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Nazli Namazi PhD, Soghra Aliasgharzadeh MSc, Reza Mahdavi PhD & Fariba Kolahdooz PhD

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Accuracy of the Common Predictive Equations for Estimating Resting Energy Expenditure among Normal and Overweight Girl University Students

Nazli Namazi, PhD, Soghra Aliasgharzadeh, MSc, Reza Mahdavi, PhD, and Fariba Kolahdooz, PhD

Student Research Committee (N.N., S.A.), and Nutrition Research Center (N.N, S.A., R.M.), Faculty of Nutrition, Tabriz University of Medical Sciences, Tabriz, IRAN; Aboriginal and Global Health Research Group, Department of Medicine, Faculty of Medicine and Dentistry, University of Alberta, Edmonton, Alberta, CANADA (F.K.)

Key words: resting metabolic rate, predictive formula, normal weight, overweight, woman

Objective: The aim of the present study was to determine the accuracy of commonly used predictive formulas of resting metabolic rate (RMR) compared to measured RMR in normal and overweight young females.

Methods: In this cross-sectional study, 98 female university students aged 18–30 years with body mass index 18 to 30 kg/m^2 were recruited. Anthropometric indices and body compositions were measured. RMR was measured by indirect calorimetry (FitMate, Cosmed, Rome, Italy) and estimated by 11 predictive formulas. The accuracy of the RMR formulas and mean percentage differences between estimated and measured values were calculated. Paired *t* test was used to compare estimated and measured RMRs.

Result: There were no significant differences between measured and estimated RMR by the 4 commonly used formulas (Mifflin, Cunningham, and World Health Organization [WHO]/Food and Agriculture Organization [FAO]). Among all of the equations, the Mifflin formula showed the lowest bias (-2.97 ± 116.43 kcal/day) at the group level and was the most accurate formula (80.23%) in normal and overweight participants. The over- and underestimated values were about 14% and 5.5%, respectively. In normal and overweight females, Mifflin was the most accurate formula, with 75.51% and 84.61% accuracy, respectively.

Conclusion: Given the current lack of a standardized formula that consistently delivers accurate results, the Mifflin formula can be recommended for estimating energy requirements in normal and overweight females in clinical practice.

INTRODUCTION

Media outlets in many countries often portray a strong message that discriminates against obesity and promotes exceptionally thin body frames. These messages often influence many individuals, particularly women, to lose weight [1,2]. It has been reported that in the United States, 52% of men and 66% of women were not satisfied with their body weight [3]. Their primary reason for choosing to obtain a desirable body weight was not health concerns associated with obesity such as cardiovascular disease, diabetes, lipid disorders, and some cancers. Instead, dissatisfaction with their body image, even among women of normal body weight, was the driving force behind choosing to lose weight by diet self-management or consulting a dietitian [4,5].

In clinical settings, accurate estimation of individual energy requirements is the first step for proper diet planning [6]. Food-induced thermogenesis, physical activity, and resting metabolic rate (RMR) are 3 components of estimating energy requirement; however, RMR is the largest component of total energy expenditure (50%–70%) [7]. Elective methods for RMR measurement are doubly labeled water, direct and indirect calorimetry [8]. Among these, indirect calorimetry is the most commonly used method. However, it is time consuming, expensive, and not feasible in clinical settings [8,9]. Therefore, RMR is usually estimated with predictive formulas based on

Address correspondence to: Reza Mahdavi, Nutrition Research Center, Faculty of Nutrition, Tabriz University of Medical Sciences, Tabriz, IRAN. E-mail: mahdavir@tbzmed.ac.ir

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individual's characteristic. Harris-Benedict, Mifflin, Schofield, Owen, Wang and Cunningham are the most common RMR predictive formulas [8,10,11].

Some previous studies have reported the accuracy of predictive formulas to be different in obese, overweight, and normal-weight individuals [10,12,13]. Shaneshin et al. reported that the Mifflin and Owen formulas underestimated RMR in all body mass index (BMI) groups, whereas the Abbreviation and Schofield formulas had low bias in only normal-weight women, and Cunningham estimated RMR correctly only in overweight participants [13]. Li et al.'s study among young Canadian female participants also indicated that some predictive formulas overestimate RMR [14]. RMR can be influenced by other factors such as age, sex, ethnicity, and physical activity level [13,14]. The present study compares the accuracy of estimated RMR by commonly used formulas with measured RMR in normal- and overweight Iranian female university students.

