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Validation of predictive equations for resting energy expenditure in obese adolescents[1–3]

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ABSTRACT

Background: When the resting energy expenditure (REE) of overweight and obese adolescents cannot be measured by indirect calorimetry, it has to be predicted with an equation.

Objective: The aim of this study was to examine the validity of published equations for REE compared with indirect calorimetry in overweight and obese adolescents.

Design: Predictive equations based on weight, height, sex, age, fat-free mass (FFM), and fat mass were compared with measured REE. REE was measured by indirect calorimetry, and body composition was measured by dual-energy X-ray absorptiometry. The accuracy of the REE equations was evaluated on the basis of the percentage of adolescents predicted within 10% of REE measured, the mean percentage difference between predicted and measured values (bias), and the root mean squared prediction error (RMSE).

Results: Forty-three predictive equations (of which 12 were based on FFM) were included. Validation was based on 70 girls and 51 boys with a mean age of 14.5 y and a mean (±SD) body mass index SD score of 2.93 ± 0.45. The percentage of adolescents with accurate predictions ranged from 74% to 12% depending on the equation used. The most accurate and precise equation for these adolescents was the Molnar equation (accurate predictions: 74%; bias: –1.2%; RMSE: 174 kcal/d). The often-used Schofield-weight equation for age 10–18 y was not accurate (accurate predictions: 50%; bias: +10.7%; RMSE: 276 kcal/d).

Conclusions: Indirect calorimetry remains the method of choice for REE in overweight and obese adolescents. However, the sex-specific Molnar REE prediction equation appears to be the most accurate for overweight and obese adolescents aged 12–18 y. This trial was registered at www.trialregister.nl with the Netherlands Trial Register as ISRCTN27626398. *Am J Clin Nutr* 2010;91:1244–54.

INTRODUCTION

The prevalence of overweight and obesity in adolescents is high and increasing (1–4). The ability to predict resting energy expenditure (REE) accurately in overweight and obese adolescents is important for establishing reachable goals for dietary intake and weight-loss programs. Energy requirement can be measured by indirect calorimetry, but it is hardly feasible in most dietetic settings. To predict REE without measuring energy expenditure, several REE predictive equations were developed. Only a few REE predictive equations have been specifically designed for overweight or obese adolescents (5–9). Several studies have validated REE predictive equations in healthy children; however, only a few studies have validated REE predictive equations in obese adolescents (5, 10–13). Rodriguez et al (10) found that the Schofield weight and height equation for 10 to 18 y was the most accurate equation in a mixed population of obese and nonobese children and adolescents. Dietz et al (11) concluded in a small group of obese adolescents ($n = 28$) that the FAO/WHO/UNU weight and height (10–18 y) equation was the most accurate. Derumeaux-Burel et al (5) had similar conclusions, although it is unclear whether this equation included both weight and height. The only Dutch study among obese adolescents, by Van Mil et al (12), recommends the FAO/WHO/UNU weight equation for ages 18–30 y. Therefore, there is no consensus on which REE predictive equation to use in obese adolescents. Although the level of obesity is increasing especially in specific ethnic groups, no information about accurate REE predictive equations for obese persons was found (4). Currently, the FAO/WHO/UNU weight equation for age 10–18 y is the most widely used predictive equation in the Netherlands. As part of evidence-based practice, we sought the most accurate and precise REE predictive equation for overweight and obese adolescents using a comparison with indirect calorimetry.

SUBJECTS AND METHODS

Subjects

The subjects were recruited from the Pediatric Obesity Outpatient Clinic of the VU University Medical Center Amsterdam. The inclusion criteria were *1*) age between 12 and 18 y and *2*) overweight or obese (hereafter called "obese") according to the

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TABLE 1
Subject characteristics[1]

	All subjects (n = 121)	Female Western (n = 27)	Female non-Western (n = 43)	Male Western (n = 28)	Male non-Western (n = 23)
Age (y)	14.4 ± 1.7	15.1 ± 1.7	14.3 ± 1.6	14.3 ± 1.5	13.8 ± 1.7
Height (cm)	166.1 ± 9.2	167.6 ± 7.2	162.8 ± 5.4	170.0 ± 11.3	165.7 ± 11.9
Body weight (kg)	92.1 ± 16.8	93.2 ± 14.6	92.5 ± 14.0	94.5 ± 20.5	87.1 ± 19.3
BMI (kg/m^2)	33.2 ± 4.4	33.2 ± 4.9	34.8 ± 4.1	32.3 ± 4.5	31.4 ± 3.8
BMI SDS	2.93 ± 0.45	2.72 ± 0.48	2.98 ± 0.32	2.96 ± 0.47	3.04 ± 0.54
Fat mass (%)	40.9 ± 4.1	42.0 ± 3.7	42.4 ± 3.4	39.7 ± 3.6	38.3 ± 4.5
Fat mass (kg)	38.5 ± 8.6	40.1 ± 8.8	40.1 ± 8.3	38.3 ± 9.0	33.8 ± 7.2
FFM (kg)	55.2 ± 10.2	54.6 ± 7.2	53.9 ± 7.1	58.0 ± 12.9	54.9 ± 14.0
RQ	0.84 ± 0.05	0.84 ± 0.05	0.85 ± 0.05	0.84 ± 0.05	0.84 ± 0.05
REE (kcal/d)	1887 ± 291	1865 ± 248	1769 ± 263	2040 ± 302	1956 ± 288

[1] All values are means ± SDs. SDS, SD score; RQ, respiratory quotient; FFM, fat-free mass; REE, resting energy expenditure.

definition of Cole et al (14). Exclusion criteria for the study were as follows: not speaking the Dutch language, overweight/obesity as a result of a known syndrome or organic cause (hypothyroidism), mental retardation, physical limitations that would not allow participation in a physical activity program, and diagnosis of type 2 diabetes mellitus.

