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Original Research Article

BOD POD® versus Parvo Medics TrueOne® 2400 Canopy System for Determining Resting Metabolic Rate

Jaime Calvin[1], Katherine Highstead[1], Fred Miller[1]

[1]Department of Kinesiology, Huntington University, Huntington, IN, USA

Abstract

Introduction: Resting Metabolic Rate (RMR) is the measure of energy the body uses at rest. The Parvo Medics TrueOne® 2400 Canopy System is considered a "gold standard" system when measuring RMR. The BOD POD® estimates RMR using the Nelson Equation, which takes into account fat-free mass and fat mass. However, the accuracy of the BOD POD® RMR estimate compared to a gold standard is unknown. **Purpose:** This study sought to determine the accuracy of the BOD POD® RMR estimate with indirect calorimetry (i.e., Parvo Medics TrueOne® 2400 Canopy System). **Methods:** Thirty-one 18 to 21-year-old female college soccer players (mean ± SD: height, weight, and percentage body fat = 164.04 ± 4.14 cm, 65.12 ± 12.07 kg, 26.95 ± 6.46 %, respectively) attending a Midwest University performed both a BOD POD® test and a measured RMR via the Parvo Medics TrueOne® 2400 Canopy System. **Results:** A significant difference ($p < 0.001$) for RMR was found between the BOD POD® and the Canopy System (1301.48 ± 152.67 kcal/day vs. 1540.23 ± 158.77 kcal/day, respectively). The BOD POD® on average underestimated RMR by 238.74 kcal/day. **Conclusions:** The BOD POD® is considered a gold standard for measuring percentage body fat, but not for estimating RMR. This study found the BOD POD® underestimates RMR on average by more than 200 calories per day compared to RMR measured via indirect calorimetry. Thus, caution is advised when using RMR estimates from the BOD POD®, especially if weight management is a goal.

Key Words: Caloric, Energy Expenditure, Metabolism, RMR

Introduction

Resting Metabolic Rate (RMR) is the measure of energy the body burns at rest[1]. RMR represents 60-70% of total daily expenditure for an individual and is composed of resting metabolic rate, thermic effect of exercise, and thermic effect of food[2]. In active individuals, RMR percentages are close to 60%, where sedentary individuals are closer to 75%[3]. An accurate determination of a person's RMR is beneficial for nutritional care such as weight management[2]. Determining RMR is essential when it comes to food intake because not consuming enough calories can cause malnutrition, which can lead to a slower immune response. Excessive consumption of calories can result in added weight, likely excess fat weight. RMR is dependent on energy balance state, body size, fat-free weight, age, dietary intake, hormonal profile, environmental conditions, and physical activity level[3]. RMR measurement is used for weight-management strategy, but also provides information for all populations including the elderly, disabled, athletes, healthy people and hospital patients. For RMR measures to be useful to health care professionals and for individuals, the system measuring RMR must be accurate[4].

A gold standard of measuring human metabolic rate is direct calorimetry. The time and equipment required for measurement is substantial, thus direct calorimetry is rarely used[5]. Indirect calorimetry is the most widely used method for RMR measurements for many reasons such as less space needed for the equipment, lower cost, and less time required for testing[6]. Indirect calorimetry measures oxygen consumption and carbon dioxide production and then calculates energy expenditure from one liter of oxygen consumed[7,8]. Indirect calorimetry is highly accurate with an error rate of less than 1%[9]. Indirect calorimetry is used for measuring RMR through methods such as room open-circuit, the Douglas bag, open-circuit expiratory collection and the hood/canopy open-circuit. Nieman and colleagues (2006) tested the accuracy of a new indirect calorimetry system (a.k.a. FitMate) with an established system, the Douglas bag, to assess the validity and reliability of the FitMate metabolic system in measuring RMR[10]. Results showed no significant difference between the FitMate system and the Douglas bag system for oxygen consumption or RMR[10].

