Accuracy and Applicability of Resting Metabolic Rate Prediction Equations Differ for Women Across the Lifespan

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Abstract: *Background*: Nutrition clinicians need accurate and reliable resting metabolic rate (RMR) assessments to determine energy needs and an appropriate nutrition care plan.

Material/Methods: This cross-sectional study compared the accuracy of eight RMR prediction equations (Harris-Benedict, Robertson and Reid, Cunningham 1980, FAO/WHO/UNU, Owen, Mifflin-St. Jeor, Cunningham 1991, and Nelson) to measured RMR by indirect calorimetry among young (n=57; age: 25±3 years), midlife (n=57; age: 44±3 years), and older (n=46; age: 68±5 years) women. Paired *t*-tests examined differences between predicted and measured RMR. Statistical analyses were conducted using SPSS (version 21), with significance defined as p<0.05. Bland-Altman plots displayed prediction bias and agreement. Prediction accuracy was defined when predicted RMR was ±10% of measured RMR. Serum thyroid stimulating hormone and follicle stimulating hormone concentrations were measured to assess thyroid function and ovarian reserve, respectively.

Results: The difference between predicted and measured RMR ranged from +0.6% (Owen) to +17.7% (Cunningham 1980) for the young, -2.8% (Nelson) to +18.1% (Cunningham 1980) midlife, and +2.8 (Nelson) to +26.7% (Cunningham 1980) older women. For the young women, only the Owen equation predicted RMR similar to measured RMR (p=0.905). For the older women, only the Nelson equation predicted RMR similar to measured RMR (p=0.051). All estimates using prediction equations were significantly different from measured values for midlife women.

Conclusion: Many RMR prediction equations have limited applicability for women at difference stages of the lifespan, thus impacting patient outcomes. Additional research is necessary to determine the appropriateness of RMR prediction equations among women of all ages.

Keywords: Resting metabolic rate (RMR), indirect calorimetry, RMR prediction equation, women, lifespan.

Accurate resting metabolic rate (RMR) assessments are necessary for Registered Dietitian Nutritionists and nutrition clinicians to estimate energy requirements and generate an appropriate nutrition care plan. RMR describes the energy required to support physiologic function and maintain body temperature when the body is in a rested and fasted state [1]. Several factors may impact RMR including: age [2,3], body composition [2], weight [3], sex [2,4], heart rate [3], menstrual cycle [5], smoking status [3], and caffeine intake [6]. Because RMR typically represents the largest component of total daily energy expenditure in healthy adults [2], Registered Dietitian Nutritionists and nutrition clinicians need reliable resting metabolic rate (RMR) estimates when determining energy needs for patients [7].

Currently, indirect calorimetry (IC) remains the "gold standard" for metabolic rate measurement [8]. Unfortunately IC is not available in most clinical settings [9,10]. Consequently, multiple RMR prediction equations have been developed to estimate total daily energy requirements and are common in both inpatient and outpatient practice (Table **1**). However, the characteristics of the participants used to derive the prediction equation may influence the RMR estimate, potentially contributing to over- and underfeeding of patients. Thus, knowledge of the demographics of the original sample may help determine applicability of the prediction equations to different demographic groups (i.e., sex, body weight, race/ethnicity, health status) [7].

Harris and Benedict [11] developed the first RMR prediction equation using height and weight measurements from predominantly young, normal-weight participants in the early 1900s. During the 1950s, Robertson and Reid [12] developed an equation

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Table 1: Formulas and Characteristics of Eight Resting Metabolic Rate Prediction Equations for Women

Prediction Equation	Formula	Characteristics of Participants in the Development of the Prediction Equation
Harris-Benedict 1919 [11]	kcal/day = 655.0955 + 9.5634 x weight(kg) + 1.8496 x height(cm) – 4.6756 x age(years)	n = 103 women Age: mean (range) = 31 years (15 – 74 years) 20 – 30 years (n = 55), 40 – 50 years (n = 8), >60 years (n = 6) Predominantly normal – weight women Weight mean (range) = 56.4 kg (35.6 – 94.1 kg)
Robertson and Reid 1952 [12]	kcal/day = BSA(m^2)^a x 24 x (age specific value)	n = 1323 women Female nurses in training at Middlesex Hospital, England, medical students and other hospital staff, children attending welfare clinics and on tonsillectomy waiting lists, members of the public who responded to newspaper appeals Age = 3 – 74 years 20 – 30 years (n = 377), 40 – 50 years (n = 94), >60 years (n = 35) Weight was not provided
Cunningham 1980 [19]	kcal/day = 500 + 22 x lean body mass	n = 223 (103 women, 120 men) Original Harris-Benedict population, excluding 16 male athletes Age[b]: mean (range) = 29 years (15 – 74 years) 20 – 30 years (n = 138), 40 – 50 years (n = 14), >60 years (n = 9) Weight[b]: mean (range) = 59.7 kg (33.2 – 94.1 kg)
FAO/WHO/UNU 1985 [13]	18-30 years: kcal/day = 13.3 x weight(kg) + 334 x height(m) + 35 30-60 years: kcal/day = 8.7 x weight(kg) – 25 x height(m) + 865 >60 years: kcal/day= 9.2 x weight (kg)+ 637 x height(m) – 302	n = 11,000 men, women, and children Developed using data from Schofield *et al.* [14,15] Healthy individuals of varied age, weight, and height included; however, limited representation of older adults Age and weight characteristics not provided
Owen *et al.* 1986 [17]	Nonathletes[c]: kcal/day = 795 + 7.18 x weight (kg)	n = 36 women (excluding 8 athletes) Age: mean (range) = 36 years (18 – 65 years) 20 – 30 years (n = 14), 40 – 50 years (n = 3), >60 years (n = 1) Weight: mean (range) = 79 kg (43 – 143 kg) Included a wide range of weight categories: underweight (n = 1), normal weight (n = 15), overweight (n = 4), obese (n = 10), and extremely obese (n = 6)
Mifflin-St. Jeor 1990 [18]	kcal/day = 9.99 x weight(kg) + 6.25 x height(cm) – 4.92 x age(years) –161	n = 247 women Age mean (range) = 44.6 years (20 – 76 years) Weight mean (range) = 70.2 kg (46 – 120 kg) Normal weight (n = 135) and obese (n = 112) Detailed age information of individual participants not provided
Cunningham 1991 [20]	kcal/day = 370 + 21.6 x FFM[d](kg)	n = 1483 men and women Derived from a compilation of studies published between 1980 – 1989 Detailed age information not provided Included lean and obese male and female participants
Nelson *et al.* 1992 [21]	kcal/day = 25.80 x FFM[d](kg) + 4.04 x FM[e](kg)	n = 213 (86 adult men and 127 adult women) Derived from a compilation of data sets that included FFM, FM, and REE[f] Detailed age information not provided Included non-obese (n = 81) and obese (n = 132) participants