METHODS

Study Design and Population

In this cross-sectional study, 98 female university students (50 normal-weight and 48 overweight) aged 18–30 years with BMI between 18.5 and 30 kg/m^2 were recruited between August and December 2012 in Tabriz, Iran.

Sample size was calculated on the basis of Shaneshin et al.'s study [13] and considering differences between measured RMR and Abbreviation formula with a confidence level of 95% and power of 90%. Participants were randomly selected from female students who participated in the study on body image at Tabriz University of Medical Sciences. Participants were not eligible if they had underlying conditions such as diabetes or cardiovascular or thyroid disorders and if they were taking any weight gain or loss medications with possible effects on RMR, such as antipsychotic; corticosteroid, and diuretic medications, during the past 3 months. Protocols of the study were approved by the ethics committee of Tabriz University of Medical Sciences. At the beginning of the study, all procedures were explained to the young female students who agreed to participate in this study and signed an informed consent.

Anthropometric Measurements

Weight was measured with minimum clothing and without shoes to the nearest 0.1 kg. Height was measured without shoes using a SECA stadiometer (Seca instruments Ltd., Hamburg, Germany) to the nearest 0.1 cm. Weight and height were measured twice and the average of the 2 values was recorded. BMI was calculated by dividing weight in kilograms by height in square meters. Participants were classified as being normal weight (BMI = 18.5–24.9 kg/m^2) or overweigh (BMI = 25–29.9 kg/m^2).

Body Composition Measurements

Body composition was measured with a TANITA Bioelectrical Impedance Analyzer (BC-418 MA, 50 kHz, Tanita Co., Tokyo, Japan) after 12–14 hours of fasting. We estimated the amount of fat mass (FM) and fat-free mass (FFM) with an accuracy of ±0.1%. Previous studies indicated a significant correlation between TANITA and dual-energy x-ray absorptiometry tests for body composition measurements [15–17].

Physical Activity Assessment

The long version of International Physical Activity Questionnaire was applied to estimate physical activity levels using face-to-face interviews. Based on calculated scores, participants were classified as being sedentary, moderately active, or severely active.

RMR Measurement

After 12–14 hours of fasting, RMR was measured between 8:30 and 11:00 AM using FitMate (Cosmed, Rome, Italy). This is an indirect tool to measure resting energy expenditure based on the volume of oxygen consumption (VO_2) and produced CO_2 (VCO_2) using a respiratory quotient of 0.85.

Previous studies indicated that FitMate indirect calorimetry is a valid instrument to measure RMR when compared with the Douglas bag system in adults and it can be used for individuals with a wide range of BMI [18–20].

Participants were asked to avoid consuming caffeinated beverages, severe physical activity, smoking, and drinking alcohol before RMR measurement. Participants placed the FitMate mask to cover their nose and mouth in a supine position in a quiet room with a temperature around 25°C. They were asked to breathe for 15 minutes. FitMate was calibrated before each measurement. RMR was calculated with 11 commonly used formulas as listed in the Appendix. Nine of 11 predictive formulas are dependent on sex and include anthropometric parameters, whereas the Cunningham and Nelson equations are based on body composition (FM, FFM) variables and are independent of sex.

Statistical Analysis

Quantitative variables are presented as mean ± SD. Frequency of qualitative variables is reported in percentages. Independent *t* test was used to compare general characteristic of participants between 2 groups. The mean difference (bias) between estimated and measured RMR was calculated for each formula. Correlations between measured and predictive RMR were calculated by linear regression analysis.

