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Comparison of the Cosmed K4b² Portable Metabolic System in Measuring Steady-State Walking Energy Expenditure

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Abstract

Background and Aims: Recent introduction of the Cosmed K4b^2 portable metabolic analyzer allows measurement of oxygen consumption outside of a laboratory setting in more typical clinical or household environments and thus may be used to obtain information on the metabolic costs of specific daily life activities. The purpose of this study was to assess the accuracy of the Cosmed K4b^2 portable metabolic analyzer against a traditional, stationary gas exchange system (the Medgraphics D-Series) during steady-state, submaximal walking exercise.

Methods: Nineteen men and women (9 women, 10 men) with an average age of 39.8 years (±13.8) completed two 400 meter walk tests using the two systems at a constant, self-selected pace on a treadmill. Average oxygen consumption (VO_2) and carbon dioxide production (VCO_2) from each walk were compared.

Results: Intraclass Correlation Coefficient (ICC) and Pearson correlation coefficients between the two systems for weight indexed VO_2 (ml/kg/min), total VO_2 (ml/min), and VCO_2 (ml/min) ranged from 0.93 to 0.97. Comparison of the average values obtained using the Cosmed K4b^2 and Medgraphics systems using paired t-tests indicate no significant difference for VO_2 (ml/kg/min) overall ($p = 0.25$), or when stratified by sex ($p = 0.21$ women, $p = 0.69$ men). The mean difference between analyzers was – 0.296 ml/kg/min (±0.26). Results were not significantly different for VO_2 (ml/min) or VCO_2 (ml/min) within the study population ($p = 0.16$ and $p = 0.08$, respectively), or when stratified by sex (VO_2: $p = 0.51$ women, $p = 0.16$ men; VCO_2: $p = .11$ women, $p = 0.53$ men).

Conclusion: The Cosmed K4b^2 portable metabolic analyzer provides measures of VO_2 and VCO_2 during steady-state, submaximal exercise similar to a traditional, stationary gas exchange system.

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Introduction

Measurement of the oxygen and carbon dioxide content of expired air during exercise is vital to the assessment of cardiovascular function and energy expenditure prediction. Oxygen exchange (VO_2) is one of the most fundamental and widely recognized measures of energy consumption as defined by two key components: the delivery of oxygen to skeletal muscle and the ability of the muscle to extract and use oxygen [1]. In healthy individuals, most activities require only a fraction of maximal working capacity, as assessed by maximal VO_2 (VO_2 Max). However, in individuals with substantially reduced VO_2 Max, because of disease or disability, the oxygen consumption required to perform activities of daily living may represent a larger percentage of VO_2 Max, and thus may theoretically be a limiting factor for independence. Individuals facing these challenges may show greater fatigue and reduced endurance [2].

Walking is the most widespread form of physical activity in adults and is also central to performing many activities critical for independent living [1]. Measuring VO_2 while walking at various workloads may provide a reasonable approach for estimating energy costs associated with daily activities of varying intensity. Measurement of VO_2 has been traditionally confined to laboratory settings and use of a treadmill due to the sophisticated equipment required. Recent introduction of the Cosmed K4b^2 portable metabolic analyzer (Cosmed K4b^2, Cosmed, Rome, Italy) allows measurement of VO_2 outside of a laboratory setting in more typical clinical or household environments and thus may be used to obtain information on the metabolic costs of specific daily life activities. It has been documented that treadmill walking can affect gait mechanics and thus may not accurately reflect true energy expenditure while walking at a given speed over the ground [3,4]. Thus, it is vital to examine energy expenditure directly during over-the-ground walking to accurately assess performance and exertion [5].