Data on ethnicity were collected during the first visit to the pediatrician at the Pediatric Outpatient Clinic. We asked for the country of birth of both parents. According to the Netherlands Bureau of Statistics (15), an adolescent is considered to be of Dutch ethnicity when both parents are born in the Netherlands (Western category). Adolescents with at least one parent born outside the Netherlands, but inside Europe, were classified as Western immigrants (Western category). An adolescent with at least one parent born in a foreign country outside Europe is considered to be of foreign nonwestern ethnicity (non-Western category). The subjects were measured between November 2006 and August 2008. The study was approved by the Medical Ethics Committee of the VU University Medical Center Amsterdam.

Indirect calorimetry and body composition

The indirect calorimetry measurements were performed with a ventilated-hood system (Vmax Encore n29; Viasys Health Care, Houten, Netherlands). The Vmax system was calibrated daily for flow. Also, the system is calibrated daily with 2 different standard gases (1 with 26% O_2 and 0% CO_2 and 1 with 16% O_2 and 4% CO_2) immediately before use and every 5 min during the measurement. Oxygen analyzer sensitivity is checked yearly by the supplier. Measurements were standardized by internal guidelines. The subjects were in a supine position and awake and had fasted overnight. Data from the first 5 min of the measurements were removed. Oxygen consumption and carbon dioxide production were measured, and energy expenditure was calculated by using the Weir formula (16). The acceptable CV was 10%. The measurements took place for 30 min.

Body composition was assessed with dual-energy X-ray absorptiometry (DXA; Hologic QDR4500-Delphi, software 12.3.3. S/N 45665; Tromp Medical, Castricum, Netherlands). The subjects were scanned for 10 min while wearing underwear and lying in a supine position with arms not touching the trunk and legs not touching each other. The DXA method measures bone mineral content, lean tissue mass, and fat mass (FM). In the present study fat-free mass (FFM) was defined as bone mineral content + lean tissue mass.

Body weight was measured (with subjects wearing underwear) and recorded within 0.1 kg with a calibrated electronic flat scale (SECA 861; Schinkel, Nieuwegein, Netherlands). Height was measured and recorded with an accuracy of 1 mm with an electronic stadiometer (KERN 250D; De Grood Metaaltechniek, Nijmegen, Netherlands). Weight and height were used to calculate BMI (weight in kg divided by the square of height in m). BMI SD score (SDS) was calculated with the Growth Analyzer (www.growthanalyser.org; version 3.5; reference Dutch population 1997).

REE predictive equations

PubMed was used to conduct a systematic search for publications on Mesh-derived keys "energy metabolism," "energy expenditure," "basal metabolism," and additional terms ("predict*," "estimat*," "equation*," and "formula*") in every possible combination. Applied limitations were "English language," "humans," not "critical illness," and "intensive care." More references were obtained by screening the publications cited. Equations were included when based on body weight, height, age (children and adults), sex, FFM, and/or FM. Exclusion criteria were as follows: age range (age <12 y or only elderly), only one sex, patients, normal weight based on Cole et al (14) (not applicable to large databases of Harris and Benedict, Schofield, and Oxford), insufficient information, only a nomogram, only a specific ethnic group (other than white), small sample size ($n < 50$), impractical or suspect body composition as a variable, glucose concentrations or diabetes as a variable, total energy expenditure, athletes. and duplicate publications.

For each subject, the REE was predicted by the selected equations in kcal/d and compared with measured REE. The actual body weight at the time of the indirect calorimetry measurement was used for this calculation.

Statistics

Subject characteristics were analyzed by independent-samples t test. The percentage of subjects that had an REE predicted within ±10% of REE measured was considered a measure of accuracy at an individual level (17). A prediction between 90% and 110% of REE measured was considered an accurate prediction, a prediction <90% of REE measured was classified as an

TABLE 2

Predictive equations for resting energy expenditure (REE) based on children and adolescents with normal weight, both normal weight and obese, and obese only[1]

