Measured and predicted resting metabolic rate in obese and nonobese adolescents

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Objectives: **The validity of equations for the calculation of resting metabolic rate (RMR) were studied and new predictive equations were developed.**
Study design: **The RMR was measured in a sample of 371 10- to 16-year-old prepubertal and postpubertal children. The study group included 193 male (116 nonobese and 77 obese) and 178 female (119 nonobese and 59 obese) subjects; for each group the RMRs predicted from five equations recommended for this age group were compared. The RMR was assessed by indirect calorimetry with a ventilated hood system for 45 minutes after an overnight fast. Body composition was estimated from skin-fold measurements.**
Results: **The mean ± SD RMR was found to be 5600 ± 972 kJ/24 hr and 7223 ± 1220 kJ/24 hr in nonobese and obese boys, and 5112 ± 632 kJ/24 hr and 6665 ± 1106 kJ/24 hr in nonobese and obese girls, respectively. All five equations applicable to 10- to 16-year-old children overestimated RMR by 7.5% to 18.1% ($p < 0.001$ for each equation). Stepwise regression analysis, with independent variables such as age, weight, height, and gender, allowed development of new predictive equations for the calculation of RMR in 10- to 16-year-old boys (RMR = 50.9 Weight (kg) + 25.3 Height (cm) −50.3 Age (yr) + 26.9; $R^2 = 0.884$, $p < 0.0001$) and girls (RMR = 51.2 Weight (kg) + 24.5 Height (cm) − 207.5 Age (yr) + 1629.8; $R^2 = 0.824$, $p < 0.0001$). These predictive equations were tested in a second, independent cohort of children (80 male and 61 female subject) and were found to give a reliable estimate of RMR in 10- to 16-year-old obese and nonobese adolescents.**
Conclusions: **The currently used predictive equations overestimate RMR in 10- to 16-year-old children. The use of the newly developed equations is recommended. (J Pediatr 1995;127:571-7)**

There is a growing clinical emphasis on accurately predicting an individual's energy requirement. Among the main areas of concern are the prevention and treatment of childhood obesity, and the nutritional care of critically ill hospitalized patients, in whom the avoidance of overnutrition and undernutrition is equally important.[1,2] Resting metabolic rate is the main component of the overall energy requirement and accounts for approximately 60% to 70% of the daily energy expenditure, depending on the level of physical activity.[3-5]

LBM	Lean body mass
RMR	Resting metabolic rate
RQ	Respiratory quotient

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Table I. Physical characteristics of the subjects

	Age (yr)	Weight (kg)	Height (cm)	Relative weight (%)	BFM (kg)	LBM (kg)	Waist/hip ratio
First cohort							
Male (n = 193)							
Lean (n = 116)	13.1 ± 1.7	44.5 ± 11.6	157.6 ± 13.2	94.0 ± 10.4	9.6 ± 3.9	34.9 ± 8.6	0.82 ± 0.05
Obese (n = 77)	12.8 ± 1.8	74.3 ± 19.2*	159.5 ± 12.6	153.4 ± 23.4*	26.2 ± 7.8*	48.1 ± 11.8*	0.89 ± 0.05*
Female (n = 178)							
Lean (n = 119)	13.1 ± 1.7	46.0 ± 9.3	157.3 ± 9.0	95.9 ± 11.2	12.4 ± 4.9	33.6 ± 5.4	0.74 ± 0.05
Obese (n = 59)	13.2 ± 1.9	75.8 ± 18.7*	158.3 ± 10.1	155.0 ± 22.8*	30.9 ± 10.0*	44.9 ± 9.2*	0.81 ± 0.06*
Second cohort							
Male (n = 80)							
Lean (n = 31)	12.9 ± 1.7	44.7 ± 12.4	157.7 ± 13.4	94.74 ± 9.7	9.3 ± 4.4	35.4 ± 9.2	0.84 ± 0.06
Obese (n = 49)	12.6 ± 1.4	82.3 ± 21.6*	160.3 ± 12.5	169.8 ± 22.3*	30.3 ± 9.4*	51.9 ± 12.6*	0.90 ± 0.05*
Female (n = 61)							
Lean (n = 31)	13.0 ± 1.8	48.9 ± 10.0	158.5 ± 9.1	99.5 ± 10.2	14.0 ± 4.6	34.6 ± 5.9	0.75 ± 0.05
Obese (n = 30)	13.4 ± 1.7	86.0 ± 22.2*	160.7 ± 10.1	170.5 ± 29.3*	37.3 ± 11.6*	48.7 ± 11.0*	0.81 ± 0.06*

