Elevated energy expenditure and reduced energy intake in obese prepubertal children: Paradox of poor dietary reliability in obesity?

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The purpose of this study was to assess the validity of two common methods used to assess energy intake. A 3-day weighed dietary record and a dietary history were collected and compared with the total daily energy expenditure (TEE) assessed by the heart rate method in a group of 12 obese and 12 nonobese prepubertal children (mean age 9.3 ± 1.1 years vs 9.3 ± 0.4 years). The TEE value was higher in obese than in nonobese children (9.89 ± 1.08 vs 8.13 ± 1.39 MJ/day; *p* <0.01). Energy intake assessed by the dietary record was significantly lower than TEE in the obese children (7.06 ± 0.98 MJ/day; *p* <0.001) but comparable to TEE in the nonobese children (8.03 ± 0.99 MJ/day; *p* = not significant). Energy intake assessed by diet history was lower than TEE in the obese children (8.37 ± 1.35 MJ/day, *p* <0.05) but close to TEE in the nonobese children (8.64 ± 1.54 MJ/day, *p* = not significant). These results suggest that obese children underreport food intake and that the dietary record and the diet history are not valid means of assessing energy intake in obese prepubertal children. (J PEDIATR 1994;124:348-54)

Knowledge of both total daily energy intake and total daily energy expenditure is useful in planning the treatment of obese children. However, the measurement of energy expenditure is impractical and costly. Thus, in clinical practice, only energy intake data are usually available. Recent studies have shown dietary intake calculations to be inaccurate in obese adults and adolescents.[1,2] Few data are available on the comparison between energy intake and TEE in obese prepubertal children.

Our study was performed to determine whether differences in reporting of energy intake exist between prepubertal obese children and children of normal weight and to validate two of the most common and classic methods of assessing energy intake—the 3-day weighed dietary record and the dietary history—while assessing 24-hour energy expenditure by heart rate monitoring in groups of obese and normal-weight children.

FFM	Fat-free mass
HR	Heart rate
PMR	Post-absorptive metabolic rate
TEE	Total daily energy expenditure
$\dot{V}CO_2$	Carbon dioxide production
$\dot{V}O_2$	Oxygen consumption

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METHODS

Twenty-four prepubertal children participated in the study. Twelve were obese (six boys, six girls; mean age, 9.3 ± 1.1 years) and twelve were not obese (six boys; six girls; mean age, 9.3 ± 0.4 years). Physical examination revealed no health problems other than obesity. Pubertal stage was assessed according to the method of Tanner.[3] Informed consent was obtained from the parents of all children. The protocol was approved by the ethics committee of the University Hospital of Verona, Italy.

Physical characteristics. Anthropometric measurements (weight, height, and skin-fold thicknesses) were carried out by the same investigator. Height was measured to the nearest 0.5 cm on a standardized, wall-mounted height board. Weight was determined to the nearest 0.5 kg on a standard physician's beam scale with the child dressed only in light underwear and wearing no shoes. On the basis of the Tanner table,[4] overweight (percentage) was calculated from the ratio between the actual weight and the ideal body weight for height, age, and gender.[5] Obesity was defined as weight >20% in excess of ideal; normal weight was defined as a body weight within 10% of the ideal weight. Body mass index was calculated by dividing weight (in kilograms) by height (in square meters). Harpenden skin-fold calipers (CMS Weighing Equipment, Ltd., London, United Kingdom) were used to measure skin folds at the biceps, triceps, suprailiac, and subscapular sites. Body fat as a percentage of body weight was calculated from the sum of the four skin folds.[6] Fat-free mass was calculated as the difference between body weight and fat mass.

Experimental design. During the days preceding the postabsorptive metabolic rate and HR measurements, children were on an unrestricted diet. They were told not to engage in any intense physical activity on the day before the test. The children arrived by car at the department of pediatrics at 7:30 AM after a 12-hour fast. After 30 minutes of rest, during which the subjects were lying on hospital beds in a comfortable, temperature-controlled environment, continuous respiratory exchange measurements were conducted by indirect calorimetry. During the post-absorptive metabolic rate measurements the children were watching cartoons, which helped them to remain still during the calorimetric measurement. After the measurement of PMR, the subjects were given a light breakfast. Approximately 2½ hours later a treadmill test was performed. During the interim period, children were informed of the procedure to be used and were allowed to become familiar with the experimental apparatus, in particular breathing through the mouthpiece and running on the treadmill.