Table 1. Baseline Characteristics and Anthropometric Indices of Participants in Study Groups*

Variable	Overweight ($n = 48$)	Normal Weight ($n = 50$)	P Value†
Age (years)	22.50 ± 2.94	23.04 ± 2.62	0.36
Weight (kg)	70.93 ± 7.46	55.42 ± 5.60	<0.01
Height (cm)	161.84 ± 4.40	160.87 ± 6.23	<0.01
BMI (kg/m^2)	27.06 ± 2.45	21.37 ± 1.22	<0.01
Waist circumference (cm)	84.27 ± 6.97	72.17 ± 4.80	<0.01
Hip circumference (cm)	106.54 ± 7.41	97.85 ± 4.02	<0.01
Fat mass (%)	33.64 ± 4.09	25.78 ± 4.20	<0.01
Fat-free mass (%)	66.36 ± 4.63	74.22 ± 9.74	<0.01
Physical activity (%)			
Sedentary	83	81	0.15††
Medium	17	19	

BMI = body mass index.
*All values except physical activity are mean ± SD.
†Independent t test. ††Fisher's exact test. $P < 0.05$ considered significant.

Accuracy of predictive formulas was defined as the percentage of participants with a difference between predicted and measured RMR within ±10% of measured RMR value [13]. Bland-Altman plots were used to display bias and agreement of the most accurate predictive formula in each group. Paired sample t test was used to compare measured RMR with predicted RMR. P value < 0.05 was considered significant. SPSS software (version 15.0, SPSS Inc. Chicago, IL) was used for statistical analysis.

RESULTS

General characteristics of the study participants are presented in Table 1. The mean age and BMI of participants was 22.77 ± 2.78 years and 24 ± 1.83 kg/m^2, respectively. As shown in Table 2, there was a significant correlation between measured RMR and all 11 predictive formulas in the study groups ($P < 0.01$). Comparisons of measured and estimated RMRs are presented in Table 3. The bias between measured RMR and Mifflin, Schofield, Cunningham, and WHO/FAO (2 separate formulas) formulas were not statistically significant at the group level. In both normal- and overweight women, among 11 commonly used predictive formulas, the Mifflin formula was the most accurate (80.23%) at the individual level and under- and overestimation were observed in about 5 and 14 of 98 participants, respectively (Table 3).

Table 2. Correlation between Measured and Predictive RMR Formulas in the Study Group ($N = 98$)

Formula	R^2	P Value†
Mifflin	0.47	<0.01
Harris-Benedict	0.50	<0.01
Owen	0.50	<0.01
Liu	0.49	<0.01
Imna	0.49	<0.01
Bernstein	0.51	<0.01
Cunningham	0.29	<0.01
Abbreviation	0.50	<0.01
WHO/FAO (weight)	0.3	<0.01
WHO/FAO (height and weight	0.50	<0.01
Nelson	0.3	<0.01

RMR = resting metabolic rate, WHO = World Health Organization, FAO = Food and Agriculture Organization.
†Linear regression. $P < 0.05$ considered significant.

A comparison of mean measured and estimated RMR for normal- and overweight participants is presented in Table 4. Among normal-weight women, there was no significant difference between measured RMR and estimated RMR using Mifflin, Schofield, Cunningham, Abbreviation, and WHO/FAO formulas. However, at the individual level, Mifflin and WHO/FAO/United Nations University (UNU) formulas were the most accurate formulas to predict RMR with similar levels of accuracy (75.51%; Table 4).

Among overweight participants there was no significant difference between measured RMR and the Mifflin formula at the individual and group levels. At the individual level, the Mifflin formula was the most accurate formula, with 84.61% accuracy, among 11 commonly used formulas to predict RMR (Table 4). Bland-Altman plots display bias and agreement of the Mifflin equation in normal- and overweight participants (Fig. 1). In normal-weight individuals, the mean difference between Mifflin formula and measured RMR was 12.19 kcal and the 95% limit of agreement was between 252.83 and −228.45 kcal. In overweight participants, the mean difference was 20.68 kcal and the 95% limit of agreement was between 228.23 and −186.87 kcal.

