Predicting basal metabolic rates in Malaysian adult elite athletes

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INTRODUCTION This study aimed to measure the basal metabolic rate (BMR) of elite athletes and develop a gender-specific predictive equation to estimate their energy requirements.

METHODS 92 men and 33 women (aged 18–31 years) from 15 sports, who had been training six hours daily for at least one year, were included in the study. Body composition was measured using the bioimpedance technique, and BMR by indirect calorimetry. The differences between measured and estimated BMR using various predictive equations were calculated. The novel equation derived from stepwise multiple regression was evaluated using Bland and Altman analysis.

RESULTS The predictive equations of Cunningham and the Food and Agriculture Organization/World Health Organization/United Nations University either over- or underestimated the measured BMR by up to ± 6%, while the equations of Ismail et al, developed from the local non-athletic population, underestimated the measured BMR by 14%. The novel predictive equation for the BMR of athletes was BMR (kcal/day) = 669 + 13 (weight in kg) + 192 (gender: 1 for men and 0 for women) (R^2 0.548; standard error of estimates 163 kcal). Predicted BMRs of elite athletes by this equation were within 1.2% ± 9.5% of the measured BMR values.

CONCLUSION The novel predictive equation presented in this study can be used to calculate BMR for adult Malaysian elite athletes. Further studies may be required to validate its predictive capabilities for other sports, nationalities and age groups.

Keywords: athletes, basal metabolic rate, body composition, energy requirement, predictive equation
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INTRODUCTION

As one of the most active groups in the population, elite athletes possess higher energy needs for daily training and recovery than the rest of the population. Meeting energy requirements is a nutritional priority for athletes to maintain appropriate body weight and composition in order to achieve peak performance in sports.(1) As such, being able to accurately determine the energy requirements of athletes is an important component of developing nutritional plans and providing recommendations to enhance sports performance. Under- or overestimation of athletes' energy requirements could result in a loss of body mass, increase in fat mass, compromise of sports performance, increase in the risk of sports injuries and, potentially, growth failures in young athletes.(2,3) Following the recommendation of the Food and Agriculture Organization/World Health Organization/United Nations University (FAO/WHO/UNU),(4) estimation of basal metabolic rate (BMR) using the factorial method has become the main approach for the estimation of energy requirements.

BMR is defined as the minimum energy required while awake to maintain the physiological functions of the body.(5) BMR accounts for approximately 45% to 70% of total energy expenditure in most healthy adults.(6) BMR is directly influenced by gender, age, body surface area, body composition, genetic composition, pregnancy and hormonal status.(4,7) Although studies have reported the influence of ethnicity on BMR, their results have often been contradictory.(8-11) The difference in BMR between athletic and non-athletic populations is marked by two main factors – fat-free mass and physical activity levels.(12-14)

Although calorimetry remains the method of choice for determining BMR, this method is impractical, time-consuming and expensive in field settings. Therefore, predictive equations have been widely used to estimate BMRs. The most widely used predictive equation was developed by Schofield,(5) which was adopted by the FAO/WHO/UNU reports in 1985 and 2004.(4,6) However, the accuracy and adequacy of this widely used FAO/WHO/UNU(4) equation, even in normal populations, have been questioned,(15-17) and its suitability for highly trained populations of different ethno-geographic backgrounds extensively discussed.(6)

Due to variability in body composition, body mass and training programmes, athletes possess BMRs that are different from those in the general population.(13,18,19) However, there are only a limited number of equations available to estimate BMR in an athletic population.(20) We postulated that existing predictive equations, which were developed for normal populations, may not be suitable for estimating the BMR of elite athletes.

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The aims of this study were multipronged. We set out to: (a) measure the BMR of elite athletes in Malaysia by using indirect calorimetry; (b) propose a novel gender-specific predictive equation for the estimation of BMR in local athletic populations; and (c) compare the new equation with established local and international predictive equations.

