Resting metabolic rate in six- to ten-year-old obese and nonobese children

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The resting metabolic rate (RMR) and body composition of 130 obese and nonobese prepubertal children, aged 6 to 10 years, were assessed by indirect calorimetry and skin-fold thickness, respectively. The mean (±SD) RMR was 4619 ± 449 kJ · day^{-1} (164 ± 31 kJ · kg body $weight^{-1}$ · day^{-1}) in the 62 boys and 4449 ± 520 kJ · day^{-1} (147 ± 32 kJ · kg body $weight^{-1}$ · day^{-1}) in the 68 girls. Fat-free mass was the best single predictor of RMR ($R^2 = 0.64$; $p < 0.001$). Step-down multiple regression analysis, with independent variables such as age, gender, weight, and height, allowed several RMR predictive equations to be developed. An equation for boys is as follows: RMR (kJ · day^{-1}) = 1287 + 28.6 · Weight (kg) + 23.6 · Height (cm) − 69.1 · Age (yr) ($R^2 = 0.58$; $p < 0.001$). An equation for girls is as follows: RMR (kJ · day^{-1} = 1552 + 35.8 · Weight (kg) + 15.6 · Height (cm) − 36.3 · Age (yr) ($R^2 = 0.69$; $p < 0.001$). Comparison between the measured RMR and that predicted by currently used formulas showed that most of these equations tended to overestimate the RMR of both genders, especially in overweight children. (J Pediatr 1993;122:556-62)

In sedentary individuals the resting metabolic rate is considered to be the best predictor of 24-hour energy expenditure because it accounts for 60% to 70% of the latter, both in adults and in adolescents.[1-3] By multiplying the RMR of an individual by an activity factor (which depends on the activity level and duration), one can obtain an estimate of the 24-hour energy expenditure by the factorial method.[3] Underestimation or overestimation of RMR may have practical implications for planning the energy allowances of a population.

Many authors, starting in 1919 with Harris and Benedict,[4] have proposed formulas to predict the resting energy expenditure in adults. On the contrary, the number of predictive equations for RMR in children younger than 10 years of age is small, and the equations generally were developed in the first part of this century.[3, 5-8] Therefore the aim of our study was to derive new predictive equations for resting energy expenditure based on a sample of 130 prepu-

BMI	Body mass index
FAO	Food and Agriculture Organization
FFM	Fat-free mass
FM	Fat mass
RMR	Resting metabolic rate
UNU	United Nations University
WHO	World Health Organization

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Table I. Physical characteristics of obese and nonobese children

Weight for height (%)	No.	Age (yr)	Weight (kg)	Height (cm)	Weight for height (%)	BMI (kg/m²)	Fat (%)	FFM (kg)
Boys								
90 to 119	48	7.6 ± 1.5	26.7 ± 6.4	127.3 ± 8.1	100.6 ± 8.6	17.0 ± 2.6	13.3 ± 4.7	22.8 ± 4.2
≥120	14	8.3 ± 1.6	38.7 ± 8.2	130.8 ± 8.4	140.8 ± 17.2	22.1 ± 2.6	26.5 ± 4.6	28.0 ± 4.7
TOTAL	62	7.8 ± 1.5	29.8 ± 8.7	128.3 ± 8.3	111.2 ± 21.1	18.2 ± 3.5	16.6 ± 7.5	24.2 ± 4.9
Girls								
90 to 119	49	7.8 ± 1.2	27.2 ± 7.0	128.3 ± 8.2	96.2 ± 10.1	16.6 ± 2.3	17.6 ± 6.0	22.0 ± 4.2
≥120	19	8.5 ± 1.2	42.2 ± 6.7	133.5 ± 7.2	133.2 ± 8.7	24.3 ± 2.8	32.5 ± 2.8	28.0 ± 4.0
TOTAL	68	8.1 ± 1.4	32.1 ± 9.8	130.0 ± 8.2	108.2 ± 20.0	19.1 ± 4.4	22.4 ± 8.7	24.0 ± 5.1
All boys and girls								
90 to 119	97	7.7 ± 1.3	27.0 ± 6.7	127.8 ± 8.1	98.4 ± 9.6	16.8 ± 2.5	15.5 ± 3.8	22.4 ± 4.2
≥120	33	8.4 ± 1.3	40.7 ± 7.5	132.4 ± 7.7	136.4 ± 13.3	23.4 ± 2.9	30.0 ± 4.7	28.1 ± 4.2
TOTAL	130	8.0 ± 1.5	31.0 ± 9.4	129.2 ± 8.2	109.6 ± 20.5	18.7 ± 4.0	19.7 ± 8.6	24.1 ± 5.0

