Original article

Is there any predictive equation to determine resting metabolic rate in ultra-endurance athletes?

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Summary. *Background/aims:* Only a few studies determined some equations to predict resting metabolic rate (RMR) in endurance athletes, however the validity in ultra-endurance athletes, such as triathletes and ultra-marathoners, had not been examined previously. The aim of this study was to assess the accuracy of commonly used RMR predictive equations (Harris-Benedict, Mifflin-St. Jeor, Cunningham, WHO/FAO/UNU (calculated by using body mass and height and body mass alone), Wang, and Sabounchi (Structure 4, 5, and 11) equations) comparing with measured RMR in ultra-endurance athletes. *Methods:* Male (n=15) and female (n=15) ultra-endurance athletes age 23 to 55 years from Ankyra Sports Club were included. The Bland-Altman plot was performed to determine mean bias and limits of agreement between measured and predicted RMRs. Linear regression analysis was used to determine the accuracy of each predictive equation by computing the standard error of estimate and root-mean-squared prediction error (RMSPE). *Results:* Mifflin-St. Jeor equation was found to be the best predictive equation with lowest RMSPE (275.85 kcal/day for men and 388.34 kcal/day for women) and mean difference (3.04±285.51 kcal/day for men and 185.57±353.10 for women) in ultra-endurance athletes. The Cunningham equation could be used in estimating RMR in male athletes (RMSPE, 310.77 kcal/day, the bias between measured vs. predicted RMR, 147.68±283.04 kcal/day). *Conclusions:* The Mifflin- St. Jeor and Cunningham equations for men and the Mifflin-St. Jeor equation in women could be used with caution in the absence of indirect calorimetry in ultra-endurance athletes. All other predictions significantly underestimated RMR for both sexes.

Key words: ultra-endurance athletes, resting metabolic rate, predictive equation, indirect calorimetry, energy metabolism

Introduction

Given the intensive and long periods of ultra-endurance events (>6 h/race), providing sufficient energy to maintain body mass and avoid performance decline plays an important role in achieving performance goals and maintaining health status, and the estimation of energy requirements is critical for ultra-endurance athletes to maintain their body hormesis and develop their race strategies (1).

The basic component of sports nutrition assessment is to estimate the energy expenditure and intake during the training and race. In case the energy cost of training or race exceeds energy intake, the athlete has a negative energy balance, and this leads to a decline in performance and may result in failure of achieving his/

her goals (2, 3). The Australian Institute of Sport determined resting metabolic rate (RMR) as an important tool for athletes, especially when they could not reach their performance targets in response to personal training interventions (1).

RMR is one of the largest components of total energy expenditure (approximately 60-80% for sedentary adults and 38-47% for elite endurance athletes) and could be measured by using direct or indirect calorimetry measurement (4). Although it is important, this technique is not commonly preferred in energy measurement of athletes because long measurement periods and expensive laboratory equipment are required to measure RMR and trained personnel are also needed to obtain accurate results. Therefore, several predictive equations are developed to offer an alternative low-cost method of RMR estimation (5, 6).

Predictive equations are developed based on sex, body height and weight, and fat-free mass (FFM), and each of these is validated from a different range of populations, ages, and body compositions (7). For example, Harris and Benedict (8) first developed an equation on 239 healthy adults (136 men, 103 women; mean body mass index for men, 21.4, and women, 24.4) and frequently used the equation to predict RMR. The RMR predictive equation of Mifflin et al. (9) was derived from 264 normal weight and 234 obese adult samples using body weight, height, and age. The World Health Organization (WHO)/Food and Agricultural Organization (FAO)/United Nations University (UNU) predictive equations (10) were developed using data from Schofield and James, including 2526 adults (2,279 men, 247 women; with 47% of Italian population) and using either body weight and height or body weight alone. Cunningham (11) used the variables of Harris and Benedict by adding 60 new trained adults, and developed an equation to predict RMR using lean body mass of the subjects, and revealed that the equation is more accurate in certain populations. Wang et al. (12) found a linear relationship between FFM and RMR and developed an equation using data from 6 different studies. Sabounchi et al. (13) used 47 population-specific predictive equations of RMR and developed the resulting "structures" based on different characteristics of target population to be more specific for different populations. The American College of Sports Medicine (ACSM) position statement recommended the use of the Cunningham or Harris-Benedict equation to obtain a reasonable estimate of RMR in athletes (4).