[a]BSA estimated from stature and body weight by DuBois and DuBois formula [46]: A(cm^2)=W(kg)$^{0.425}$ x H(cm)$^{0.725}$ x 71.84.
[b]Calculated from original Harris-Benedict tables (Table C and D) [11].
[c]Owen *et al.* published two prediction equations; in the present study the equation for nonathletes was used.
[d]FFM = fat free mass.
[e]FM = fat mass.
[f]REE = resting energy expenditure.

that took into account age and sex-specific body surface area to predict metabolic rate. Derivation of the Robertson and Reid equation [12] was based on anthropometric measurements of British children, medical students, hospital employees, and volunteers, representing an age range of more than 70 years. In 1985, the Food and Agricultural Organization/World Health Organization/United Nations University (FAO/WHO/UNU) [13] introduced a series of age-specific RMR prediction equations based on an analysis conducted by Schofield *et al*. [14,15] that included 114 studies published between 1917 and 1983, with an international sample of participants. Although this review included a large sample size, the participants were primarily young and midlife men and women, limiting the generalizability [14,15]. Conversely, the Owen [16,17] and Mifflin-St. Jeor [18] equations were developed using smaller sample sizes but representing a wide range of ages (18 – 65 years and 20 – 76 years, respectively) and body weights (43 – 143 kg and 46 – 120 kg, respectively). Similar to the Harris-Benedict [11] and FAO/WHO/UNU [13] equations, the Mifflin-St. Jeor [18] equation calculates RMR using sex, weight, and height as part of the prediction equation.

Given the relationship between lean body mass and RMR, additional equations take into consideration body composition when predicting metabolic rate. The original Cunningham equation (1980) [19] predicts metabolic rate using lean body mass (LBM). The equation [19] was derived using the weight, age, and height values of physically inactive men and women from the original Harris-Benedict study. In 1991, Cunningham revised the equation utilizing a two-compartment model of body composition, fat mass (FM) and fat-free mass (FFM), and expanded the original sample to include men and women with a large range of body weights [20]. Similarly, Nelson *et al*. [21] combined the datasets of seven studies published from 1982 to 1989 [16,17,22–26], including normal weight, overweight, and obese men and women between the ages of 18-82, to derive an equation that predicts RMR based on FM and FFM.

Because of the importance of accurate energy expenditure estimations, the research literature has examined the applicability of prediction equations within diverse populations [27–33]. Unfortunately, many RMR prediction equations were derived from samples that did not include individuals from all stages of the lifespan. Thus, the applicability of these equations to some age groups is limited [7,30]. For example,

validation studies conducted with young adults [27,28] suggest that commonly-used equations, such as the Harris-Benedict and Mifflin-St. Jeor, may not accurately predict RMR in young women. Other studies evaluating the accuracy of RMR prediction have observed that several RMR prediction equations over or under-estimate RMR among older adults [29,31–33]. To date, only one published study has investigated the applicability of RMR prediction equations for midlife women [34].

Research is needed to examine the prediction accuracy of current RMR prediction equations on adults throughout the lifespan to identify the most appropriate equation. Therefore, the primary objective of this study was to compare the accuracy of eight RMR prediction equations (Harris-Benedict [11], Robertson and Reid [12], Cunningham 1980 [19], FAO/WHO/UNU [13], Owen [17], Mifflin-St. Jeor [18], Cunningham 1991 [20], and Nelson [21]) to measured RMR by IC among a sample of young, midlife, and older women.

METHODS

Study Design

This cross-sectional study assessed the accuracy of eight RMR prediction equations to measured RMR. The study visits were completed at Arizona State University (ASU) and the data analysis was completed at New York University (NYU). Both the Human Subjects Institutional Review Board at ASU and the University Committee on Activities Involving Human Subjects (UCAIHS) at NYU approved the study procedures.

Participant Recruitment

Women (n=207), between the ages of 20-77, were recruited from the Phoenix, Arizona metropolitan area using flyers posted at libraries, churches, college campuses, and community centers. The flyers briefly described the study and invited potential participants to contact the study investigators for more information. Women were eligible for inclusion if they were young (20 – 30 years), midlife (40 – 50 years), and older (≥ 60 years), at a stable body weight (defined by < 2.2 kg fluctuation over the past two years), body mass index (BMI) < 30.0 kg/m^2, and nonsmokers. Eligible young and midlife participants needed to report regular menstruation, defined by menstrual cycle duration of approximately 28 days, 12 cycles yearly. Investigators

excluded women from participating if, at the time of the study, they reported unresolved health conditions, such as diabetes mellitus, cardiovascular disease, cancer, high blood pressure, an eating disorder, or thyroid disease. Researchers determined eligibility over the telephone.

Once preliminary eligibility was established, study investigators invited the potential participants to schedule a research study visit. During the first visit, all participants received detailed information about the study, signed an informed consent form, completed a health history questionnaire, and were interviewed about dietary supplement (vitamin, mineral, herbal) and medication (prescription and over-the-counter) use. At this visit, investigators also provided participants written and verbal instructions for the subsequent study visits that include an RMR measurement, a fasting blood draw, and body composition assessment.

Anthropometry

Participants completed anthropometric measurements using a balance beam scale (HealthOMeter, Sunbeam Products, Boca Raton, FL). Body composition was assessed by dual-energy x-ray absorptiometry using the LUNAR DPX-IQ (GE Healthcare, Madison, WI) instrument.

Biochemical Analysis

Serum thyroid stimulating hormone (TSH) and follicle stimulating hormone (FSH) concentrations were determined in duplicate by radioimmunoassay from an eight-hour fasting blood sample (MP Biomedicals, Inc, Irvine, CA). Women with a serum TSH concentration exceeding 6.75 µIU/mL were excluded from the study.