Values are expressed as mean ± SD.

Table II. Equations and standards for estimation of resting metabolic rate in children

Source of equation	Sex	No.	Equations/standards	Age range (yr)
FAO/WHO/UNU[3]	M	338	RMR* = 95 · Weight (kg) + 2071	3-10
	F	413	RMR = 94 · Weight (kg) + 2088	3-10
Robertson and Reid[5]	M	125	RMR = 100.4 · RMR† (kJ/m²) · Surface area (m²)	6-10
	F	106	RMR = 100.4 · RMR† (kJ/m²) · Surface area (m²)	6-10
Fleisch[6]	M	(‡)	RMR = 100.4 · RMR† (kJ/m²) · Surface area (m²)	6-10
	F	(‡)	RMR = 100.4 · RMR† (kJ/m²) · Surface area (m²)	6-10
Talbot[7]	M	2200	RMR = Sex- and weight- or sex- and height-specific tables	
	F	800	RMR = Sex- and weight- or sex- and height-specific tables	
Mayo Clinic (nomogram)[8]	M	119	RMR = 100.4 · RMR† (kJ/m²) · Surface area (m²)	6-10
	F	110	RMR = 100.4 · RMR† (kJ/m²) · Surface area (m²)	6-10

*Resting metabolic rate is expressed in units of kJ · day^{-1}.
†Age and sex specific.
‡The values were generated by a "best fit by eye" procedure between various classic standards plotted graphically.

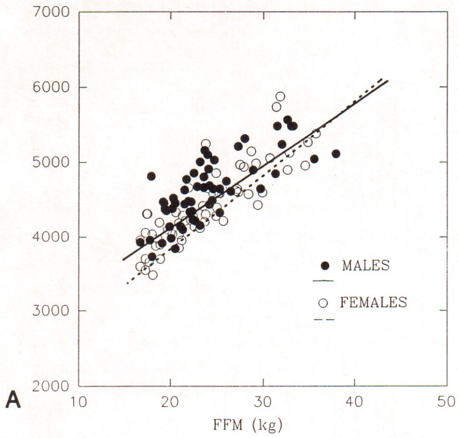
bertal boys and girls. In addition, we explored the error of prediction of RMR, using the classic equations reported in the literature. This constitutes a complementary contribution to the work of Dietz et al.,[9] who recently examined the RMR of obese and nonobese adolescents.

METHODS

Subjects. Investigations were carried out in 130 prepubertal healthy white children divided into two groups: (1) nonobese children (n = 97) with body weight ranging from 90% to 119% of the expected weight for height (from Tanner et al.[10]) and (2) obese children (n = 33) with weight 20% or more above that predicted for height. The pubertal stage was assessed according to Tanner.[11] The anthropometric description of the subjects is summarized in Table I. The sample was randomly chosen from a group of 396 children who participated in a school interview project developed to study the food habits of children living in the area of Verona, Italy. Subjects with diabetes mellitus or other metabolic or endocrine disorders were excluded; on this basis three children were excluded from the study. Physical examination and routine laboratory tests documented the absence of any health problems. None of the subjects reported significant changes in body weight during the month preceding the study. No child was taking any drug.

The protocol was approved by the ethical committee of the University Hospital of Verona. Informed consent was obtained from the parents of each child.

