Original Article

Validity and reliability of BodyGem for measuring resting metabolic rate on Taiwanese women

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Resting metabolic rate (RMR) accounts for about two thirds of total energy expenditure. The widely used Harris-Benedict equations systematically overestimate RMR. This study assessed overall reliability and validity of a handheld indirect calorimeter, BodyGem, on a sample of women. Thirty healthy nurses participated in this study with an age of 41.9 ± 9.0 years old and a body mass index of 24.0 ± 2.8 kg/m^2. The Deltatrac Metabolic Monitor was used as the criterion method to validate BodyGem. Reliability was estimated by repeated measures of BodyGem to test internal consistency and stability. Analysis indicated that measurements of Deltatrac and BodyGem are well correlated (r = 0.76, P < 0.001). The correlation coefficients of two BodyGem RMR measurements were of large statistical significance (r = 0.96, P <0.001, mean difference = 15.8±55.8 Kcal/d). A significant difference (F = 3.81, P = 0.04) in repeated measures ANOVA and post hoc revealed a difference between BodyGem and Deltatrac. There was a systematic difference between both methods (mean difference between BodyGem and Deltatrac = 36.4~52.2 Kcal/d). After adjustment of additional energy demand by holding BodyGem in position, the difference became non-significant (F = 1.62, P = 0.22). Bland-Altman plots revealed that there was no significant trend in both methods, and repeated measurements of Bodygem. In conclusion, RMR obtained using the BodyGem has a high degree of reproducibility and an acceptable validity compared to the Deltatrac. Further validity research is needed in Taiwanese women.

Key Words: women, reliability, validity, resting metabolic rate, indirect calorimeter, Harris-Benedict equations, Taiwan

Introduction

Daily energy expenditure is usually divided into the following three components: resting metabolic rate (RMR), the thermic effect of food, and energy expended in exercise and physical activity.[1] Among these, RMR accounts for 60 to 75% of total daily expenditure in sedentary individuals, and shows little day-to-day variation. RMR is an important factor of energy metabolism in humans.[2] The principle of treatment of obesity is to keep calorie intake below calorie expenditure. To achieve the desired weight loss requires accurate measurement of energy expenditure.[3-5] Hence, it is important to assess RMR accurately in order to achieve a negative balance of energy.[6, 7]

For clinical convenience, RMR is often estimated using predictive equations, such as Harris-Benedict (H-B),[8] Bernstein,[9] Mifflin,[10] and World Health Organization (WHO)[11] equations, which involve variables such as height, weight, age, gender, and fat-free mass. However, only 50-70% of the variability in RMR is explained by these prediction equations.[12-14] Indirect calorimetry is also used clinically to determine RMR.[2,7] However, not only does the current indirect calorimetry measure require highly skilled technicians, it is also costly and impractical for most clinical and community settings. Therefore, there has been a strong interest in the development of a more sensitive, easy-to-use, portable and accurate device to measure RMR, which can be used in non-laboratory settings. BodyGem (Health Tech Inc., Golden, CO), a small, hand-held device, is an example of such technology. Melanson[15] and Nieman[16] tested BodyGem by comparing it with metabolic cart and Douglas bag measurements and both showed that BodyGem provided valid and reliable measurements of RMR. However, there are few studies on the Asian population. At present, H-B equations that were derived in 1910 and based on the Caucasians are still widely used in clinical and experimental studies in Asia. HB equations overestimate RMR by 10-15% in the United States[4, 10, 12] and 15~20% in Asians.[17]

In addition, H-B equations give the same RMR in people of the same gender, age, body height and weight. However, it is known that individuals differ in RMR.

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Accepted 29th November 2005

Accurate estimation of RMR is crucial to achieve an energy metabolism balance. It is especially important for the Asians to develop a reliable and individualized method for measuring RMR. Therefore, the purpose of this study was to evaluate the validity and reliability of BodyGem on a sample of Taiwanese women.

Materials and Methods

Subjects

Thirty volunteer nurses were recruited in the Wan Fang hospitals and stratified into one of three body mass index (BMI) categories: normal, 19-22.9; overweight, 23-24.9; and obese, $\geq$25 according to the World Health Organization definition of obesity for the Asia-Pacific countries.[18] Selection eligibility criteria included the following: apparently healthy women, age of 18 or above, non-smoking, non-alcohol drinking, and not having been on any recent weight reduction program (weight stable for the previous 4 months). Women who had been previously diagnosed as having diabetes mellitus, thyroid disease, renal insufficiency, cardiovascular disease, pulmonary dysfunction, severe hypertension, or taking medications that could affect RMR were excluded. T3, T4, and TSH were also checked to rule out thyroid disease. This study was approved by the Institutional Human Subject Review Board of Tri-Service General Hospital, Taiwan. All subjects gave written informed consent before participa-ting.