DISCUSSION

Dieting to obtain a desired body weight is a common practice among many young females. For the purposes of accurate diet planning, RMR estimation is essential. Due to the cumbersome nature of indirect calorimetry, different predictive

Table 3. Comparison of Measured RMR with Estimated RMR by Different Formulas and Their Accuracy Rates in Nonobese Subjects ($N = 98$)*

	RMR (kcal/day)	Bias (kcal/day)	P Value†	Accuracy[1] (%)	Overestimated[2] (%)	Underestimated[3] (%)
Measured RMR	1362.12 ± 159.91	—	—	—	—	—
Predictive RMR						
Mifflin	1359.14 ± 121.76	−2.97 ± 116.43	0.80	80.23	14.28	5.49
Harris-Benedict	1445.17 ± 102.64	83.05 ± 112.67	<0.01	74.63	24.18	1.19
Owen	1244.34 ± 72.72	−117.77 ± 119.89	<0.01	42.85	7.70	49.45
Liu	1515.91 ± 152.85	153.79 ± 120.30	<0.01	52.75	47.25	0
Imna	1571.18 ± 132.16	209.06 ± 115.58	<0.01	26.37	73.63	0
Bernstein	1175.98 ± 75.08	−186.13 ± 118.18	<0.01	19.79	3.29	76.92
Cunningham	1332.96 ± 118.92	−27.32 ± 138.99	0.06	73.63	15.38	10.99
Abbreviation	1426.87 ± 230.93	64.75 ± 162.94	<0.01	62.64	28.57	8.80
WHO/FAO (weight)	1415.96 ± 148.89	53.84 ± 118.27	0.08	73.62	24.19	2.19
WHO/FAO (height and weight)	1406.16 ± 144.31	44.04 ± 118.52	0.23	78.03	19.78	2.19
Nelson	1183.32 ± 159.18	174.83 ± 140.93	<0.01	18.18	6.81	75

RMR = resting metabolic rate, WHO = World Health Organization, FAO = Food and Agriculture Organization.
*All values are mean difference± SD.
[1]Percentage of subjects with a difference between predicted and measured RMR within± 10% of measured value.
[2]Percentage of subjects with a difference between predicted and measured RMR within >10% of measured value.
[3]Percentage of subjects with a difference between predicted and measured RMR within <10% of measured value.
†P values obtained by paired t test.

formulas are usually used to estimate RMR. However, there is a debate regarding the accuracy of predictive formulas among people with different BMIs. Previous studies have suggested that the accuracy of predictive formulas may be influenced by BMI values [13]. Our findings indicated that among young normal-weight and overweight females, Mifflin, Cunningham, and WHO/FAO formulas can predict RMR accurately at the group level. The Mifflin formula was the most accurate predictive formula (80.23%) among these 4 formulas.

Similar to our findings, Frankenfield reported that Mifflin's formula was the most accurate predictive equation (accuracy: 87%) among nonobese American participants. They reported that it overestimated RMR for 12% and underestimated RMR for 8% of participants [17].

In our study, over- and underestimation was observed in about 14% and 6% of participants using the Mifflin formula. In Belgian women with a wide range of BMI (18.5 to >50 kg/m^2), Mifflin predicted RMR accurately in 68% of participants aged 20–35 years [21]. In addition, de Oliveira et al. reported that Mifflin was one of the most accurate formulas compared to Deltatract indirect calorimetry in overweight and obese Brazilian men aged 20–43 years old [22]. However, Shaneshin et al. indicated that differences between measured RMR using indirect calorimetry and the Mifflin formula were significant and it underestimated RMR among women aged 34.9 ± 8.1 years with a mean BMI of 27.7 ± 5.8 kg/m^2 [13]. Controversial results may be due to differences in mean range of age, BMI, and race of participants.

We found no significant difference between measured and predicted RMR using the WHO/FAO/UNU formula (including weight and height) at the group level and its accuracy was 78.03% in normal-weight participants. Similar to our findings, Muller et al. showed no difference between the WHO/FAO/UNU formula with measured RMR among participants aged 5–91 years with a mean BMI of 27 ± 9.71 kg/m^2 [23]. In addition, Frankenfield et al. reported that the accuracy of the WHO/FAO/UNU formula was 71% in nonobese American participants [17]. However, another study reported that the WHO/FAO/UNU formula is not reliable to estimate RMR at the group level among females with a mean BMI of 27.7 ± 5.8 kg/m^2 [13]. These discrepancies between the studies may be due to the differences in BMI, age, and race of the participants and instrument errors.