Reference	No. of subjects, sex, age range or mean, BMI range or mean, body-composition method when applicable, remarks on large databases, REE units	Sex	Age	Height	Weight	BMI	REE predictive equations	Statistics and cross-validation
			y	*m*	*kg*	*kg/m²*		
Equations based on children and adolescents with normal weight								
Henry et al (21)	*n* = 195 (78 M, 117 F), age 10–15 y, skinfold-thickness measurement, kJ/d	M	12.2 ± 1.1[2]	1.51 ± 9.8	43.6 ± 10.3	18.8 ± 3.3	M: 66.9 Wt + 2876	R^2 = 0.61, rsd = 575
		F	12.2 ± 1.1	1.51 ± 8.1	47.0 ± 11.0	20.1 ± 3.8	F: 47.9 Wt + 3230	R^2 = 0.52, rsd = 519
Henry (20)	*n* = 10,552 (5794 M, 4702 F), Oxford database (166 separate investigations), excluded all the Italian subjects, included 4018) persons from the tropics. Age group 10–18 y, (863 M, 1063 F), kcal/d	M	12.7 ± 2.1	1.49 ± 0.2	40.0 ± 12.5	17.7 ± 2.7	M: 18.4 Wt + 581	*r* = 0.86, SE = 0.57
		F	13.0 ± 2.4	1.50 ± 0.1	43.4 ± 12.9	15.8 ± 3.6	M:15.6 Wt + 266 HTm + 299	*r* = 0.86, SE = 0.56
							F: 11.1 Wt + 761	*r* = 0.75, SE = 0.53
							F: 9.4 Wt + 249 Htm + 462	*r* = 0.76, SE = 0.52
Schofield (23)	*n* = 1309 (734 M, 575 F), age 10–18 y, Most European and North American subjects, MJ/d	M	13.7 ± 2.4	1.49 ± 0.2	41.8 ± 14.6	18.1 ± 2.7	M: 0.074 Wt + 2.754	*R* = 0.80, SE = 0.44
		F	12.8 ± 2.3	1.46 ± 0.1	38.5 ± 11.2	17.6 ± 2.6	M: 0.068 Wt + 0.574 HTm + 2.157	*R* = 0.93, SE = 0.44
							F: 0.056 Wt + 2.898	*R* = 0.80, SE = 0.47
							F: 0.035 Wt + 1.948 HTm + 0.837	*R* = 0.82, SE = 0.45
FAO/WHO/UNU (24)							M: 17.5 Wt + 651	SE = 0.90, rsd = 100
							M: 16.6 Wt + 77 HTm + 572	SE = 0.89, rsd 100
							F: 12.2 Wt + 746	SE = 0.75, rsd = 117
							F: 7.4 Wt + 482 HTm + 217	SE = 0.77, rsd = 113
Equations based on both normal weight and obese children and adolescents								
Molnar et al (7)	*n* = 371, C1: to develop 193 M (116 ML, 77 MO), 178 F (119 FL, 59 FO). C2: validate; 80 M (31 ML, 49 MO), 61 F (31 FL, 30 FO). Age 10–16 y, skinfold-thickness measurement, kJ/d	C1: ML	13.1 ± 1.7	1.58 ± 13.2	44.5 ± 11.6		M: 50.9 Wt + 25.3 HTcm − 50.3 AGE + 26.9	R^2 = 0.88
		MO	12.8 ± 1.8	1.60 ± 12.6	74.3 ± 19.2			
		FL	13.1 ± 1.7	1.57 ± 9.0	46.0 ± 9.3			
		FO	13.2 ± 1.9	1.58 ± 10.1	75.8 ± 18.7		F: 51.2 Wt + 24.5 HTcm − 207.5 AGE + 1629.8	R^2 = 0.82
							T: 50.2 Wt + 29.6 HTcm − 144.5 AGE – 550 SEX 1 + 594.3	R^2 = 0.86

(Continued)

TABLE 2 (*Continued*)

Reference	No. of subjects, sex, age range or mean, BMI range or mean, body-composition method when applicable, remarks on large databases, REE units	Sex	Age	Height	Weight	BMI	REE predictive equations	Statistics and cross-validation
			y	*m*	*kg*	*kg/m²*		
		C2: ML MO FL FO	12.9 ± 1.7 12.6 ± 1.4 13.0 ± 1.8 13.4 ± 1.7	1.58 ± 13.4 1.60 ± 12.5 1.59 ± 9.1 1.61 ± 10.1	44.7 ± 12.4 48.9 ± 10.0 48.9 ± 10.0 86.0 ± 22.2			
Muller et al (22)	*n* = 188 (99 M, 89 F), age 5–11 y *n* = 55 (28 M, 27 F), age 12–17 y; BIA or skinfold-thickness measurement, MJ/d	M M F F	5–11 12–17 5–11 12–17	1.38 ± 12.5 1.71 ± 10.8 1.38 ± 12.2 1.66 ± 7.8	43.2 ± 15.4 81.3 ± 28.4 43.1 ± 16.0 61.9 ± 18.6	22.2 ± 5.1 27.3 ± 8.0 22.1 ± 5.5 22.2 ± 5.9	T (5–17 y): 0.02606 Wt + 0.04129 HTcm + 0.311 SEX − 0.08369 Age − 0.808	R^2 = 0.72, SEE = 0.67
							T (5–17 y): 0.07885 FFM + 0.02132 FM + 0.327 SEX + 2.694	R^2 = 0.72, SEE = 0.65
Equations based on obese children and adolescents only								
Derumeaux-Burel et al (5)	*n* = 752, C1: to establish predictive equations; *n* = 471 (280 M, 191 F). C2: to validate; *n* = 211 (62 M, 149 F). C3: to examine in postobese state; *n* = 70 (24 M, 46 F), age 3–18 y; BIA, MJ/d	C1: M F C2: M F C3: M F	11.4 ± 2.7 11.5 ± 3.2 13.0 ± 2.8 12.7 ± 3.2 13.4 ± 2.3 14.2 ± 2.4	1.50 ± 0.2 1.48 ± 0.2 1.58 ± 0.2 1.53 ± 0.2 1.61 ± 0.1 1.58 ± 0.1	64.5 ± 22.2 63.0 ± 21.7 72.7 ± 22.1 70.4 ± 23.5 72.0 ± 19.0 70.5 ± 16.6	27.84 ± 4.7 27.74 ± 5.1 28.22 ± 4.8 29.04 ± 6.0 27.09 ± 4.1 27.73 ± 4.3	M: 0.1096 FFM + 2.8862	R^2 = 0.79, SE = 0.64
							F: 0.1371 FFM − 0.1644 AGE + 3.3647	R^2 = 0.76, SE = 0.56
Lazzer et al (9)	*n* = 574 (242 M, 332 F); age 7–18 y; BIA, kJ/d	M F	14.1 ± 2.2 14.8 ± 2.1	1.64 ± 0.1 1.60 ± 0.1	98.2 ± 25.8 89.3 ± 17.7	36.05 ± 6.6 34.71 ± 5.7	T: 54.96 Wt + 1816.23 HTm + 892.68 SEX – 115.93 AGE + 1484.50	R^2 = 0.66, SE = 1029
							T: 68.39 FFM + 55.19 FM + 909.12 SEX – 107.48 AGE + 3631.23	R^2 = 0.66, SE = 1034

(*Continued*)

TABLE 2 (*Continued*)