Protocol

Subjects fasted, avoided caffeine beverages for at least 8 hours, and abstained from strenuous exercise for 24 hours prior to the test. After arriving in the lab, subjects were measured for their body height, body weight, and percentage of body fat and then rested quietly in a semi-recumbent position for approximately 30 min in an isolated room with the temperature maintained around 24□. RMR was measured by the same technician using both the BodyGem and an indirect caloriometry method (Deltatrac Metabolic Monitor, Datex Inc., Helsinki, Finland) on the same morning (8:30 ~ 10: 30) to reduce the effect of diurnal variation. Two trials of BodyGem and one of Deltatrac were made in a random order. Subjects were given a break of 20-30 minutes between tests. During the break, subjects remained seated and were asked to remain awake and relaxed.

Resting metabolic rate measurements

BodyGem

BodyGem is designed to measure the human RMR. The principle of BodyGem has been described elsewhere.[15, 16] Each subject is asked to breathe through the device with a disposable mouthpiece and a nose clip for a period of 5-12 minutes, during which the device measures the volume and content of the breaths, flow rate, oxygen concentration, temperature, pressure, and humidity. The RMR is calculated from oxygen consumption and a fixed respiratory quotient (RQ) of 0.85 using a modified Weir equation.[19]

Deltatrac metabolic monitor

Deltatrac Metabolic Monitor is a continuous open-circuit indirect calorimetry for measuring energy expenditure using a ventilated hood system. This device collects continuously the subjects' O_2 and CO_2 concentrations in inspired and expired air diluted in a constant airflow (40L air/min) generated by the analyzer. One-minute data were taken for half an hour. For each set of data, the first 10 minutes were discarded and the mean value of the data for the remaining 20 minutes was used in the calculations.

Anthropometry

Height and weight measurements were taken with participant's clothes and without shoes. Body weight was measured to the nearest 0.1kg on a calibrated clinical balance scale. Body height was measured to the nearest 0.1cm using a standard stadiometer. Body mass index (BMI; kg/m^2) was calculated from the weight in kilograms divided by the height in meters squared. Body composition was determined using a multiple frequency bio-impedance analysis (Inbody 3.0 Biospace Co, Korea).[20] Fat mass (FM) was calculated by multiplying percentage of body fat times body mass (kg). Fat-free mass (FFM) was determined by subtracting FM (kg) from total body mass (kg).

Statistical analyses

Data were analyzed using the SPSS for Windows statistics program, version 11.0 (SPSS, Chicago, USA). Pearson correlation coefficients were used to evaluate the relationship between the measurements obtained by the two methods. A repeated measures ANOVA was employed to test the dependability of BodyGem in measuring RMR. A significant overall F-statistic was followed by *post hoc* pairwise comparisons to determine which means differed significantly from the others. The homoskedasticity was explored by inspection of Bland-Altman plots[21] and quantified with Pearson's correlations. The results are expressed as mean $\pm$ SD. A two-tailed P-value of less than 0.05 was considered statistically significant.

Results

The volunteer women had a mean age of 42.0 ± 9.0 (21.3~54.8) years old and a mean BMI of 24.0 ± 2.8 (19.2~31.9) kg/m^2. Ten had a BMI less than 23, ten had a BMI between 23 and 25, whereas ten had a BMI greater than 25. The characteristics of subjects and the different methods of predicting RMR among study subjects are summarized in Table 1.

Based on the RMR measurement of Deltatrac, there was a mean 20.0% overestimation (19.6% in the normal group, 18.4% in the overweight group, and 22.1% in the obese group, F=0.34, P = 0.72) of RMR predicted by the H-B equations among subjects. These results indicate that the commonly used H-B equations overestimate RMR of the Asians in all three BMI categories. It would be problematic if a weight loss program was based on such inaccurate RMR predictions.

Concurrent validity is the degree to which the scores on an instrument correlate with some external criterion.[22] In this study, Pearson correlation analysis indicated that the RMR measures from BodyGem (mean of two trials) and Deltatrac are well related (r = 0.76, P < 0.001).