Body composition. Anthropometric measurements were carried out immediately after RMR measurement by the same investigator and included weight, height, and skin-fold thickness. Body weight was determined to the nearest 0.05 kg on a standard physician's beam scale with the child dressed only in light underwear and wearing no shoes.



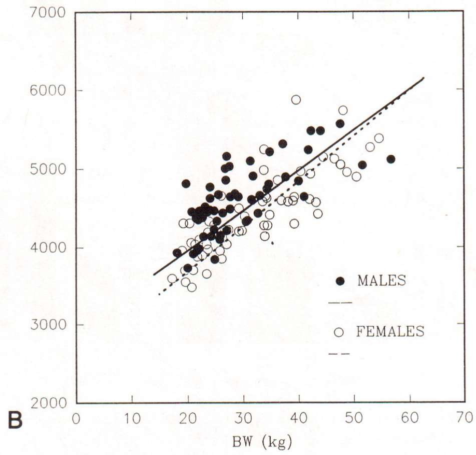


Fig. 1. **A,** Relationship between RMR (kJ · day^{-1}) and FFM for male (n = 62) and female (n = 68) children. **B,** Relationship between RMR (kJ · day^{-1}) and body weight *(BW)* for male (n = 62) and female (n = 68) children.

Height was measured to the nearest 0.5 cm on a standardized wall-mounted height board under the following conditions: without shoes; heels together; child's heels, buttocks, shoulders, and head touching the vertical wall surface; and with line of sight aligned horizontally. The percentage of weight for height was determined from the Tanner tables,[10] and the body mass index was calculated by dividing weight (in kilograms) by height (in square meters). Skin-fold thicknesses were measured to the nearest millimeter in triplicate at the triceps and subscapular sites by means of

Table III. Measured resting metabolic rate in a sample of prepubertal boys and girls with normal or excess body weight

Weight/height (%)	No.	RMR (kJ · day^{-1})
Boys		
90 to 119	48	4535 ± 444
>120	14	4871 ± 374
TOTAL	62	4619 ± 449
Girls		
90 to 119	49	4237 ± 441
>120	19	4848 ± 393
TOTAL	68	4449 ± 520
Boys and girls		
90 to 119	97	4383 ± 463
>120	33	4857 ± 380
TOTAL	130	4527 ± 494

Values for RMR are expressed as mean ± SD.

Table IV. Correlation coefficients between RMR and anthropometric-considered variables

	RMR (kJ · day^{-1})		
	All children	Boys	Girls
FFM (kg)	0.798	0.762	0.847
Weight (kg)	0.741	0.725	0.825
Height (cm)	0.670	0.684	0.722
BMI (kg/m^2)	0.646	0.598	0.743
Weight/height ratio	0.522	0.433	0.592
FM (%)	0.603	0.614	0.735
Age (yr)	0.502	0.480	0.577

Harpenden skin-fold calipers (CMS Weighing Equipment Ltd., London, United Kingdom). The formulas of Lohman[12] were used to estimate relative body fat. Fat-free mass was calculated by subtracting fat mass from body weight; FM was obtained by multiplying the percentage of body fat by body weight.

Experimental design. During the days before the indirect calorimetry test, the children were on an unrestricted diet and no attempt was made to influence their usual diet. The day before the test, they avoided intense physical activity.

On the day of the test, the children arrived by car at the pediatrics department at approximately 7:30 AM, having fasted from 8 PM the day before. They lay down on a hospital bed that had been placed in a comfortable temperature-controlled (24° C) and humidity-controlled environment. After 30 minutes of absolute rest, considered as an adaptation period during which the procedure was explained to the child, and after an additional adaptation period of 15 minutes under the transparent ventilated hood system, continuous respiratory exchange measurements were initiated. During the calorimetric measurement, each child rested quietly while watching children's videotapes. Special care was taken to prevent spontaneous movements that might contribute to increased energy expenditure.