Because of differences in body composition, training/race load, or other endurance-related characteristics of ultra-endurance athletes, there remains a need for a valid predictive equation that could be used to estimate RMR of athletes. Thus, the aim of this study was to compare the RMR predicted according to gender by 9 RMR predictive equations with RMR measured by indirect calorimetry in ultra-endurance athletes to determine which one of these predictive equations is more suitable to use in the populations.

Materials and methods

Subjects

Fifteen male (triathletes, n=10; ultra-marathoners, n=5) (38.46±5.32 years; 178.27±7.36 cm; 73.01±7.38 kg; 63.36±6.39 kg of FFM; 13.16±3.89 body fat [BF%]) and female (triathletes, n=6; ultra-marathoners, n=9) (37.13±7.87 years; 162.67±3.72 cm; 56.46±4.07 kg; 45.31±2.78 kg of FFM; 19.64±3.14 BF%) ultra-endurance athletes participated in this study. The inclusion criteria were as follows: 1) participation in ultra-endurance races/events, 2) >15-18 h/week training for at least three years, and 3) no history of metabolic disorders. Athletes who are using any ergogenic aids or medications and have a history of metabolic or eating disorders were excluded from this study. The study was conducted at the Center of Athlete Training and Health Research of the Ministry of Youth and Sports between March 20, 2018 and April 25, 2018. Subjects were recruited from Ankyra Sports Club in Ankara. All athletes were informed about the study protocol and provided written informed consent form at the beginning of the study.

Data Collection

Anthropometric Measurements

Anthropometric measurements (body height, body mass, FFM, and fat mass [FM]) were performed while the athletes wearing underwear in a fasting state (12 h). Body mass, FM, and FFM were measured using multifrequency bioelectrical impedance analyzer (MF-

BIA) (TANITA MC-780, Japan; 0.1 kg accuracy), and height was measured while athletes were standing, head positioned in Frankfort horizontal plane, using a portable stadiometer (portable stadiometer, Holtain, London, United Kingdom; 0.1 cm accuracy).

Indirect Calorimetry

Indirect calorimetry was used with the reason it is a valid measurement to reach actual RMR value. All athletes completed an RMR test using indirect calorimetry (COSMED K5 metabolic cart; COSMED, Rome, Italy). The system was recalibrated after every 3 athletes.

RMR measurement was standardized according to the procedures in a systematic review conducted by Compher et al (5). All athletes were asked to visit the Exercise Performance Laboratory in a fasting (at least 5 h) and resting (24 h, without doing vigorous exercise the day before the test) state and refraining from caffeine (at least 4 h), cigarette (at least 2 h), and alcohol (at least 2 h) consumption. The RMR test was performed at 8:00 to 9:00 AM, and the athletes rested without falling asleep, lying in a supine position for 20 min, in a dusk, silent room with an ambient temperature of 20-25°C. After the resting period, the test protocol was started while athletes were placed in a physically comfortable supine position and lasted for approximately 20 min. Data were recorded 5 min after the start of the test, and measurement was stopped after reaching a minimum of 5 min in steady-state conditions (achieving a 5-min period with ≤10% coefficient of variation for oxygen consumption [VO_2] and carbon dioxide production [VCO_2]).

Predictive Equations

RMRs for each participant were estimated using 9 commonly used standard predictive equations as presented in Table 1.

Statistical Analysis

Data were analyzed according to sex using SPSS version 23.0. Sample size was calculated using the formula (n= (ln(1-γ)/ln(1-π))4 based on Viechtbauer W et. al (14). We determined probability (π) of the study based on the results of similar studies (19, 25) and defined confidence interval (γ) as 0.95. Paired-sample t-test was used to compare measured and predicted RMRs. Linear regression analysis and Bland-Altman plot were used to determine the accuracy of each RMR predictive equation by comparing the indirect calorimetry measurement values and identify a proportional bias. The RMSPE was calculated to evaluate the accuracy of predicted RMR compared with the actual measured RMR for each athlete. Intraclass correlation coefficient was calculated to determine agreement between measured and predicted RMR. Data were represented as mean ± standard deviation (SD), and statistical significance was set at a P-value <0.05.