Energy expenditure. Postabsorptive metabolic rate was measured by respiratory gas exchange for 30 to 40 minutes, as previously described.[7] An open-circuit computerized indirect calorimeter (Deltatrac; Instrumentarium Oy, Datex Division, Helsinki, Finland) connected to a transparent hood system was used. Briefly, room air was drawn through the transparent ventilated canopy at a fixed flow rate (40 L/min). In one child whose body weight was lower than 25 kg, the pediatric canopy mode of the Deltatrac calorimeter (flow rate, 11 L/min) was used. The instrument was calibrated before each test with a standardized gas mixture (oxygen 95.2% and carbon dioxide 4.8%). Oxygen consumption and carbon dioxide production were printed out at 1-minute intervals, and the mean of the last 20 to 25 minutes was used to determine PMR. Energy expenditure was calculated according to Lusk's formula.[8]

Calculation of energy expenditure from heart rate. The relationship between HR and $\dot{V}O_2$ was established in each child as a result of the treadmill test. The individual HR–$\dot{V}O_2$ regression line was determined by means of a physical exercise test, during which $\dot{V}O_2$ and HR were simultaneously measured under standardized conditions. We measured $\dot{V}O_2$ and $\dot{V}CO_2$ by a standard open-circuit method. The expired air was collected through a two-way nonrebreathing valve and a nose clip by means of a Douglas bag and analyzed for total volume (gas meter MCG; SIM, Rome, Italy) and for oxygen and carbon dioxide concentrations (Oxinos 100 and Binos C gas analyzers; Leybold Heraeus Gmbh, Hanau, Germany). Gas analyzers were calibrated with standard gases, and the system was cleared of room air before each measurement was started.

Heart rate was measured with a cardiotachometer (Polar Sport Tester; Polar Electro Ky, Kempele, Finland), which consisted of an electrode-belt transmitter and a wrist microcomputer receiver. The resting values of $\dot{V}O_2$ (Douglas bag method) and HR were obtained when the subjects were lying down, sitting, and standing. The resting metabolic rate was defined as the mean of the energy expenditure value for the three resting activities, as calculated from $\dot{V}O_2$ values.

Five calibration points for the nonresting activities were made while the children were walking and running on the treadmill (PV Rolling Belt; Beta, Reggio Emilia, Milan, Italy) at speeds of 2, 3, 5, 6, and 7 km/hr, respectively. Each bout of exercise lasted for 6 minutes. An 8- to 10-minute recovery period was observed between two workloads to prevent fatigue. The measurements of $\dot{V}O_2$ and HR were made during the last 3 minutes of each walking or running period (i.e., in steady-state condition). Energy expenditure was calculated from $\dot{V}O_2$ by means of the simplified Weir formula, which assigns 20.5 kJ/Liter of oxygen consumed.[9]

A critical HR, the "flex" HR, was determined for each child as previously described.[10] The flex HR is an individually predetermined HR cutoff point that can be used to discriminate between resting and exercise HR in free-living conditions. It was calculated as the arithmetic mean between the highest HR obtained for the resting activities (lying down, sitting, and standing up) and the lowest HR obtained during the lightest imposed exercise. Above the flex value, the calibration curve used to estimate the energy expenditure corresponded to that of the active period, and below the flex value the resting metabolic rate was used to determine the energy expenditure during inactivity.

Total energy expenditure was calculated by summation of sleeping energy expenditure, sedentary energy expenditure, and activity energy expenditure. To assess sleeping energy expenditure, we multiplied the sleeping time (in minutes) by PMR (in kilojoules per minute). We calculated sedentary energy expenditure by multiplying the nonsleeping time (daily time under flex HR) by the resting metabolic rate. We calculated activity energy expenditure by determining $\dot{V}O_2$ for each HR greater than the flex HR from each individual calibration line.

The HR was recorded continuously for 3 to 4 days (2 weekdays and 1 weekend day) during normal daily activities under free-living conditions. The HR transmitter was attached with an elastic band on the chest. The elastic band in which the electrodes were incorporated was fixed by means of plasters stuck to the skin to reduce the possibility of detachment. Parents were instructed to fix the band with the electrodes and the HR transmitter on the chest and to turn the recorder on and off at the wrist. Pulse rate was recorded at 1-minute intervals continuously for up to 16 hours. Information was retrieved daily at the subject's home by the same operator (M. Z.) by means of an interface unit and a personal computer for which an additional program was designed to compute energy expenditure from HR. The HR monitoring started when the children arose in the morning and continued until bedtime, when the parents or the children themselves, or both, removed the instrument. When the HR daily recording was incomplete, the subjects were asked to repeat the monitoring and to keep the diet record for an additional day. At the end of the study, complete 3-day HR measurements were obtained from each child.

