# Validity of the BodyGem calorimeter and prediction equations for the assessment of resting energy expenditure in overweight and obese Saudi males

*Ali M. Almajwal, MSc, PhD, Peter G. Williams, MHP, PhD, Marijka J. Batterham, MSc, PhD.*


## ABSTRACT

**الأهداف:** تقدير مدى دقة قياس صرف الطاقة في وقت الراحة لدى عينة من الذكور السعوديين المصابين بالسمنة أو زيادة الوزن وذلك باستخدام مقياس السعرات الحرارية المحمول "بودي جيم"، ومقارنة نتائجه بطريقة غرفة قياس الطاقة الكاملة (قياس نسبة استهلاك الأوكسجين في زمن محدد)، بالإضافة إلى تقييم دقة معادلات الطاقة التنبؤية.

**الطريقة:** أُجريت هذه الدراسة في جامعة ولونجونج، أستراليا خلال الفترة من فبراير 2007م إلى مارس 2008م. شملت الدراسة 38 مشاركاً (متوسط العمر26.8±3.7 عاماً، ومؤشر كتلة الجسم 31.0±4.8). لقد تم قياس صرف الطاقة في وقت الراحة باستخدام غرفة قياس الطاقة الكاملة، ومقياس الطاقة المحمول، وكذلك باستخدام 7 معادلات تنبؤية للطاقة. وبعد ذلك تم حساب متوسط الاختلاف، والتحيز، ونسبة التحيز، ودقة التقدير.

**النتائج:** أشارت نتائج الدراسة إلى عدم اختلاف القياسات المتكررة لمقياس الطاقة المحمول (دقة التقدير: 81.6%، نسبة التحيز: 1.1±6.3) (*p*>0.24) مع حدود اتفاق تتراوح ما بين 242+ إلى 200- كيلو كالوري. وكانت القياسات التي تم الحصول عليها باستخدام مقياس الطاقة المحمول أقل إحصائياً من القياسات التي تم الحصول عليها باستخدام غرفة قياس الطاقة الكاملة (دقة التقدير: 47.4%، نسبة التحيز: 11.0±14.6) (*p*=0.0001) ومع حدود اتفاق غير مقبولة إحصائياً. لقد كانت المعادلات التالية: معادلة هارس بندقت، ومعادلة سكوفيلد، ومعادلة منظمة الصحة العالمية من أكثر المعادلات دقةً حيث أنها أعطت نتائج لم يتجاوز اختلافها عن 10% مقارنةً بالنتائج التي تم الحصول عليها باستخدام غرفة قياس الطاقة الكاملة، غير أنها لم تكن دقيقة على مستوى الأفراد.

**خاتمة:** بينت هذه الدراسة أن هناك اتفاق ضعيف بين قياسات الطاقة باستخدام غرفة قياس الطاقة الكاملة ونتائج مقياس الطاقة المحمول وكذلك معادلات الطاقة التنبؤية. لقد كان مقياس الطاقة المحمول دقيقاً في 47.4% من المشاركين فقط.

**Objectives:** To assess the accuracy of resting energy expenditure (REE) measurement in a sample of overweight and obese Saudi males, using the BodyGem device (BG) with whole room calorimetry (WRC) as a reference, and to evaluate the accuracy of predictive equations.

**Methods:** Thirty-eight subjects (mean±SD, age 26.8±3.7 years, body mass index 31.0±4.8) were recruited during the period from 5 February 2007 to 28 March 2008. Resting energy expenditure was measured using a WRC and BG device, and also calculated using 7 prediction equations. Mean differences, bias, percent of bias (%bias), accurate estimation, underestimation and overestimation were calculated.

**Results:** Repeated measures with the BG were not significantly different (accurate prediction: 81.6%; %bias 1.1±6.3, *p*>0.24) with limits of agreement ranging from +242 to -200 kcal. Resting energy expenditure measured by BG was significantly less than WRC values (accurate prediction: 47.4%; %bias: 11.0±14.6, *p*=0.0001) with unacceptably wide limits of agreement. Harris-Benedict, Schofield and World Health Organization equations were the most accurate, estimating REE within 10% of measured REE, but none seem appropriate to predict the REE of individuals.

**Conclusion:** There was a poor agreement between the REE measured by WRC compared to BG or predictive equations. The BG assessed REE accurately in 47.4% of the subjects on an individual level.