The Parvo Medics TrueOne® 2400 Canopy System is a compact, combined metabolic measurement system that tests indirect calorimetry and maximal O_2 consumption measurements[11]. The Parvo Medics TrueOne® 2400 Canopy System has been compared to other systems during rest and exercise tests and has been found to have consistent agreement between multiple experiments[12]. Bassett et al. (2001) reported that compared to the Douglas Bag, the TrueMax 2400 provided highly accurate measures of minute ventilation, oxygen consumption, and carbon dioxide production[13].

BOD POD® testing has become a common way to determine body composition. Itis non-invasive and determines body composition through Air Displacement Plethysmography (ADP). In addition to assessing body composition, the BOD POD® provides an estimated RMR via a prediction equation that includes the measured fat-free and fat mass from the BOD POD®. However, studies on the accuracy of the BOD POD® RMR is unknown when compared to indirect calorimetry. We are

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not aware of any studies, to date, of how accurate the Bod Pod is when estimating RMR. However, RMR prediction equations have been compared to other indirect calorimetry devices. For example, two studies[14,15] compared equations to the Fitmate indirect calorimetry system and found the RMR prediction equations unreliable.

A person's resting metabolic rate can be measured using a variety of systems or estimated via equations. Having an accurate method to determine RMR is essential due to subjects using this information to help manage their weight and for possible other reasons (e.g., helping to build muscle mass). It is unclear if the BOD POD® accurately estimates RMR. Only one study was found comparing the accuracy of the BOD POD® RMR with a gold standard system. Thus, the purpose of this study was to compare to compare the RMR estimated from the BOD POD® with the Parvo Medics TrueOne® 2400 Canopy System. It was hypothesized that RMR would be similar between the BOD POD® and the Parvo Medics TrueOne® 2400 Canopy System.

Methods

Participants

Thirty-One healthy university women soccer players between the ages 18-22 years (20.2 ± 1.4) volunteered to participate in this study. All non-Huntington University Women's soccer players were excluded from participation. This study was conducted during the competitive season, near the end of the season. The competitive season included two hour practices that took place on Monday, Tuesday, Thursday, and Friday on an outside grass field. Wednesdays and Saturdays typically were game days that included a 45 minute warm up. Sundays were rest days. Practice included more "on ball work" (i.e, skill training) than conditioning. There were some practices with more running than others but overall, conditioning was minimal. Two months prior to this study, players had three a-days two times a week, with one of these sessions being conditioning only. Pre-season only lasted three weeks. Participants were instructed to fast for eight hours (water was allowed) before testing and refrain from strenuous exercise for twenty-four hours before testing. Regarding testing, participants were informed of the study's risks and testing requirements upon entering the lab and then signed a consent form to participate. This study was approved by the IRB (Institutional Review Board) prior to any testing.

Experimental design

On arrival to the laboratory, participants were asked to complete the IRB paperwork. After completing the paperwork, participants were instructed to use the restroom before testing started. Participants were also given instructions about testing. For example, participants were instructed to relax and not talk during both BOD POD® and Canopy testing. All participants were tested before 12 pm.

Testing was conducted in a lab with lights on and minimal noise. Only four people were in the lab at one time, which included the two researchers. Participants performed the Bod Pod first, then the canopy second. The BOD POD® was calibrated before testing the first participant of the day and between participants when multiple participants were tested within the same day. For BOD POD® testing, participants wore Lycra or skin type compression shorts and a lightweight sports bra with no padding or wires. All jewelry was removed, and a swim cap was placed on the participant's head. Next, the participant's height and weight were measured using the laboratories stadiometer. The participant then entered the BOD POD® and was instructed to sit and relax. BOD POD® testing took approximately 5 minutes.

After the BOD POD® was complete, the participant laid supine on an athletic table for 30 minutes. While the participant rested, the Canopy System was calibrated. The gas calibration was 1% CO_2 and 16%O_2 with a base of Nitrogen (per manufacturer guidelines). The flow calibration was five strokes of 40-50L/min of a 3L syringe. After the calibration and the 30 minutes of rest, the canopy hood and drape was placed over the participant's head, chest, and torso. Participants were instructed to relax and not fall asleep during testing. Then 30 minutes of canopy testing begin. Once the participant had been tested with the BOD POD® and the Canopy System they were finished and were free to leave.