Previous research comparing the Cosmed K4b^2 portable analyzer to more traditional analyzers has been inconclusive, making it difficult to assess whether these devices can be used interchangeably [6,7,8,9,10,11]. The use of different machines and intensities in each research study makes it impossible to determine whether conflicting results are a function of the different reference methods used or of a specific deficiency with the Cosmed K4b^2 system. Our laboratory intends to use the Cosmed K4b^2 during submaximal testing of over-the-ground walking, thus this study aims to assess the accuracy of measuring VO_2 and VCO_2 by the Cosmed K4b^2 system using a Medgraphics D-series gas exchange system (Medgraphics, Medical Graphics Corporation, St Paul, MN), a widely used breath-by-breath analyzer, as the reference standard during a steady-state walking test [12,13]. Although the test protocol encompasses a narrow range of exercise ventilation values, it still permits assessment of the accuracy of the Cosmed K4b^2 over a range of moderate intensity walking speeds, which is very valuable for assessing the metabolic costs of steady-state walking exercise. Additionally, although our end objective is to use the Cosmed K4b^2 in a non-laboratory setting, a treadmill was used in this study to ensure a constant walking speed and facilitate comparison of data from the two analyzers. If the Cosmed K4b^2 and the Medgraphics tests provide similar results, these techniques can be used in the same individuals to assess metabolic rate in a number of different experimental conditions and to obtain values that are directly comparable.

Methods

Nineteen healthy community dwelling men and women (9 women, 10 men) volunteered to participate (Table 1). The study protocol was approved by the Medstar Research Institute Institutional Review Board and each participant read and signed a written informed consent document, and agreed to storage of their information in the hospital database for use in future research. All participants were able to walk ¼ mile without difficulty and were not affected by major medical conditions. Prior to testing, information on height and weight were collected. All participants were instructed to refrain from eating for a minimum of 2 hours prior to testing.

The exercise modality, duration and intensity utilized in this testing protocol were selected to simulate the Long Distance Corridor Walk (LDCW) test which has been validated as a method of assessment of physical function in the elderly [4]. The LDCW is also of sufficient length to allow participants to adapt to the level of exertion and enter a metabolic steady-state. Achievement of a steady-state period during exercise testing reduces error in the assessment of energy expenditure [14,15]. Definitions of steady-state exercise vary in the literature, but generally call for a 3 to 5 minute period where VO_2 and VCO_2 vary by $<$10–15% [15,16].

Table 1. Participant characteristics (mean ± SD).

	Men (N = 10)	Women (N = 9)	p-value
Age (yrs)	37.90±13.79	41.78±14.38	0.278
Height (cm)	181.20±4.80	164.89±7.20	<0.0001*
Weight (kg)	86.90±29.71	66.00±10.95	0.032*
BMI (kg/m2)	26.33±8.16	24.41±4.59	0.014*
Smoking status (N)	1	0	N/A

*significant at the p = 0.05 level.

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The Cosmed K4b^2 Analyzer

The Cosmed K4b^2 analyzer has been described in detail elsewhere [10]. Briefly, it utilizes a breath-by-breath measurement of gas exchange through a rubberized facemask and a turbine for gas collection, secured by a mesh headpiece. The facemask is available in different sizes and the headpiece is adjustable to ensure a proper fit. The system is portable and worn by the participants using a harness. The weight of the system is approximately 3 pounds.

The Medgraphics D-Series Gas Exchange System

The Medgraphics D-Series Gas Exchange System was the metabolic cart used for comparison against the Cosmed K4b^2. The system also utilizes breath-by-breath measurement of gas exchange. During gas collection, the system uses a rubber mouthpiece with nose-clips to ensure minimal air leakage. The system is not portable, thus test subjects must exercise on stationary equipment such as a treadmill or bicycle ergometer while connected.

Testing Procedures

Prior to testing, both the Cosmed K4b^2 and the Medgraphics analyzers were warmed-up for a minimum of 20 minutes. Following the warm-up period, the O_2 and CO_2 analyzers of both systems were calibrated using reference gases of known concentrations.