Data expressed as mean ± SD.
BFM, Body fat mass; *LBM*, lean body mass.
*p <0.001; obese vs lean.

Table II. Equations for the estimation of resting metabolic rate

References	Sex	No.	Age range (yr)	Equations
FAO/WHO/UNU[5]				
Equation 1	M	734	10-18	RMR = 17.5 Weight (kg) + 651
	F	575	10-18	RMR = 12.2 Weight (kg) + 746
Equation 2	M	734	10-18	RMR = 16.6 Weight (kg) + 77 (Height (m) + 572
	F	575		RMR = 7.4 Weight (kg) + 482 (height (m) + 217
Robertson and Reid[6]	M	198	10-16	RMR = 24 (RMR* [kcal/m^2]) (Surface area [m^2])
	F	194	10-16	RMR = 24 (RMR* [kcal/m^2] (Surface area [m^2])
Fleisch[7]	M	Note†	10-16	RMR = 24 (RMR* [kcal/m^2]) (Surface area [m^2])
	F	Note†	10-16	RMR = 24 (RMR* [kcal/m^2]) (Surface area [m^2])
Mayo nomogram (Boothby et al.[8])	M	178	10-16	RMR = 24 (RMR* [kcal/m^2]) (Surface area [m^2])
	F	148	10-16	RMR = 24 (RMR* [kcal/m^2]) (Surface area [m^2])

Resting metabolic rate is expressed as kilocalories per day.
*Gender- and age-specific RMR.
†Values were generated by a "best fit by eye" procedure between various classic standards plotted graphically.

When the total energy requirement cannot be directly measured, the expert committee of the Food and Agriculture Organization, World Health Organization, and United Nations University (FAO/WHO/UNU) has recommended use of the factorial method (multiplying RMR by an activity factor) for the calculation of RMR.[5] An underestimation or overestimation of RMR may lead to large errors in planning energy allowances of a population and in calculating the energy needs of an individual. To avoid the need to measure RMR, several formulas have been developed to predict RMR from simple variables such as weight, height, gender, and age. The currently used equations for the prediction of RMR of children and adolescents are based on measurements carried out in the first half of this century.[5-8] Whether these reference standards can be applied to our population today remains uncertain for the following reasons. (1) Early studies on RMR were performed with closed-circuit spirometry and with short expired-air collection periods; the method did not allow measurement of respiratory quotient and the assessment of steady-state conditions. (2) The onset of puberty occurs at a younger age than several decades ago, so the effect of the rapid rate of weight gain on RMR during puberty may be shifted to a lower age. The body composition of children of our population and that of those who lived in the first half of the century is probably different because of changes in nutrition, lifestyle, and physical activity. (3) Several studies found that the "old" standards overestimated RMR in adults.[9-12] (4) The results of the three studies conducted in children and adolescents investigating the validity of the widely used standards are contradictory.[13-15] Furthermore, the number of patients studied by Dietz et al.[13] was relatively small, and Firouzbakhsh et al.[15] measured postprandial instead of postabsorptive RMR.