Results

The general information of the athletes is presented in Table 2. Table 3 represents the mean differences between measured and predicted RMR in ultra-endurance athletes. In men, values from all predictive equations with the exceptions of the Mifflin-St. Jeor (mean difference, 3.04±285.51 kcal) and Cunningham equations (mean difference, 147.68±283.04 kcal) were significantly different from the measured RMRs. The Harris Benedict, WHO/FAO/UNU (calculated with body mass and height), WHO/FAO/UNU (calculated with body mass alone), Wang, and all Sabounchi equations (Structures 4, 5, and 11) underestimated actual RMRs.

Values from all predictive equations with the exception of the Mifflin-St. Jeor equation (mean difference, 185.57±353.10 kcal) were significantly different from the measured RMRs in female ultra-endurance athletes. The Harris Benedict, Cunningham, WHO/FAO/UNU (calculated with body mass and height), WHO/FAO/UNU (calculated with body mass alone), Wang, and all Sabounchi equations (Structures 4, 5, and 11) prediction underestimated actual RMRs.

Table 4 presents the percentage of accuracy of each predictive equation according to the measured RMRs. Mifflin-St. Jeor and Cunningham equations in men (in 7 of 15 male athletes) and Mifflin-St. Jeor equation in women (in 8 of 15 female athletes) provided the most accurate RMR predictions.

Based on the regression analysis between measured and predicted RMRs for male ultra-endurance

Table 1. Resting metabolic rate predictive equations

No	Name	Equation
1	Harris-Benedict	Men: RMR[a] (kcal.d^{-1})= 66.47 +13.75*BM[b] (kg) + 5*H[c] (cm) - 6.76*A[d] (year)
		Women: RMR (kcal.d^{-1})= 655.1+9.56*BM (kg) + 1.85*H (cm)-4.66*A (year)
2	Mifflin-St. Jeor	Men: RMR (kcal.d^{-1})= 66.7+13.75*BM (kg)+5*H (cm)-4.92*A+5
		Women: RMR (kcal.d^{-1})= 66.7+13.75*BM (kg)+5*H (cm)-4.92*A-161
3	Cunningham	RMR[a] (kcal.d^{-1})= 500 + 22*FFM[e] (kg)
4	WHO/FAO/UNU[f]	BM (kg) and H (m):
		Men: age (year)
		8-30 RMR (kcal.d^{-1})= 15.4*BM (kg)-27*H (m)+717
		31-60 RMR (kcal.d^{-1})= 11.3*BM (kg) + 16*H (m)+901
		>60 RMR (kcal.d^{-1})= 8.8*BM (kg) +1.128*H (m)-1.071
		Women: age (year)
		18-30 RMR (kcal.d^{-1})= 13.3*BM (kg)+334*H (m)+35
		31-60 RMR (kcal.d^{-1})= 8.7*BM (kg) -25*H (m)+865
		>60 RMR (kcal.d^{-1})= 9.2*BM (kg) +637*H (m)-302
5	WHO/FAO/UNU[f]	BM (kg) alone:
		Men: age (year)
		18-30 RMR (kcal.d^{-1})= 15.3*BM (kg)+679
		31-60 RMR (kcal.d^{-1})= 11.3*BM (kg)+879
		>60 RMR (kcal.d^{-1})= 13.5*BM (kg)+487
		Women: age (year)
		18-30 RMR (kcal.d^{-1})= 14.7*BM (kg)+496
		31-60 RMR (kcal.d^{-1})= 8.7*BM (kg) +829
		>60 RMR (kcal.d^{-1})= 10.5*BM (kg) +596
6	Wang	RMR (kcal.d^{-1})= 24.6*FFM (kg) +175
7	Structure[h] 4	Men: RMR (kcal.d^{-1})= 361+21.1* FFM (kg) +4.77*FM[g] (kg)
		Women: RMR (kcal.d^{-1})= 360 + 21* FFM (kg) + 4.68* FM (kg)
8	Structure 5	Men: RMR (kcal.d^{-1})= 503 + 18.3*FFM (kg)
		Women: RMR (kcal.d^{-1})=473 + 20.1* FFM (kg)
9	Structure 11	Men: RMR (kcal.d^{-1})= 898-3.32*A + 14.3*FFM (kg) +6.46* FM (kg)
		Women: RMR (kcal.d^{-1})= 682-3.08*A+12.9*FFM (kg) +5.9* FM (kg)