Energy intake

Weighed dietary records. During the 3 consecutive days of HR recording, a 3-day weighed dietary record of food and fluid and the amounts consumed was kept by the parents. Food was weighed on the family's scale, usually by the child's mother or in a few instances by the grandmother. Parents reported food intake of their children at meals, and the children were encouraged to note all the foods, including snacks, consumed outside the home. Kitchen supervisory staff recorded in a notebook the food consumed at school. Children were provided with a logbook for recording foods and beverages consumed. Written instructions with examples of completed forms were provided. A complete description of how the food was prepared and recipes for composite dishes were also requested. A dietitian checked logbooks with each family for completeness and accuracy.

Food energy values were calculated from tables of food composition set out by the Italian Institute of Nutrition[11] with the use of a computerized database and analysis program (Contrali, Dietosystem, Milan, Italy).

Diet history. Usual weekly meal and snack intakes were determined from an interview with mothers and children.[12] Information regarding portion size, food preparation, and place of consumption was also requested. A dietitian reviewed with the family the foods and portions consumed that had not been mentioned. As an aid to determination of the amount of food consumed, pictures of different food items were presented, along with cups, glasses, spoons, and food shapes of different portion sizes. The dietitian assessed food intake at school by reviewing a typical week's menu with the children and asking them to indicate which and how much of these meals they usually ate. Meals, snacks, portion size, and frequency of eating were recorded on a standard form. The energy intakes were calculated as described. All interviews were conducted by the same dietitian.

Statistical analysis. The results are expressed as means ± SD. An unpaired *t* test was used to compare anthropometric characteristics of obese and nonobese children and to compare the regression coefficients between $\dot{V}O_2$ and HR for workloads above the flex HR between the two groups. Analysis of covariance, with FFM as the covariate, was used to compare the slopes relating PMR versus FFM and TEE versus FFM in obese and nonobese children, and to calculate PMR adjusted for FFM.[13] A *t* test for paired data was performed to compare reported energy intake and TEE calculated from HR monitoring. Agreement between estimates of TEE and energy intake (obtained by dietary record and diet history) was assessed by the method of Bland and Altman.[14] Correlations between body weight, body fatness, and reported energy intake as a percentage of TEE were determined by means of Pearson product-moment correlations.

RESULTS

Physical characteristics. Physical characteristics and body composition of obese and nonobese children are shown in Table I. Age and height were comparable in the two groups; weight, FFM, fat mass, body mass index, and percentage of overweight were significantly (p <0.01) higher in the obese group.

Energy expenditure

Postabsorptive metabolic rate. Expressed in absolute

Table I. Physical characteristics and body composition of obese and nonobese children

	Age (yr)	Weight (kg)	Height (cm)	BMI (kg/m²)	Overweight (%)	FM (%)	FM (kg)	FFM (kg)
Obese								
Boys (n = 6)	9.1 ± 1.5	45.2 ± 10.2	136 ± 8	24.6 ± 4.0	149 ± 19	34.1 ± 10.4	16.1 ± 7.1	29.1 ± 4.4
Girls (n = 6)	9.5 ± 0.5	44.9 ± 8.8	139 ± 9	23.5 ± 2.3	130 ± 4	34.9 ± 4.0	15.8 ± 4.5	29.0 ± 4.8
All (n = 12)	9.3 ± 1.1	45.0 ± 9.1	137 ± 8	24.1 ± 3.2	139 ± 12	34.5 ± 7.5	16.0 ± 5.7	29.0 ± 4.4
Nonobese								
Boys (n = 6)	9.4 ± 0.5	30.4 ± 4.8	137 ± 8	16.2 ± 1.4	102 ± 7	15.3 ± 7.0	4.8 ± 2.5	25.5 ± 3.5
Girls (n = 6)	9.1 ± 0.3	29.7 ± 2.8	136 ± 6	16.1 ± 2.3	94 ± 5	18.0 ± 4.3	5.3 ± 1.2	24.3 ± 2.9
All (n = 12)	9.3 ± 0.4	30.0 ± 3.8*	137 ± 7	16.2 ± 1.1*	97 ± 6*	16.7 ± 5.6*	5.1 ± 1.9*	24.9 ± 3.2†