Measurements/Instruments

Each participant's RMR was measured using the Parvo Medics TrueOne® 2400 Canopy System and estimated via the BOD POD®. The BOD POD® estimates RMR using a prediction equation that includes fat-free mass and fat mass. During BOD POD® testing, each participant's body mass (weight) was measured with an attached calibrated scale and their body volume was determined next, while sitting motionless inside the BOD POD® for approximately 2 minutes. Body density was then calculated from the participant's mass and volume using the Siri equation. The measured body fat-free mass and fat mass were used in the Nelson equation [RMR = 25.80 x FFM(kg) + 4.04 x FM(kg)] to determine RMR[16]. Other measurements such as height and resting time were determined by a stadiometer and timer, respectively.

Statistical analyses

All analyses were performed using Excel. Descriptive statistics (i.e., means, standard deviations, minimum, and maximum) were calculated for height, weight, and percent body fat. The dependent variables included the BOD POD® RMR and the Parvo Medics TrueOne® 2400 Canopy System RMR. A paired sample t-test was used to determine statistical differences between the RMR of the Canopy System and the BOD POD®. Statistical significance was set at $p \leq 0.05$.

Results

The participant characteristics are presented in Table 1. Descriptive data for RMR is presented in Table 2. The paired t-test revealed a significant difference ($p < 0.001$) in the RMRs between the Parvo Medics TrueOne® 2400 Canopy System and the BOD POD®. The BOD POD® on average underestimated RMR by 238.74 kcal/day. As seen in Figure 1, the Parvo Medics TrueOne® 2400 Canopy System was consistently higher than the BOD POD® for each participant. The lowest difference between the two systems when measuring an individual was 4 kcal/day, and the highest was 479 kcal/day.

Table 1. Characteristics of the participants.

Characteristic	Mean ± SD	Min – Max
Height (cm)	164.04 ± 4.14	155 - 175
Weight (kg)	65.12 ± 12.07	50.36 – 106.4
Body Fat (%)	26.95 ± 6.46	17.2 – 44.5

Table 2. RMR descriptive data for Bod Pod and Canopy System.

RMR measure	Mean ± SD	Min – Max
BOD POD	1301.48 ± 152.67*	1076 - 1714
Canopy System	1540.23 ± 158.77*	1310 - 1964

Note: all values are in kcal/day. *significantly different ($p < 0.001$).

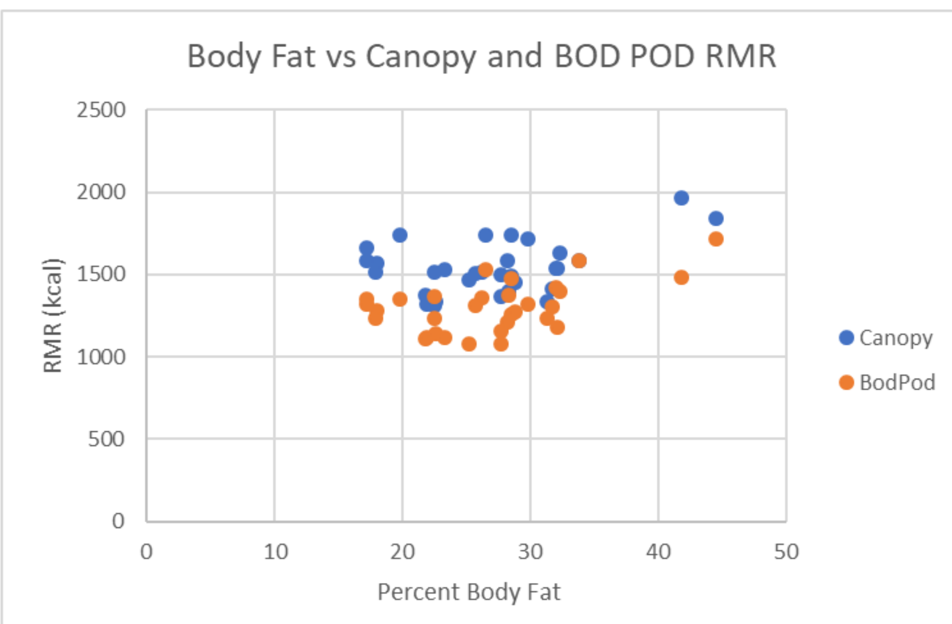

Figure 1. Body Fat Verses Canopy and BOD POD® RMR.