Resting Metabolic Rate Measurement and Prediction

RMR was measured using the Delta Trac II metabolic monitor (Viasys Healthcare, Yorba Linda, CA) using the protocol recommended by the Academy of Nutrition and Dietetics Evidence Analysis Working Group [35]. For the young and midlife women, RMR was measured within one week after the onset of menses in order to eliminate the fluctuations in RMR that occur over the course of the menstrual cycle [5]. Investigators calibrated the metabolic cart each morning, prior to the initial RMR measurement, with a gas mixture of oxygen (95%) and carbon dioxide (5%). Participants arrived for the RMR measurement after fasting for at least eight hours and abstaining from

caffeine [6,36] and physical activity [37] for 24 and 48 hours, respectively. Participants rested in a recumbent position for at least 20-minutes before testing began. Investigators conducted two 25-minute RMR measurements and discarded the data recorded during the first 5-minutes. A mean RMR value from the two measurements was computed for the data analysis. RMR was then calculated using eight common prediction equations (Table **1**): Harris-Benedict [11], Robertson and Reid [12], Cunningham 1980 [19], FAO/WHO/UNU [13], Owen [17], Mifflin-St. Jeor [18], Cunningham 1991 [20], and Nelson [21].

Statistical Analysis

The Statistical Package for Social Sciences (SPSS), Version 21.0 (SPSS Institute, Chicago, IL) was used for all statistical analyses. Participants were grouped into 3 age groups, young (20 – 30 years), midlife (40 – 50 years), and older (≥ 60 years), based on self-reported age during the first study visit. Researchers completed separate analyses for each age category. Descriptive statistics (mean ± standard deviation) were computed for age, height, weight, BMI, % body fat, TSH, FSH, and measured RMR. One-way analysis of variance (ANOVA) using the post-hoc Bonferroni test explored the impact of age on the descriptive variables. A paired- samples *t*-test was conducted to compare measured RMR to predicted RMR for each of the eight prediction equations. Significance was defined as $p < 0.05$.

The limits identified by Bland and Altman [38] were applied to visually depict the most and least appropriate prediction equations for each age group. The appropriateness of each equation was identified by the extent of prediction bias, the mean difference (predicted RMR – measured RMR) for each equation. Bland-Altman plots displayed the calculated mean of predicted and measured RMR against the calculated difference between predicted and measured RMR for each study participant. The mean difference was defined by a solid horizontal line and the prediction bias was represented by the distance of the mean difference line from the zero difference point. Data points plotted closest to the zero difference point represent participants with a predicted RMR similar to the measured RMR. Two dashed lines, located two standard deviations (SD) above and below the mean difference line, correspond to the limits of agreement defined by Bland and Altman [38]. Prediction accuracy for each equation was defined as the percentage of women with a predicted RMR within ± 10% of

measured RMR, a previously accepted error limit utilized by other investigators [7,33]. The percentage of women whose predicted RMR surpassed the limit of agreement, resulting in over or under-predictions, was also calculated for the eight equations and reported according to age category.

RESULTS

Of the initial 207 women who provided informed consent, 17 did not complete the RMR measurement, 12 were excluded due to occasional smoking, 16 were excluded due to a measured BMI ≥30.0 (kg/m^2), and two had elevated serum TSH concentrations (>6.75 µIU/mL). The present analysis includes data for 160 women (young, n=57; midlife, n=57; and older, n=46).

Table **2** displays the descriptive characteristics of the participants. The mean age of the young, midlife, and older women was 25 ± 3 years, 44 ± 3 years, and 68 ± 5 years, respectively. For the older women, mean height (161 ± 6 cm) was significantly lower than that of the young (166 ± 7 cm) and midlife (166 ± 7 cm) (p = 0.001) women. The older women had a greater BMI (24.3 ± 2.5 kg/m^2) than that of the young women (22.4 ± 2.7 kg/m^2) (p = 0.002). The mean FSH concentration of the older women (69.9 ± 28.0 IU/L) was also significantly greater than that of the young (6.2 ± 2.5 IU/L) and midlife women (13.4 ± 13.0 IU/L) (p < 0.001).

Mean body fat percent differed between all age categories (young = 29 ± 9 %; midlife = 33 ± 9 %; older 38 ± 8 %) (p < 0.001), appearing lowest among the young women and highest among the older women.

The RMR values from the eight prediction equations and the measured RMR are shown in Table **3**. The mean calculated difference (predicted RMR – measured RMR) represents the bias between predicted RMR and measured RMR. For the young and midlife women, mean differences ranged from -50 and -38 (Nelson) to +211 and +213 (Cunningham 1980), respectively. The Owen equation provided RMR predictions that were closest to measured RMR for the younger (+1) and midlife (+35) women. For the older women, mean differences ranged from +27 (Nelson) to +281 (Cunningham 1980); the Nelson equation provided the least biased RMR predictions. The percentage of difference from measured RMR ranged from +0.6% (Owen) to +17.7% (Cunningham 1980) for the young women, -2.8% (Nelson) to +18.1% (Cunningham 1980) for the midlife women, and +2.8 (Nelson) to +26.7% (Cunningham 1980) for the older women. The RMR estimate predicted from the Owen equation was not significantly different from measured RMR for young women (p=0.905). In contrast, for the midlife women, all of the equations provided RMR predictions that were significantly different from measured values. For the older women, the Nelson

Table 2: Descriptive Characteristics of Young, Midlife, and Older Women[a]

Characteristics	Young n= 57 Mean ± SD[b]	Range[c]	Midlife n=57 Mean ± SD[b]	Range[c]	Older n= 46 Mean ± SD[b]	Range[c]	p-value
Age (y)	25 ± 3	20 – 30	44 ± 3	40 – 50	68 ± 5	60 – 77	---
Height (cm)	166 ± 7[#]	151 – 177	166 ± 7[#]	151 – 182	161 ± 6[§]	150 – 174	0.001*
Weight (kg)	61 ± 9	41 – 79	64 ± 7	52 – 88	63 ± 8	46 – 84	0.254
BMI (kg/m^2)[d]	22.4 ± 2.7[#]	17.3 – 29.6	23.2 ± 2.6	18.5 – 29.5	24.3 ± 2.5[§]	19.0 – 29.3	0.002*
Body Fat (%)[e]	29 ± 9[#]	8 – 50	33 ± 9[§]	16 – 52	38 ± 8[¥]	10 – 60	<0.001*
TSH (µIU/mL)[f]	2.2 ± 1.2	0.3 – 6.0	2.2 ± 1.1	0.0 – 5.8	2.6 ± 1.7	0.0 – 6.7	0.259
FSH (IU/L) [g,h]	6.2 ± 2.5[#]	0.2 – 11.2	13.4 ± 13.0[#]	1.3 – 62.1	69.9 ± 28.0[§]	14.9 – 127.7	<0.001*
Measured RMR[i]	1234 ± 118[#]	945 – 1520	1218 ± 117[#]	985 – 1500	1080 ± 111[§]	825 – 1455	<0.001*