We found that the Mifflin and WHO/FAO/UNU formulas were the most accurate formulas among normal-weight women and had similar accuracies. We also found that WHO/FAO/UNU formulas including weight and height were the most accurate among normal-weight females. There are limited studies among normal-weight women to compare predictive formulas with measured RMR. Rao et al. studied normal-weight Chinese women with a mean BMI of 19.4 ± 1.2 kg/m^2 and found that WHO/FAO/UNU formulas were the most accurate (50%) among 5 other formulas, including Harris-Benedict, WHO/FAO, Owen, Mifflin, and Liu formulas [24]. They did not report the accuracy of the WHO/FAO/UNU formulas.

In our study, the Mifflin formula served as the most accurate for overweight participants, out of the 11 commonly used formulas. Similar to our findings, Weijs assessed the validity of predictive formulas in American and Dutch overweight adults. They found that Mifflin was the most accurate formula among American participants (accuracy 79%), whereas the WHO/FAO/UNU formula was more accurate for Dutch participants (accuracy 68%) [25]. They concluded that ethnicity is an important factor influencing the accuracy of predictive formulas.

Table 4. Comparison of Measured RMR with Estimated RMR by Different Formulas in Normal- and Overweight Subjects

Weight Indices RMR Predictive Equations	Normal Weight ($n = 50$)						Overweight ($n = 48$)					
	RMR (kcal/day)	Bias[1] (kcal/day)	P Value†	Accuracy* (%)	Overestimated†† (%)	Underestimated‡ (%)	RMR (kcal/day)	Bias* (kcal/day)	P Value†	Accuracy* (%)	Overestimated†† (%)	Underestimated‡ (%)
Measured RMR (FitMate)	1271.32 ± 133.68	—	—	—	—	—	1468.04 ± 1175	—	—	—	—	—
Mifflin	1283.52 ± 89.72	12.19 ± 123.41	0.49	75.51	20.4	4.09	1447.36 ± 91.17	−20.68 ± 106.44	0.21	84.61	7.69	7.69
Harris-Benedict	1374.75 ± 62.58	103.42 ± 119.18	<0.01	67.34	30.61	2.04	1527.33 ± 75.50	59. 28 ± 100.82	0.2	83.30	16.7	0
Owen	1192.94 ± 40.25	−78.37 ± 123.41	<0.01	51.02	12.24	36.74	1304.30 ± 53.59	−163.74 ± 98.51	<0.01	33.33	2.38	64.29
Liu	1413.85 ± 99.07	142.52 ± 127.53	<0.01	55.1	44.90	0	1672.32 ± 98.11	166.94 ± 111.35	<0.01	51.28	48.72	0
Imna	1484.50 ± 88.91	213.17 ± 123.88	<0.01	24.48	75.52	0	1634.99 ± 113.23	204.27 ± 106.38	<0.01	30.77	69.23	0
Bernstein	1121.88 ± 39.27	−149.44 ± 121.53	<0.01	26.53	4.08	69.39	1239.10 ± 54.67	−228.94 ± 99.41	<0.01	10.27	2.56	87.17
Cunningham	1271.31 ± 114.77	0.58 ± 154.41	0.97	67.34	21.83	10.83	1406.94 ± 73.36	−60.81 ± 110.69	0.17	73.62	1	12.82
Abbreviation	1263.67 ± 127.82	−7.64 ± 143.78	0.53	67.34	16.00	16.66	1617.28 ± 170.20	149.23 ± 143.18	0.01	58.97	41.03	0
WHO/FAO (weight)	1310.74 ± 82.41	39.41 ± 126.24	0.42	73.46	22.44	4.10	1538.72 ± 109.73	70.67 ± 107.28	0.30	73.69	26.31	0
WHO/FAO (height and weight)	1309.47 ± 92.28	38.15 ± 127.94	0.31	75.51	20.4	4.09	1518.97 ± 107.40	50.92 ± 107.63	0.29	78.95	21.05	0
Nelson	1090.77 ± 139.14	−179.95 ± 165.35	<0.01	32.65	6.13	61.22	1297.22 ± 96.27	168.54 ± 105.16	<0.01	30.76	5.12	64.12

RMR = resting metabolic rate, WHO = World Health Organization, FAO = Food and Agriculture Organization.
[1]Differences between measured and predicted RMR.
†Paired sample t test between RMR measured by FitMate and estimated RMR.
*Percentage of subjects with a difference between predicted and measured RMR within ± 10% of measured value.
††Percentage of subjects with a difference between predicted and measured RMR within >10% of measured value.
‡Percentage of subjects with a difference between predicted and measured RMR within <10% of measured value.