METHODS

A total of 125 elite athletes (men n = 92; women n = 33; age 18–31 years) were recruited from the National Sports Complex at Bukit Jalil, Kuala Lumpur, Malaysia. The participants were national athletes training under the Malaysia elite sports programme that is directed by the National Sports Council of Malaysia. Athletes from 15 sports were recruited. The sports represented in the study were racquet sports (squash and badminton), combat sports (boxing, karate, taekwondo, silat and wushu), aquatic sports (diving), gymnastics (artistic and rhythmic), skilled sports (fencing and archery), weightlifting, and team sports (football and hockey). The largest number of participants by sports group was from combat sports (combat sports n = 44; racquet sports n = 28; team sports n = 22; skilled sports n = 21; others n = 10).

All participants were screened for eligibility prior to recruitment in the study. The inclusion criteria for participants included: (a) men or women in the adult age group; (b) athletes who had been undergoing sports training for an average of six hours a day; (c) athletes who had been training centrally under the national elite sports programme for a minimum of one year in their specialised sport; and (d) female athletes who were eumenorrheic (identified by self-reporting of 10–13 menstruation cycles in a year,[21,22] using a 16-item menstrual history questionnaire).[23] The exclusion criteria included: (a) athletes who were on any type of medication; (b) women who were taking oral contraceptives; (c) athletes who had sustained injury within two weeks prior to measurement; and (d) athletes who had any form of eating disorders or presented with subclinical eating problems. To ensure strict adherence, all female athletes were carefully screened using the Eating Disorder Inventory 2[24] prior to inclusion in the study.

Data collection was conducted collectively from August 2005 to April 2007 via three local studies[25-27] using the same methodology and protocol. These studies had been approved by the Medical Research and Ethics Committee of Universiti Kebangsaan Malaysia, and had been set up with the same primary objective to assess BMR, but among different sports groups. The present study collated and reanalysed the BMR data of these three study samples. All participants were handed detailed information regarding the study, and they provided written informed consent prior to participating in the study.

In accordance with a standardised measurement protocol, all measurements were done in a specially assigned room at the athletes' residential hostel early in the morning (6.00–9.00 am) on non-training days, or on light-training days when the former was not possible. Participants were first measured for their body weight and height, followed by body composition. Body weight, measured in light clothing without shoes, using a digital weighing scale (Model HD309; Tanita Corporation, Tokyo, Japan), was recorded to the nearest 0.5 kg. Standing height was measured to the nearest 0.1 cm using a stadiometer (SECA Bodymeter 208; SECA Deutschland, Hamburg, Germany). For the measurement of body composition, a bioelectrical impedance analysis (BIA) technique was used (Bodystat Model 1500 MDD; Bodystat Ltd, Isle of Man, British Isles). As per standard protocol for BIA measurements to ensure good hydration status, participants were instructed to refrain from strenuous exercise, caffeine and alcohol intake, and to drink plenty of water on the day prior to measurement. The coefficient of variation for BIA measurements in our study ranged from 0.13% for fat mass to 0.48% for lean body mass, which is similar to that reported by other studies.[28,29]

A few days prior to BMR measurements, participants were briefed on the BMR measurement protocol, which included fasting for 12 hours and refraining from strenuous exercise, alcohol and caffeine intake, or supplementation for at least 12 hours before measurement. Exercise and food intakes (excluding plain water) were refrained from 7.00 pm onwards on the previous night, as BMR measurements were scheduled to begin at 7.00 am the following day. For female participants, BMR measurements were scheduled during non-menstruation days, usually within a week after menses had ended (i.e. in the follicular phase), when BMR has been reported to be the lowest.[7] To minimise movements prior to measurements, 27 participants (21.6%) who lived outside the hostel were driven by car to the measurement room. All participants rested in bed for at least 30 minutes before BMR measurements were taken.