[a]Means with different superscripts are significantly different from one another (p<0.05).
[b]SD = standard deviation.
[c]Range = minimum – maximum.
[d]BMI = body mass index.
[e]Three young participants did not complete DXA assessment; mean and standard deviation include 54 young participants.
[f]TSH = thyroid stimulating hormone.
[g]FSH = follicle stimulating hormone.
[h]One young participant did not complete the FSH assessment; mean and standard deviation reflect 56 young participants.
[i]RMR = resting metabolic rate.
*p < 0.05.

Table 3:　Mean RMR[a] Calculated with Eight Prediction Equations, Compared to Mean RMR[a] Measured by Indirect Calorimetry (IC)

|	RMR [a,b]	Difference (kcal) (Predicted RMR[a] – Measured RMR[a])	Percentage of Difference (Difference/Measured RMR[a] x 100%)	t-statistic	p-value
Measured RMR [a]					
Young	1234 ± 118	---	---	---	---
Midlife	1218 ± 117	---	---	---	---
Older	1080 ± 111	---	---	---	---
Harris-Benedict					
Young	1430 ± 92	+196	16.4%	20.7	< 0.001*
Midlife	1363 ± 77	+146	12.6%	11.2	< 0.001*
Older	1236 ± 89	+155	15.0%	12.2	< 0.001*
Robertson and Reid					
Young	1368 ± 113	+135	11.3%	13.3	< 0.001*
Midlife	1323 ± 86	+106	9.3%	8.1	< 0.001*
Older	1236 ± 91	+156	15.0%	12.9	< 0.001*
Cunningham 1980					
Young	1446 ± 111	+211	17.7%	14.1	< 0.001*
Midlife	1431 ± 116	+213	18.1%	13.4	< 0.001*
Older	1362 ± 106	+281	26.7%	20.6	< 0.001*
FAO/WHO/UNU					
Young	1403 ± 133	+169	14.0%	15.5	< 0.001*
Midlife	1378 ± 61	+160	13.9%	11.7	< 0.001*
Older	1310 ± 100	+230	21.9%	17.9	< 0.001*
Owen *et al.*					
Young	1235 ± 64	+1	0.6%	0.12	0.905
Midlife	1252 ± 51	+35	3.6%	2.5	0.014*
Older	1247 ± 57	+166	16.2%	13.1	< 0.001*
Mifflin-St. Jeor					
Young	1363 ± 117	+129	10.7%	12.6	< 0.001*
Midlife	1292 ± 99	+74	6.6%	5.6	< 0.001*
Older	1140 ± 110	+60	5.9%	4.5	< 0.001*
Cunningham 1991					
Young	1299 ± 109	+63	5.7%	4.3	< 0.001*
Midlife	1284 ± 114	+66	6.0%	4.2	< 0.001*
Older	1216 ± 104	+136	13.1%	10.0	< 0.001*
Nelson *et al.*					
Young	1185 ± 134	-50	-3.9%	-3.5	0.001*
Midlife	1180 ± 128	-38	-2.8%	-2.4	0.020*
Older	1108 ± 125	+27	2.8%	2.0	0.051

[a]RMR = resting metabolic rate; expressed in kcal.
[b]Expressed as mean ± standard deviation.
*p < 0.05.

equation was the only equation that was not significantly different from measured RMR (p=0.051).

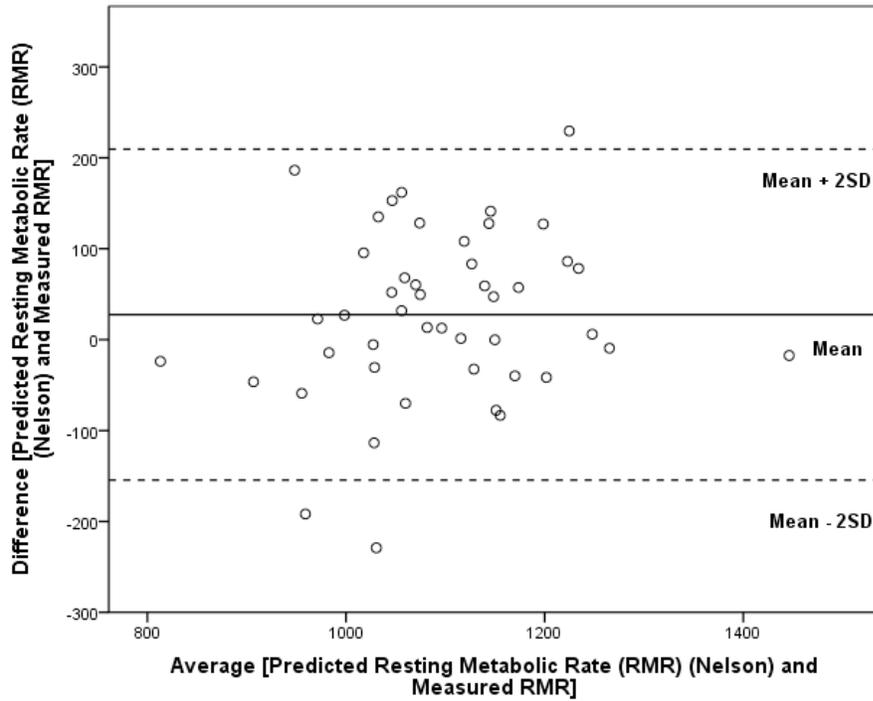Bland-Altman plots were included for the equations providing the least and greatest mean prediction bias