Reference	No. of subjects, sex, age range or mean, BMI range or mean, body-composition method when applicable, remarks on large databases, REE units	Sex	Age	Height	Weight	BMI	REE predictive equations	Statistics and cross-validation
			y	*m*	*kg*	*kg/m²*		
Schmelzle et al (8)	*n* = 82 (49 M, 33 F), age 4–15 y, DXA, kcal/d	M	12.9 ± 1.3	1.63 ± 11.0	80.5 ± 18.7	29.90 ± 4.4	M: 6.6 Wt + 13.1 HTcm − 794	*R* = 0.76, SEE = 203
		F	13.2 ± 1.6	1.61 ± 9.0	88.2 ± 17.1	33.8 ± 5.3	F: 11.9 Wt + 0.84 HTcm + 579	*R* = 0.81, SEE = 156
Tverskaya et al (6)	*n* = 110 (50 M, 60 F), age 10–18 y (81% white, 11% Hispanic, 8% African American), BIA, kcal/d	T	11.7 ± 2.8	1.52 ± 14.0	14.0 ± 73.0		T: 775 + 28.4 FFM + 3.3 FM − 37 AGE + 82 SEX	R^2 = 0.84, SE = 0.61

[1] T, total (male and female); SEX (M = 1, F = 0); SEX 1 (M = 0, F = 1); ML, male lean; FL, female lean; MO, male obese; FO, female obese; DXA, dual-energy X-ray absorptiometry; BIA, bioelectrical impedance analysis; Wt, weight in kg; HTcm, height in cm; HTm, height in m; AGE, age in y; FFM, fat-free mass; FM, fat mass; C1, cohort 1; C2, cohort 2; C3, cohort 3; rsd, residual standard deviation.

[2] Mean ± SD (all such values).

underestimation, and a prediction >110% of REE measured was classified as an overestimation. The mean percentage difference between REE predicted and REE measured (bias) was considered a measure of accuracy on a group level. The root mean squared prediction error (RMSE) was used to indicate how well the model predicted in our data set (18, 19). Data were analyzed by using SPSS 15.0 (SPSS Inc, Chicago, IL) and RMSE with Excel (Microsoft Office Excel 2003; Amsterdam, Netherlands).

RESULTS

A total of 125 adolescents participated in this study. Four of these subjects were excluded because of incomplete data, which was due to a body weight higher than allowed for DXA (>125 kg). Subject characteristics of the 121 (70 females, 51 males) adolescents, by sex and ethnicity, are shown in **Table 1**. According to the criteria of Cole et al (14), 4 of the 70 girls and 6 of the 51 boys were overweight, and the other children were obese. Girls had a significantly higher BMI ($P = 0.043$; 95% CI: 0.053, 3.42), body fat percentage ($P < 0.001$; 95% CI: 1.78, 4.52) and FM ($P = 0.015$; 95% CI: 0.77, 6.93) than did boys. The REE (in kcal/d was 10% lower and in kcal/kg body wt was 12.5% lower in girls than in boys (both $P < 0.001$).

A total of 48 scientific papers or reports were retrieved for REE predictive equations. Twenty-six articles were excluded: age range, 1; one sex study, 3; insufficient information, 6; specific ethnic group, 5; small sample size, 8; impractical variable, 2; and another method (measuring REE in sitting position), 1. Of the 22 included articles, we selected the best equations based on explained variance in regression analysis, and more than one equation was included when based on weight and height (compared with weight only). Also, extra equations were included when based on FFM and FM or if the equations were based on specific age groups (eg, 10–18 and 18–30 y). After this procedure, we included a total of 43 equations, 31 weight-based equations, and 12 FFM-based equations.

The quality of the indirect calorimetry procedure in these studies, according to the procedure of Frankenfield et al (17), resulted in no further exclusion. Ten articles (including 16 equations) were based on children aged <18 y; only 11 equations were based on adolescents in aged 10–18 y (5–9, 20–24) (**Table 2**). Five of these equations were based on obese adolescents or obese and nonobese adolescents (5–9). None of the included equations were based on Dutch adolescents.

In **Tables 3** and **4**, the REE data are provided as mean measured REE (in kcal/d), the percentage of accurate underpredictions and overpredictions, the percentage bias, the maximum values found for negative errors (underprediction) and positive errors (overprediction), and the RMSE (in kcal/d). The percentage accurate predictions varied between equations from 74% to 12%. The bias for equations varied from −19.8% to 10.8%, and the RMSE varied from 174 to 434 kcal/d. The RMSE is based on an average value of squared differences (predicted minus measured value) for individuals; therefore, individual values can be much worse as shown by maximum negative and maximum positive error. The percentage of accurate predictions, percentage bias, and RMSE for the total group of adolescents by sex and ethnicity for equations based on children and adolescents are shown in **Figure 1**.

TABLE 3
Evaluation of resting energy expenditure (REE) predictive equations in 121 Dutch obese adolescents based on bias, root mean squared prediction error (RMSE), and percentage accurate prediction sorted by equations based on weight/height and fat-free mass (FFM) of children and adolescents sorted by percentage accurate prediction[1]