[a]RMR, resting metabolic rate in kcal/day. [b]BM, body mass (kilograms). [c]H, height (all equations [except the WHO/FAO/UNU equation, which uses height in meters] use height in centimeters). [d]A, age (year). [e]FFM, fat-free mass (kilograms). [f]WHO/FAO/UNU, World Health Organization/Food and Agricultural Organization/United Nations University. [g]FM, fat mass (kilograms). [c]Population-specific meta-regression predictive equation developed by Sabounchi et al.

Table 2. Baseline characteristics of ultra-endurance athletes*

	Men (n=15)	Women (n=15)
Age (year)	38.46±5.32	37.13±7.87
Height (cm)	178.27±7.36	162.67±3.72**
Body mass (kg)	73.01±7.38	56.46±4.07**
Body fat (%)	13.16±3.89	19.64±3.14**
Fat-free mass (kg)	63.36±6.39	45.31±2.78**
Fat mass (kg)	9.65±2.99	11.15±2.29
Duration of training, hours/week	16.33±1.95	15.41±0.73
Maximum oxygen consumption (VO_2max), mL/min/kg	59.78±7.77	51.18±5.09**

** Mean ± standard deviation. **p<0.05*

athletes, the variance in predicted RMRs ranged from a standard error of estimate (SEE)=282.09 kcal/day from the WHO/FAO/UNU equation (calculated with H and BM) to a SEE= 293.20 kcal/day from the Harris Benedict equation, accounting for 18.5% and 11% of the variance in male ultra-endurance athletes, respectively. The Mifflin-St. Jeor equation yielded the lowest RMSPE value of 275.85 kcal and the highest intraclass correlation coefficient (ICC) of 0.76, which indicated that it has good reliability in estimating RMR for male ultra-endurance athletes, whereas the Structure 5 equation yielded the highest RMSPE value of 466.44 kcal.

Table 3. Comparison of measured and predicted RMRs in ultra-endurance athletes*

	Men (n=15)		Women (n=15)	
	RMR	Mean difference	RMR	Mean difference
RMR[a] measured	2041.60±301.03		1788.20±340.96	
Harris Benedict	1700.96±120.78	340.64±283.04**	1322.40±81.84	465.88±311.95**
Mifflin-St.Jeor	2038.56±125.56	3.04±285.51	1602.63±59.49	185.57±353.10
Cunningham	1893.92±140.61	147.68±283.04	1496.89±61.23	291.31±332.75**
WHO/FAO/UNU[b] *(calculated with BM[c] and H[d])*	1725.95±85.57	315.65±275.33**	1321.92±36.97	466.28±330.41**
WHO/FAO/UNU *(calculated with BM)*	1754.57±84.24	287.03±275.82**	1388.10±41.41	400.10±348.12**
Wang	1733.66±157.23	307.94±285.45**	1289.71±68.47	498.49±332.51**
Structure 4[e]	1743.94±137.31	297.66±279.10**	1363.75±62.30	424.45±331.06**
Structure 5[e]	1662.49±116.96	379.11±281.69**	1383.80±55.95	404.40±333.02**
Structure 11[e]	1738.70±89.06	302.90±277.89**	1158.41±29.79	629.79±334.65**

**Mean±standard deviation. **p<0.05. [a]RMR, resting metabolic rate in kcal/day. [b]WHO/FAO/UNU, World Health Organization/Food and Agricultural Organization/United Nations University. [c]BM, body mass (kilograms). [d]H, height (centimeters). [e]Population-specific meta-regression predictive equation developed by Sabounchi et al.*