Indirect calorimetry. Respiratory exchange measurements were determined by means of open-circuit, indirect computerized calorimetry (Deltatrac calorimeter; Instrumentarium Oy, Datex Division, Helsinki, Finland) with a rigid, transparent ventilated canopy. In children whose body weight was less than 25 kg, we utilized the pediatric mode of the Deltatrac calorimeter, especially designed for this population.

Before each test, the calorimeter was calibrated with a reference gas mixture (95% oxygen, 5% carbon dioxide). Briefly, room air was drawn through the transparent ventilated canopy at a fixed flow rate (40 L/min). A constant fraction of the air flowing out of the hood was continuously collected and analyzed for oxygen and carbon dioxide concentrations by a differential paramagnetic sensor and an infrared carbon dioxide analyzer, respectively. Resting metabolic rate was calculated from oxygen consumption and carbon dioxide production by using the formula of Lusk.[13]

To assess the precision of the indirect calorimeter, we measured oxygen consumption, carbon dioxide production, and energy expenditure on five occasions during a 30-minute period, burning a given volume of acetone. The coefficient of variation of repeated RMR determinations averaged 3.3%.

By performing three serial determinations of RMR on the same three subjects on different days during the month preceding the start of the study, we confirmed the degree of precision obtained in the acetone test (2% to 3%) and corroborated the values reported in the literature.[14] To calculate the day-to-day intrasubject variability of the RMR measurement, we measured the resting energy expenditure of three children participating in the study on three different days of the same week; the coefficient of variation of the repeated tests averaged 3%.

Resting metabolic rate measured in the boys and the girls (either with normal body weight or excess body weight) was compared with the RMR (or basal metabolic rate) calculated on the basis of five types of predictive equations commonly utilized by pediatricians to estimate the RMR in preschool children: (1) the equations published by the Food and Agriculture Organization, World Health Organization, and United Nations University,[3] (2) the British standards of Robertson and Reid,[5] (3) the American standards of Talbot,[7] (4) the Fleisch tables,[6] and (5) the Mayo Clinic nomograms.[8] The equations are presented in Table II. For simplicity we have considered that in children the RMR is essentially identical to the basal metabolic rate.

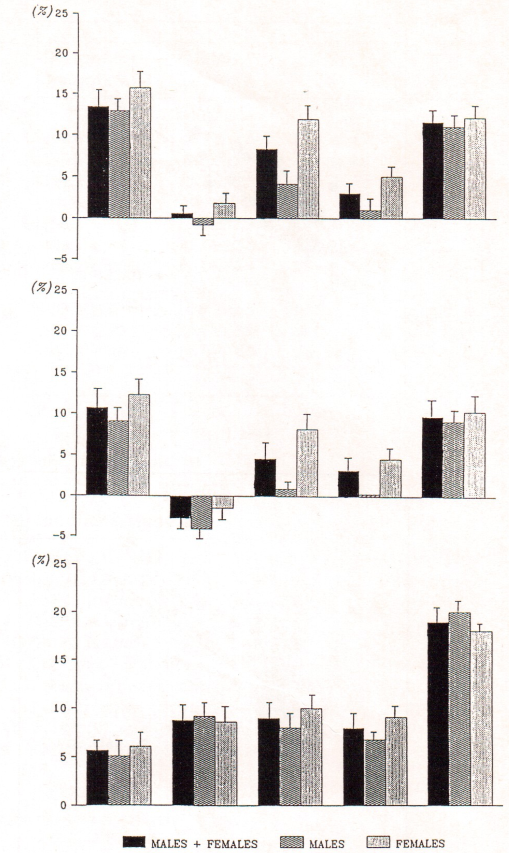


Fig. 2. Relative difference between RMR values predicted from various formulas (see Table II) and those measured in obese and normal children *(upper panel)*, in children of normal body weight *(middle panel)*, and in obese children *(lower panel)*. (Data from Robertson JD, Reid DD [Lancet 1952;1:940-3]; Talbot FB [Am J Dis Child 1938;55:455-6]; World Health Organization [Energy and protein requirements: report of a joint FAO/WHO/UNU expert consultation. Geneva: World Health Organization, 1985:71]; Fleisch A [Helv Med Acta 1951;18:23-45]; and [Mayo Clinic] Boothby WM, Berkson J, Dunn HL [Am J Physiol 1936;116:468-84]).