(Figures **1-6**). The Owen equation provided the least biased RMR predictions for the young (Figure **1**) and midlife women (Figure **2**), indicated by the close proximity of the solid mean difference line to the zero-difference point on the y-axis. Similarly, the Nelson
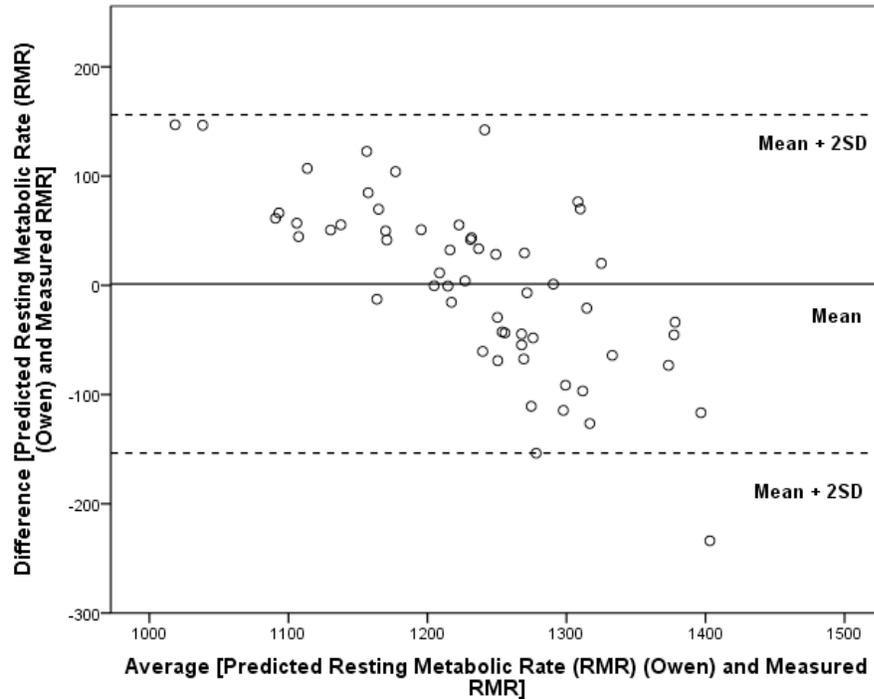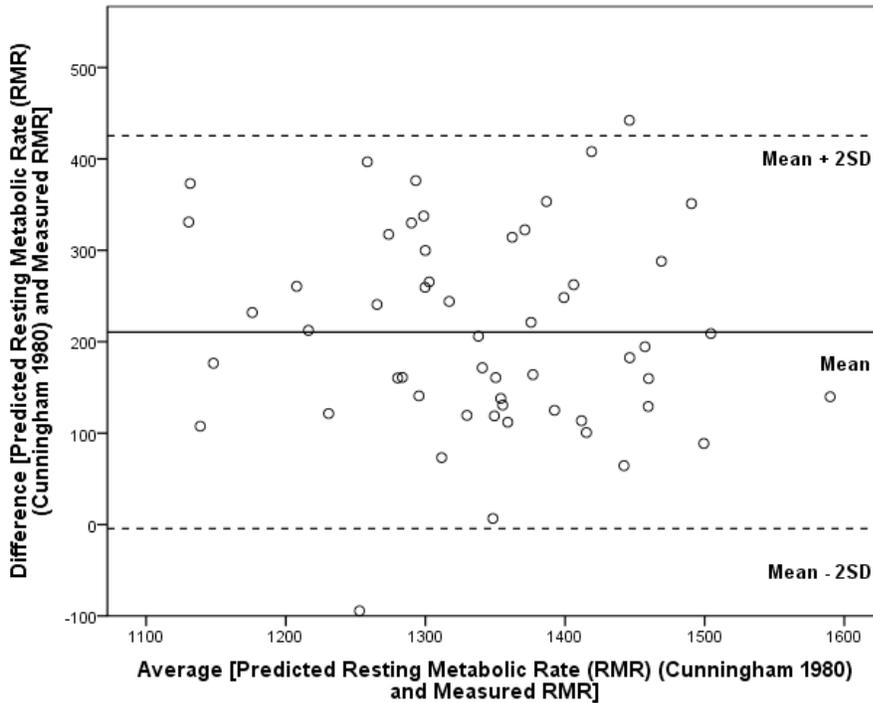