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*From the College of Applied Medical Sciences, Department of Community Health Sciences (Almajwal), Clinical Nutrition Program, King Saud University, Riyadh, Kingdom of Saudi Arabia, School of Health Sciences, Department of Nutrition and Dietetics (Williams), and the Centre for Statistical and Survey Methodology (Batterham), University of Wollongong, NSW, Australia.*

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*Address correspondence and reprint request to: Dr. Ali Almajwal, College of Applied Medical Sciences, Department of Community Health Sciences, Clinical Nutrition Program, King Saud University, PO Box 10219, Riyadh 11433, Kingdom of Saudi Arabia. Tel. +966 (1) 4693678. Fax. +966 (1) 4693698. E-mail: aalmejwal@hotmail.com*

Obesity has become a global epidemic and the prevalence of both overweight and obesity is still increasing in Saudi Arabia.[1-3] Weight-reduction programs usually aim to establish an achievable energy intake goal for weight reduction, therefore clinicians may need to assess individuals' total energy expenditure (TEE). Resting energy expenditure (REE) represents the majority (60-75%) of TEE in sedentary people,[4] thus accurate assessment of REE is an important factor in planning interventions for overweight and obese individuals. Indirect calorimetry techniques such whole room calorimetry (WRC) and metabolic carts are considered the "gold standard" for determining energy requirements. However, the equipment is expensive and the technique requires highly skilled personnel. Recently, researchers have developed hand held calorimetry devices useful in clinical settings due to its portability, low cost, and small size. Only a limited number of studies have validated their use[5-15] and results have been inconsistent.[16] Furthermore, none of the previous studies were conducted with obese subjects. Given the uncertainty about the accuracy of these devices, clinicians usually use predictive equations to assess energy requirements. Predictive equations have generally been developed in healthy people. For some equations, overweight and obese people were included, but their relative contribution to the final equation often remains unclear. It is also uncertain how well predictive equations derived from one population can be applied to a different population, and many studies show that the race has an influence on metabolic rate.[17-19] Most of the predictive equations have been derived from American and European populations; no equation has been developed or validated for the Saudi population. The goals of this study were to assess the validity of the BodyGem$^{TM}$ (BG) and predictive equations for estimating REE in overweight and obese Saudi subjects and to provide clinicians with recommendations regarding the use of these techniques.

**Methods.** Overweight or obese Saudi male participants aged 20-34 years were recruited for the study, conducted at the University of Wollongong (UOW) in Australia during the period from February 2007 to March 2008. Participants were recruited by email advertisements through the Saudi Students Association. A phone interview was used to screen applicants and informed consent was obtained. Healthy participants with body mass index (BMI) >25 kg/m$^2$ and aged more than 18 years were included. Participants were not on any particular diet and had maintained a steady weight for the previous 3 months (varying ±3 kg from the initial weight). Participants with diabetes or major illness or chronic diseases that affect REE were excluded. Study approval was given by the UOW Human Research Ethics Committee.

Height was measured in an upright position without shoes and weight and percent body fat were measured using scales with a bioelectrical impedance component (Tanita TBF-622). The measurements of REE were performed on 2 mornings, once with the WRC and 2 measures with the same BG device (HealtheTech Inc., Golden, CO, USA) separated by approximately a one week period. The protocol for measurements required that participants had been fasting, not smoking, and avoiding coffee and tea for at least 10 hours. Subjects had to refrain from drinking alcohol or doing any physical activity in the 24 hours measurements preceding.

The UOW WRC facility, described in detail elsewhere,[20] consists of 2 separate air-tight, ventilated and air-conditioned chambers (3 x 2.1 x 2.4 m). Each chamber has a bed, desk, chair, hand basin TV/VCR, computer, phone and toilet. The room was calibrated every day using fresh air, span and nitrogen gases and approximately every 3 weeks by means of the methanol burning test. Oxygen consumption ($VO_2$) and carbon dioxide production ($VCO_2$) were converted to REE using the abbreviated Weir formula:[21]

$$REE = VO_2\ (3.941) + VCO_2\ (1.106),$$

where REE is measured in kcal/day and $VO_2$ and $VCO_2$ in L/d.

For REE measurements, each subject was asked to stay in the chamber for approximately 2 hours and measurement was started in the second hour with the subject lying quietly on a bed. The first hour should be sufficient to reach steady-state levels in the WRC. The WRC gives the measurement for $O_2$ consumption and $CO_2$ production at 10-minute intervals. The measurements were considered only when respiratory quotient (RQ), $O_2$ consumption and $CO_2$ production were stable for at least 3 consecutive readings (coefficient variation (CV) <10%).

Measurement of REE using the BG was taken immediately after the measurement of REE in the WRC while the subject was still lying down. Subjects were asked to wear a nose clip and to breathe into a disposable plastic mouth-piece for approximately 10 minutes. BodyGem devices usually begin to collect data when the first breath is detected and continue until a steady state is reached or stop after 12 minutes.[5] Carbon dioxide production is not measured by BG

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devices and an RQ of 0.85 is assumed. These devices are autocalibrated prior to each measurement. For the second REE measurements with the BG, participants were asked to rest for 25 minutes before measurements were taken. This time period was sufficient to reach steady-state levels.