The aim of this study was to compare measured and pre-

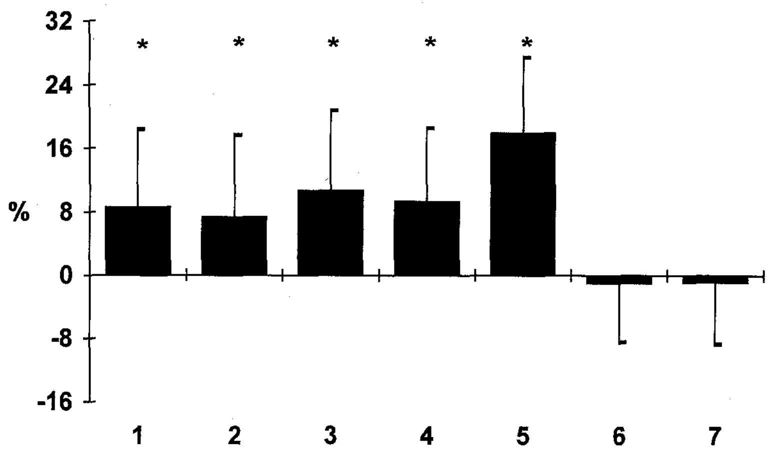

Figure. Relative difference (mean ± SD) between RMR predicted from various methods and those measured by indirect calorimetry in the total cohorts. *1,* FAO/WHO/UNU equation 1; *2,* FAO/WHO/UNU equation 2; *3,* Robertson and Reid[6]; *4,* Fleisch[7]; *5,* Mayo Clinic nomogram[8]; *6,* equations 1, *A* and *B* (Table V); *7,* equation 2 (Table V); n = 371 in 1 through 5; n = 141 in 6 and 7. *p <0.001 (predicted vs measured RMR).

dicted RMR in a large number of obese and nonobese 10- to 16-year-old children and adolescents, and to derive new predictive equations for this age group.

METHODS

Subjects. The investigations were conducted in two independent cohorts of adolescents. The first cohort, comprised of 235 nonobese (119 female) and 136 obese (77 male) children ranging in age from 10 to 16 years, was used to investigate the validity of the currently used predictive equations and to develop new equations. The new equations were tested in a second group of children that included 62 nonobese (31 children of each gender) and 79 obese children (49 male subjects). The nonobese children had body weight <120% of the expected weight for height[16] and were recruited from primary and secondary schools. Obese children with body weight exceeding predicted body weight for height by 20% or more were recruited from patients referred to the obesity clinic of the Department of Pediatrics, University Medical School of Pécs. Pubertal stage was assessed according to Tanner.[17] Subjects with diabetes mellitus or other metabolic or endocrine diseases were excluded. Physical examination and routine laboratory tests documented the absence of any health problems. None of the subjects included in the study took any medicine, drank alcohol, or smoked. The relevant data of the first and second cohort of patients are listed in Table I. The study was approved by the ethics committee of the University of Pécs and conducted in accordance with the Declaration of Helsinki II.

Body composition. Anthropometric measurements were obtained immediately after or before the RMR measurement by the same investigator and included weight, height, waist and hip circumference, and skin-fold thicknesses. Weight was obtained with subjects wearing light clothing (shorts or dress and tee-shirt, without shoes) to the nearest 0.1 kg on a standard beam scale. Height was measured without shoes to the nearest 0.1 cm by a Holtain stadiometer. Skin-fold thickness measurements (triceps, biceps, suprailiac, subscapular, and calf skin folds, in millimeters) were performed three times on the left side of the body with a Holtain caliper. Relative body fat was estimated from five skin-fold thicknesses according to Parizkova and Roth.[18] Lean body mass was calculated by subtracting body fat mass (i.e., the percentage body fat × body weight) from body weight.

Experimental design. The children were asked to consume their usual diets and on the day before the test they avoided strenuous exercise. The patients arrived at the laboratory after an overnight fast (from 8 pm the day before) at approximately 7:30 AM and rested on a comfortable bed, under the canopy in a temperature-controlled room (25° to 27° C), for at least 30 minutes to accommodate to the environment before the commencement of gas exchange measurements. Children watched videofilms (animated cartoons) during the investigation to reduce spontaneous movements and nervousness that might have increased energy expenditure.