Data are shown as mean ± SD.
BMI, Body mass index; *FM*, fat mass.
All obese versus all nonobese.
*p <0.001.
†p <0.05.

values, PMR was significantly higher in obese than in nonobese children (3.73 ± 0.50 vs 3.02 ± 0.38 kJ/min; p <0.01). Expressed per kilogram of body weight, PMR was significantly (p <0.001) lower in obese than in lean children (121 ± 13 vs 146 ± 11 kJ/kg per day). With analysis of covariance, no difference was found in the two groups when the PMR was adjusted for FFM (covariate), that is, the metabolically active tissue (5071 ± 336 vs 4734 ± 271 kJ/day [p = not significant] in obese and nonobese children, respectively). The slopes relating PMR *(y)* versus FFM *(x)* were comparable in the two groups (146.0 vs 142.8; p = not significant).

Total daily energy expenditure. The critical HR (flex HR) was comparable in obese and nonobese children (99 ± 4 vs 95 ± 7 beats/min; p = not significant). Overweight children had a significantly (p <0.01) higher energy expenditure lying down (4.18 ± 0.75 vs 3.39 ± 0.54 kJ/min), sitting (4.56 ± 0.92 vs 3.56 ± 0.58 kJ/min), and standing (4.77 ± 0.92 vs 3.85 ± 0.63 kJ/min). The average slopes between HR *(x)* and $\dot{V}O_2$ *(y)* for workloads above the flex HR were significantly higher (p <0.05) in obese than in nonobese children (regression coefficients 0.0147 ± 0.0045 vs 0.0110 ± 0.0028). The slopes relating TEE *(y)* versus FFM *(x)* were comparable in the two groups (regression coefficients, 151.9 vs 188.4 [p = not significant] in obese and control children, respectively).

The absolute values for TEE were significantly higher (p <0.01) in obese than in nonobese children (Table II), whereas when expressed per kilogram of FFM they were similar in the two groups (343 ± 38 vs 329 ± 59 kJ/kg FFM per day; p = not significant). Expressed per kilogram of body weight, TEE was significantly (p <0.01) lower in obese than in lean children (221 ± 40 vs 272 ± 32 kJ/kg per day).

The energy expenditure devoted to physical activity (including thermogenesis), that is, TEE − PMR, expressed in absolute values (4517 ± 832 vs 3931 ± 1060 kJ/day), per kilogram of FFM (158 ± 34 vs 161 ± 41 kJ/kg FFM per day), or per kilogram of body weight (105 ± 29 vs 123 ± 42 kJ/kg per day) was similar in obese and nonobese children.

The activity index, or TEE/PMR ratio, of obese children was comparable to that of nonobese children (1.86 ± 0.19 vs 1.87 ± 0.22; p = not significant).

Energy intake

Weighed dietary record. In the obese group, mean energy intake assessed by dietary record was significantly (p <0.001) lower than TEE (Table II). The level of agreement between the two measures was poor at the individual level (mean difference, −2.8 MJ/day; limits of agreement [i.e., mean difference ± 2 SD], −5.67 to 0.01 MJ/day) as well as at the group level (95% confidence interval for the bias, −3.73 to −1.93 MJ/day).

Nonobese children had comparable values (not significant) between TEE and dietary record (Table II), with an acceptable level of agreement between the two measures on an individual basis (mean difference, −0.1 MJ/day; range of agreement, −2.22 to 2.01 MJ/day). At the group level, the agreement was good (95% confidence interval for the bias, −0.78 to 0.56 MJ/day).

Energy intake assessed by dietary record and expressed as a percentage of TEE showed a significant inverse correlation with body weight and percentage of body fat (r = −0.80, p <0.001 and r = −0.72, p <0.001, respectively) (Fig. 1).

Diet history. Energy intake assessed by diet history was significantly (p <0.05) lower than TEE (Table II) in obese children, especially in boys. The level of agreement was poor both on an individual basis (mean difference, −1.52 MJ/day; range of agreement, −5.44 to 2.40 MJ/day) and at the group level (95% confidence interval for the bias, −2.77 to 0.27 MJ/day).