The Weir equation and the assumed 0.85 RQ value was used to calculate $VO_2$ and the following equation was derived to be used since the BG does not measure

$$VO_2 \text{ (L/d)} = \text{REE (kcal)}/4.8811$$

To assess the source of error in BG, REE was estimated using the mean measured oxygen by BG and the actual (measured by WRC) and fixed (0.85) RQs. Also REE was estimated using mean oxygen measured by WRC and BG and the actual RQ. The following equation was used:[21]

$$\text{REE (kcal/d)} = (3.941 * VO_2) + (0.85 * 1.106 * VO_2)$$

Where $VO_2$ is measured in L/d.

Seven prediction equations were used to calculate REE for each subject.[22-28] These equations are commonly used in clinical practice particularly in Saudi Arabia.[29, 30] Resting energy expenditure was calculated using actual body weight. For the Harris-Benedict equation only, all subjects with a BMI more than 30 had an adjusted weight substituted in the equation: Adjusted weight (kg) = [(actual weight – ideal weight) * 0.25] + ideal weight.[31] With the Harris-Benedict equation, REE was calculated by 3 different versions of that formula that are commonly used clinically in Saudi Arabia: using actual body weight, adjusted body weight, and with adjustment of the REE by a factor of 1.1.[29]

The data are reported as mean ± SD. The level of bias between the REE measured by WRC and by BG or predicted by equations was evaluated using Bland-Altman analysis.[32] A priori, an error of greater than 250 kcal from REE measured by WRC was considered clinically unacceptable.[9] The paired t-test was used to determine statistically significant differences between REE measured by WRC or BG or predicted from the equations. Regression analysis was performed to examine relationships between the accuracy of BG and factors such as age, BMI, and body fat.

The percentage of participants with an REE estimated within ±10% of the REE measured by WRC was considered a measure of accuracy on an individual level. Pearson's correlation was used to compare measured REE by WRC to BG and each predictive equation. A one sample t test was used to compare the measured RQ with the fixed (0.85) RQ used by BG.

A $p$-value less than 0.05 was considered statistically significant. The data were analyzed using the Statistical Package for Social Sciences (Version 15.0, 2006) (SPSS Inc., Chicago, IL). Estimation between 90% and 110% of the REE measured by WRC was considered an accurate estimation; estimations <90% or >110% of the measured REE were classified as underestimation or overestimation.

**Results.** Thirty-eight Saudi male participants completed the study (**Table 1**). Three did not repeat the measurement of BG due to discomfort caused by the device. The mean age was 26.8 ± 3.7 years and BMI was 31.0 ± 4.8 kg/m$^2$. There were no significant differences between overweight and obese subjects in terms of the accuracy of the BodyGem or predictions equations. Therefore, results are presented for the whole study group.

Paired t tests and Bland-Altman analysis indicated that BG is a reliable device for measurement of REE, with good between-test reproducibility. The mean REE values from the 2 BG measurements were not statistically different (1907 ± 381 versus 1886 ± 394 kcal/day) ($p$>0.24) (**Table 2**). The mean difference between the 2 readings was 21 ± 110 kcal, with limits of agreement ranged from +242 to -200 kcal (**Figure 1**), within the

**Table 1 -** Subjects characteristics (n=38).

| Variables | Mean ± SD | Range |
|---|---|---|
| Age (year) | 26.8 ± 3.7 | 20-34 |
| Height (cm) | 1.7 ± 0.1 | 1.6-2.0 |
| Weight (kg) | 92.0 ± 18.1 | 66.3 -174.0 |
| Body mass index (kg/m$^2$) | 31.0 ± 4.8 | 25.1-50.0 |
| Body fat (%) | 28.8 ± 5.3 | 19.0-41.0 |

**Table 2 -** Accuracy of resting energy expenditure (REE), oxygen consuption ($VO_2$) and respiratory quotient (RQ) measured by whole room calorimetry (WRC) and BodyGem (BG).

| Accuracy of REE | BG1 (n=38) | BG2 (n=35) |
|---|---|---|
| *REE (kcal/day)* | 1907 ± 381 | 1886 ± 394 |
| Bias | 21 ± 110 | |
| %Bias | 1.1 ± 6.3 | |
| *REE (kcal/day)* | 1896 ± 383 | 2069 ± 336* |
| Bias | 173 ± 262 | |
| % Bias | 11.0 ± 14.6 | |
| *$VO_2$ (ml/min)* | 269.8 ± 54.5 | 289.8 ± 52.1* |
| Bias | 20 ± 42 | |
| %Bias | 9.1 ± 16.4 | |
| *RQ* | 0.85 (fixed value) | 0.81 ± 0.15 |
| Bias | - 0.4 | |
| %Bias | - 4.7 | |

Data are expressed as mean±Standard Deviation.
Bias = measured by WRC - measured by BG,
%Bias = was measured by WRC and BG multiply by 100)/measured by BG.
*Significantly different from BG, $p$=0.0001 ($P$ value from paired t test).