Discussion

This is the first study known to compare RMR values between the BOD POD® and Parvo Medics TrueOne® 2400 Canopy System. The purpose of this study was to determine the accuracy of the BOD POD® RMR estimate with indirect calorimetry (i.e., Parvo Medics TrueOne® 2400 Canopy System). It was hypothesized that the BOD POD® would produce RMR values similar to the Parvo Medics TrueOne® 2400 Canopy System. Our hypothesis was rejected as there was a significant difference in RMR between the Parvo Medics TrueOne® 2400 Canopy System and the BOD POD®. The BOD POD® underestimated RMR by more than 200 calories. This result suggests that caution be used in using the predicted RMR value from the BOD POD®.

Flack et al. (2016) tested the validity of several predictions equations, including the Nelson equation[16], which is used by the BOD POD® to estimate RMR[18]. They found that the prediction equations were unreliable at the individual level. They did find though that at the group level two equations (Harris-Benedict and World Health Organizations)[18] were similar to measured RMR values, but the Nelson equation was not one of them. This finding is similar to the current study's findings in that the BOD POD® prediction equation was significantly different than measured RMR via indirect calorimetry. The Nelson equation significantly underestimated RMR in the current study.

A study similar to the present study was that by Jagim et al. (2018)[19]. The purpose of their study was to determine the accuracy of five different RMR prediction equations. One of the five equations was the Nelson equation. The researchers measured RMR using the Parvo Medics TrueOne® 2400 Canopy System, which was the same system used in the present study. When compared with measured RMR, the researchers found the Nelson, Mifflin-St. Jeor, and Harris-Benedict equations significantly underestimated RMR and the De Lorenzo significantly overestimated RMR in female athletes. The Cunningham equation was the only one that was not significantly different from measured RMR[19]. When comparing the Jagim et al. study (2018)[19] with the present study a lot of similarities were found. For example, both studies measured RMR with the canopy system, used the BOD POD® to determine body composition, and the subjects of both studies were similar in several ways. The similarity in subjects included being college female soccer players (31 in present study and 15 of 22 in Jagim study) and have relatively close percent body fat levels (present study was 26.95% and Jagim et al. study was 23.4%). Furthermore, the measured and predicted values were similar. In Jagim et al. (2018), the average measured RMR and Nelson predicted RMR for females was 1,544 and 1,331 kcal/d, respectively[19]. The average measured RMR and BOD POD® (based on the Nelson equation) in the present study

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was 1,540 and 1,301 kcal/day, respectively. Finally, both studies found the Nelson equation to underestimate RMR, which has been reported in other studies[18,20,21].

Pavlidou et al. (2018) conducted a study similar to the current study in that they compared RMR prediction equations to measured RMR using indirect calorimetry[14]. The participant underwent a fasting period overnight; there were no stimulants for 12 hours before testing, and participants refrained from exercise for 24 hours before the trial. The participants in the present study also fasted for 8 hours overnight, refrained from exercise for 24 hours, and were asked to relax during testing. Pavlidou et al. (2018) found no significance difference between the indirect calorimetry system and the equations used to calculate RMR[14]. These findings were in contrast to the present study, in which a significant difference was found between measured RMR and predicted. However, the current study did not limit stimulants prior to testing. Thus participants in the current study could have consumed stimulants (e.g., caffeine) prior to testing, which could have led to the different results found between studies. Furthermore, the different findings in the two studies could have also been due to differences in participants. For example, the current study included only female soccer players (mean age 20.2 years), where as Pavlidou et al. (2018) included both men and women of all fitness levels and an average age of 37.5 years.