Each participant completed two trials in the same session which varied only with respect to the device used to measure VO_2 (Cosmed K4b^2 or Medgraphics). Test order was randomly determined. Although the Cosmed K4b^2 is designed to facilitate measurement of VO_2 and VCO_2 in a non-laboratory setting, a treadmill was used to ensure a constant walking speed and facilitate comparison of data from the two analyzers. Participants were permitted to select their own "comfortable" walking speed, which ranged from 2.7–4.6 mph, at 0% grade. Both tests were performed at this identical speed with a 10 minute "wash-out" period in between.

After an initial 10 minute rest period, participants were fitted with either the Medgraphics system or Cosmed K4b^2 analyzer, then continued to sit for two additional minutes to allow adaptation to the equipment. After 2 minutes, the participant stood for 30 seconds, the treadmill was started and immediately programmed to the previously selected speed. At the completion of ¼ mile, the test was stopped and the participant was immediately seated, with breath collection continuing for an additional 2 minutes.

After completing the first test, the analyzer was removed and the participant rested for 10 minutes while seated. Immediately

Table 2. Correlations among measurements of VO_2 (ml/kg/min), VO_2 (ml/min), and VCO_2 (ml/min) between tests (N = 19).

	ICC	Pearson's
VO_2 (ml/kg/min)	0.9512	0.9582
VO_2 (ml/min)	0.9698	0.9718
VCO_2 (ml/min)	0.9285	0.9735

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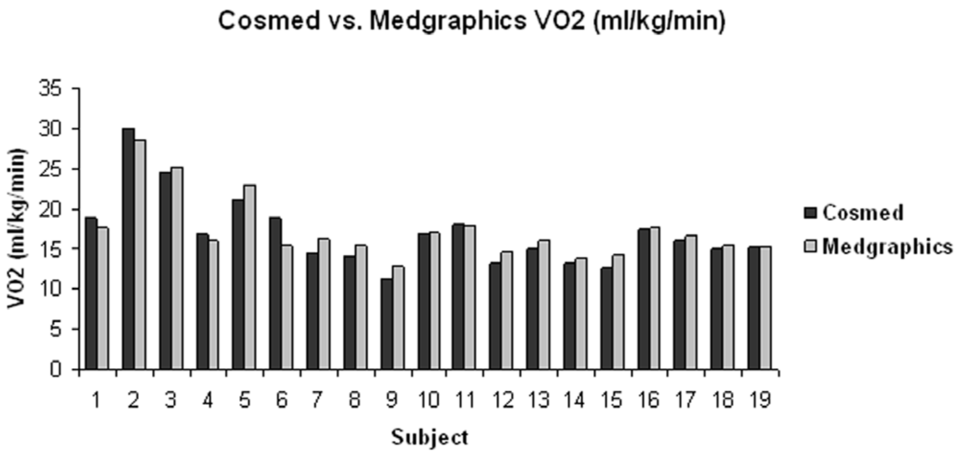

Figure 1. Comparison of VO_2 (ml/kg/min) values between the Cosmed $K4b^2$ and Medgraphics metabolic analyzers.
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following the rest period, a second test was performed using the alternate system and following the procedures described above.

Statistical Analysis

Breath-by-breath values from both systems were averaged over thirty-second intervals. Both the Cosmed $K4b^2$ and Medgraphics systems utilize the Weir equation to predict energy expenditure from CO_2 production and O_2 consumption [17].

An average steady-state value was calculated for each test by manually extracting the metabolic steady-state data and averaging the corresponding values. Data both preceding and following the steady-state portion of the tests were removed and an average steady-state value was calculated from the remaining test data. This strategy eliminates values that may skew the true steady-state values due to variations between the beginning and the end of a test. A minimum of three minutes of data was used to compute the average VO_2 (ml/kg/min and ml/min) and VCO_2 (ml/min) values for each individual.

The average value for the corresponding time interval collected by the Medgraphics and the Cosmed $K4b^2$ analyzers were compared using paired sample t-tests. Measurement accuracy was assessed by calculating the intraclass correlation and Pearson coefficients and visually exploring Bland-Altman plots. Statistical analyses were conducted using Intercooled Stata version 9.2 (Stata Corp, LP, College Station, TX) and the significance level was fixed at $p<0.05$.