Nonobese children slightly overestimated energy intake

Table II. Total daily energy expenditure estimated from heart rate monitoring and total energy intake by 3-day weighed dietary record and by dietary history in obese and nonobese children

	TEE (MJ/day)	WDR (MJ/day)	WDR/TEE (%)	DH (MJ/day)	DH/TEE (%)
Obese					
Boys (n = 6)	10.14 ± 1.31	7.25 ± 0.89*	72 ± 11	7.96 ± 1.07‡	80 ± 18
Girls (n = 6)	9.63 ± 0.84	6.86 ± 1.10*	72 ± 14	8.77 ± 1.57	92 ± 20
All (n = 12)	9.89 ± 1.08	7.06 ± 0.98†	72 ± 12	8.37 ± 1.35‡	86 ± 19
Nonobese					
Boys (n = 6)	8.71 ± 1.22	8.21 ± 0.85	95 ± 13	9.57 ± 1.19	111 ± 19
Girls (n = 6)	7.56 ± 1.40	7.84 ± 1.16	105 ± 11	7.91 ± 1.45	105 ± 10
All (n = 12)	8.13 ± 1.39	8.03 ± 0.99	100 ± 12	8.64 ± 1.54	108 ± 14
Obese and nonobese					
Boys (n = 12)	9.43 ± 1.42	7.73 ± 0.97*	84 ± 17	8.82 ± 1.40	96 ± 25
Girls (n = 12)	8.59 ± 1.55	7.35 ± 1.19*	88 ± 21	8.39 ± 1.49	99 ± 17
All (n = 24)	9.01 ± 1.51	7.54 ± 1.08	86 ± 19	8.60 ± 1.43	98 ± 21

Data are shown as mean ± SD.
WDR, Weighed dietary record; *DH*, dietary history.
**p* <0.01 (TEE versus WDR).
†*p* <0.001 (TEE versus WDR).
‡*p* <0.05 (TEE versus DH).

(Table II). The level of agreement between the two estimates was acceptable on an individual basis (mean difference, 0.7 MJ/day; limits of agreement, −1.49 to 2.91 MJ/day) and was good at the group level (95% confidence interval for the bias, 0.01 to 1.41 MJ/day).

Energy intake assessed by diet history and expressed as a percentage of TEE showed a significant inverse correlation with body weight or percentage of body fat ($r = -0.71$, $p < 0.001$ and $r = -0.58$, $p < 0.01$, respectively) (Fig. 2).

DISCUSSION

The results of our study show that TEE in prepubertal obese children was 21% greater than in nonobese children, principally because of both a higher PMR and a higher energy expenditure in resting conditions (lying down, sitting, standing) in obese than in nonobese children. The larger FFM (the metabolically active tissue) in the obese group may explain the greatest part of this difference.[1, 13, 15] The TEE/PMR ratio, an index of physical activity, was comparable in the obese and nonobese children, suggesting that the proportion of energy spent on activity was similar in the two groups. This is of practical importance in terms of predicting the TEE of prepubertal children with different body weights and amounts of body fat because this factorial approach has been recommended by the National Academy of Science, in the United States, as a way to estimate the energy requirement from resting energy expenditure.[16]

The energy expended above the postabsorptive metabolic rate (TEE − PMR) includes the energy expenditure devoted to physical activity, postprandial thermogenesis, and the metabolic cost of growth (assumed to be negligible and within our error of measurement in 9-year-old children). Although TEE − PMR was not significantly different in the two groups, in absolute terms it was 24% higher in obese children; for a similar level of activity, the greater body weight of obese children causes a higher energy cost of weight-bearing activities than in nonobese children.

The concept of "small eaters" among obese prepubertal children, suggested by investigators who studied only one side of the energy balance equation (i.e., energy intake) is challenged by our results. In addition, recent data in adults suggest that obese persons do not have an extraordinary energy-sparing mechanism that makes them more fuel efficient than their lean counterparts.[17] Therefore this study does not support the hypothesis of a metabolic defect in maintenance energy expenditure or in activity-related energy expenditure, at least in prepubertal children who are already obese. The role of an impaired control of food intake rather than a disturbance in the regulation of energy expenditure seems to be the main factor affecting the development and maintenance of obesity in childhood.