Figure 1: Bland-Altman plot: Mean bias and distribution of resting metabolic rate (RMR) prediction with the Owen equation for 57 young women.
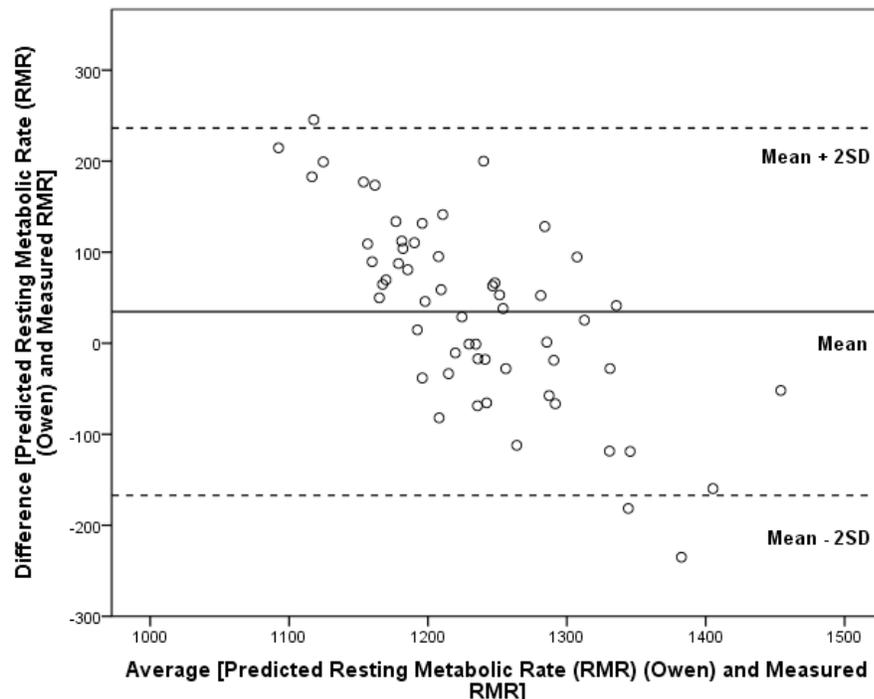
Figure 2: Bland-Altman plot: Mean bias and distribution of resting metabolic rate (RMR) prediction with the Owen equation for 57 midlife women.
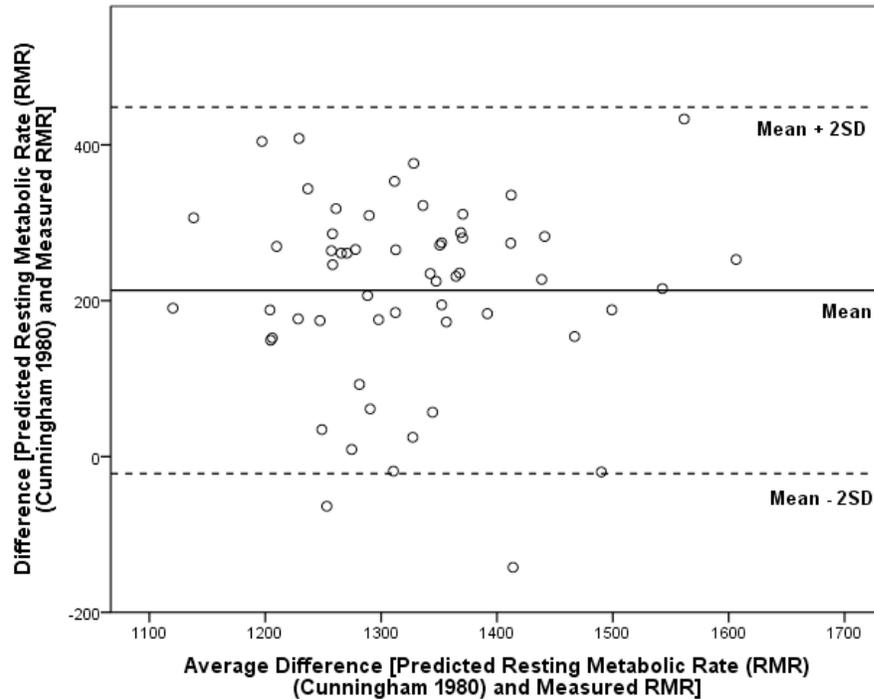
Figure 3: Bland-Altman plot: Mean bias and distribution of resting metabolic rate (RMR) prediction with the Nelson equation for 46 older women.
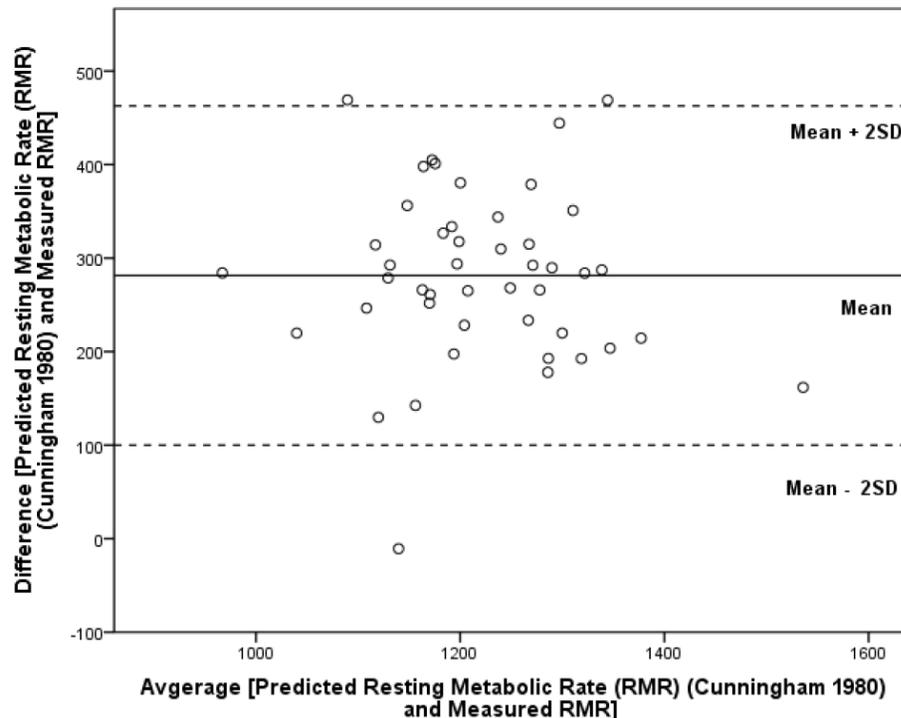

Figure 4: Bland-Altman plot: Mean bias and distribution of resting metabolic rate (RMR) prediction with the Cunningham 1980 equation for 54 young women.

equation provided the least biased RMR predictions for the older women (Figure **3**). The Cunningham 1980 equation resulted in the greatest mean prediction bias for all age categories (Figures **4-6**).

Table **4** depicts the results of prediction accuracy assessments conducted for each equation according to the RMR predictions for each age group. The Owen equation provided the best prediction accuracy for the

Figure 5: Bland-Altman plot: Mean bias and distribution of resting metabolic rate (RMR) prediction with the Cunningham 1980 equation for 57 midlife women.

Figure 6: Bland-Altman plot: Mean bias and distribution of resting metabolic rate (RMR) prediction with the Cunningham 1980 equation for 46 older women.

young women (87.7%). For the midlife women, the Owen and Nelson equations had the greatest prediction accuracy (75.4% for both equations). The Nelson equation also provided the most accurate RMR

prediction among the older women (71.7%). The Cunningham 1980 equation most frequently over-predicted RMR for the midlife (82.5%) and older women (97.8%), while the Harris-Benedict equation

Table 4: **Assessment of Prediction Accuracy for each Age Group in Comparison to Measured RMR[a] by Indirect Calorimetry, Using the Commonly Accepted Error Limit of ± 10% of Measured RMR[a]**