Results

All participants ($N=19$) successfully completed both tests. Pearson and intraclass (ICC) correlation coefficients for the average values are shown in Table 2. VO_2 normalized for body weight (ml/kg/min), VO_2 (ml/min), and VCO_2 (ml/min) were highly intercorrelated, suggesting a strong, positive linear relationship. The bar graphs in Figures 1, Figure 2 and Figure 3 clearly show that the values generated by the two different analyzers were nearly super-imposable. The Bland-Altman plot (Figure 4) indicates acceptable limits of agreement between the two systems for VO_2 (ml/kg/min), with all but one of the data points falling within two standard deviations of the mean value [18]. Additionally, the Pitman's test of difference in variance indicates that the two groups have identical probability distributions ($p=0.125$).

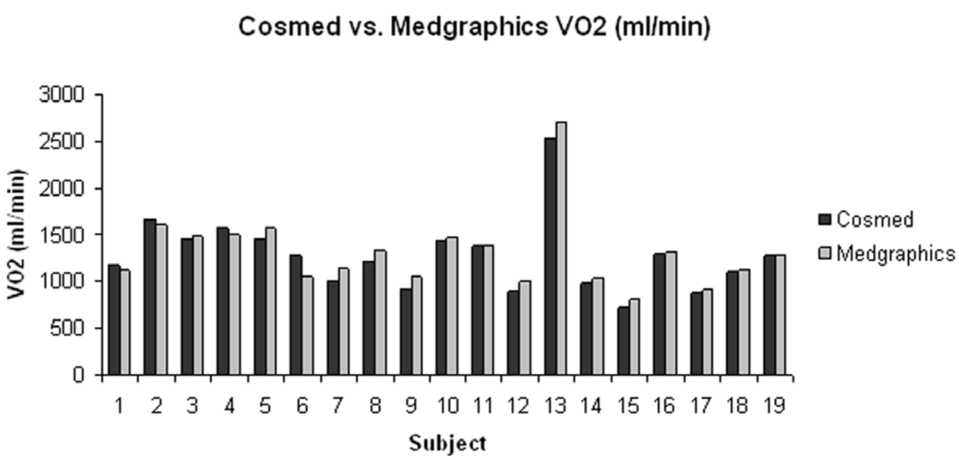

Figure 2. Comparison of VO_2 (ml/min) values between the Cosmed $K4b^2$ and Medgraphics metabolic analyzers.
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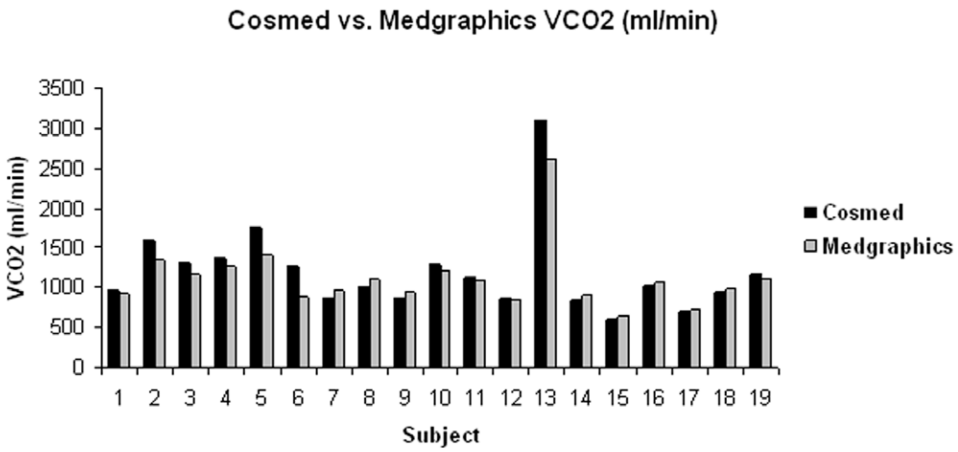