Table 4. Percentage of ultra-endurance athletes whose RMR was accurate, overpredicted, or underpredicted as per predictive equation*

Equation	Men (n=15)			Women (n=15)		
	Accurate[a]	Overpredicted[b]	Underpredicted[c]	Accurate[a]	Overpredicted[b]	Underpredicted[c]
Harris Benedict	20.00	6.67	73.33	13.33	0.00	86.67
Mifflin-St.Jeor	46.67	26.66	26.66	53.33	13.33	33.34
Cunningham	46.67	33.34	20.00	20.00	13.33	66.67
WHO/FAO/UNU[d] *(calculated with BM[e] and f[g])*	20.00	6.66	73.34	13.33	0.00	86.67
WHO/FAO/UNU *(calculated with BM)*	20.00	6.66	73.34	26.66	0.00	73.34
Wang	26.67	6.66	66.7	13.33	0.00	86.67
Structure 4[g]	26.67	6.66	66.7	20.00	0.00	80.00
Structure 5[g]	13.34	6.66	80.00	26.66	0.00	73.34
Structure 11[g]	20.00	6.67	73.33	6.66	0.00	93.34

**For each equation, data are expressed as percent of the total sample. Each row sums to 100%. [a]Accurately predicted resting metabolic rate falls within ±10% of the value obtained from measured RMR. [b]Overpredicted resting metabolic rate is ≥10% of the value obtained from measured RMR. [c]Underpredicted resting metabolic rate is ≤ -10% of the value obtained from measured RMR. [d]WHO/FAO/UNU, World Health Organization/Food and Agricultural Organization/United Nations University. [e]BM, body mass (kilograms). [f]H, height(centimeters). [g]Population-specific meta-regression predictive equation developed by Sabounchi et al.*

According to the regression analysis of the bias (measured vs. predicted) for female ultra-endurance athletes, the variances ranged from a SEE= 303.12 kcal/day (Harris Benedict equation) to a SEE= 351.53 kcal/day (WHO/FAO/UNU equation [calculated with BM]), accounting for 26.6% and 1.3% of the variance, respectively. The Mifflin-St. Jeor equation presented the most accurate predictive equation in all used RMR predictions with the lowest RMSPE value of 388.34 kcal and had good reliability with ICC of 0.75, whereas the Structure 11 equation (with the highest RMSPE value [707.93 kcals], ICC of 0.11) had the worst performance in predicting the RMRs of female ultra-endurance athletes.

The results of the Bland-Altman plot analysis of each predictive equation for male and female ultra-endurance athletes are presented in Figures 1 and 2, respectively. A positive value indicates that the pre-