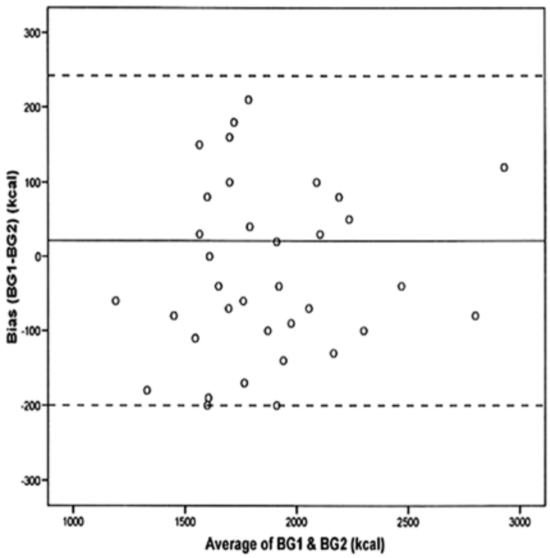


**Figure 1 -** Bland-Altman plot of differences in resting energy expenditure (REE) measures between 2 BodyGem (BG) measurements with the same device in overweight and obese Saudi males (n=35). Solid line indicates mean difference between the 2 measures and dashed lines indicate mean ± 2 standard deviation (limits of agreement).

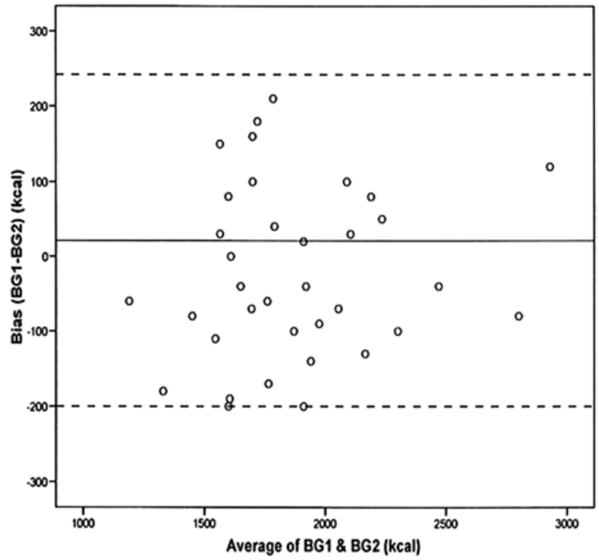


**Figure 2 -** Bland-Altman plot of differences in resting energy expenditure (REE) measures between one Whole Room Calorimetry (WRC) measure and the mean of 2 BodyGem (BG) measurements in overweight and obese Saudi males (n=38). Solid line indicates mean difference between the 2 measures and dashed lines indicate mean ± 2 standard deviation (limits of agreement).

250 kcal margin of acceptable error. The correlation coefficients of the 2 BG measurements were statistical significant (r =0.96, $p$=0.0001). When individual BG values were compared, 81.6% were within the acceptable 10% difference.

Mean REE and oxygen consumption were significantly different between WRC and BG, with a mean difference of 173±262 kcal/d and 20.0±41.9 ml/min, respectively. Limits of agreement of REE ranged from 697 to -351 kcal. These values were clinically unacceptable. Bland-Altman plots did not show any specific trend (**Figure 2**). However, BG underestimated REE by 11.0±14.6 and $VO_2$ by 9.1±16.4%. Mean RQ measured by WRC (0.81±0.15) was significantly lower than the fixed RQ (0.85) used to calculate REE by BG.