In comparison with the nonobese children, the higher TEE observed in obese children was not consistent with the lower energy intake assessed on the basis of both the dietary record and the diet history methods. The discrepancy between energy intake and energy expenditure in the obese group suggests that obese children significantly underestimate their food intake. However, the children's parents, particularly the mothers, who were primarily responsible for recording food intake at meals, also underestimated the intake of their obese children. The mothers of the obese children were also overweight and had a significantly higher

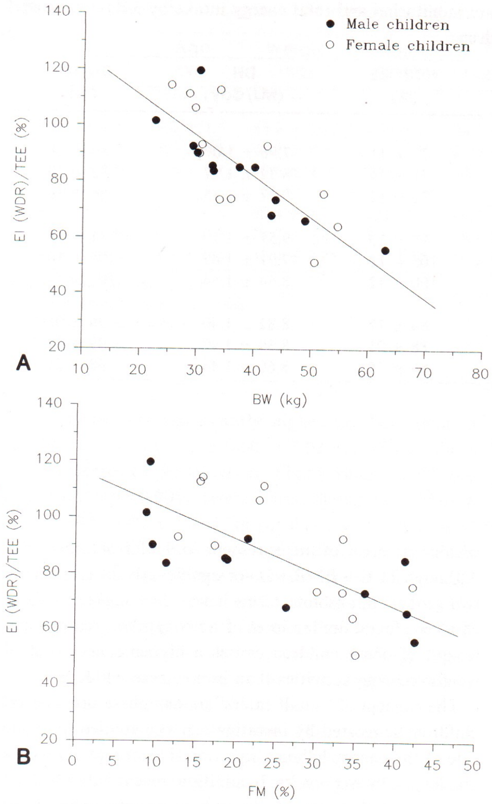

Fig. 1. Regression line between energy intake *(EI)* assessed by dietary record *(WDR)* and expressed as a percentage of total energy expenditure *(TEE)* and (**A**) body weight *(BW)* and (**B**) percentage of fat mass *(FM)*.

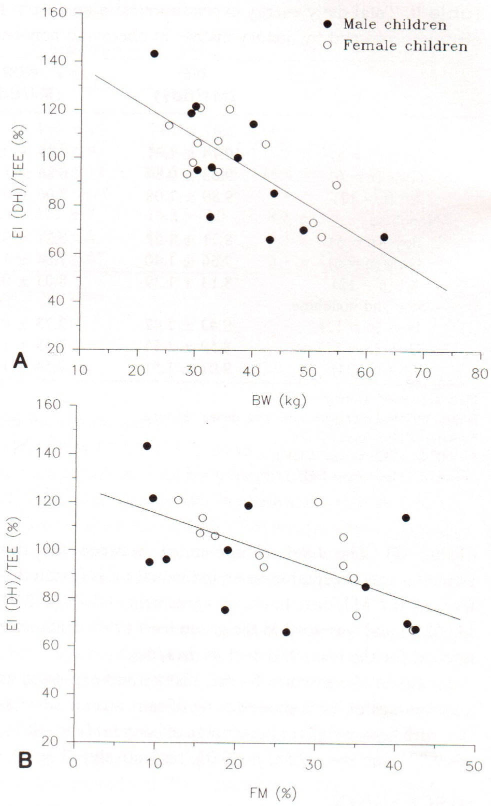

Fig. 2. Regression line between energy intake *(EI)* assessed by diet history *(DH)* and expressed as a percentage of total energy expenditure *(TEE)* and (**A**) body weight *(BW)* and (**B**) percentage of fat mass *(FM)*.

body mass index than the mothers of the nonobese children (29.0 ± 4.8 vs 23.4 ± 4.6 kg/m^2; p <0.01). In our study it was difficult to isolate the bias of the obese children from that of their overweight mothers. The inaccuracy of food intake assessment in the overweight children limits the ability to evaluate their habitual energy intake or their compliance with a dietary treatment by means of either the dietary record or the diet history techniques.

In contrast to the obese children, children of normal weight were fairly accurate in recording food intake with both the dietary record and the diet history methods, although on an individual basis the accuracy of these methods was found to be low.[18] The significant inverse correlation between body weight, as well as percentage of body fat, and energy intake (expressed as a percentage of TEE) confirms that recording errors increase with excess body weight or excess adiposity or both.[1]

We conclude that energy intake reported by the obese group was underestimated in the dietary record and, to a lesser extent, in the diet history. However, both methods showed good agreement with TEE in nonobese children. Self-reported dietary intakes are not valid measures for assessment of energy intake or energy expenditure in obese prepubertal children.

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