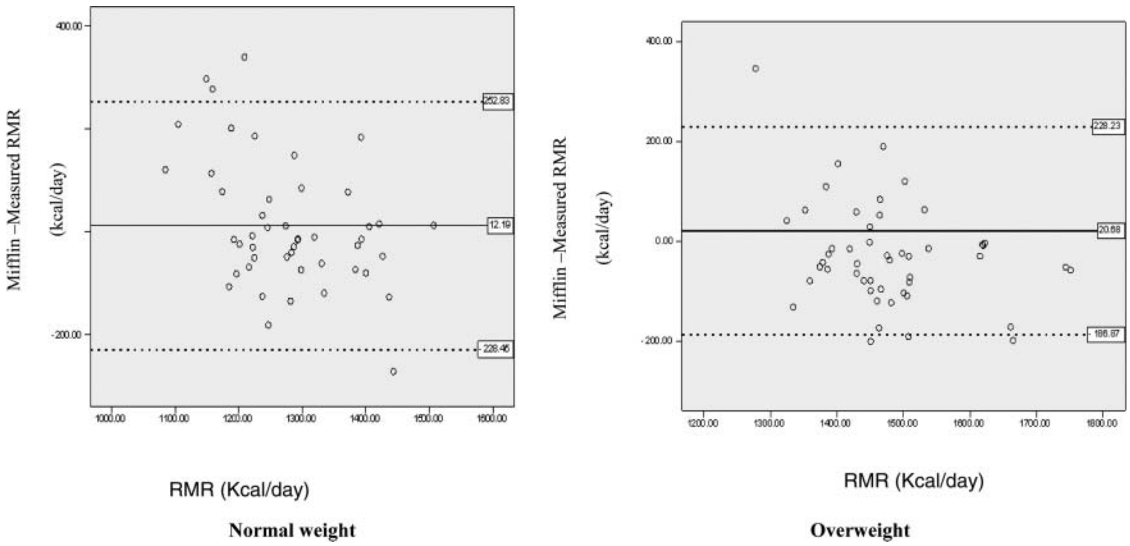

Fig. 1. Bland-Altman plots for Mifflin formula in normal- and overweight participants. Solid lines indicate the mean difference between Mifflin and measured RMR values. Dashed lines indicate the limit of agreement.

Some limitations of the present study are the (1) small sample size, (2) recruiting volunteer participants within a narrow range of BMI, and (3) single RMR measurement, which could not estimate the intra-individual variation.

CONCLUSION

Findings of the present study suggest that the Mifflin and WHO/FAO/UNU formulas in normal-weight females and the Mifflin formula in overweight participants are the most accurate formulas to predict RMR. Therefore, until a more accurate formula is developed, the Mifflin formula may be recommended for estimating energy requirements in normal- and overweight Iranian young women in a clinical setting. Further studies are suggested to determine the accuracy of predictive formulas in different regions of our country.

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APPENDIX—EQUATIONS USED FOR RMR PREDICTION (KCAL/DAY)

Mifflin	9.99 * Weight + 6.25 * Height − 4.92 * Age − 161
Harris-Benedict	665 + 9.56 * Weight + 1.84 * Height − 4.67 * Age
Owen	795 + 7.18 * Weight
Liu	(13.88 * Weight) + (4.16 * Height) − (3.43 * Age) − 58.06
Imna	204 − (4 * Age) + (4.505 * Height) + (11.69 * Weight)
Bernstein	(7.48 + Weight) − (0.42 * Height) − (3 * Age) + 844
Cunningham	(21.6 * FFM) + 370
Abbreviation	0.95 * 24 * Weight
WHO/FAO[1] (weight)	14.7 * Weight + 496
WHO/FAO[2] (height and weight)	13.3 * Weight + (334 * Height) + 35
Nelson	25.80 * FFM + 4.04 * FM

RMR = resting metabolic rate, FFM = fat-free mass, WHO = World Health Organization, FAO = Food and Agriculture Organization, FM = fat mass.
[1]Based on weight variable.
[2]Based on weight and height variables.