To assess the source of errors in BG, REE was calculated using the oxygen uptake as measured by BG (269.8 ml/min) and the actual (0.81) or fixed (0.85) RQ values and this result in an estimated REE of 1896 and 1879 kcal/d, respectively. The use of the fixed RQ in the modified Weir equation introduced a mean error of 1.0% or 18 kcal/d. Similarly, REE was calculated using the actual RQ (0.81) and the measured oxygen by WRC (289.8 ml/min) and BG (269.8 ml/min) and this result in an estimated REE of 2019 and 1879 kcal/d, respectively. Therefore, measurement of $VO_2$ by BG introduced a mean error of 7.4% or 140 kcal/d. Logistic regression analysis did not show any significant relationships between the accuracy of BG and other factors such as age, weight, height, BMI and body fat percentage. All predictive equations were highly correlated with the REE measured by WRC. Paired t test indicated that Schofield, WHO and Harris-Benedict equations were the most accurate equations (**Table 3**). The mean numerical bias and the mean percentage bias estimates for Schofield (wt) was 20±22 kcal (underestimation: 1.0±10.4%), Schofield (wt & ht) 28±22 kcal (underestimation: 1.0±10.4%), WHO (wt) 13±22 kcal (underestimation: 1.0±10.3%), WHO (wt & ht) 15±21 kcal (underestimation: 1.0±10.2%), and Harris-Benedict was 60±197 kcal (underestimation: 3.0±9.9%). The prediction accuracies were 60.5%, 65.8%, 63.2%, 65.8% and 68.4%, respectively.

The Harris-Benedict equation showed the highest percentage of accurate prediction (68.4%), but with higher percentages of underestimation (28.9%) and bias (3%) compared to Schofield and WHO equations. When adjusted body weight was used with an adjustment factor of 1.1, the percentage of accurate prediction decreased (39.5 and 47.4%, respectively).

The 5 other equations were not accurate according to the paired t test. The Owen, Mifflin and Bernstein equations underestimated REE in all subjects; the Ireton equation overestimated REE for all subjects with a very low accurate prediction (13%).

Accuracy was also evaluated using the Bland-Altman analysis. Considering the numerical and bias percentage, the lowest values were shown by the WHO (wt) equation; however, the extent of error was between +450

**Table 3** - Accuracy of Resting Energy Expenditure (REE) measured by BodyGem (BG) and REE predicted from prediction equations.

| Tools | REE (kcal/day) | Bias | %Bias | Accurate estimation | Under-estimation (%) | Over-estimation (%) | r |
|---|---|---|---|---|---|---|---|
| Whole room calorimetry (WRC) | 2069 ± 336 | - | - | - | - | - | - |
| BG | 896 ± 383* | 173 ± 262 | -11.0 ± 14.6 | 47.4 | 47.4 | 5.3 | 0.74 |
| Harris Benedict (HB)[22] | 2010 ± 267 | 60 ± 197 | -3.0 ± 9.9 | 68.4 | 28.9 | 2.6 | 0.81 |
| HB*1.1 | 2211 ± 294* | -141 ± 198 | +6.9 ± 9.0 | 47.4 | 5.3 | 47.4 | 0.81 |
| HB (adjusted body weight) | 1827 ± 150* | 243 ± 278 | -13.0 ± 14.7 | 39.5 | 57.9 | 2.6 | 0.57 |
| Owen[26] | 1818 ± 184* | 252 ± 227 | -14.0 ± 12.1 | 60.5 | 39.5 | 0.0 | 0.77 |
| Schofield (wt)[24] | 2050 ± 232 | 20 ± 219 | -1.0 ± 10.4 | 60.5 | 18.4 | 21.1 | 0.76 |
| Schofield, (wt & ht)[24] | 2042 ± 231 | 28 ± 219 | -1.0 ± 10.4 | 65.8 | 18.4 | 15.8 | 0.76 |
| Mifflin[28] | 1867 ± 207* | 203 ± 204 | -11.0 ± 10.6 | 63.2 | 36.8 | 0.0 | 0.82 |
| WHO (wt)[25] | 2057 ± 235 | 13 ± 218 | -1.0 ± 10.3 | 63.2 | 15.8 | 21.1 | 0.76 |
| WHO (wt & ht)[25] | 2055 ± 222 | 15 ± 214 | -1.0 ± 10.2 | 65.8 | 15.8 | 18.4 | 0.78 |
| Ireton[27] | 2557 ± 161* | -487 ± 227 | +19.0 ± 9.1 | 13.2 | 0.0 | 86.8 | 0.81 |
| Bernstein[23] | 1585 ± 246* | 485 ± 193 | -31.0 ± 12.8 | 0.0 | 100 | 0.00 | 0.82 |

Bias - REE measured by WRC – REE measured by BG or predicted by applied equations
%Bias - [(REE measured by WRC – REE measured by BG or predicted by equations) * 100] / REE measured by BG or predicted by equations
Accurate estimation: percentage of all subjects whose REE was within 90% to 110% of measured REE by WRC
Underestimation: percentage of all subjects whose REE was less than 90% of measured REE by WRC
Overestimation: percentage of all subjects whose REE was more than 110% of measured REE by WRC
*Statistically difference between REE measured by WRC and REE measured by BG or predicted by equations on a two-tailed paired t-test ($p$=0.0001)
r - Pearson's Correlation Coefficient between REE measured by WRC and REE measured by BG or predicted by applied equation

kcal and -425 kcal daily. The Harris-Benedict equation had the highest accurate prediction percentage, but the error range was +454 kcal to -335 kcal/day. The errors across all equations were more than the acceptable 250 kcal maximum (Figures are not shown). From visual examination, it appears to be more variation as the mean REE increased.