REE predictive equation	REE[2]	SD	Accurate predictions[3]	Underpredictions[4]	Overpredictions[5]	Bias[6]	Maximum negative error[7]	Maximum positive error[8]	RMSE
	kcal/d		*%*	*%*	*%*	*%*	*%*	*%*	*kcal/d*
REE measured	1887	291							
Equations based on weight and/or height of children and adolescents									
Molnar[9] (7)	1849	239	74	16	11	−1.2	−21.7	28.9	174
Molnar (sex-specific)[9] (7)	1849	250	73	18	9	−1.3	−22.3	27.3	174
Lazzer06[10] (9, 13)	1977	254	72	2	26	5.6	−17.2	35.8	192
Schmelze[10] (8)	1901	239	71	12	17	1.7	−20.5	36.0	186
Henry99[11](21)	1965	286	63	5	32	4.9	−20.3	38.8	206
MullerChild[9] (22)	1764	173	58	37	5	−5.4	−27.6	26.6	224
Henry1018wh[11] (20)	1923	323	56	13	31	2.4	−25.0	35.8	219
FAO1018w[11] (24)	2033	319	53	3	44	8.4	−18.1	41.1	252
Henry1018w[11] (20)	1988	353	53	9	38	5.8	−22.2	43.1	254
Schofield1018wh[11] (23)	1947	342	51	15	34	3.7	−25.6	38.7	240
FAO1018wh[11] (24)	1915	351	51	19	30	1.9	−27.9	38.2	246
Schofield1018w[11] (23)	2076	318	50	2	48	10.7	−15.2	43.8	276
Equations based on FM/FFM of children and adolescents									
MullerChildffm[9] (22)	1913	228	73	9	18	2.4	−18.7	36.8	185
Tverskayaffm[10] (6)	1972	291	69	4	26	5.1	−15.0	40.1	206
Lazzer06ffm[10] (9, 13)	2000	258	64	2	33	6.8	−15.4	37.8	207
Derumeauxffm[10] (5)	2076	290	53	1	46	10.8	−10.7	47.9	268

[1] FM, fat mass.
[2] As measured.
[3] The percentage of subjects predicted by this predictive equation within 10% of the measured value.
[4] The percentage of subjects predicted by this predictive equation within <10% of the measured value.
[5] The percentage of subjects predicted by this predictive equation within >10% of the measured value.
[6] Mean percentage error between the predictive equation and the measured value.
[7] The largest underprediction found with this predictive equation as a percentage of the measured value.
[8] The largest overprediction found with this predictive equation as a percentage of the measured value.
[9] Equation based on both normal-weight and obese persons.
[10] Equation based on obese persons.
[11] Equation based on normal-weight persons.

For the total group of adolescents, the Molnar equation had the smallest RMSE (174 kcal/d), 74% accurate predictions (with 16% underprediction and 9% overprediction), and a small bias (−1.2%). The Schofield weight and height equations for 18–30 y provided 74% accurate predictions, 8% underpredictions, 17% overpredictions, a bias of 2.8%, and an RMSE of 184 kcal/d. The Henry equation based on weight for 18–30 y provided 73% accurate predictions (15% underpredictions and 12% overpredictions), a bias of −3.9%, and an RMSE of 200 kcal/d. The Schofield weight equation for 10–18 y provided only 50% accurate predictions, with 2% underpredictions and 48% overpredictions, a bias of 10.7%, and an RMSE of 276 kcal/d.

When split by sex and ethnicity, the sex-specific Molnar equation had the narrowest range in accurate predictions and RSME for the 4 sex and ethnic groups. For Western girls and Western boys, the Schofield weight and height equation for age 18–30 y had the highest percentage accurate predictions (89% and 79%, respectively), a bias of −0.1% for Western girls and of 3.85% for Western boys, and an RMSE of 147 kcal/d for Western girls and of 188 kcal/d for Western boys. For the Non-Western group the highest percentage of accurate predictions was found for the Muller equation, based on adults with a BMI > 30 (65% and 87%), biases of 0.24% and 0.33%, and RMSEs of 208 and 131 kcal/d for girls and boys, respectively. The inclusion of FFM in the REE prediction equation provided no benefit over inclusion of body weight (**Figure 2**). The inclusion of weight and height compared with weight-only equations improved 3 of the 6 REE prediction equations, with a slight difference in percentage accurate predictions. The Bland-Altman plots for the 3 best and the worst (Schofield1018w) performing REE predictive equations, based on children and adolescents, are shown in **Figure 3**.

DISCUSSION

From this study it appears that REE for obese adolescents can best be predicted with the Molnar equation, which was

TABLE 4
Evaluation of resting energy expenditure (REE) predictive equations in 121 Dutch obese adolescents based on bias, root mean squared prediction error (RMSE), and percentage accurate prediction sorted by equations based on weight/height and fat-free mass (FFM) of adults sorted by percentage accurate prediction[1]

REE predictive equation	REE[2]	SD	Accurate predictions[3]	Underpredictions[4]	Overpredictions[5]	Bias[6]	Maximum negative error[7]	Maximum positive error[8]	RMSE
	kcal/d		*%*	*%*	*%*	*%*	*%*	*%*	*kcal/d*
REE measured	1887	291							
Equations based on weight and/or height of adults									
Schofield1830wh[9] (23)	1927	274	74	8	17	2.8	−19.2	32.9	184
MullerBMI30[10] (22)	1856	232	73	16	12	−0.8	−23.2	30.0	180
Marra[10] (25)	1923	216	73	7	20	3.0	−20.1	39.2	181
Henry1830w[9] (20)	1870	275	73	15	12	−0.2	−21.8	30.2	184
FAO1830wh[9] (24)	1927	280	73	8	19	2.8	−19.8	32.2	186
Korthwh[11] (26)	1935	263	72	7	21	3.4	−21.6	32.0	187
MullerTot[9] (22)	1853	217	71	17	12	−0.8	−23.4	32.0	181
HayterHenrywNEA[9] (27)	1822	226	71	20	9	−2.6	−24.5	30.1	189
MullerBMI2530[10] (22)	1854	210	70	17	13	−0.7	−23.6	32.9	182
HB1984[9] (28)	1872	268	70	16	14	−0.1	−24.7	32.4	186
HB1919[9] (29)	1906	270	70	12	18	1.7	−23.1	36.0	187
Schofield1830w[9] (23)	1947	271	69	7	24	3.9	−17.3	35.3	192
FAO1830w[9] (24)	1950	275	69	7	25	4.1	−17.4	35.2	193
Lazzer07[10] (30, 31)	1830	292	68	21	11	−2.5	−25.6	26.8	199
Livingston[11] (32)	1817	202	67	23	10	−2.6	−27.1	31.7	199
Mifflin[11] (33)	1796	226	65	27	7	−4.0	−25.4	25.4	197
Henry1830wh[9] (20)	1804	276	65	27	7	−3.9	−26.3	23.7	200
Huang[10] (34)	1744	239	55	40	4	−6.9	−29.1	19.6	229
Bernstein[10] (35)	1503	241	12	88	1	−19.8	−40.1	10.5	429
Equations based on FM/FFM of adults									
MullerBMI30ffm[10] (22)	1826	220	73	17	10	−2.3	−23.7	28.8	186
MullerTotffm[11] (22)	1818	213	71	20	9	−2.7	−24.6	29.2	190
Lazzer07ffm[10] (30, 31)	1808	297	64	30	7	−3.8	−25.2	25.2	206
MullerBMI2530ffm[10] (22)	1766	175	64	30	6	−5.2	−28.5	30.1	225
Johnstoneffm[11] (36)	1824	264	62	24	14	−2.6	−23.3	32.4	212
Korthffmbia[11] (26)	1750	261	50	41	9	−6.6	−24.4	26.6	243
Huangffm[10] (34)	1733	231	49	46	5	−7.4	−27.9	19.4	234
Mifflinffm[11] (33)	1500	202	13	87	0	−19.8	−35.4	8.0	434