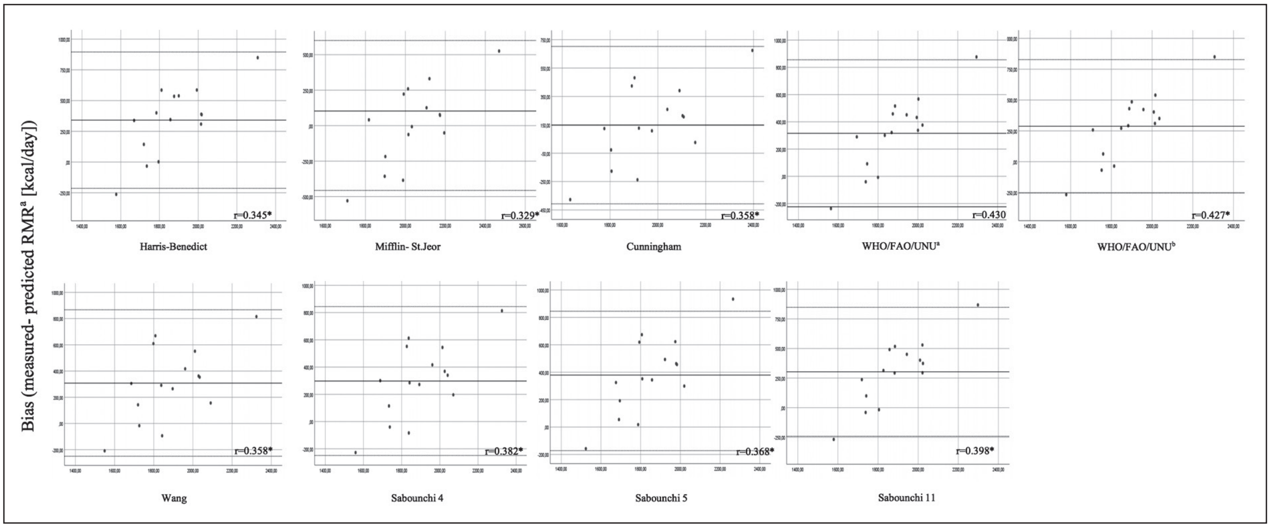

Figure 1. Solid line represents bias between measured and predicted RMR (kcal/day). Dashed lines represent ±1.96 SD of bias. [a]WHO/FAO/UNU, World Health Organization/Food and Agricultural Organization/United Nations University (calculated with body mass [kg] and height [m]). [b]WHO/FAO/UNU, World Health Organization/Food and Agricultural Organization/United Nations University (calculated with body mass alone [kg]). *p<0.05.

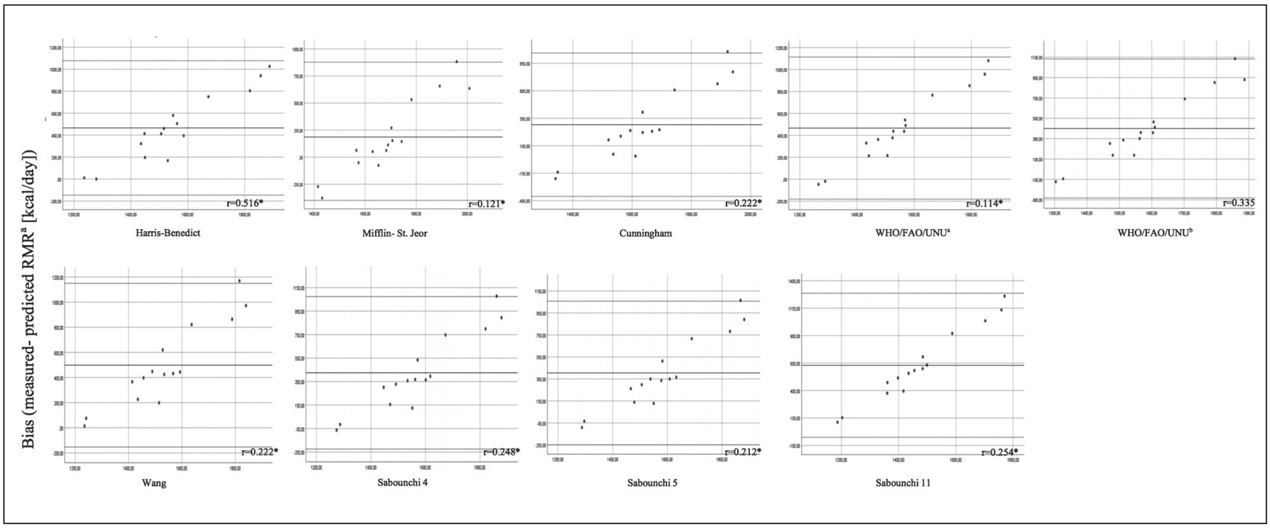

Figure 2. Solid line represents bias between measured and predicted RMR (kcal/day). Dashed lines represent ±1.96 SD of bias. [a]WHO/FAO/UNU, World Health Organization/Food and Agricultural Organization/United Nations University (calculated with body mass [kg] and height [m]). [b]WHO/FAO/UNU, World Health Organization/Food and Agricultural Organization/United Nations University (calculated with body mass [kg]). *p<0.05.