Table 1. General characteristics of study subjects

	Mean (SD)	Range
Age, year	41.9 (9.0)	21-54
Height, cm	158.9 (5.5)	147-170
Weight, kg	60.9 (9.3)	47.0-86.7
Body fat, %	35.8 (4.9)	24.3-45.1
Body mass index, kg/m^2	24.0 (2.8)	19.2-31.9
19-22.9, normal (N = 10)	21.2 (1.0)	19.2-22.2
23-24.9, overweight (N = 10)	24.0 (0.5)	23.3-24.9
$\geq$25, obese (N = 10)	27.0 (2.1)	25.1-31.9
Resting metabolic rate, kcal/d		
H-B equation [a]	1351.8 (106.9)	1162.5-1682.5
BodyGem	1179.3 (142.9)	970.0-1640.0
Deltatrac	1134.5 (136.1)	874.0-1450.0

[a]Resting metabolic rate predicted by Harris-Benedict equations.

In particular, for those with BMI greater than 25, the correlation coefficient is up to 0.89 (P < 0.001). Besides, in order to determine the degree of agreement between three measurements (two trials of BodyGem and one Deltatrac), repeated measures ANOVA with post hoc pair-wise comparisons showed that there is a statistically significant difference (F=3.81, P=0.04) between measurements of Deltatrac and BodyGem trial #2. When method-to-method differences were analyzed using Bland-Altman plots, though there was no significant trend in two methods (Fig 1 for BodyGem trial #1 vs. Deltatrac, mean difference = 36.4±106.3 Kcal/d, r = 0.029, P = 0.88; Fig 2 for BodyGem trial #2 vs. Deltatrac, mean difference = 52.2±107.0 Kcal/d, r = 0.16, P = 0.40). The RMR measured by the BodyGem was higher than that by the Deltatrac. It has been discussed in Melanson's study[15] that RMR measures by the BodyGem was an average of 255 kj/d (60 kcal/d) higher due to the energy demand for holding the BodyGem in position. In the current study, after adjusting the estimated energy demand, the differences between the Deltatrac and Body-Gem were no longer significant (F = 1.62, P = 0.22). Reliability can be equated with the stability and consistency of a measuring tool.[22] In this study, the correlation coefficient of two trials of RMR measurements by BodyGem was of large statistical significance (r = 0.96, P <0.001), implying that the instrument could obtain homogeneous results in all subjects. When trial-to-trial differences were analyzed using Bland-Altman plots, there was no significant trend in two trials of BodyGem (Fig 3, mean difference = 15.8 ± 55.8 Kcal/d, r = -0.24, P = 0.20). These results indicate a high degree of stability and internal consistency of BodyGem.

FFM, representative of the most highly metabolically active tissue, is a strong predictor of RMR. In this study, FFM was well correlated with RMR measured by the BodyGem (r = 0.70, P<0.001) and the Deltatrac (r = 0.65, P <0.001).

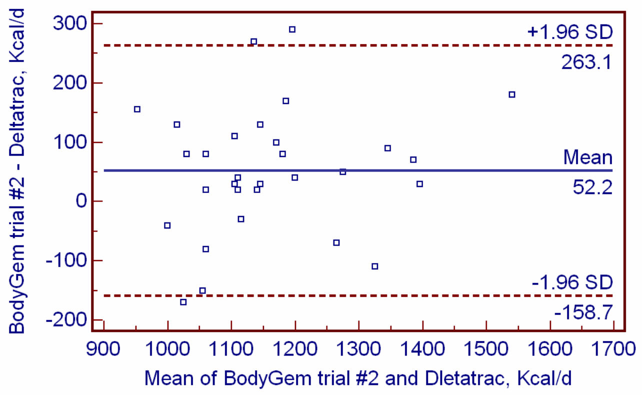

Figure 2. Bland-Altman plot depicting difference in resting metabolic rate values between the Deltatrac and BodyGem trial #2 versus mean values. Solid line depicts the mean difference between the methods and dotted lines 2 standard deviations from this mean.

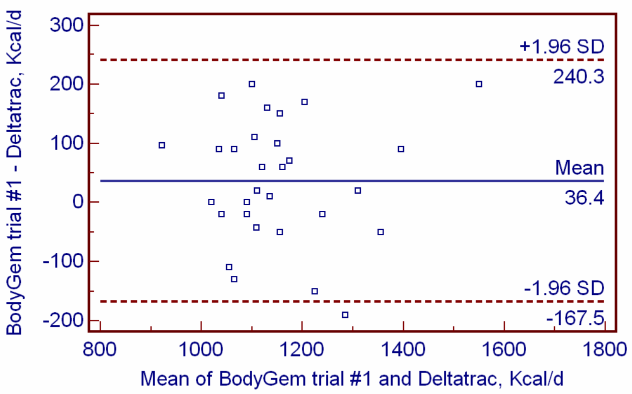

Figure 1. Bland-Altman plot depicting difference in resting metabolic rate values between the Deltatrac and BodyGem trial #1 versus mean values. Solid line depicts the mean difference between the methods and dotted lines 2 standard deviations from this mean.