Energy expenditure measurements. Resting energy expenditure was measured by means of a Deltatrac indirect calorimeter (Datex, Instrumentarium OY, Helsinki, Finland) using the ventilated hood technique. After a steady state was achieved (which took typically 5 to 10 minutes), the RMR was measured for 45 minutes. Oxygen consumption, carbon dioxide production, RQ, and energy expenditure, standardized for temperature, barometric pressure, and humidity, were measured at 1-minute intervals and averaged over the entire measurement period. Oxygen and carbon dioxide concentrations were analyzed by a differential paramagnetic

Table III. Comparison of measured resting metabolic rate with RMR estimated from standard predictive equations for adolescents

Subjects		Resting metabolic rate				
		Measured	WHO No. 1		WHO No. 2	
Category	No.	KJ/24 hr	(kJ/24 hr)	Δ%	kJ/24 hr	Δ%
Male						
Nonobese	116	5600 ± 972	5988 ± 853*	7.8 ± 8.4	5998 ± 848*	8.0 ± 8.3
Obese	77	7223 ± 1220	8170 ± 1404*	13.4 ± 9.2	8073 ± 1365*	12.0 ± 9.0
Total	193	6248 ± 1338	6858 ± 1538*	10.0 ± 9.2	6825 ± 1486*	9.6 ± 8.8
Female						
Nonobese	119	5112 ± 632	5475 ± 476*	8.0 ± 9.9	5510 ± 447*	8.7 ± 10.0
Obese	59	6665 ± 1106	6996 ± 954‡	5.8 ± 10.0	6452 ± 752	−2.0 ± 9.8
Total	178	5627 ± 1098	5979 ± 982*	7.3 ± 10.0	5822 ± 718†	5.1 ± 11.1

Data are expressed as mean ± SD.
Δ%, ([Predicted RMR − Measured RMR]/Measured RMR) × 100; *WHO No. 1*, FAO/WHO/UNU equation 1; *WHO No. 2*, FAO/WHO/UNU equation 2.
*$p < 0.001$ predicted vs measured RMR.
†$p < 0.01$ predicted vs measured RMR.
‡$p < 0.05$ predicted vs measured RMR.

Table IV. Correlation coefficients between RMR and anthropometric variables

	Resting metabolic rate (kJ/day)		
	All children	Boys	Girls
Weight (kg)	0.881*	0.928*	0.862*
Height (cm)	0.612*	0.707*	0.474*
LBM (kg)	0.894*	0.935*	0.830*
BFM (kg)	0.782*	0.838*	0.862*
BMI (kg/m^2)	0.774*	0.782	0.836*
Age (yr)	0.294†	0.431*	0.175†

*$p < 0.001$.
†$p < 0.05$.
LBM, Lean body mass; *BFM*, body fat mass; *BMI*, body mass index.

sensor and an infrared carbon dioxide analyzer, respectively.

Before each test the calorimeter was calibrated with a reference gas mixture (95% oxygen, 5% carbon dioxide). To assess the precision of the indirect calorimeter, ethanol burning tests were performed on 10 occasions. The error (mean ± SD) of oxygen consumption and carbon dioxide production obtained in the repeated tests were 3.9% ± 2.9% and 3.6% ± 1.7%, respectively. The mean ± SD of measured RQ was 0.668 ± 0.008 (and was the same as the RQ of ethanol = 0.666) with a mean error of 1.1%± 0.6%. The coefficient of variation on RMR of a 1-day and a 1-week interval was less than 3%.

Measured RMR values were compared with the RMR calculated on the basis of five different predictive equations commonly used in children (Table II).[5-8]

Statistical analysis. All results are expressed as mean ± SD. Statistical differences were assessed by the unpaired Student *t* test in which overweight children were compared with control children. Analysis of variance and the Fisher least significant difference comparison test were used to compare the mean measured RMR values with mean predicted values. Simple and stepwise regression analyses were used for the evaluation of the relationship between measured RMR and anthropometric measurements (SOLO 4.0 program, BMDP Statistical Software, Inc., Los Angeles, Calif.).

RESULTS

All five equations (except the second FAO/WHO/UNU equation in obese female subjects) grossly overestimated RMR in all groups of subjects (Table III) and in the whole cohort of 371 children (Figure). The individual error of the estimated RMR was high, as shown by the large SD values and the wide range of individual differences between predicted and measured values. Consequently, the individual RMR could be substantially underestimated (by 16%) or overestimated (by 35%) even with the use of the second FAO/WHO/UNU equation, which provided the relatively best approximation of RMR.

