Comparison of energy intake by semiquantitative food-frequency questionnaire with total energy expenditure by the doubly labeled water method in young children[1–3]

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ABSTRACT We assessed the validity of a semiquantitative food-frequency questionnaire to estimate energy intake in young children by comparison with total energy expenditure (TEE). TEE was measured in 45 children (22 males and 23 females; 4.2–6.9 y of age) by the doubly labeled water method and body composition was estimated from bioelectrical resistance (20.2 ± 4.0 kg body weight, 4.6 ± 2.1 kg fat mass, and 15.6 ± 3.1 kg fat-free mass). The sample included 36 white children and 9 Mohawk Native American children. The children's mothers completed one Willett food-frequency questionnaire to reflect the child's usual dietary intake over the last year. Total energy intake by food-frequency questionnaire (9.12 ± 2.28 MJ/d) was significantly higher than TEE (5.74 ± 1.13 MJ/d; $P < 0.001$). Misreporting of intake by food-frequency questionnaire ranged from 9.57 MJ/d overestimation to 1.58 MJ/d underestimation and was not significantly influenced by sex or body composition of the children. We conclude that use of the food-frequency questionnaire significantly overestimates energy intake in children. *Am J Clin Nutr* 1994;60:43–7.

KEY WORDS Food-frequency questionnaire, children, energy intake misreporting

Introduction

Dietary energy-intake methodologies previously examined in children include weighed-diet records (1), diet histories (1), 24-h diet recalls (2–7), and food-frequency questionnaires (8–10). Unfortunately, the lack of a reasonable criterion against which the validity of energy-intake methodologies can be tested has hindered critical appraisal of the aforementioned techniques. Previous assessment of energy-intake methodologies in children have used 24-h dietary recalls as the criterion method and thus are limited by a lack of true validity due to the unknown absolute accuracy of the 24-h recall method. One exception is the work done by Livingstone et al (1), which incorporated doubly labeled water as the validation criterion method and found that diet histories approximated habitual energy intake in 4–5-y old children to within 11 ± 19% of total energy expenditure.

Measurement of total energy expenditure by the doubly labeled water method has proven a useful tool with which to test the validity of energy intake measures (1, 11–13) on the basis of the premise that in subjects who are in energy balance, total energy intake is equivalent to total energy expenditure. This approach is limited to the validation of total energy intake rather than specific macronutrient intake. In addition, use of total energy expenditure as the criterion method is unlikely to be useful for assessment of individual measures of energy intake because of large interindividual variability of energy intake, but is a valuable criterion for testing energy intake at the group level (12).

The semiquantitative food-frequency questionnaire represents a simple tool for measuring energy intake and has potential for widespread use because of the ease with which it can be administered and the simplicity with which it can be analyzed. The food-frequency questionnaire was originally developed for use in epidemiological research to classify individuals on a continuum of nutrient-intake distributions (14, 15). One of the original designs of the food-frequency questionnaire was as a measure of semiquantitative food intake (ie, relative macronutrient intake), which incorporated typical serving sizes for adults, thereby allowing for quantification of total energy intake (16). The reliability of the food-frequency questionnaire in adults is good [eg, reliability coefficient for total energy intake 0.63 (16) and 0.65 (17)], but weaker in children [eg, reliability coefficient for total energy intake 0.46 (10); 0.28 in boys and 0.48 in girls (9)].

Although the food-frequency questionnaire has limited reliability, the accuracy (ie, validity) of the technique for measuring absolute energy intake in children is unknown. In addition, the Willett et al food-frequency questionnaire used in this study is currently being marketed for use with children but has not been previously tested in this population. Because the food-frequency questionnaire is a widely used tool to measure dietary intake, determination of its validity is an important issue to confront.

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Therefore, the aim of this study was to test the accuracy of the food-frequency questionnaire for estimating dietary energy intake in young children by comparison with measurements of total energy expenditure by using the doubly labeled water method.