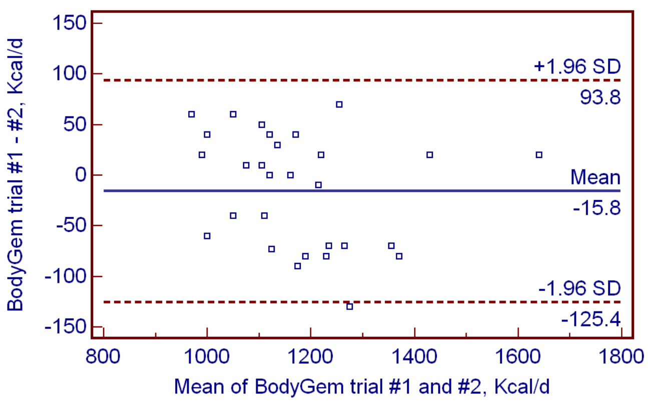

Figure 3. Bland-Altman plot depicting difference in resting metabolic rate values between the BodyGem trial #1 and #2 versus mean values. Solid line depicts the mean difference between the methods and dotted lines 2 standard deviations from this mean.

Discussion

Results of the present study indicate that measurements of RMR obtained with the BodyGem are well correlated with measurements obtained with the Deltatrac. BodyGem demonstrated a high degree of reliability between repeated trials. RMR measurements either by BodyGem or Deltatrac were similarly correlated with FFM, a strong predictor of RMR. To our knowledge, this is the first study comparing this newly developed device to Deltatrac in the Asians. In this study, there was a mean 20.0% overestimation of RMR using H-B equations compared to that measured by Deltatrac. Our results confirmed the findings of an overestimation of RMR by the commonly used equations among normal, overweight, and obese subjects (Fig 4).[4,7,12,23-25]

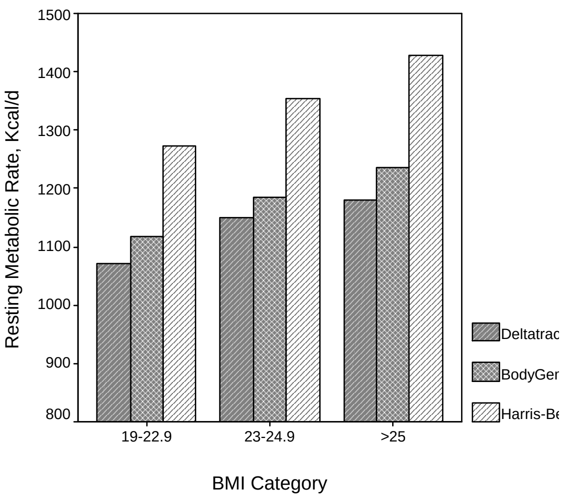

Figure 4. Resting metabolic rate values measured by the Deltatrac, BodyGem, and predicted from the Harris-Benedict equations for three BMI categories.

Cross-Bu *et al.,*[26] supported the need for developing a portable, accurate device for measuring RMR at the bedside. Unlike those expensive and complicated metabolic devices, BodyGem can be used in the field, office and home. This handheld device can be used easily by a wide variety of health professionals to measure RMR. There are several recent publications on the validation of BodyGem. Melanson *et al.,*[15] found the mean difference between measurements by BodyGem and a metabolic cart to be only 46~101 kj/d after adjustment. Nieman[16] reported that correlation coefficients for oxygen consumption ranged from 0.81 to 0.87 when comparing data from the BodyGem to the Douglas bag and SEE ranged from 22 to 28 mL/min. BodyGem seems to be a valid method as compared with the standard. However, Alam's recent publication[27] suggests that the reproducibility and validity of MedGem (Health-Tech, Golden, CO), another type of handheld indirect calorimetry that was identical to BodyGem but differed on the display, was poor compared to the Deltatrac method in a sample of women. Besides, Compher *et al.,*[28] compared MedGem with Deltatrac and found the MedGem RMR measures are frequently lower than Deltatrac measures and require further validation.