Prediction Equation	Young n=57	Midlife n=57	Older n=46	All Age Groups n=160
	n(%)			
Harris-Benedict				
Below Range of Agreement	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Within Range of Agreement	9 (15.8)	22 (38.6)	10 (21.7)	41 (25.6)
Above Range of Agreement	48 (84.2)	35 (61.4)	36 (78.3)	119 (74.4)
Robertson-Reid				
Below Range of Agreement	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Within Range of Agreement	27 (47.4)	32 (56.1)	10 (21.7)	69 (43.1)
Above Range of Agreement	30 (52.6)	25 (43.9)	36 (78.3)	91 (56.9)
Cunningham 1980[b]				
Below Range of Agreement	1 (1.8)	0 (0.0)	0 (0.0)	1 (0.6)
Within Range of Agreement	13 (24.1)	10 (17.5)	1 (2.2)	24 (15.3)
Above Range of Agreement	40 (74.1)	47 (82.5)	45 (97.8)	132 (84.1)
FAO/WHO/UNU				
Below Range of Agreement	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Within Range of Agreement	15 (26.3)	22 (38.6)	5 (10.9)	42 (26.2)
Above Range of Agreement	42 (73.7)	35 (61.4)	41 (89.1)	118 (73.8)
Owen				
Below Range of Agreement	2 (3.5)	3 (5.3)	0 (0.0)	5 (3.1)
Within Range of Agreement	50 (87.7)	43 (75.4)	12 (26.1)	105 (65.6)
Above Range of Agreement	5 (8.8)	11 (19.3)	34 (73.9)	50 (31.3)
Mifflin-St. Jeor				
Below Range of Agreement	0 (0.0)	1 (1.8)	4 (8.7)	5 (3.1)
Within Range of Agreement	28 (49.1)	37 (64.9)	27 (58.7)	92 (57.5)
Above Range of Agreement	29 (50.9)	19 (33.3)	15 (32.6)	63 (39.4)
Cunningham 1991[b]				
Below Range of Agreement	17 (31.5)	5 (8.8)	1 (2.2)	23 (14.6)
Within Range of Agreement	35 (64.8)	24 (42.1)	13 (28.3)	72 (45.9)
Above Range of Agreement	2 (3.7)	28 (49.1)	32 (69.5)	62 (39.5)
Nelson[b]				
Below Range of Agreement	14 (25.9)	10 (17.5)	3 (6.5)	27 (17.2)
Within Range of Agreement	37 (68.5)	43 (75.4)	33 (71.7)	113 (72.0)
Above Range of Agreement	3 (5.6)	4 (7.0)	10 (21.7)	17 (10.8)

[a]RMR = resting metabolic rate.
[b]Three young participants did not complete DXA assessment; therefore prediction equations using body composition measures could not be completed.

most frequently over-predicted RMR among the young women (84.2%). With the exception of two equations (Cunningham 1991 and Nelson for the young and midlife women, respectively), over-predictions were more common than under-predictions for all equations, among the age groups.

DISCUSSION

This study found that accuracy of RMR prediction equations differed by age. The Owen and Nelson equations predicted RMR with the least bias and greatest accuracy for the young and older women, respectively. For the midlife women, all equations significantly overestimated RMR in comparison to the measured RMR, except the Nelson equation, which under-estimated RMR.

Three of the prediction equations examined in this study incorporate body composition as part of the equation (Cunningham 1980 [19], Cunningham 1991 [20], and Nelson [21]). One of these equations, the Nelson equation, provided the highest prediction accuracy for all age groups. The Nelson equation

incorporates both FFM and FM in the RMR estimation. Although FFM is considered the most metabolically active tissue in the body, recent research suggests that the metabolic rate of adipose tissue is higher in women than men [39]. When the Nelson, Cunningham 1980 and Cunningham 1991 equations were developed, different methodology was used to assess body composition. For example, the Cunningham 1980 equation incorporated the Moore equation [40] (based on weight and age) to estimate the LBM of participants. In contrast, body composition for the Cunningham 1991 and Nelson equations was measured *via* densitometry, anthropometry, and total body potassium. In the current study, body composition was assessed using DXA and may have provided results similar to the more recently developed RMR prediction equations [20,21]. Advances in body composition methodologies [41] may continue to influence the accuracy of body composition-dependent RMR prediction equations.

For the younger women in the current study, the Owen equation provided the greatest RMR prediction accuracy (Table **4**). The accuracy of a prediction equation may be impacted when the descriptive characteristics (i.e., sex, age, weight, height, body composition, physical activity level) of the participants included in the derivation of the prediction equation differ from the population under study. Approximately 40% of the non-athletic participants included in the development of the Owen equation were between 20 and 30 years old [17]. Unfortunately, body composition of these young women was not reported. Despite the inclusion of young women in the original Harris-Benedict sample [11], the Harris-Benedict equation overestimated RMR for 84.2% of the young women in the current study. The descriptive characteristics of the young individuals included in the development of this RMR prediction equation may not have appropriately represented those of the young participants in the current study.

RMR validation studies with young participants have also found that the accuracy of RMR prediction equations varies [27,28,42]. For instance, Garrel *et al*. [42] examined the accuracy of seven equations among 28 normal-weight women (mean age = 23 ± 3 years). Similar to results of the current study, the Owen equation predicted RMR within 10% of measured RMR for approximately 80% of the women and the Harris-Benedict equation over-predicted RMR for the majority of the women [42]. In contrast, Garrel *et al*. [42] reported that predictions from the FAO/WHO/UNU equation were within 10% of measured values for all

study participants. In another RMR validation study with young women, Siervo *et al*. [28] included 157 normal weight, overweight, and obese women aged 18 – 35 years (mean age = 24 ± 4, 25 ± 5, and 24 ± 5 years, respectively). For the normal weight women, the Owen equation provided the most accurate RMR predictions. However, for the overweight women, another equation, the Bernstein equation, was most accurate [28]. Similar to the current study, Siervo *et al*. [28] found the Harris-Benedict and FAO/WHO/UNU equations over-predicted RMR for normal weight and overweight women. A more recent study [27] examined the accuracy of RMR equations among healthy young female college students aged 20 – 33 years (mean age = 22 ± 3 years; mean BMI = 21.8 ± 2.1 kg/m^2) and reported that six RMR prediction equations over-predicted RMR (p <0.001). The consistent over-predictions may be attributed to the relatively low measured RMR values of the sample (mean RMR measured by IC = 1027 ± 171 kcal). The researchers reported that the Nelson and Owen equations provided RMR predictions with the lowest mean difference from measured values, while the Harris-Benedict equation produced the greatest over-prediction [27]. In the current study, the Owen and Nelson equations did not regularly over-predict RMR and the mean measured RMR of the young women was 1234 ± 118 kcal. Thus, research to date seems to consistently support the use of the Owen and Nelson RMR prediction equations for young women.