**Discussion.** The results showed that the mean bias between REE measured by BG was neither statistically nor clinically different. Therefore, the device can be considered to be reliable (consistent), but mean measurements of REE with the BG differed significantly, both statistically and clinically, from the WRC results and underestimated REE by 11% (about 173 kcal/d). Five studies have investigated the use of BG for REE measurements and all demonstrated within instrument reliability.[5,6,13,33,34] Herring[34] found that 2 of 3 BG devices used gave consistently lower values (12% and 9%) compared to the metabolic carts. Similarly, Blanton et al[33] found that the BG device significantly underestimated REE by about 95 kcal. Two other studies reported that BG significantly overestimated REE.[6,13] Both authors adjusted their findings, considering the energy expenditure due to holding the device during the measurements. After adjustment the difference became non-significant and the authors concluded that the BG provides valid and reliable measurements of REE. Only one study has reported that BG is an accurate and reliable device without any adjustment.[5]

One systematic review indicated that the hand-held calorimeters are reliable and valid for the measurement of REE.[35] However, that conclusion was based only on 4 studies in which the Douglas-bag system was used as the reference method. The present study supports the conclusion in a more recent review[16] that the majority of studies with BG devices report significant differences between the BG measurements and standard metabolic carts. Studies that evaluated other portable hand-held calorimeters such as MedGem,[5,7-12,36-38] Fitmate,[39] VO2000 calorimeter[40] and MOXUS modular $VO_2$ system[14] have also provided inconsistent results.

Several possible reasons might explain these differences in studies of the measurement of REE by BG and WRC. Firstly, each technique uses different equations to calculate REE. The WRC measures both $VO_2$ and $VCO_2$, whereas the BG measures only $VO_2$ and assumes that the RQ of the subject is 0.85. In this study REE was calculated using the measured $VO_2$ by BG and RQ measured by WRC. The results showed that the difference in REE due to the assumption of the fixed RQ is relatively small (1.0% or 18 kcal/d). Secondly, each technique measures REE over periods of different duration. The BG runs the test for 10 minutes; the WRC measurement lasted approximately one hour giving more time for subjects to reach a steady state. Thirdly, each technique uses different collection systems and gas analysis, which may introduce other errors.

The REE predicted by Schofield, WHO and Harris-Benedict equations was not significantly different from REE measured by WRC. For individuals, the limits of agreement of REE from the WRC compared to 7 predictive equations were well outside clinically acceptable levels (error >250kcal). The HB equation was the most accurate of the predictive equations and accurate prediction by Schofield (wt & ht) (65.8%) and

WHO (wt & ht) (65.8%) equations were also very close to the HB equation (68.4%). The Mifflin and Owen equations were less accurate and both equations tend to underestimate REE in overweight and obese people, as has been reported elsewhere.[30] When equations developed in obese populations were used (Bernstein and Ireton), measured REE was significantly different from the predictions,, which is consistent with previous reports.[41] Several statistical methods were included in this study to examine the accuracy of BG and prediction equations in the assessment of REE. To study validity, the aim should be to examine whether the outcomes are equal. Paired t-test, regression analysis and correlation coefficient can be used, but tell us little about 'is the same'. Bias and bias percent are essential, however over- and underestimations counter balance, therefore provide no information on 'is the same'. Accurate estimation is a good measure but may not be appropriate to be used in this project due to the small sample size. However, paired t test, bias, %bias and accurate estimation indicated that HB, Schofield, and WHO equations are more accurate than other equations.

There are several limitations to this study. First, it included only men, and further investigation is needed in women. Secondly, the sample size is small and included young subjects (<35 years) only. Thirdly, the study included only overweight and obese Saudi subjects. This is the group in which the measurement of REE is likely to be of most relevance, however, the use of normal weight subjects could produce different results. Fourthly, random order for the measurement of REE using WRC and BG were not undertaken. The primary reason is that the WRC requires one hour to reach steady-state level and therefore, for convenience the first measurement of REE using BG was undertaken after the measurement of REE using WRC.