Our results showed that the RMR obtained by BodyGem was significantly higher than that by the Deltatrac method. This finding was compatible with Melanson's study. Melanson *et al*[15] proposed that RMR measured by the BodyGem was an average of 255 kj/d (60 kcal/d) higher due to the energy demand for holding the BodyGem in position. Controversially, Compher's study[28] revealed that the MedGem RMR measures are frequently lower than Deltatrac measures. They attributed the difference to the assumption of RQ of 0.85, undetected air leaks around the mouthpiece or nose clip, and anxiety during performing MedGem. Further research is needed before BodyGem can be used to replace the Deltatrac in a clinical population.

We use the Deltatrac metabolic monitor as the criterion method for evaluating the BodyGem. According to previous reports and studies,[13,29,30] Deltatrac is a reliable method, and is accurate within 3% for gas exchange and RMR. Hence, it has been widely accepted as a standard for measuring energy expenditure.[27,28, 31-34]

RMR and basal metabolic rate (BMR) are always used interchangeably. In this study, RMR was measured after an overnight fasting, so RMR was measured close to BMR condition. Haugen *et al.,*[35] used a protocol measuring RMR in the morning (fasting 12 hours) and in the after-noon (fasting 4 hours) and found that a <100 Kcal/d difference in RMR. Since the difference between BMR and RMR was minimal and in order to avoid the contamination of thermic effect of food, we designed our protocol to measure RMR in the morning. Fasting for 8 hours before testing is a reasonable requirement for a clinical population.

There were several limitations to this study. First, since we enrolled our subjects from nurses of the hospital, the subjects were only women. Second, a wider range of subjects' age and BMI is needed for a study of validation, such as those who are malnourished, have morbid obesity or are old. Third, in this study, body composition was measured by a multi-frequency BIA, which might be less accurate than DEXA. However, its usefulness in assessing the body composition has been documented.[20,36] Last, with respect to the validity of BodyGem, the assumption of RQ of 0.85 may apply to healthy people but its application and utility in malnourished people or people with coexistent medical problems may not be valid. Furthermore, the Deltatrac metabolic monitor may be more accurate to predict metabolic rate when compared with other methods.

Conclusion

In sum, the BodyGem provides a more accurate measure of RMR than that predicted by the H-B equations. We found that the BodyGem has a high reproducibility by repeated measurements, but its validity is just acceptable compared to the Deltatrac. Further research is needed to validate BodyGem in Taiwanese women.

Acknowledgement

The study was supported by a grant from Microlife Corporation, Taiwan. We appreciate Drs. F. Xavier Pi-Sunyer, and Blandine Laferrère at New York Obesity Research Center, St. Luke's-Roosevelt Hospital, New York and Dr. Pesus Chou at Community Medicine Research Center and Institute of Public Health, National Yang-Ming University, Taipei, Taiwan for their professional advice and revision. The authors have no

known conflicts of interest, financial or otherwise, with any of the products mentioned in this manuscript.

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BodyGem 用于测定台湾妇女休息代谢率的有效性和可靠性

休息代谢率（RMR）约占总能量消耗率的三分之二。目前广泛使用的 Harris-Benedict 方程计算 RMR 值结果偏高。本次研究评价了身握式间接热量计，**BodyGem** 用于测定一组妇女样本 RMR 的可靠性和有效性。共 30 名健康护士参与了此项研究，她们平均年龄 41.9±9 岁,身体质量指数为 24.0 + 2.8 kg/m^2。Deltatrac 代谢监测器用来确认身体珍宝测定的结果。用身体珍宝重复测定以估算出结果的一致性和稳定性。分析结果表明，Deltatrac 方法和 **BodyGem** 方法相关性良好(r = 0.76, *P*< 0.001)，两次 **BodyGem** 测定 RMR 的结果间相关系数在统计上有极显著相关(r = 0.96, *P* <0.001,均差 15.8±55.8 Kcal/d)。用 ANOVA 重复测定结果的显著差异性(F = 3.81, *P* = 0.04)反应了用 **BodyGem** 和 Deltatrac 方法间的差异性。在两种方法间存在系统差异（二者平均差 36.4~52.2 Kcal/d），在通过正确的手握 **BodyGem** 后可以调整额外的能量需要，二者间的差异变得不显著(F = 1.62, *P* = 0.22)。Bland-Altman 图表显示两种方法间以及用 **BodyGem** 重复测定结果间无显著性差异。总之，用 **BodyGem** 测得的 RMR 值与 Deltatrac 方法相比有高的重复性和可被接受的有效性，对该方法进一步的有效性研究有必要在台湾妇女中继续开展。

关键词：妇女、可靠度、有效性、休息代谢率、间接热量计、Harris-Benedict 方程、台湾。