The correlation analysis showed that anthropometric variables such as lean body mass, body fat mass, body weight, and height had highly significant correlations with measured RMR in boys and girls, as well as in the combined group (Table IV). The strongest correlation was observed between RMR and LBM in the combined group and in male subjects, explaining 80% and 87% (R^2: 0.8 and 0.87) of the variability in RMR, respectively; in female subjects the best correlation was found between weight and RMR (Table IV).

New predictive formulas of RMR were developed by stepwise regression analysis (Table V). The major determinants of RMR were the weight, explaining 77.6% (p <0.0001); height, explaining 1% (p <0.0001); age, explain-

Resting metabolic rate					
Robertson		Fleisch		Mayo	
kJ/24 hr	Δ%	kJ/24 hr	Δ%	kJ/24 hr	Δ%
Male					
6219 ± 853*	12.1 ± 9.4	6017 ± 944*	8.0 ± 7.7	6617 ± 1047*	18.7 ± 8.4
7833 ± 928*	9.7 ± 10.6	7583 ± 1094	5.6 ± 8.3	8337 ± 1223*	16.1 ± 9.0
6863 ± 1185*	11.1 ± 9.9	6641 ± 1264†	7.1 ± 8.0	7303 ± 1401*	17.7 ± 8.8
Female					
5701 ± 577	12.2 ± 9.7	5789 ± 613	13.8 ± 9.4	6133 ± 635*	20.0 ± 9.6
7034 ± 769‡	6.9 ± 10.3	7141 ± 887†	8.2 ± 9.5	7559 ± 905*	14.6 ± 10.1
6143 ± 901*	10.4 ± 10.2	6237 ± 957*	12.0 ± 9.8	6605 ± 995*	18.6 ± 10.2

Table V. New predictive formulas for the calculation of RMR in 10- to 16-year-old children (RMR kJ/24h)

	Sex	Regression equations	R^2	p
Equation 1A	M	RMR = 50.9 Weight (kg) + 25.3 Height (cm) – 50.3 Age (yr) + 26.9	0.884	<0.001
Equation 1B	F	RMR = 51.2 Weight (kg) + 24.5 Height (cm) – 207.5 Age (yr) + 1629.8	0.824	<0.001
Equation 2	M + F	RMR = 50.2 Weight (kg) + 29.6 Height (cm) – 144.5 Age (yr) – 550 Sex* + 594.3	0.859	<0.001

Resting metabolic rate was measured in kilojoules per 24 hours.
*Zero for boys, one for girls.

Table VI. Comparison of measured resting metabolic rate with RMR estimated from newly developed predictive equations

		Resting metabolic rate				
		Measured	Equation 1 A & B		Equation 2	
Subjects	No.	(kJ/24 hr	kJ/24 hr	Δ% (min – max)	kJ/24 hr	Δ% (min – max)
Male						
Nonobese	31	5604 ± 1099	5643 ± 879	1.5 (–11, +12) ± 6.1	5640 ± 802	1.7 (–13, +11) ± 6.8
Obese	49	7992 ± 1273	7639 ± 1279	–4.3 (–15, +14) ± 6.9	7655 ± 1143	–3.8 (–14, +15) ± 6.6
Total	80	7067 ± 1677	6866 ± 1499	–2.1 (–15, +14) ± 7.2	6874 ± 1419	–1.7 (–14, +14) ± 7.2
Female						
Nonobese	31	5296 ± 590	5313 ± 506	0.7 (–11, +14) ± 7.1	5308 ± 573	0.6 (–15, +14) ± 7.7
Obese	30	7300 ± 1575	7194 ± 1215	–0.3 (–15, +15) ± 8.1	7185 ± 1267	–0.6 (–14, +12) ± 7.7
Total	61	6281 ± 1547	6238 ± 1319	0.2 (–15, +15) ± 7.5	6231 ± 1354	–0.03 (–15, +14) ± 7.7