dicted RMR were greater than the measured RMR. All predictive equations were tested for each individual bias value near or exceeding the ±2 SD limits of agreement. The relationship between average and bias of measured and predicted RMRs were statistically significant for all predictive equations in men (Harris-Benedict, r=0.345; Mifflin-St. Jeor, r=0.329; Cunningham, r=0.358; WHO/FAO/UNU [calculating with BM and H]; r=0.430, WHO/FAO/UNU [calculating with BM alone], r=0.427; Wang, r=0.358; Structure 4, r=0.382; Structure 5, r=0.368; Structure 11, r=0.398), and significant for all predictive equation in women (Harris-Benedict, r=0.516; Mifflin-St. Jeor, r=0.121; Cunningham, r=0.222; WHO/FAO/UNU [calculating with BM and H]; r=0.114; WHO/FAO/UNU [calculating with BM alone], r=0.335; Wang, r=0.222; Structure 4, r=0.248; Structure 5, r=0.212; Structure 11, r=0.254).

Discussion

The physiology and training loads of men and women significantly differ from each other, therefore physiological evaluation criteria and formulations also differ according to sexes, for instance, an equation would be suitable for men while the same equation is not suitable for women. Therefore, the purposes of this study were to evaluate the accuracy of nine commonly used RMR predictive equations in a sample of ultra-endurance athletes and identify the differences in the accuracy of predictive equations between sexes.

In the last position stand on nutrition and physical activity conducted by the ACSM (4), sufficient energy intake for athletes was described as a cornerstone, and the use of the Cunningham and Harris-Benedict equations is recommended to predict RMR in athletic population. But, this recommendation was generalized for all athletic population, not specialized for any specific population. As all sports branches have required specific abilities and training conditions, the energy metabolism of athletes could be affected and changed according to sports type. Several studies emphasized that the Cunningham equation was recommended to be used for RMR prediction in athletes (15-17), while others reported that the equation underestimated the actual RMR (18, 19). The study found that Mifflin-St. Jeor (9) and Cunningham (11) equations for men and Mifflin-St. Jeor (9) equation for women had greater accuracy and predicted measured RMR within acceptable values in ultra-endurance athletes. The Harris-Benedict equation did not accurately predict measured RMR in both male (RMSPE, 436.81 kcal/day; R^2, 11.9%) and female (RMSPE, 554.86 kcal/day; R^2, 26.6%) ultra-endurance athletes in agreement with Jagim et al (16).

The Cunningham equation had good performance (RMSPE, 310.77 kcal/day; 44.5% of the variance; accuracy, 46.67% of the athletes, mean difference, 147.68±283.04 [p>0.05]) in male ultra-endurance athletes in this study, consistant with De Lorenzo et al (20). De Lorenzo et al (20) found that the Cunningham equation had the best performance in predicting RMR in 51 male athletes (12 judo, 22 water polo, 17 karate), accounting for 77% of the variance. However, even though the RMSPE of the Cunningham equation was low (433.82 kcal/day) compared with those of other equations except the Mifflin-St. Jeor equation and good based on the variance (68.4%) in female ultra-endurance athletes, the mean difference between measured and predicted values was statistically significant (291.31±332.75, p<0.05), and values were accurate in only 20.0% and underpredicted in 66.7% of the athletes in this study. As a result, the Cunningham equation accurately predicted RMR only in male ultra-endurance athletes.

It is known that pathophysiology of ultra-endurance athletes are complicated, and compared to all sports, even other endurance sports, could be defined as one of the most challenging conditions of training durations and race distances compared to all sports, even other endurance sports .These conditions could be reflected to their performance-related measurements like resting metabolic rate. Tthe Mifflin-St. Jeor equation was found to be the most accurate predictive equation in both male and female ultra-endurance athletes with the lowest RMSPE value of 275.85 and 388.34 kcal/day, predicted accurately in 46.6% and 53.3% of subjects, accounting for 52.4% and 88.7% of the variance in this study, respectively. Furthermore, the mean difference between measured and Mifflin-St. Jeor equation values was not significant for both sexes (3.04±285.51 kcal/day for men and 185.57±353.10 kcal/day for women). These results indicated that the Mifflin-St. Jeor equation could be used to predict RMR in both male and female ultra-endurance athletes. In contrast, Thompson and Manore (15) conducted a study on 37 endurance athletes (24 male, 13 female) and demonstrated that the Cunningham equation was the only predictive equation with accurate RMRs in both male and female endurance athletes, while the Mifflin-St. Jeor equation had underpredicted RMRs of endurance athletes. These results indicated that resting metabolic rate could be also varied between endurance and ultra-endurance athletes, therefore, this result should be considered in predicting the resting metabolic rate.