BMR was measured using a ventilated hood system (Deltatrac Metabolic Monitor MBM-200; Datex-Ohmeda, Helsinki, Finland). The system was calibrated using a calibration gas mixture of 95% oxygen and 5% carbon dioxide (calibration gas; Datex Instrumentation, Helsinki, Finland) each morning before BMR measurements were started. Measurements were carried out in a quiet room under thermoneutral conditions (temperature 24–26°C; air pressure 764–770 mmHg). Humidity ranged from 62% to 82%, although the hood system corrected gas concentrations to STPD (standard temperature, pressure and dry) during measurements. Following a ten-minute adaptation period, BMR measurements were taken for a period of 30 minutes. 30 minutes of steady state measurements (indicated by five consecutive one-minute measurements, with ≤ 5% coefficient of variation in VO_2 and VCO_2) were used to calculate the BMR for each participant. Participants were measured in the awake postabsorptive state and at complete physical rest in a supine position. They were instructed not to move during the measurement period. Less than 5% of participants, with spurious measurement values (indicated by respiratory quotient < 0.73 or > 1.0) due to hyperventilation or restlessness,[30] underwent repeat measurements. The intraindividual coefficient of variation

Table I. BMR predictive equations for men and women aged 18–30 years included in the study.

Method	BMR predictive equations	
	Men	Women
FAO/WHO/UNU[4] (MJ/day)	0.064 W + 2.84	0.0615 W + 2.08
Ismail et al[15] (MJ/day)	0.055 W + 2.480	0.0535 W + 1.994
De Lorenzo et al[20] (kcal/day)	−857 + 9.0 W + 11.7 H	--
Cunningham[32] (MJ/day)	500 + 22 LBM	500 + 22 LBM
Harris et al[33] (kcal/day)	66.5 + 13.75 W + 5.003 H − 6.775 A	655.1 + 9.563 W + 1.850 H − 4.676 A

A: age in years; H: height in cm; LBM: lean body mass in kg; W: weight in kg

Table II. Physical characteristics of participants.

Characteristic	Mean ± SD	
	Men (n = 92)	Women (n = 33)
Age (yrs)	21.4 ± 3.0	20.4 ± 2.1
Weight (kg)	66.1 ± 8.5*	55.4 ± 5.7
Height (cm)	170.6 ± 6.5*	160.7 ± 4.8
Body mass index (kg/m²)	22.7 ± 2.8†	21.4 ± 2.0
Lean body mass (kg)	57.1 ± 7.4*	43.2 ± 3.7
Adjusted lean body mass (kg/body weight)	0.86 ± 0.04*	0.78 ± 0.04
Fat mass (kg)	9.1 ± 3.2	12.1 ± 3.2*
Adjusted fat mass (kg/kg body weight)	0.14 ± 0.04	0.22 ± 0.04*
Body fat (%)	13.7 ± 4.0	21.7 ± 4.0*

*p < 0.001 according to independent sample *t*-test. †p < 0.05 according to independent sample *t*-test. SD: standard deviation

Table III. Mean BMR measured by indirect calorimetry and estimated using predictive equations.

Method	Mean BMR ± SD			
	Men (n = 92)		Women (n = 33)	
	Indirect calorimetry (kcal/day)	Predictive equations (kcal/kg/day)	Indirect calorimetry (kcal/day)	Predictive equations (kcal/kg/day)
Measured (present study)	1,715 ± 204	26.2 ± 3.0	1,384 ± 147	25.1 ± 3.1
Estimated				
FAO/WHO/UNU[4]	1,690 ± 130	25.7 ± 1.3	1,311 ± 83‡	23.8 ± 1.0‡
Ismail et al[15]	1,461 ± 111†	22.3 ± 1.2†	1,185 ± 72†	21.5 ± 0.9†
De Lorenzo et al[20]	1,734 ± 129	26.5 ± 2.0	--	--
Cunningham[32]	1,760 ± 163*	26.8 ± 1.6*	1,451 ± 81‡	26.3 ± 1.6‡
Harris et al[33]	1,684 ± 140	25.6 ± 1.4	1,387 ± 57	25.2 ± 1.6

*p < 0.05 according to paired *t*-tests. †p < 0.001 according to paired *t*-tests. ‡p < 0.01 according to paired *t*-tests.
BMR: basal metabolic rate; SD: standard deviation

for BMR averaged at 2.2%. BMR was calculated from oxygen consumption (VO_2) and carbon dioxide production (VCO_2) rates using the Weir formula,[31] as follows: BMR (kJ/min) = 0.0163 VO_2 + 0.064 VCO_2.