Methodological considerations

This research study had three possible limitations and two strengths. First, possible errors could have occurred when measuring the RMR with the BOD POD® due to a few females wearing a padded bra or cotton clothing instead of the required lycra. Each participant was asked to wear the required lycra, but not all did. Second, air could have leaked out the sides of the hood during the Canopy System testing of each participant. Although this study did not measure possible air leakage, the plastic covering (a.k.a., drape) attached to the hood was used to seal the gaps and prevent any air leakage. Using the plastic covering with the hood reduces any possible air leakage. Siirala et al. (2012) found that the accuracy of using a canopy system to measure REE is similar to a respirator mode, if air leakages are "carefully eliminated"[23]. Third, the large range in percent body fat of participants (17.2% to 44.4%) may have affected the BOD POD® RMR accuracy. It is possible that an accurate RMR would have occurred with a group of participants having similar body fat percentages.

The first strength of our study was that each participant followed the same protocol for both Bod Pod and Canopy testing. For example, participants did not eat within 8 hours of testing, they refrained from exercise 24 hours prior to testing, all participants were tested before 12 pm, and everyone was given the same instructions during testing. Even though participants refrained from exercise 24 hours prior to testing, previous research has reported RMR can be affected by exercise up to 72-96 hours. Furthermore, although participants were tested before 12 p.m., differences in RMR measures may exist between subjects tested earlier versus later in the morning due to different "waking" activity levels prior to testing. The second strength of the study included each participant having rested approximately the same amount of time prior to the canopy test. For example, every participant performed the Bod Pod first, then the canopy second. Just prior to testing of the RMR via the canopy system, participants laid on their back for 30 minutes prior to the start of the 30 minute of Canopy system testing.

Conclusions

This study, to our knowledge, is the first study to compare the predictive BOD POD® RMR with the Parvo Medics TrueOne® 2400 Canopy System, which measures RMR via indirect calorimetry. Findings from this study found the BOD POD® significantly underestimates RMR on average by more than 200 calories per day compared to RMR measured via indirect calorimetry. Thus one should consider this underestimation when interpreting the RMR BOD POD® results. Overall, the knowledge gained from this study provides additional information in the field of exercise physiology related to energy expenditure, metabolism, and body composition. Specifically, even though fat mass and fat free mass affect RMR, these two values alone are not sufficient in providing an accurate RMR value. Thus, it is best if one wants an accurate RMR value to use a gold standard such as the Parvo Medics TrueOne® 2400 Canopy System. Even though the BOD POD® provides accurate percent body fat readings, caution is advised when using the RMR values, especially if weight management is a goal.

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Address for Correspondence

Fred Miller, Ph.D., Department of Kinesiology, Huntington University, 2303 College Ave., Huntington, IN, United States, 46750. Phone: (260)-359-4148; Email: fmiller@huntington.edu.

References

1. Stiegler P, Cunliffe A. (2006). The role of diet and exercise for the maintenance of fat-free mass and resting metabolic rate during weight loss. *Sports medicine*, 36, 239–262.
2. Wang X, Wang Y, Ding Z, Cao G, Hu F, Sun Y, Ma Z, Zhou D., Su B. (2018). Relative validity of an indirect calorimetry device for measuring resting energy expenditure and respiratory quotient. *Asia Pac J Clin Nutr*, 27, 72–77.
3. Vandarakis D, Salacinski AJ, Broeder CE. (2013). A comparison of COSMED metabolic systems for the determination of resting metabolic rate. *Res Sports Med*, 21, 187–194.
4. Haugen HA, Melanson EL, Tran ZV, Kearney JT, Hill JO. (2003). Variability of measured resting metabolic rate. *Am J Clin Nutr*, 78, 1141–1144.

