Review

Do Hand-Held Calorimeters Provide Reliable and Accurate Estimates of Resting Metabolic Rate?

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Key words: indirect calorimetry, methods, reliability, validity, portable instrument

This paper provides an overview of a new technique for indirect calorimetry and the assessment of resting metabolic rate. Information from the research literature includes findings on the reliability and validity of a new hand-held indirect calorimeter as well as use in clinical and field settings. Research findings to date are of mixed results. The MedGem instrument has provided more consistent results when compared to the Douglas bag method of measuring metabolic rate. The BodyGem instrument has been shown to be less accurate when compared to standard metabolic carts. Furthermore, when the Body Gem has been used with clinical patients or with under nourished individuals the results have not been acceptable. Overall, there is not a large enough body of evidence to definitively support the use of these hand-held devices for assessment of metabolic rate in a wide variety of clinical or research environments.

Key teaching points:

- A major component of energy expenditure is resting metabolic rate, about 60–70% a day.
- Energy cost of physical activity can be measured using indirect calorimetry.
- Information from research literature includes findings on the reliability and validity of a new hand-held indirect calorimeter.
- There is not a large enough body of evidence to definitively support the use of the hand-held devices.

Introduction

Indirect calorimetry is the primary method used for the assessment of energy expenditure (EE) [1]. Indirect calorimetry is also used to determine caloric requirements of individuals, monitor changes in EE as a result of dietary or exercise interventions, illness or disease progression. A major component of EE is resting metabolic rate (RMR) which represents approximately 60–70% of daily EE [2]. RMR is calculated from measurements of oxygen consumption and carbon dioxide production and can also be used to evaluate substrate utilization. Information regarding changes in RMR is important in clinical settings when establishment of caloric requirements is important for recovery from illnesses. Energy cost of physical activity can also be measured using indirect calorimetry [3].

Metabolic carts have been used successfully for many years to determine EE, RMR and substrate utilization and are the standard method for such assessment [1]. However, metabolic carts are not conducive to use in field settings or for large scale epidemiology studies. Additionally, costs associated with the use of metabolic carts can be high. The initial cost of the instrument may exceed $25,000 plus there is the need for experienced technical staff, and expensive repairs are all deterrents to the use of metabolic carts in many environments. Therefore, there is a need for a smaller, less expensive, but accurate device for assessment of RMR. Furthermore, if determination of RMR is to be useful to healthcare providers methods for making this determination must be more user-friendly, reliable and accurate.

Recently a new hand-held device for determination of RMR has been developed. This device, developed by HealthETech [4], comes in two models: the BodyGem™ (BG) and the MedGem™ (MG). These devices are small, portable, easy to use and are relatively inexpensive compared to traditional metabolic carts. To date there is a limited number of research

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The author has no personal or financial interest in the Body Gem instruments of the HealtheTech company.

Journal of the American College of Nutrition, Vol. 26, No. 6, 625–629 (2007)
Published by the American College of Nutrition

reports comparing the use of either model with the traditional metabolic cart as the reference method. Furthermore, the results using these devices have been inconsistent. Therefore, it is the purpose of this review to provide an overview of the most recent research findings using the hand-held indirect calorimeters developed by HealthETech.

Methods

The BodyGem™ (BG) and MedGem™ (MG) are hand-held indirect calorimeters currently being sold in fitness, weight loss, and research settings. They measure oxygen in the inspired and expired airflow by dual channel fluorescent quenching sensors. The principle of the BG or MG technology is based on the deactivation of ruthenium in the presence of oxygen. Ruthenium cells are activated by an internal light source and the activation results in florescence. In the presence of oxygen this reaction is quenched and the fluorescence is suppressed. The amount of suppression is proportional to the oxygen concentration in the air being sampled; either inspired or expired airflow. The dual-channel fluorescent sensor has a response time of 50-ms. The volume of airflow is measured using ultrasonic pulse technology and a transducer at the ends of the airflow tube emits a sound pulse; the time elapse between the sending and receiving of the sound pulse to the transducers is proportional to the rate of airflow. The BodyGem and MedGem are manufactured by the same company and are marketed as providing the same results. However, research findings suggest otherwise. Therefore, this paper will provide a review of the research literature using these 2 devices. Because the 2 models have been used by different investigators in different ways, the findings for the Body Gem (BG) and Med Gem (MG) will be presented separately.

