method. When measurements from the first three stages of the Bruce treadmill protocol were averaged and compared, the mean difference for oxygen consumption was small and statistically insignificant. This indicates that graded exercise testing with the FitMate™ will give accurate oxygen consumption measurements.

Other small metabolic devices have been developed for measuring oxygen consumption and ventilation, but they are expensive and require skilled technicians. The FitMate™ is easy to use, inexpensive, and small,

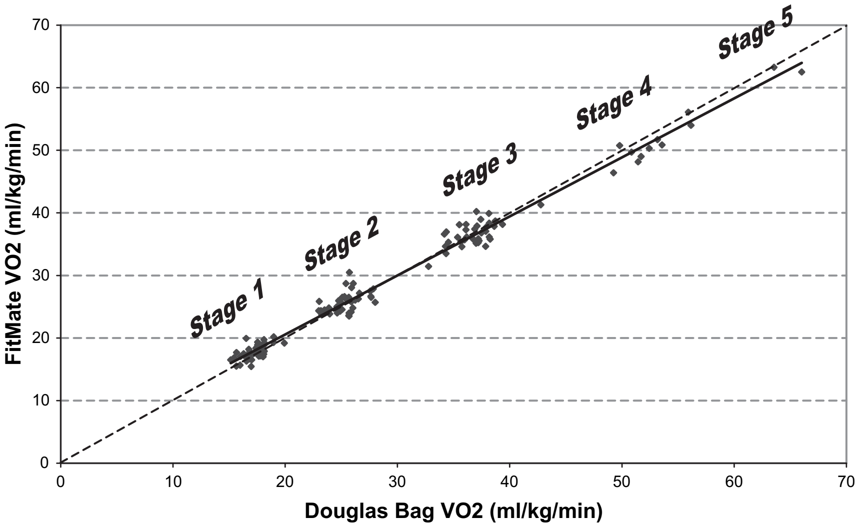

Figure 1. Scatterplot VO2 Douglas bag versus FitMate.

but it does not have a CO2 analyzer. Our data indicate that ramping the RER between 0.8 and 1.2 in accordance with the increase in heart rate results in minimal error. For example, during the second treadmill stage, RER varied between 0.81 and 1.095 as measured with the Douglas bag system, with a group mean of 0.88. This range in RER would cause a variation in VO2 estimates of about 7.5%, but this error was markedly reduced with the Cosmed ramping paradigm.

The K2 from Cosmed Inc. (Rome, Italy) was another portable metabolic system that lacked a CO2 analyzer (Crandall et al. 1993; Lucia et al. 1993). Since there was no CO2 analyzer, the K2 assumed a constant RER of 1.0 for all exercise workloads. In one study, the K2 underestimated VO2 at lower workloads and overestimated VO2 at higher workloads due to the assumption of a constant RER of 1.0 (Crandall et al. 1993). Studies indicated that when the subjects' actual RER value was measured with the Douglas bag system or other metabolic systems, and the K2 calculations were corrected using the true RER value, errors in VO2 estimates during graded exercise were diminished (Crandall et al., 1993; Lucia et al. 1993). Since the FitMate™ increases RER in a linear relationship to heart rate during maximal graded exercise from 0.8 to 1.2, this calculation eliminates the type of error that occurred with the K2 by assuming an RER of 1.0.

The FitMate™ system utilizes a facemask with a turbine device and a sampling line, thus prohibiting simultaneous measurement of oxygen consumption and ventilation with the Douglas bag system. Due to the intrinsic workings of the FitMate™ metabolic system, the FitMate™ measurements had to be made prior to the Douglas bag measurements during each stage. This resulted in small but significant differences in FeO_2, ventilation, and heart rate between the FitMate™ and Douglas bag systems. These differences, however, were more than likely due to a small drift in metabolic responses during 2 to 3 minutes of measurements during steady state exercise at the end of each 3-minute treadmill stage.

In conclusion, the FitMate™ metabolic system accurately measured oxygen consumption during graded treadmill exercise in male and female young adults. Despite the lack of a CO2 analyzer, the system adequately adjusted by ramping RER in accordance with the heart rate. The dynamic, miniaturized mixing chamber with intrinsic adjustments for RER allowed for accurate measurements of oxygen consumption by the FitMate™ system. Another unique feature of the FitMate™ is that calibration occurs automatically just prior to exercise and at set intervals during the exercise test without interruption. The FitMate™ is a small, inexpensive, user-friendly, lightweight, battery-powered unit, facilitating accurate metabolic measurements in both the field and in the lab.

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