The measured BMRs of the participants in our study were compared to BMR values estimated from calculations that used the Cunningham,[32] FAO/WHO/UNU,[4] Harris and Benedict,[33] and Ismail et al[15] equations, which were meant for use in the general population. The predictive equation for male athletes proposed by De Lorenzo et al[20] was also included for comparison purposes (Table I). Statistical analysis was performed using the Microsoft Excel database and the Statistical Package for the Social Sciences for Windows version 16.0 (SPSS Inc, Chicago, IL, USA). In addition to descriptive analysis, differences between measured and estimated BMR values were compared using paired *t*-tests. Pearson's correlations were used to evaluate the relationships between measured and estimated BMR values, while root mean squared prediction errors (RMSPEs) were used to determine how well the various equations predicted BMR. RMSPE was calculated as the square root of the sum of squared difference between the measured and estimated BMR values, divided by the number of participants.

A novel predictive equation was derived using stepwise multiple regression analysis with BMR predictors (such as gender, age, body weight, height, lean body mass, fat mass and percentage body fat) as independent variables. Such analysis, which produces the best model by entering significant predictors in an order based on F-test values of 0.05, has been described in detail by van Belle et al.[34] The agreement between the measured and predicted BMR values was determined using Bland and Altman analysis.[35] Statistical significance was set at $p < 0.05$ for all analyses.

RESULTS

Overall, men were significantly heavier and taller, with a higher body mass index (BMI) and more lean body mass compared to women, even after adjusting for body weight (Table II).

BMR values were significantly higher for men than women (Table III). However, when expressed relative to body weight, the BMR values did not differ significantly between men and women. Generally, there was no significant difference in the measured BMR values across participants from the various sports groups, except between those from team and racquet sports. Participants from racquet sports possessed significantly higher ($p < 0.01$) adjusted BMR values (27 kcal/kg body weight) than those from team sports (24 kcal/kg body weight; data not shown).

When BMR was estimated using the various predictive equations, it was found that values were highest when using the Cunningham equation,[32] but lowest when using the equations of Ismail et al,[15] which was derived for the Malaysian general

Table IV. Measured basal metabolic rate relative to estimated values (kcal/day).

Method	Men (n = 92)					Women (n = 33)				
	Difference*	Percentage of difference†	RMSPE (kcal/day)	r	p-value	Difference*	Percentage of difference†	RMSPE (kcal/day)	r	p-value
FAO/WHO/UNU[4]	25 ± 18	0.6 ± 9.4	171.8	0.554	0.001	73 ± 24	4.5 ± 9.2	154.1	0.389	0.025
Ismail et al[15]	253 ± 18	14.1 ± 8.1	304.6	0.554	0.001	199 ± 24	13.7 ± 8.3	240.3	0.389	0.025
De Lorenzo et al[20]	−19 ± 17	−2.0 ± 1.0	167.5	0.576	0.001	--	--	--	--	--
Present study (novel predictive equation proposed)	−4.1 ± 18	−1.2 ± 9.5	171.5	0.554	0.001	−19.6 ± 24	−1.2 ± 9.6	134.6	0.389	0.025
Cunningham[32]	−45 ± 18	−3.4 ± 10.1	177.9	0.577	0.001	−67 ± 22	−5.7 ± 9.4	141.2	0.510	0.002
Harris et al[33]	31 ± 17.6	2.0 ± 9.9	170.2	0.577	0.001	−2 ± 23.2	−0.2 ± 9.7	131.1	0.422	0.001

*Data is presented as mean ± standard error of mean. †Data is presented as mean ± standard deviation.
RMSPE: root mean squared prediction error

Table V. Predictors of measured basal metabolic rate (kcal/day).

Model	Variables	Regression	R^2	SEE
1	Weight	BMR = 505 + 18 W	0.456	178
2	Weight, gender	BMR = 669 + 13 W + 192 S	0.548	163
3	Weight, gender, BMI	BMR = 820 + 19 W + 157 S − 23 BMI	0.568	160

BMI: body mass index in kg/m2; BMR: basal metabolic rate; SEE: standard error of estimates; S: gender (1 for men, 0 for women); W: body weight in kg

population. A similar pattern was observed in the BMR predictions for men and women. BMR estimates from the equations of FAO/WHO/UNU,[4] Harris and Benedict,[33] and De Lorenzo et al[20] were similar to the values of BMR measured by indirect calorimetry for adult men. For women, only the Harris and Benedict equation gave BMR estimates that were similar in value to those measured (Table III).