[1] FM, fat mass.
[2] As measured.
[3] The percentage of subjects predicted by this predictive equation within 10% of the measured value.
[4] The percentage of subjects predicted by this predictive equation within <10% of the measured value.
[5] The percentage of subjects predicted by this predictive equation within >10% of the measured value.
[6] Mean percentage error between predictive equation and measured value.
[7] The largest underprediction that was found with this predictive equation as a percentage of the measured value.
[8] The largest overprediction that was found with this predictive equation as a percentage of the measured value.
[9] Equation based on normal-weight persons.
[10] Equation based on obese persons.
[11] Equation based on both normal-weight and obese persons.

developed in Hungarian obese adolescents. The most commonly used equations in children overestimated the REE for obese adolescents. The frequently used Schofield-weight equation for age 10–18 y and FAO/WHO/UNU-weight equation for age 10–18 y provided 48% and 44% overestimations, respectively, in line with high positive biases of 10.7% and 8.4%, respectively.

On the other hand, the Schofield equations for age 18–30 y, based on much larger body weight and height as observed in these obese adolescents, were much more accurate and were a valid surrogate for the Molnar equation.

According to the criteria of Cole et al (14), 4 of the 70 girls and 6 of the 51 boys were overweight, and the other children were obese. Therefore we repeated the analysis without the overweight group. We observed no apparent differences in percentage accurate prediction, bias, and RMSE.

Only a few validation studies were conducted in this specific population (5, 10–13), and they compared a different and very small set of equations (usually ≤4). Comparisons of the Schofield or FAO/WHO/UNU equations are based only on children aged 3–10 and 10–18 y. The results are therefore difficult to compare. The Schofield and FAO/WHO/UNU equations