Figure 3. Comparison of VCO_2 (ml/min) values between the Cosmed K4b[2] and Medgraphics metabolic analyzers.
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Comparison of the average values from the two systems using paired t-tests are shown in Table 3. Results indicate no significant difference ($p>0.05$) for VO_2 (ml/kg/min) overall ($p=0.25$) or in women ($p=0.21$) and men ($p=0.68$) analyzed separately. The mean difference between analyzers was -0.296 ml/kg/min (±0.26). Results were not significantly different for VO_2 (ml/min) or VCO_2 (ml/min) over all participants, or when stratified by sex. The mean differences between analyzers were -32.474 ml/min (±22.13) and -72.767 ml/min (±39.89) for VO_2 and VCO_2, respectively.

There was a non-significant trend towards lower VO_2 values and higher VCO_2 values with the Cosmed K4b[2] system, as shown by the mean results in Table 3. Additionally, although this study was specifically designed to assess differences in metabolic measurements, it should be noted that there was a trend towards significant differences in ventilation between the two units, particularly at higher workloads.

Discussion

This study tested the accuracy of the Cosmed K4b[2] portable metabolic analyzer against a Medgraphics D-Series gas exchange system during steady-state walking on a treadmill at a self-selected pace. We found high correlation and low systematic variance between the two systems as evidenced by strong ICC values and acceptable limits of agreement from a Bland-Altman plot analysis.

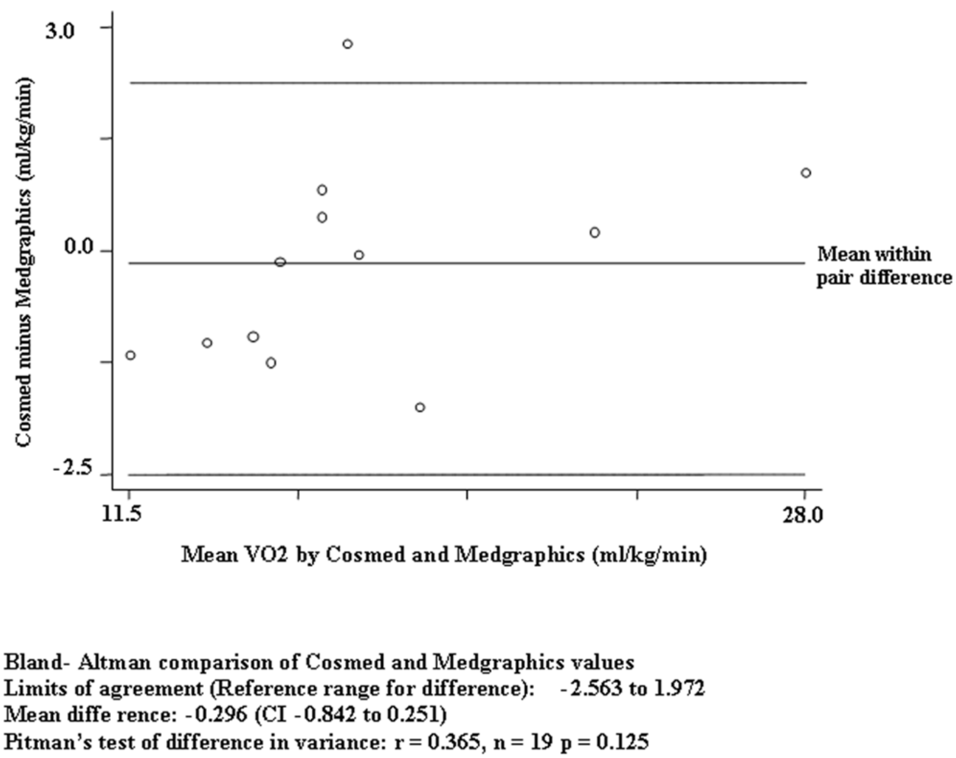

Figure 4. Bland-Altman plot of the difference in the average VO_2 (ml/kg/min) values in 19 participants.
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Table 3. Comparison of measures for Cosmed K4b2 and Medgraphics (mean ± SD), overall (N = 19) and stratified by gender (N = 9 females, N = 10 males).