There were moderate-to-good correlations between measured BMR and the BMRs estimated using different predictive equations (r = 0.389–0.577; Table IV). In comparison with measured BMR values, the equation of Ismail et al[15] consistently underestimated BMR by an average of 253 kcal for men and 199 kcal for women in spite of being developed for the local general population. This equation also showed the highest RMSPE. On the other hand, the Cunningham equation[32] consistently overestimated BMR for both men and women by an average of 51 kcal. The differences between measured BMR and estimated BMR, as calculated using the five equations given in Table III, for men and women in our study ranged from −5.7% to 14.1%.

Using stepwise regression analysis, the variables of body weight, gender and BMI were found to be significant predictors of BMR (Table V). As shown in Table V, body weight was the single best predictor of BMR, which accounted for 45.6% of the variation in BMR (adjusted R^2 0.452). On the inclusion of gender and BMI into model 3, an additional 9.2% and 2.0% of the variation in BMR was accounted for, respectively. After accounting for field practicality, the final model of our prediction equation for BMR in athletes, as given below, was found to be both gender and weight specific:

BMR (kcal/day) = 669 + 13 (weight in kg) + 192 (gender: 1 for men and 0 for women)

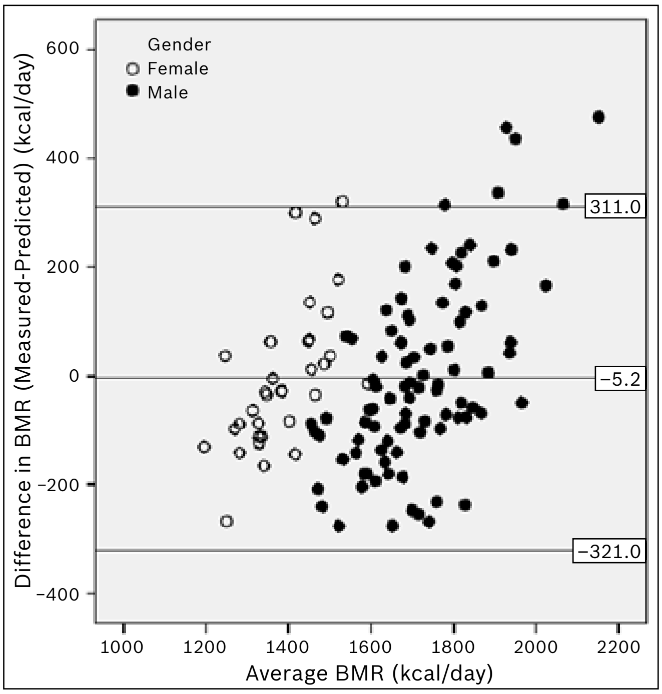

Fig. 1 Differences between basal metabolic rate values measured by indirect calorimetry and estimated using the novel predictive equation (n = 125).

This novel predictive equation for the BMR of Malaysian athletes showed significant correlation with measured BMR values (n = 125, r = 0.740; p = 0.001, data not shown). As shown in the Bland-Altman plot (Fig. 1), the distribution of differences between BMR values measured by indirect calorimetry and estimated using the novel predictive equation for our study participants was fairly homogenous and not affected by the BMR of participants. The average bias was small (5.2 kcal/day; 95% confidence interval −33.8 to 23.3 kcal/day) and the prediction errors were on average 153 kcal/day for both genders (Table IV). 96% of BMR values were within the limits of agreement (−5.2 ± 317 kcal).

DISCUSSION

When compared with the general Malaysian population of the same age group, which has a mean reported BMI of 24.4 kg/m^2,[36] our study enrolled a lean and physically active group of participants who had relatively low BMIs. Recruited from 15 different sports, our participants were representative of highly trained elite athletes in Malaysia. This is the first study that has measured the BMR of Malaysian elite athletes involved in a wide range of sports.