Reliability and Validity of the Body Gem

One of the first studies to report the reliability and validity of the BG was done in comparison to a mechanical simulator. This study tested the BG against a mechanical simulator in order to establish validity independent of biological or human variability (HealthETech Inc., personal communication). Twenty-two units were tested over three days for reliability and validity. The average variation in the repeated tests with the same device was 1.45% or 20 kcal/day. This study demonstrated that under conditions of mechanical testing the BG device was both reliable and accurate.

Four studies have been reported using the BG with research volunteers. The first 2 studies reported repeated measurement of RMR by the BG model over time [5,6]. Herring [5] used a randomized repeated measures design for the purpose of evaluating the reliability of 3 BG devices. Each of 3 body gem instruments (A, B, and C) was tested 3 times in random order by 24 adults. Each test session was conducted following the same test conditions on each of the three test days. For example, volunteers came to the laboratory after an overnight fast of at least 12 hours and having refrained from vigorous physical activity for 24 hours prior to testing. The time of the last meal consumed and the time of the last exercise bout were recorded. Subjects rested quietly prior to testing to minimize any effects that traveling to the laboratory had on metabolic rate. Instructions were given to maintain a quiet, resting body position and normal, continuous breathing pattern during each test session. Individuals were instructed to maintain the same diet and activity patterns throughout the 3 days of reliability testing. Under these controlled testing conditions, Herring found that the 3 instruments were reliable within themselves and across the 3 test sessions. In other words instrument A provided the same value when tested on the 3 different occasions, as did instruments B and C, and thus demonstrated a within instrument reliability. However, a difference was observed between the 3 instruments; BG-A gave consistently lower results (approximately 7–10%; $p < 0.05$) compared to instruments B and C. To identify which, if any, of the 3 BG instruments provided values comparable to standard laboratory metabolic cart additional testing was undertaken comparing the 3 BG instruments against a standard metabolic cart (TrueMax 2400 metabolic cart, Parvo Medics; Sandy, UT). Using a repeated measures analysis of variance (ANOVA) to determine statistical differences, she found that two of the three BG instruments (A and C) gave consistently lower results (12% and 9%) compared to the metabolic cart. Only BG-B provided estimates for RMR that were not different from the estimate from the metabolic cart.

Blanton and co-workers [6] also reported findings for both reliability and validity of the BG instrument. Results reported by Blanton were similar to those of Herring for the reliability evaluation of the BG. Blanton and colleagues tested 6 BGs in random order on 3 three consecutive mornings followed by metabolic cart measurements. The volunteers were premenopausal women with an average age was 30.8 yrs and average body mass index (BMI) of 21.5 kg/m^2. Repeated measurements showed no significant differences on a given day or between days for the BG instruments. Therefore, the BG devices were considered to be reliable. However, compared to the metabolic cart results the BG estimates of RMR were significantly lower; about 95 kilocalories. These authors concluded that in normal weight women BG provided reliable measurements, but significantly under estimated RMR compared to a metabolic cart.

Nieman co-workers [7] reported findings from 63 research volunteers (43 women, 20 men; average age was 41.3 yrs.) in which each volunteer completed two BG tests and two Douglas bag tests on two separate test days. Testing was done in random and counterbalanced order. The reliability for the measurement of oxygen consumption was highly correlated on both days for BG instruments ($r = 0.97$). The average oxygen consumption (241 ± 46 and 240 ± 45 ml/min) and RMR (1657 ± 324 and 1650 ± 307 kcals) were not significantly different between the two methods. These data indicate that the BG gave both reproducible and accurate oxygen consumption measurements compared to the Douglas bag method for this group of research volunteers.

Similar findings were reported by Melanson et al. [8] for reliability and validity of the Body Gem device compared to a metabolic cart (SM2900, Sensor Medics Metabolic Cart model 2900, Yorba Linda, CA.). Melanson and colleagues performed resting metabolic rate measurements on 41 health adults, 21–61 years of age, and with BMI values ranging from 20.6 to 35.4 which included normal weight, overweight, and obese individuals. The authors reported no trial to trial differences in the RMR measurements by either the BG devices or the SM2900 cart. Thus confirming the reliability observed by others. However, they did observe that the BG values for RMR were significantly higher than the values obtained from the SM2900; suggesting that the BG device was reliable but not valid when compared to a SM2900 cart. The investigators pursed the difference between the BGs and SM2900 and determined that the higher RMR values obtained on the BG were the result of the energy cost of holding the BG in position when using a mouthpiece. After correcting for this effect no significant differences were found in RMR values between the 2 methods. The authors, therefore, concluded that the BG was both reliable and valid.