	Cosmed K4b2	Medgraphics	p-value*
VO_2 (ml/kg/min)	16.94±4.50	17.31±4.02	0.249
Men	16.61±2.41	16.80±2.50	0.689
Women	17.32±6.22	17.87±5.35	0.215
VO_2 (ml/min)	1274.97±399.84	1307.44±408.84	0.159
Men	1422.15±427.31	1446.88±478.51	0.507
Women	1111.44±311.66	1152.51±259.22	0.160
VCO_2 (ml/min)	1190.52±549.03	1117.75±414.22	0.085
Men	1370.78±662.64	1254.04±506.95	0.115
Women	990.23±313.86	965.22±217.25	0.528

*From paired t-tests.
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Furthermore, no significant differences were found between systems in measuring VO_2 (ml/kg/min), VO_2 (ml/min), or VCO_2 (ml/min).

Previous research comparing the Cosmed to more traditional laboratory analyzers has been inconclusive. Doyon et al. reported no significant difference ($p>0.05$) in VO_2 measurements between the Cosmed K4b2 and a laboratory mixing box during an incremental treadmill test [6]. Similarly, LaBreche and McKenzie reported no significant differences ($p>0.05$) in VO_2 or VCO_2 max during a maximal incremental cycle ergometer test between the Cosmed K4b2 and a Physio-Dyne System [8]. When testing the system at various workloads, McLaughlin et al. found no differences ($p>0.05$) in VO_2 between the Cosmed K4b2 and Douglas bag method at rest and high workload (250 Watts), but significant differences ($p<0.05$) at workloads of 50, 100, 150, and 200 Watts [9]. Finally, Duffield et al. reported significantly ($p<0.05$) higher values of VO_2 and VCO_2 measurements by the Cosmed K4b2 when compared to a laboratory metabolic cart during a treadmill running session [7]. These conflicting results may be a function of the different reference analyzers and intensities used over systematically different laboratories. Additionally, there was variation in sample size, with the largest consisting of twelve individuals. Our study had a sample size of nineteen, and generated findings indicating that the Cosmed K4b2 provides data comparable to the Medgraphics D-Series, a widely utilized gas exchange analyzer, during collection of data of low-to-moderate intensity.

Tolerability of the Cosmed K4b2 was uniformly high in study participants. They experienced no problems wearing the face mask or harness containing the battery pack and analyzer unit. In contrast, the mouthpiece associated with the Medgraphics system produced discomfort for some participants and may have contributed to higher, but non-significant within-person variability between tests. In fact, differences in efficiency between using a mask versus mouthpiece may account for much of the small difference in values observed between the two systems.

This study has several limitations. The study is not a true "validation study" as a Douglas Bag was not the reference "gold standard" method for comparison purposes. Additionally, only a narrow range of intensities was used to assess comparability between the Cosmed and Medgraphics units. However, the purpose of this study was to assess the accuracy of the Cosmed during steady state, low-intensity walking exercise, a mode of exercise indicative of the cost of activities of daily living, which to our knowledge has not previously been investigated. Any higher intensity exercise would have been beyond the scope of this study.

Conclusion

In conclusion, study findings indicate that the Cosmed K4b2 portable metabolic analyzer produces acceptable measurements of VO_2 and VCO_2 during steady-state, low intensity exercise in male and female adults over a wide age range. These results support the use of the Cosmed K4b2 portable metabolic analyzer over a range of low-intensity exercise in various laboratory and non-laboratory settings.

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Author Contributions

Conceived and designed the experiments: JAS EMS LF. Performed the experiments: JAS. Analyzed the data: JAS. Contributed reagents/materials/analysis tools: LF. Wrote the paper: JAS EMS LF.

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