In conclusion, this project indicates that the HB, Schofield and WHO equations predict REE more accurately than the BG device. However, their accuracy was not clinically acceptable on an individual level. Without more studies to clarify these issues, the evidence from this single small study is insufficient to recommend changes in practice. Until then dietitians and other health professionals in Saudi Arabia may need to continue using the available international predictive equations for the assessment of individual energy requirements, while being aware of their inherent inaccuracy.

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## References

1. Al-Hazzaa HM. Rising trends in BMI of Saudi adolescents: evidence from three national cross sectional studies. ***Asia Pac J Clin Nutr*** 2007; 16: 462-466.
2. Al-Nozha MM, Al-Mazrou YY, Al-Maatouq MA, Arafah MR, Khalil MZ, Khan NB, et al. Obesity in Saudi Arabia. ***Saudi Med J*** 2005; 26: 824-829.
3. Al-Othaimeen AI, Al-Nozha M, Osman AK. Obesity: an emerging problem in Saudi Arabia. Analysis of data from the National Nutrition Survey. ***East Mediter Health J*** 2007; 13: 441-448.
4. da Rocha EE, Alves VG, Silva MH, Chiesa CA, da Fonseca RB. Can measured resting energy expenditure be estimated by formulae in daily clinical nutrition practice? ***Curr Opin Clin Nutr Metab Care*** 2005; 8: 319-328.
5. Nieman DC, Trone GA, Austin MD. A new handheld device for measuring resting metabolic rate and oxygen consumption. ***J Am Diet Assoc*** 2003; 103: 588-592.
6. Melanson EL, Coelho LB, Tran ZV, Haugen HA, Kearney JT, Hill JO. Validation of the BodyGem hand-held calorimeter. ***Int J Obes Relat Metab Disord*** 2004; 28: 1479-1484.
7. St-Onge MP, Rubiano F, Jones A Jr, Heymsfield SB. A new hand-held indirect calorimeter to measure postprandial energy expenditure. ***Obes Res*** 2004; 12: 704-709.
8. Alam DS, Hulshof PJM, Roordink D, Meltzer M, Yunus M, Salam MA, et al. Validity and reproducibility of resting metabolic rate measurements in rural Bangladeshi women: comparison of measurements obtained by Medgem and by Deltatrac device. ***Eur J Clin Nutr*** 2005; 59: 651-657.
9. Compher C, Hise M, Sternberg A, Kinosian BP. Comparison between Medgem and Deltatrac resting metabolic rate measurements. ***Eur J Clin Nutr*** 2005; 59: 1136-1141.
10. Hlynsky J, Birmingham CL, Johnston M, Gritzner S. The agreement between the MedGem indirect calorimeter and a standard indirect calorimeter in anorexia nervosa. ***Eating Weight Dis*** 2005; 10: 83-87.
11. Reeves MM, Capra S, Bauer J, Davies PS, Battistutta D. Clinical accuracy of the MedGem indirect calorimeter for measuring resting energy expenditure in cancer patients. ***Eur J Clin Nutr*** 2005; 59: 603-610.
12. Stewart CL, Goody CM, Branson R. Comparison of two systems of measuring energy expenditure. ***JPEN J Parenter Enteral Nutr*** 2005; 29: 212-217.
13. Liou T, Chen C, Chung W, Chu N. Validity and reliability of BodyGem for measuring resting metabolic rate on Taiwanese women. ***Asia Pac J Clin Nutr*** 2006; 15: 317-322.
14. Roffey DM, Byrne NM, Hills AP. Day-to-Day Variance in Measurement of Resting Metabolic Rate Using Ventilated-Hood and Mouthpiece & Nose-Clip Indirect Calorimetry Systems. ***JPEN J Parenter Enteral Nutr*** 2006; 30: 426-432.
15. Rubenbauer JR, Johannsen DL, Baier MS, Litchfield R, Flakoll P. The use of a handheld calorimetry unit to estimate energy expenditure during different physiological conditions. ***JPEN J Parenter Enteral Nutr*** 2006; 30: 246-250.
16. Van Loan MD. Do hand-held calorimeters provide reliable and accurate estimates of resting metabolic rate? ***J Am Coll Nutr*** 2007; 26: 625-629.
17. DeLany JP, Bray GA, W Harsha DW, Volaufova J. nergy expenditure in African American and white boys and girls in a 2-y follow-up of the Baton Rouge Children's Study. ***Am J Clin Nutr*** 2004; 79: 268-274.
18. Kelley Martin, Penny Wallace, Philip F Rust, W Timothy Garvey. Estimation of Resting Energy Expenditure Considering Effects of Race and Diabetes Status. ***Diabetes Care*** 2004; 27: 1405-1411.