Statistical analysis. All the results given are expressed as mean ± SD. The children were divided into groups according to gender and excess weight (weight for height >120%)

Table V. Predictive formulas (multiple linear regression equations) of resting metabolic rate (dependent variable) and various anthropometric variables (independent variables) in the total sample and in boys and girls separated

Independent variables	Sex	Regression equations	r^2	p
Weight + height + age + sex	M	RMR* = 28.6 · Weight (kg) + 23.6 · Height (cm) − 69.1 · Age (yr) + 1287	0.58	<0.001
	F	RMR = 35.8 · Weight (kg) + 15.6 · Height (cm) − 36.3 · Age (yr) + 1552	0.69	<0.001
	M + F	RMR = 33.1 · Weight (kg) + 20.1 · Height (cm) − 60.9 · Age (yr) − 285 · sex (M = 0, F = 1) + 1542	0.66	<0.001
FFM + age + sex	M	RMR = 82.7 · FFM (kg) − 49.1 · Age (yr) + 3015	0.60	<0.001
	F	RMR = 96.6 · FFM (kg) − 60.2 · Age (yr) + 2600	0.73	<0.001
	M + F	RMR = 91.1 · FFM (kg) − 57.7 · Age (yr) − 166 · Sex (M = 0, F = 1) + 2879	0.68	<0.001

*Resting metabolic rate is expressed in units of kJ · day.$^{-1}$

and "normal" weight (90% to 119% of weight for height). The degree of association between two variables was quantified by using the Pearson product moment linear correlation coefficient.

Statistical differences were assessed by using the unpaired Student *t* test in which overweight children were compared with the control children.

The relationships between measured RMR and weight, height, age, sex, FFM, FM, percentage of weight for height, and BMI were assessed by use of simple and step-down multiple regression analysis. As a result, some predictive equations were developed. In the analysis, gender was entered as a dummy variable, with boys assigned a value of 0 and girls a value of 1.

The two-way analysis of variance for repeated measures (with subjects and formula as factors) and the Dunnett test were used to compare the mean values of the RMR measured in children with those predicted by the formulas found in the literature.

RESULTS

The average RMR of each group, partitioned into gender, varied from 4237 ± 441 kJ · day^{-1} in normal girls to 4871 ± 374 kJ · day^{-1} in overweight boys (Table III). The correlation analysis showed that numerous variables, such as FFM, weight, height, BMI, and FM, were all significantly correlated with resting energy expenditure in boys and girls and in the combined group (Table IV). The best correlation was between RMR and FFM ($r = 0.80$), explaining 64% (R^2) of the variability in RMR (Fig. 1). Each of the remaining variables—body weight, height, BMI, percentage of weight for height, and FM—were highly correlated with FFM and consequently with RMR. The correlation coefficients between RMR and FFM or body weight were slightly lower in obese than in normal weight control subjects ($r = 0.61$ and $r = 0.55$ vs $r = 0.79$ and $r = 0.7$, respectively).

Step-down multiple regression analysis was carried out by using either the combination of age, gender, body weight, and height, or a combination of age, gender, and FFM. The predictive equation accounted for 66% (R^2) of the RMR variability in the former, and 68% in the latter (Table V).

A greater predictive power was found in the equations derived for girls ($R^2 = 0.73$ and $R^2 = 0.69$, respectively) than for boys ($R^2 = 0.6$ and $R^2 = 0.58$, respectively) (Table V).

DISCUSSION

Our results confirm the associations in childhood, between RMR and body composition previously reported in adults and adolescents.[1-3] Fat-free mass, the tissue with the highest metabolic activity, was the best predictor of RMR in both boys and girls, although body weight also had a significant relationship to RMR but with a lower correlation coefficient.