5. Kenny GP, Notley SR, Gagnon D. (2017). Direct calorimetry: a brief historical review of its use in the study of human metabolism and thermoregulation. *Eur. J. Appl. Physiol,* 117, 1765–1785.
6. Haugen HA, Chan LN, Li F. (2007). Indirect calorimetry: a practical guide for clinicians. *Nutr Clin Pract*, 22, 377–388.
7. Schultz Y, Dulloo A. (2014). Resting Metabolic Rate, Thermic Effect of Food, and
Obesity In G. Bray & C. Bouchard (Eds.), Handbook of Obesity (3 ed., Vol. 1, pp. 267-279).
8. Weir JB. (1949). New methods for calculating metabolic rate with special reference to protein metabolism. *J. Physiol. (Lond.),* 109, 1–9.
9. Marson F, Auxiliadora Martins M, Coletto FA, Campos AD, Basile-Filho A. (2004). Correlation between oxygen consumption calculated using Fick's method and measured with indirect calorimetry in critically ill patients. *Arq. Bras. Cardiol*, 82, 72-81.
10. Nieman DC, Austin MD, Benezra L, Pearce S, McInnis T, Unick J, Gross SJ. (2006). Validation of Cosmed's FitMate in measuring oxygen consumption and estimating resting metabolic rate. *Res Sports Med*, 14, 89–96.
11. Parvo Medics - TrueOne 2400 | Making Metabolic Measurements Easy. Retrieved from http://www.parvo.com/
12. Cooper JA, Watras AC, O'Brien MJ, Luke A, Dobratz JR, Earthman CP, Schoeller DA. (2009). Assessing validity and reliability of resting metabolic rate in six gas analysis systems. *J Am Diet Assoc*, 109, 128–132.
13. Bassett D, Howley ET, Thompson DL, King GM, Strath S, McLaughlin JE, Parr BB. (2001). Validity of inspiratory and expiratory methods of measuring gas exchange with a computerized system. *Journal of applied physiology*, 91, 218–224.
14. Pavlidou E, Petridis D, Tolia M, Tsoukalas N, Poultsidi A. Fasoulas A, Kyrgias G., Giaginis C. (2018). Estimating the agreement between the metabolic rate calculated from prediction equations and from a portable indirect calorimetry device: an effort to develop a new equation for predicting resting metabolic rate. *Nutr Metab (Lond),* 15
15. Namazi N, Aliasgharzadeh S, Mahdavi R, Kolahdooz F. (2016). Accuracy of the Common Predictive Equations for Estimating Resting Energy Expenditure among Normal and Overweight Girl University Students. *J Am Coll Nutr*, 35, 136–142.
16. Nelson, KM, Weinsier RL, Long CL, Schutz Y. (1992). Prediction of resting energy expenditure from fat-free mass and fat mass. *The American Journal Of Clinical Nutrition,* 56, 848–856.
17. Riebe D. (2018). *ACSM's Guidelines for Exercise Testing and Prescription* (10th ed). Baltimore, MD: Lippincott Williams & Wilkins.
18. Flack KD, Siders WA, Johnson L, Roemmich JN. (2016). Cross-Validation of Resting Metabolic Rate Prediction Equations. *Journal of the Academy of Nutrition & Dietetics*, 116, 1413–1422.
19. Jagim AR, Camic CL, Kisiolek J, Luedke J, Erickson J, Jones MT, Oliver JM. (2018). Accuracy of Resting Metabolic Rate Prediction Equations in Athletes. *J Strength Cond Res*, 32, 1875–1881.
20. Otterstetter R, Miller B, Fridline M, Boltz M, Faciana C, Scanlon K, Mendel R. (2016). RMR Estimation Model Accuracy Using Air Displacement Plethysmography-Derived Body Composition Measures in Young Adults. *J Am Coll Nutr,* 35, 68–74.
21. Woolf K, Miller S, Reese C, Beaird L, Mason M. (2015). Accuracy and Applicability of Resting Metabolic Rate Prediction Equations Differ for Women Across the Lifespan. *Journal of Nutritional Therapeutics*, 4, 50–63.
22. Woods, AL, Garvican-Lewis LA, Rice AJ, Thompson KG. (2016). The Ventilation-Corrected ParvoMedics TrueOne 2400 Provides a Valid and Reliable Assessment of Resting Metabolic Rate (RMR) in Athletes Compared With the Douglas Bag Method. *Int J Sport Nutr Exerc Metab,* 26, 454–463.
23. Siirala W, Noponen T, Olkkola KT, Vuori A, Koivisto M, Hurme S, Aantaa R. (2012). Validation of indirect calorimetry for measurement of energy expenditure in healthy volunteers undergoing pressure controlled non-invasive ventilation support. *J Clin Monit Comput*, 26, 37–43.