Reliability and Validity of the Med Gem (MG)

An investigation conducted by Stewart and colleagues [9] compared simultaneous measurements of RMR with the hand-held MedGem device and a traditional indirect calorimeter (DeltraTrac). To achieve simultaneous measurements the MG device was placed inside the hooded canopy of the metabolic cart. The MG was placed directly over the inlet to the port delivering gases to the mixing chamber of the metabolic cart; thereby getting simultaneous measurements as the exhaled gases from the MG flowed into the mixing chamber. These investigators reported no significant differences in either oxygen consumption or RMR between the 2 methods (Med Gem vs. DeltaTrac) with an average difference of only 0.58 ± 15.33 ml/min for oxygen consumption and 4.66 ± 113.39 kcal/day. Stewart et al. concluded that the MedGem hand-held device provided accurate measurements of oxygen consumption and RMR.

Only one study to date has been reported that tested the validity of the MedGem hand-held device in children [10]. In a research design similar to that used with adults Nieman tested and compared the MedGem device to a traditional Douglas bag indirect calorimeter procedure in 59 children (29 boys, 30 girls, average age 11.0 yrs ± 0.2 yrs.). Children performed 4 RMR tests in 1 session which included 2 Douglas bags measurements and 2 MedGem measurements; tests were randomized in terms of the order of testing the Douglas bag and MedGem methods. No significant differences were found between the 2 methods for oxygen consumption or RMR. Therefore, these authors also concluded that the MedGem was a reliable and valid system for measuring oxygen consumption and RMR in children.

Clinical and Field Studies of Hand-Held Indirect Calorimeters

In 2004 St-Onge and co-workers [11] evaluated the validity of the MG to measure the increase in energy expenditure associated with the consumption of a meal (postprandial energy expenditure; PP-EE). The study was set up to test RMR in 15 healthy adult subjects with a 20 minute measurement made using the DeltaTrac metabolic cart followed by 10 minute measurements using the MG. EE was measured for 7 hours following a meal which consisted of ≈600 kcal (2510 kJ) breakfast foods. No difference in RMR was observed between the 2 methods. Additionally, the authors did not detect any bias in the measurements; one method was not consistently high or low compared to the other technique. St-Onge and colleagues concluded that the MG device provided an accurate estimate of PP-EE and was capable of tracking changes in PP-EE over an extended period of time.

There has been 1 report of the use of the MedGem hand-held calorimeter with clinical patients; 24 stable patients on home nutrition support [12]. The patients were referred for home nutrition support with parenteral feedings due to gastrointestinal dysfunction. Because of the parenteral feeding, a typical 12-hr fast before making RMR measurements was not possible. So, 3 measurements of RMR were made following a 4-h fast and 2-h abstention from exercise. A random order of testing was used for the 2 Med Gem devices or the DeltaTrac metabolic system. Because of the need for accurate RMR values in many clinical situations, the authors established *a priori* that a difference between the MG and metabolic cart of 250 kcal/d or more would be consider clinically unacceptable. Additionally, disagreement between the 2 methods of ≥10% was also deemed unacceptable. Average RMR for MedGem 1 was 1301.9 ± 180.9 kcal/d compared to MedGem 2 which was 1295.7 ± 223.4 kcal/day. The average difference between the two Med Gem devices was −6.8 kcal/d and the limits of agreement were 233 and 247 kcal/d; these differences were clinically acceptable. The DeltaTrac average RMR was 1445.7 ± 285.7 kcal/d, and the average difference between the DeltaTrac and the 2 Med Gems was −162 kcal/d with limits of agreement between 577 and −253 kcal/d. These results were clinically unacceptable. Overall, 80% of the repeated MG-RMR measurements was within 10% of each other. However, the average MG value agreed with the DeltaTrac in only 60% of all tests. While the authors found that the MG was reliable they also observed that the MG values were frequently lower than the values obtained by the DeltaTrac; suggesting that further research is needed to validate the MG device for use with patients groups.