We set out to derive a gender-specific equation that could predict the BMR of Malaysian athletes accurately with respect to measurements of BMR using a ventilated hood system and calorimeter under standardised conditions. The main limitation of our study was that the number of women enrolled was small (n = 33). Strict adherence to the meticulous study protocol was particularly challenging for this highly competitive and active group. Of the 44 women initially recruited for the study, 11 (25%) athletes were excluded for various reasons, including unavoidable injuries prior to BMR measurement, the intake of prescription drugs and insufficient uninterrupted sleep (< 8 hours).

We selected four of the most common predictive equations to estimate BMR.[4,15,32,33] In addition, the predictive equation of De Lorenzo et al,[20] which is athlete-specific, was also included for comparison purposes. Our results indicated that the equations of Cunningham[32] and Ismail et al[15] were not suitable for describing BMR in competitive or active adults, although they may be valid for estimations in untrained adults. The variation seen between the measured and predicted BMR values varied on average from −5.7% to 14.1% regardless of age and gender. All predictive equations, except for the Cunningham equation,[32] underestimated BMR. This finding is in agreement with a previous study which found that, out of seven published equations, only the Cunningham equation overestimated measured BMR in 51 male athletes.[20]

Thompson and Manore, who conducted a comparison study using five published predictive equations to estimate the actual BMR of 37 trained endurance athletes,[37] found that the Cunningham equation[32] predicted BMR most accurately, with values within 158 kcal of measured BMR for active men, and 103 kcal for active women. Interestingly, our study showed that the classic equations by Harris and Benedict[33] better predicted BMR in Malaysian athletes, with values within 170 kcal of measured BMR for men and 131 kcal for women. For men, the equation of De Lorenzo et al[20] best predicted BMR compared with the other published equations while yielding the lowest RMSPE. This result was to be expected, as the De Lorenzo equation[20] was derived from studies on 51 male water polo, judo and karate athletes using a similar ventilated hood system. The FAO/WHO/UNU[4] equations, meanwhile, were derived for Caucasian populations (more than one-third of which was Italian, including sportsmen) who generally have bigger body frames and size and therefore possess higher BMRs. Notably, the Ismail et al equation,[15] which was derived from physically untrained, sedentary adult populations using the Douglas bag technique, underestimated BMR by 14.1% and 13.7% for men and women, respectively, in our study. This finding further emphasised the influence of ethnicity and physical training on BMR, and underscored the need for a predictive equation suitable for Malaysian elite athletes.

In line with previous studies,[32,38] we too found that lean body mass contributed most to the variation in BMR, accounting for 55.5% of BMR variation in participants in our study. Although this initially seemed to indicate that lean body mass should be included as a variable in the predictive equation, body composition measurements through indirect bioimpedance analysis showed that measurements were largely influenced by hydration status and hence were potentially inaccurate. Lean body mass was therefore cast aside as an unreliable predictor of BMR.

Using a stepwise regression model, we arrived at a new predictive equation using gender and body weight as independent predictors of BMR. Standing height and its derivative BMI were considered less favourably than body weight, which was easier to measure. The simple, novel predictive model developed, which was able to estimate BMR to within 1.2% of the measured BMR values for men and women in our study, could better estimate the BMR of Malaysian athletes when compared to other currently available predictive equations. The results of BMR estimation using our novel equation also showed fair agreement with indirect calorimetry. While calorimetry remains the gold standard for the measurement of individual BMR, the novel predictive equation could be used to provide a close estimate of BMR in a field setting, where laboratory facilities and expertise may not be available.

Our study found that the measured BMR values of Malaysian athletes were significantly different from those estimated using predictive equations derived from the Malaysian general population and Caucasian populations. We recommend that the novel predictive equation proposed in this study be used to ensure that the energy requirements of Malaysian athletes are met. Future studies directed at cross-validating this equation for application in athletes involved in other sports associated with varying levels of performance or of other nationalities and age groups may be required to validate its predictive capabilities.

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