Although, in some cases, the mean difference between measured vs. predicted RMR was not statistically significant, the underestimation or overestimation of energy intake could be important and affect athletes' performance (21). The importance could be varied according to sex, types of sports (especially weight-dependent and weight-bearing sports), and periodization of training (season/off-season) (22). For instance, although the Mifflin-St. Jeor was found to be the best predicted RMR equation in women, the actual RMR is overestimated by 185 kcal/day, and it affects the total energy expenditure (TEE) by approximately 333-425.5 kcal/day as physical activity (PA) level (which was calculated as RMR*PA, PA coefficient is 1.6-2.4 in highly trained athletes) (10). The overestimation of total energy expenditure could have a negative impact on the nutrition program, which is regulated by total energy requirements, therefore more energy consumption might negatively affect sport performance (18).

Several factors had effects on RMR, especially in highly trained athletes. Although the Harris-Benedict equation (8) takes account of several body components such as body mass, height, and age, which have been proved to affect RMR, multiple studies investigated a significant relationship between FFM and measured RMR (11-13). Either FFM or both FM and FFM were utilized in predictive equations developed by Cunningham et al. (11), Wang et al (12), and Sabounchi et al (in Structures 4, 5, and 11) (13). These studies demonstrated that, since free fat is more active than adipose tissue and the best correlated component of RMR, FFM had more influence on energy requirements and could be used as a single predictor in estimating RMR (23-25). In contrast, Carlsohn et al. (18) conducted a study on 17 heavyweight endurance athletes and verified Cunningham and Harris-Benedict equations for use in the athletes and found that they had remarkable FFM (81.0±8 kg for men and 56.1±7.0 kg for women) and measured RMR (2675±526 kcal/day for men and 1577±253 kcal/day for women) and demonstrated that predictive equations underestimated the measured RMR in athletes with high FFM. Similarly, all equations that calculated RMR using FFM or both FFM and FM, with the exception of the Cunningham equations in men, underpredicted RMR in both male and female ultra-endurance athletes (underestimation percentage between 66.7% and 80% for men and between 66.67% and 93.34% for women) in the study. The difference between studies might be caused by study population characteristics, differences in measurements of FFM (via MF-BIA, DXA, or skinfold measurements), or differences in thermic effect of activity (TEA) that could be approximately 50% of TEE in elite endurance athletes (4).

The strengths of this study include actual measurement of RMR using the validated breath using the breath gas analyzer (COSMED K5 metabolic chart), and according to our knowledge, this is the first study investigating which predicted RMR equations could be used in both triathletes and ultra-marathoners. On the other hand, it should be emphasized that the sample size of the pilot study did not sufficient to generate a new predictive equation for ultra-endurance athletes, therefore our study provides the framework for future studies to generate a specific RMR equation for ultra-endurance athletes. Another limitation is that metabolic blood parameters such as thyroid hormones are not examined in this study. These factors, which may potentially have an effect on resting metabolic rate, could be determined in further studies.

In conclusion; the results of this study suggest that the Mifflin-St. Jeor and Cunningham equations for men and the Mifflin-St. Jeor equation for women remain the most accurate predictive equations in ultra-endurance athletes. Despite these findings, the bias measured vs. predicted RMR from 147.68±283.04 kcal/day (Cunningham) for men and 185.57±353 kcal/day (Mifflin-St. Jeor) for women could be considered when determining dietary requirements based on energy needs. Our study is a kind of pilot study and the findings are encouraging, and until future investigations validate or generate a new predictive RMR equation with a larger cohort of ultra-endurance athletes, the findings of this study could be used when predicting RMR in ultra-endurance athletes.

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