19. Kimm SY, Glynn NW, Aston CE, Damcott CM, Poehlman ET, Daniels SR, et al. Racial differences in the relation between uncoupling protein genes and resting energy expenditure. ***Am J Clin Nutr*** 2002; 75: 714-719.
20. Batterham M, Cavanagh R, Jenkins A, Tapsell L, Plasqui G, Clifton P. High-protein meals may benefit fat oxidation and energy expenditure in individuals with higher body fat. ***Nutr Diet*** 2008; 65: 246-252.
21. Weir JB. New methods for calculating metabolic rate with special reference to protein metabolism. ***Nutrition*** 1990; 6: 213-221.
22. Harris JA, Benedict FG. A Biometrie Study of Basal Metabolism in Man. Washington (DC): Carnegie Institute; 1919. Publication No. 279.
23. Bernstein RS, Thornton JC, Yang M-U, Wang J, Redmond A, Pierson RN, et al. Prediction of resting metabolic rate in obese patients. ***Am J Clin Nutr*** 1983; 37: 595-602.
24. Schofield WN, Schofield C, James WP. Basal metabolic rate-review and prediction, together with an annotated bibliography of source material. ***Hum Nutr Clin Nutr*** 1985; 39 C (Suppl 1): 5-41.
25. FAO/WHO/UNU. Energy and protein requirements. Report of a joint FAO/WHO/UNU expert consultation. Technical report series No. 724. Geneva (SW): World Health Organization; 1985.
26. Owen OE, Holup JL, D'Alessio DA, Craig ES, Polansky M, Smalley KJ, et al. A reappraisal of caloric requirements of men. ***Am J Clin Nutr*** 1987; 46: 875-885.
27. Ireton-Jones C. Evaluation of energy expenditure in obese patients. ***Nutr Clin Prac*** 1989; 4: 127-129.
28. Mifflin MD, St Joeor ST, Hill LA, Scott BJ. A new predictive equation for resting energy expenditure in healthy individuals. ***Am J Clin Nutr*** 1990; 51: 241-247.
29. Almajwal A, Williams P, Batterham M. Current dietetic practices of obesity management in Saudi Arabia and comparison with Australian practices and best practice criteria. ***Nutr Diet*** 2009; 66: 94-100.
30. Frankenfield D, Roth-Yousey L, Compher C. Comparison of predictive equations for resting metabolic rate in healthy nonobese and obese adults: a systematic review. ***J Am Diet Assoc*** 2005; 105: 775-789.
31. Frankenfield DC, Rowe WA, Smith JS, Cooney RN. Validation of several established equations for resting metabolic rate in obese and non-obese people. ***J Am Diet Assoc*** 2003; 103: 1152-1159.
32. Catey B. Correlation, Agreement, and Bland–Altman Analysis: Statistical Analysis of Method Comparison Studies. ***Am J Ophthalmol*** 2009; 148: 4-6.
33. Blanton C, Gale B, Gustafson-Storms M, Kretsch M. Resting metabolic rate (RMR): evaluation of a portable RMR handheld device. ***FASEB J*** 2004; 18: A112.
34. Herring E. Reliability and validity of a hand-held indirect calorimrter for estimation of resting energy expenditure (Thesis). Davis: University of California. Davis (CA): University of California; 2004. p. 27-53.
35. McDoniel S. A systematic review on use of a handheld indirect calorimeter to assess energy needs in adults and children. ***Int J Sport Nutr Exerc Metab*** 2007; 17: 491-500.
36. Murphy O, Kearny J. Validation of the MedGem device for measuring metabolic resting rate. ***Med Sci Sports Exerc*** 2004; 36 (5 Suppl): S247.
37. Strorer T, Kamps K, Dabari B, Tran Z, Rozneck R. Validation of the MedGem device for measurement of resting metabolic rate. ***Med Sci Sports Exerc*** 2004; 36 (5 Suppl): S247.
38. Nieman DC, Austin MD, Chilcote SM, Benezra L. Validation of a new handheld device for measuring resting metabolic rate and oxygen consumption in children. ***Int J Sport Nutr Exe Metab*** 2005; 15: 186-194.
39. Nieman DC, Austin MD, Benezra L, Pearce S, McInnis T, Unick J, et al. Validation of Cosmed's FitMate in measuring oxygen consumption and estimating resting metabolic rate. ***Res Sports Med*** 2006; 14: 89-96.
40. Wahrlich V, Anjos LA, Going SB, Lohman TG. Validation of the VO2000 calorimeter for measuring resting metabolic rate. ***Clin Nutr*** 2006; 25: 687-692.
41. Krupa Das S, Saltzman E, McCrory MA, George Hsu LK, Shikora SA, Dolnikowsk G, et al. Energy Expenditure Is Very High in Extremely Obese Women. ***J Nutr Elder*** 2004; 134: 1412-1416.