Values are expressed as mean ± SD.
Max, Maximum; *min*, minimum.
Δ%, ([Predicted RMR – Measured RMR]/Measured RMR]) × 100.

ing 2.7% (p <0.0001), and gender, explaining 4.7% (p <0.0001) of the variance of RMR (equation 2 in Table V). Pubertal stage was not entered into the equations because its contribution to the predictive power of the equations was insignificant by stepwise regression analysis. However, equations with LBM, age, and gender as independent variables had only slightly lower predictive power (R^2: 0.88 for male subjects and 0.78 for female subject); they were disregarded because in this study body composition was not measured, but only calculated from skin-fold measurements, and the estimation or measurement of LBM is cumbersome in everyday pediatric practice.

The new equations were validated in an independent cohort of adolescents. The age and gender distribution and the anthropometric characteristics of the subjects in the two cohorts were similar (Table I). Both equation 1 and equation 2 gave a very good approximation of RMR (Table VI). No significant difference between measured RMR values and those predicted by the new equations was found. For the total cohort the difference between the calculated and measured RMR values was only −1% (Figure). The individual error of RMR estimation with the new equations was less than 15%. The error was between 10% and 15% in 15 (11%) subjects, between 5% and 10% in 16 (11%), and less than 5% in 110 (78%) subjects.

DISCUSSION

We found that in overweight and normal-weight 10- to 16-year-old children of both genders the equations now used for this age group substantially overestimated RMR. Our findings are in accordance with the results of Maffeis et al.[14] and Thomson et al.,[19] who demonstrated similar observations in younger children.

The Schofield analysis,[20] which formed the basis for the equations used in the FAO/WHO/UNU publication on energy protein requirements,[5] was based on a metaanalysis of 114 published studies that included approximately 8000 measurements of RMR. The accuracy of the Schofield equations in the prediction of RMR in tropical countries[21, 22] and North American individuals[11] has been challenged. These equations appear to overestimate RMR in certain populations.[11, 22, 23] Our study confirms these findings in Hungarian adolescents of both genders with various degree of leanness and obesity. Moreover, our results constitute, to the best of our knowledge, the largest sample studied by the same method, the same investigators, and under the same environmental conditions. In contrast, the FAO/WHO/UNU equations and the Mayo Clinic nomogram[8] were found to be reliable estimates of RMR in children and adolescents by Dietz et al.[13] and Firouzbakhsh et al.[15] The latter authors measured postprandial instead of postabsorptive RMR; this difference explains the discrepancies in the results. The subjects studied by Dietz et al.[13] were older by 2 years on average than those in our sample, were consequently heavier and taller, and the overweight patients were much more obese than the patients in our study. These factors can at least partly explain the inconsistent results.

The measured RMR values were also compared with RMR caculated on the basis of four different predictive equations used in adults.[24-27] These equations, with the exception of the Harris and Benedict equation,[26] which overestimated RMR, significantly underestimated RMR (results not shown).

Our results obtained in a large sample of obese and nonobese adolescents allowed us to develop new predictive equations with body weight, height, and age as variables. The explained variability in RMR was 88% in male subjects and 82% in female subjects when weight, height, age, and gender were used as independent variables. The new equations were validated in an independent cohort of children and proved to be reliable in both obese and nonobese adolescents. The individual error of the estimation of RMR with the new equations was less than 5% in the majority (78%) of the subjects and did not exceed 15% in any of them. Predictive equations may never be a perfect substitute for the direct measurement of RMR, but our new equations may provide an acceptably exact estimation of RMR in those quite frequent situations when direct measurement is not possible.

CONCLUSIONS

Our study supports the following conclusions. (1) The currently used predictive equations for 10- to 16-year-old children overestimate RMR. (2) The factors comprising the newly developed predictive equations explain 82% to 88% of the variability in RMR of these children. (3) The validity of the new formulas was tested and proved in an independent group of children, so their use by pediatricians can be recommended in both obese and nonobese 10- to 16-year-old children.

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