For the midlife women in the current study, the Owen and Nelson equations provided the most accurate RMR predictions (Table **4**). However, all of the RMR estimates from the prediction equations were significantly different from measured RMR (Table **3**). Although the midlife women reported regular menstruation, the FSH concentrations of this group varied from 1.3 to 62.1 IU/L (Table **2**), suggesting heterogeneity of the perimenopausal state within this age group. This observation is notable because body composition and resting metabolic rate changes occur during the perimenopause stage of life [43,44]. Unfortunately, none of the prediction equations evaluated in this study reported FSH concentrations for the midlife women included in the derivation of the equation.

To our knowledge, few studies have evaluated the accuracy of RMR predictions for healthy midlife women. A small validation study conducted by Santos *et al*. [34] included 46 climacteric women in Brazil aged 42 – 73 years (mean age = 55 years) and observed

poor correlations between prediction equations, such as the Harris Benedict, to measured RMR by IC. In this study, the FAO/WHO/UNU equation predicted RMR with the highest concordance coefficient (concordance coefficient = 0.63). Because the participants represented a wide age range, the results may have differed if the analyses were limited to midlife women aged 40 – 50 years, such as in the current study. Identifying the best RMR prediction equation remains a challenge for midlife women due to the physiological and hormonal changes that accompany the perimenopausal state. Thus, more research is needed to determine the most appropriate RMR prediction equation for this age group of women.

Among the older women in the current study, six of the eight equations over-predicted RMR. This finding may be partially explained by the limited representation of older women in the study samples used in the derivation of the prediction equations. For example, the Owen equation included just one female participant over the age of 59 [17] and the original Harris-Benedict equation only included six older female participants [11]. Similarly, only nine older participants were included when developing the Cunningham 1980 prediction equation, representing approximately 4% of the total sample [19]. Furthermore, the FAO/WHO/UNU prediction equations were developed using part of a database complied by Schofield *et al*. [14,15]. However, only one small study aside from the Harris-Benedict study included older women, indicating that this age group was under-represented in the complete database. The Nelson equation may have resulted in the most accurate RMR predictions due to the incorporation of both FFM and FM in the calculation [21]. Since relative FFM decreases and FM increases with age [45] , accounting for the metabolic activity of both tissue types may have resulted in improved prediction accuracy for this age group.

Results of prior validation studies among older adults have illustrated the limited applicability of most RMR prediction equations for this age group [29,31–33]. Arciero *et al*. [29] measured RMR, body composition, physical activity, and dietary intakes in a cohort of 75 women aged 50 to 81 (mean age = 61 ± 8 years). Researchers [29] observed that the FAO/WHO/UNU for women >60 years (p=0.12) and Harris-Benedict (p=0.07) equations predicted RMR similar to measured RMR; however, the Mifflin-St. Jeor (p<0.01) and Owen (p<0.01) equations significantly under-predicted RMR for this group of women. In contrast, Taaffe *et al*. [32] reported that the Owen and

Harris-Benedict equations predicted RMR closest to measured RMR among 116 healthy older white women aged 60 – 82 years (mean age = 67 ± 4 years). Similar to the current study, Taaffe *et al*. [32] reported that the Cunningham 1980 equation resulted in the largest prediction error of the eight equations evaluated in the study. The largest validation study conducted with older adults was completed by Luhrmann *et al*. [31] and included 130 men and 225 women aged 60-85 years (mean age of women = 68 ± 6 years). As observed in the current study, Luhrmann *et al*. [31] reported that the FAO/WHO/UNU significantly over-predicted RMR in normal and overweight older women. In contrast, the Harris-Benedict equation significantly under-predicted RMR for these older women [31]. The under-predictions reported by Lurhmann *et al*. [31] may have occurred among participants who smoked. More recently, Melzer *et al*. [33] evaluated the prediction accuracy of five RMR equations in 119 healthy older adults (including 55 women) aged 70 – 98 years (mean age of women = 78.6 ± 5.3 years). For the women in this study [33], only the Owen and Luhrmann equations, a more recently introduced prediction equation, did not differ significantly from measured RMR. However, on an individual basis, the Harris-Benedict, Luhrmann, and Owen equations predicted RMR within 10% of measured RMR for 74.5% of the female participants [33]. The rate of progressive age-related changes in RMR due to factors, such as FFM loss, decline in organ weight, and tissue and organ cell loss [33,45] may vary on an individual basis, making older adults a relatively heterogeneous group. Additionally, the extent of these physiologic changes becomes more pronounced among individuals in the oldest-old age category in comparison to younger, older adults. Results of Melzer *et al*. [33] may have differed from the current study (mean age = 68 ± 5, range = 60 – 77 years) due to the inclusion of older participants. As indicated by the variable results of previous validation studies conducted with older women, predicting RMR of older women with equations developed from younger age groups may impact the results. The most appropriate RMR prediction equation for older women remains unknown. Since FFM commonly declines with age, RMR prediction equations that include anthropometric measurements seem best to use with older women.

To our knowledge, this study is the first to provide a comprehensive evaluation of eight RMR prediction equations with healthy, non-obese, free-living women representing three distinct age categories (young = 20

– 30 years, midlife = 40 – 50 years, and older = ≥ 60 years). Strengths of the study include the methodology with the body composition measurements completed by DXA and RMR measurements completed by indirect calorimetry. The protocol recommended by the Academy of Nutrition and Dietetics Evidence Analysis Working Group was followed for measuring RMR. Participants were also excluded from the study if they reported smoking or had abnormal thyroid hormone concentrations, confirmed by a fasting blood draw. This study is limited by the heterogeneous perimenopausal status of the midlife women. Only eight RMR prediction equations were evaluated. Since this study was limited to normal and over-weight women, results are not generalizable to men or women with a BMI >30 kg/m^2.

CONCLUSION

The current study evaluated the applicability of eight RMR prediction equations among a sample of young, midlife, and older non-obese women. The Owen and Nelson equations predicted RMR similar to measured RMR by IC for young and older women, respectively and may provide nutrition practitioners with the most accurate RMR prediction for these populations. In contrast, for midlife women, none of the equations predicted RMR similar to the measured value. For all age groups, the use of an appropriate RMR prediction equation is invaluable to Registered Dietitian Nutritionists and nutrition clinicians to determine an appropriate nutrition care plan and monitor patient care. Future studies should include larger samples of women, categorized by menstrual status rather than age. Additional research is necessary to evaluate the appropriateness of body composition-specific RMR prediction equations and optimize RMR prediction of women across the lifespan.

NOTE

At the time of the study, C Reese, L Beaird, and M Mason were students at Arizona State University and S Miller was a student at New York University.

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