When all the anthropometric variables available were utilized, the multiple regression analysis revealed that the percentage of variance in RMR accounted for was essentially the same (61%) as when the predictive equation utilized only FFM as the independent variable. This could be explained because anthropometric variables such as weight and height usually can be assessed with a higher accuracy than FFM determined from skin-fold thicknesses. For the clinician, the equations that use, as predictors, body weight in combination with age, height, and gender have the definite advantage of not requiring body composition measurements. Further experimental studies should be able to explain the residual RMR variability (excluding measurement error) not accounted for in our study (39%), after adjustment RMR (by multiple regression analysis) for age, gender, and FFM. Besides the familial heredity effect, which has been suggested to explain about a third of the RMR variability in adults,[15] the dietary intake and composition of the meals habitually eaten by the children, as well as physical activity patterns, may explain part of the residual RMR variability not accounted for.

The values for RMR per kilogram of FFM are dependent on both the relative composition of the FFM (muscle vs nonmuscle tissue) and the metabolic activity of the various organs and tissues constituting the lean mass. On the other hand, the accuracy of skin-fold thickness measurements in obesity, in comparison with classic techniques such as hydrodensitometry, can be questioned. The change in density of FFM with age and maturation constitutes an additional factor to be considered.[12] For the pediatrician, no other simple technique for the measurement of body composition in obese children is available except bioelectric impedance, which still requires validation in this age group. Further studies that use more advanced body composition methods may allow more accurate prediction of FFM, and hence RMR, in obese children.

As shown in Fig. 2, the RMR values measured were compared with those predicted on the basis of various equations. In the pooled group of overweight and normal-weight children of both genders, we found that the equations from the literature tended to overestimate RMR. In the obese children, we found a substantial overestimation of RMR compared with the measured values. This is not surprising because these standards were not intended to be used for obese children. Technical improvement in indirect calorimetry techniques, as well as differences in body composition, could partly explain these discrepancies.

Our results do not confirm the good RMR predictability of the FAO/WHO/UNU formulas as recently reported by Dietz et al.[9] in a different age group (adolescents 15 years of age). However, because of the age difference, the FAO/WHO/UNU predictive equations[3] utilized by Dietz et al. for adolescents were not the same as those used for our children.

The relative discrepancy between our data and those predicted by applying the FAO/WHO/UNU standards could be explained partially by the large age range covered by the FAO/WHO/UNU equations. The body composition of children changes greatly with age,[12] and the metabolic activity of FFM influences directly the resting energy expenditure. In addition, the sample used to derive the standards was variable in size.

The fact that most of the classic standards overestimated the RMR of normal-weight children may have important implications for the clinician. When RMR measurements cannot be made, the energy requirements of preschool children are generally calculated on the basis of the factorial approach and expressed as a multiple of RMR. A 10% overestimation of RMR, when multiplied by a given activity factor, still represents an error of 10% in the final energy expenditure estimate. This overestimation of RMR may constitute a delicate issue in the latter situation, with the evident risk of overfeeding children to meet their predicted requirements. Conversely, if the total energy intake of a group of children is compared with the RMR calculated with a formula to derive the activity (+thermogenesis) factor, the latter will be underestimated and hence the physical activity component (+thermogenesis) will be judged too low.

The results of our study have allowed new predictive equations to be developed for calculating a resting energy expenditure that is applicable to prepubertal children 6 to 10 years of age (Table V). This development is of particular interest for three reasons: (1) there is a need for more recent data on the RMR of prepubertal children; (2) the RMR measurements were performed with modern indirect calorimetry equipment; and (3) most equations available today date back from the beginning of this century (i.e., Talbot, Robertson and Reid, and Fleisch), a time when both nutritional status and the incidence and prevalence of obesity in the population differed from those observed today.

For simplicity, we propose that new equations based on height, weight, age, and sex be used (Table V). The validity of these formulas should be further tested in an independent group of children of the same age range. An important final consideration is that the use of predictive RMR equations should not be a substitute for the direct measurement of energy expenditure, particularly in sick or obese children in whom the degree of prediction will be much more uncertain than in healthy children.

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