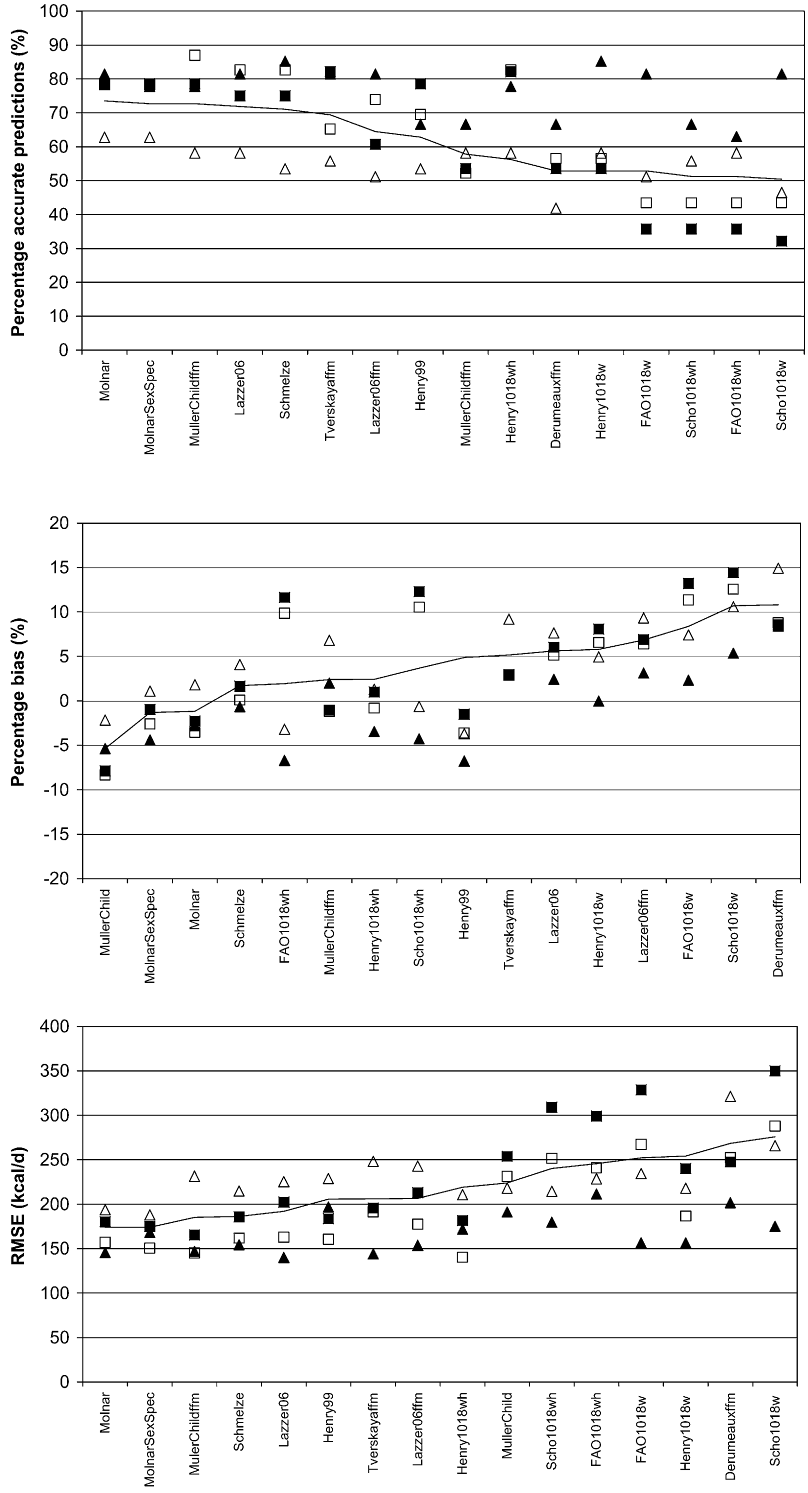

FIGURE 1. Percentage of accurate predictions, percentage bias, and root mean squared prediction error (RMSE) for Western girls (▲), Western boys (■), non-Western girls (△), and non-Western boys (□) for 43 resting energy expenditure predictive equations. For each panel, the data are sorted by mean values for all adolescents (line).

based on weight and height were found to be the best REE predictive equation by Rodriguez et al (10) and Dietz et al (11). Derumeaux-Burel (5) concluded that "the FAO equation had no systematic bias." From these studies (5, 10–13), only the Dutch study by van Mil et al (12) evaluated and found improved predictions by the FAO equations based on the older age category (18–30 y).

Five equations (Derumeaux-Burel, Lazzer, Molnar, Schmelzle, and Tverskaya) were specifically developed for obese adolescents (5–9). The Molnar equation predicted well in our group.

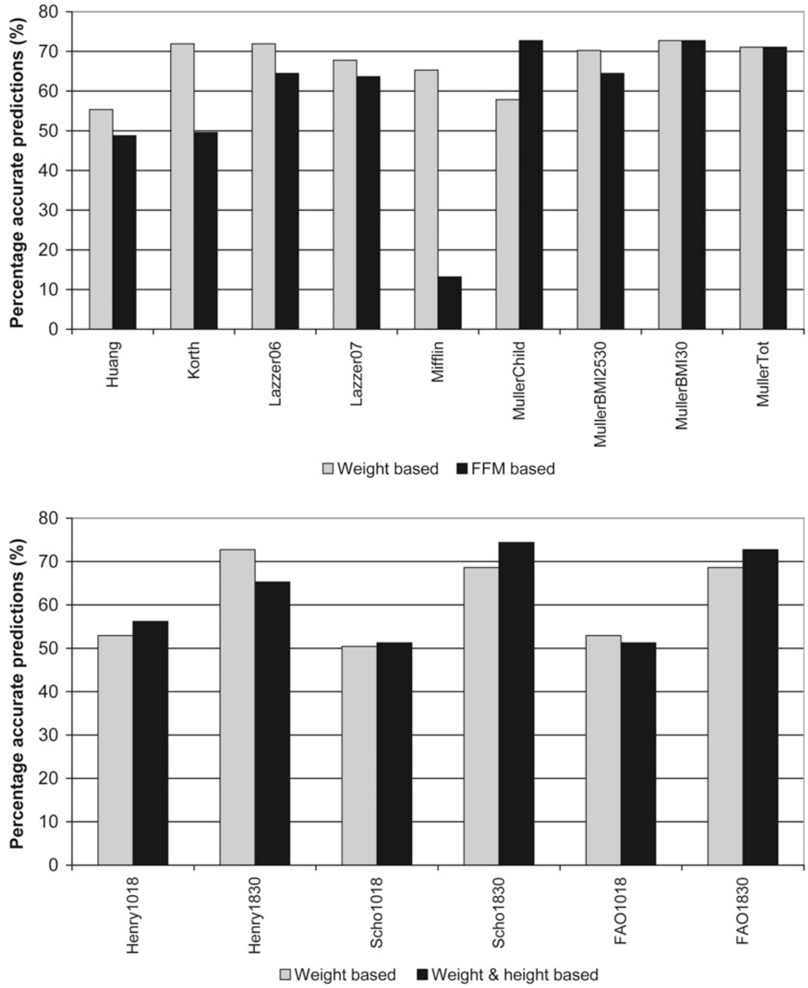

FIGURE 2. Comparison of percentage accurate predictions for weight-based compared with fat-free mass (FFM)–based resting energy expenditure predictive equations and for weight-and-height–based compared with weight-only–based predictive equations for obese adolescents.

Also, Schmelzle et al (2004; 8) predicted well with 71% accurate predictions, but with a higher RMSE. Lazzer (2007; 13) had 72% accurate predictions; however, with 26% overpredictions and a large bias of 5.6%.