To date there has been only 1 report using either the BG or MG device in a field setting [13]. Use of small, reliable and accurate instrument for use in field settings is extremely important. In the developing world where a large proportion of the population, especially women and children, suffer from micronutrient malnutrition and chronic energy deficiency [14] a hand-held device that can reliably and accurately assess RMR could provide immediate information on the success of international aid intervention programs. Toward this end, Alam and colleagues [13] assessed the reproducibility and validity of the MG to estimate RMR in 37 non-pregnant, non-lactating women (average age 27.6 yr $\pm$ 4.5; average BMI = 20.8 $\pm$ 3.1 kg.m^2) in Bangladesh. Each woman performed RMR measurements in triplicate with a MG and DeltaTrac metabolic cart in 2 separate test sessions. The reproducibility for the MG and DeltaTrac was 9% and 3%, respectively. The authors also found that differences in oxygen consumption between the MG and DeltaTrac were level dependent. In other words, the difference in oxygen consumption between the 2 devices was dependent on the level of oxygen consumed, for larger individuals with higher levels of oxygen consumption the difference was greater than for smaller individuals with lower oxygen consumption values. The MG also gave higher values than the DeltaTrac. The average difference in oxygen consumption between MG and DeltaTrac was 10%, but the difference increased at higher levels of oxygen consumption. This difference in oxygen consumption also translated to a difference in the estimation of RMR; MG had higher RMR values than DeltaTrac and the difference increased at higher RMR levels. The authors concluded the reproducibility of the MG when used in a rural setting was poor and that the validity of the instrument for measuring RMR of Bangladeshi women was questionable. They further stated that "the current reliability impedes its use as a first instrument for measuring RMR.

Conclusion

Research thus far has provided mixed findings. Although BG and MG are manufactured by the same company and are marketed as being the same, differences in most of the research results seem to follow along separate lines depending on whether the BG or MG instrument was used. In the studies that used the BG devices the majority of studies concluded that either 1) significant differences exist between BG instruments and/or 2) significant differences were found between the BG devices and standard metabolic carts. Only 1 study reported acceptable results with the BG device when the comparison was made to the Douglas bag method of indirect calorimetry for the standard reference method. Investigators that evaluated the MG devices were more positive in their results. Comparisons made to simultaneous measurements of energy expenditure, RMR in children, and postprandial energy expenditure found no differences to standard laboratory methods. However, differences were observed between the MG and standard methods when used in clinical patients on parenteral nutrition support and malnourished women; suggesting that more research on the reliability and validity of these hand-held indirect calorimeters is needed in clinical populations.

The possibility exists that the new technology used in these small hand-held indirect calorimeters is more advanced then the metabolic cart technology. Therefore, the error is in the use or selection of the reference method for comparison (Parvo Medics, Sensormedics, or DeltaTrac). Along these lines, it is interesting to note that the one BG study that made a comparison between the BG and the Douglas bag method observed no significant difference between methods. Other potential sources of error in these studies could be leaks in the BG or MG mouthpiece, leaks in the face mask connected to the metabolic cart, subject discomfort leading to hyperventilation, subject drowsiness leading to abnormally low airflows, or improper calibration of equipment. However, all testing as reported in these investigations was completed following standardized procedures and thereby reducing the likelihood of leaks, improper calibration or subject anxiety. The possibility of low airflow, especially for the women, as the source of error is worth consideration. BodyGem technical information does caution against high airflow as with exercise. Monitoring exercise airflow is beyond the capacity of these devices. Also in smaller individuals resting respiration rates and airflow may be too low. The smaller size of women compared to men and thus a lower airflow may be responsible for some of the observed difference between sexes when compared to the metabolic cart. If low airflow was the culprit for the observed differences against the cart then it raises a concern regarding the ability of this technology to accurately assess resting metabolic rate in women and children.

Finally, more investigations are needed to examine the reliability and validity of the BodyGem and MedGem instruments especially with individuals of various body sizes, under a variety of clinical conditions and with different levels of light activity such as desk work, walking, standing, watching television, and playing computer games, to name a few.

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Received September 5, 2006; Accepted September 27, 2006.