The REE predictive equations of Derumeaux-Burel (2004; 5) and Tverskaya (1998; 6), both based on FFM, had 53% and 71% accurate predictions in our population. However, the equation of Derumeaux-Burel had 46% overpredictions and a bias of 10.8%. For FFM-based equations, we did not observe any improvement in predictions. In other studies it is repeatedly shown that equations based on FFM have no added value over prediction by age, height, and weight (18, 26). Korth et al (26) compared 6 body-composition methods, and the choice of method was not the explanation for the results. Most FFM-based equations used bioimpedance for body-composition assessment, except for Johnstone et al (36), who used air-displacement plethysmography (Bodpod). According to Korth et al (26), there must be another explanation, maybe in the rather large residual (unexplained) error. Also, but less clear, the inclusion of height did not improve the REE prediction. Because height is usually available, this is not a practical limitation for use of REE prediction equations. On the basis of the present analysis, it remains unclear whether inclusion of height is better, but because the best-performing Molnar equation is also based on height, we consider height to be important enough for REE prediction in obese adolescents.

Our study showed differences between ethnic groups, but there were no systematic differences in REE in kcal, kcal/kg, or kcal/kg FFM. A review about the relation between ethnicity and REE concluded that there are sufficient data to conclude that ethnicity has been a factor in REE prediction in adults. In children, these data are inconsistent. Most of the studies reviewed involved an African American population (37). However, the non-Western population in our study was not of sub-Saharan African descent; therefore, no comparison could be made.

Our study group is not completely representative of the whole obese adolescent population in the Netherlands because of its ethnical composition. On the other hand, our study might in fact be more representative of the European or even global obese adolescent population.

In conclusion, this study showed that there is wide variation in the accuracy of predictive equations for REE in overweight and obese adolescents. Whenever available, the use of indirect calorimetry is the best option in overweight and obese adolescents; however, 3 of 4 adolescents were accurately predicted with the Molnar equation based on weight, height, age, and sex. Assessment of FFM does not improve REE predictions in overweight and obese adolescents.

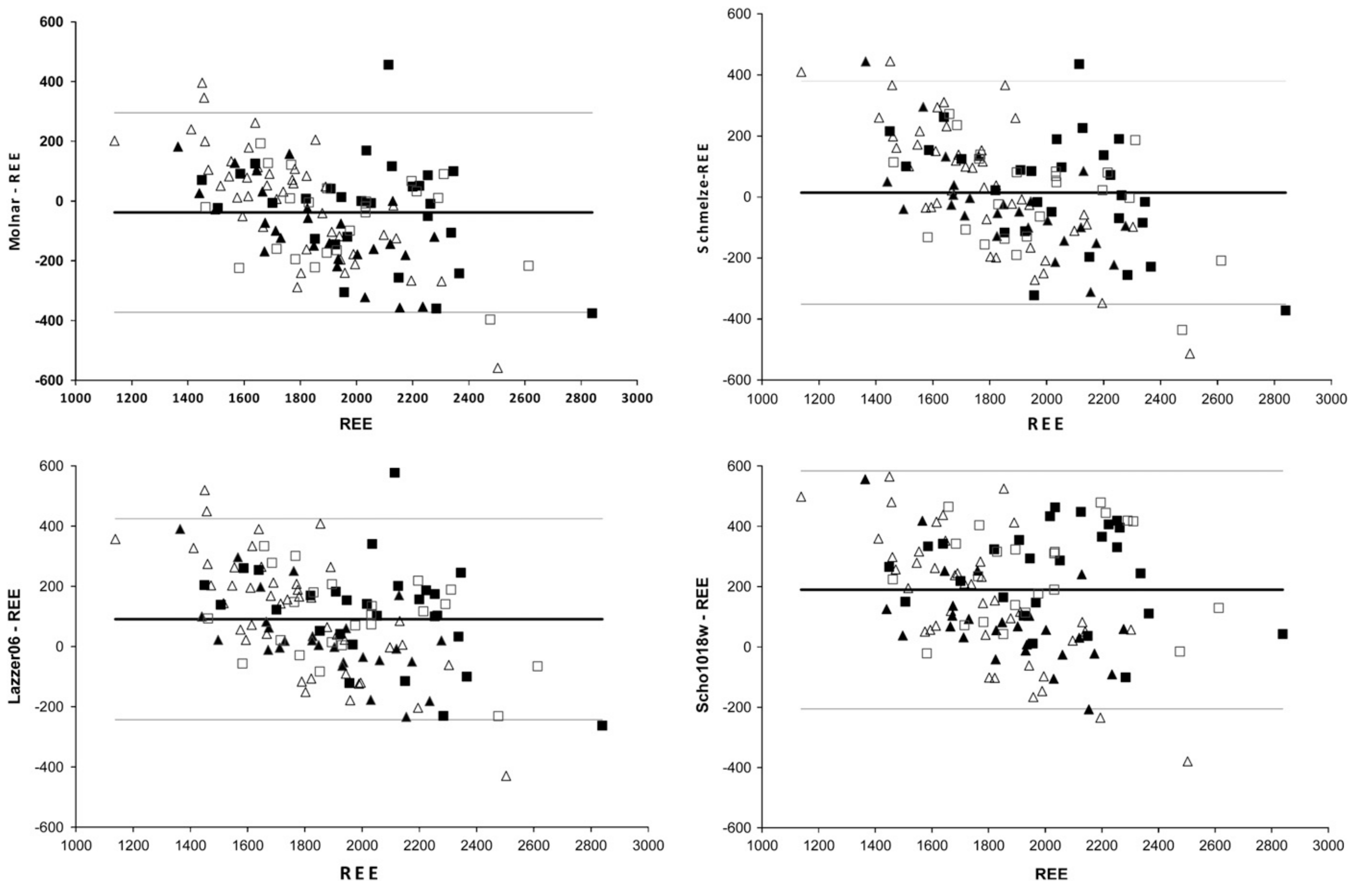

FIGURE 3. Plots for the 3 best- and the worst (Shofield1018w)-performing resting energy expenditure (REE) predictive equations based on adolescents for Western girls (▲), Western boys (■), non-Western girls (△), and non-Western boys (□). Mean indicated by the thick black line; (1.96 SD, −1.96 SD) indicated by the thin black line.

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