Methods

Subjects

The volunteers were 45 children (36 white, 9 Mohawk; 22 males and 23 females) 4.2–6.9 y of age from a total of 37 families. The families were recruited by newspaper advertisement, posters at preschools, and word of mouth from Burlington, VT and Hogansburg, NY. Informed consent was obtained from the parents of each child before participation. The study was approved by the Committee on Human Research for the Medical Sciences at the University of Vermont.

Body-composition and anthropometry measurements

Body-composition measurements were taken in both the children and their parents to examine the potential relationships between body composition and reporting of the children's energy intake. Body composition was measured in all subjects by bioelectrical resistance. Total body resistance was measured by using a four-terminal, portable bioelectrical impedance analyzer (RJL Systems, Detroit) and by following electrode placement procedures recommended by the manufacturer. The analyzer was calibrated before each test with a 500-Ω resistance cell.

Resistance, weight, and height were measured in duplicate in the children with the first and second measurements at the beginning and end of a 2-wk period, respectively. Single measures of resistance, weight, and height were obtained in the parents. Height was measured to the nearest 0.5 cm with a wall-mounted metric stadiometer and weight was measured to the nearest 0.1 kg on an electronic load cell scale (Scale-tronix, Whiteplains, NY). Total body water was estimated from height^2/resistance by using the equation of Kushner et al (18), which we previously cross-validated in 4–6-y-old children in two independent laboratory groups (19). Fat-free mass was calculated by dividing total body water by the hydration constant of fat-free mass using a value of 0.73 for adults and the age-specific constants for children (20), modified as described previously (19). Fat mass was obtained by subtracting fat-free mass from total body weight.

Total energy-intake measurement

A semiquantitative food-frequency questionnaire (16) was administered to the mother of each child. The food-frequency questionnaire used in this study was marketed by the Harvard Channing Laboratory for use with children. This questionnaire is similar to the adult food-frequency questionnaire with some minor exceptions. The adult food-frequency questionnaire, which has been shown to have good reliability in adults (16, 17), estimates the frequency of consumption of 111 common foods with serving sizes grouped as dairy foods; fruits; vegetables; meats; sweets and baked goods; breads, cereals, and starches; carbonated beverages; and miscellaneous. Serving sizes are based on typical adult portions derived from the 1980 Nurses Health study by Willett et al (16). The children's food-frequency questionnaire differs from the adult questionnaire by the omission of questions on alcohol consumption. Respondents had nine frequency choices ranging from never, or less than once per month, up to six times or greater per day for each food item. Blank spaces were available for recording food type, amount, and frequency of consumption to take into account culturally specific or uncommon foods that may be consumed but not listed on the questionnaire.

The same instructions were given to each child's mother on how to complete the food-frequency questionnaire. The instructions stated that the responses should reflect the child's usual dietary intake over the last year and that the form should be returned on the second (the following day) or third visit (2 wk). The food-frequency questionnaire was checked upon return for missing answers, which were obtained by a personal or telephone conversation with the mother. All of the questionnaires were completed by the mother, although occasionally, the father and/or the child would contribute. The completed questionnaires were sent to the Channing Laboratory at the Harvard School of Public Health for analysis.

Total energy-expenditure measurement

Total energy expenditure was measured over a 14-d period by using the doubly labeled water technique as described previously (21). Briefly, baseline urine samples were taken before oral dosing with ≈0.12 g ^2H_2O and 0.15 g $H_2{}^{18}O$/kg body mass. Two urine samples were collected the morning after dosing and another two urine samples were obtained 14 d later. Samples and prepared standard dilutions were analyzed in triplicate for $H_2{}^{18}O$ and ^2H_2O by isotope-ratio mass spectrometry at the Biomedical Mass Spectrometry Facility in the Clinical Research Center at the University of Vermont. Turnover rates and dilution spaces of $H_2{}^{18}O$ and ^2H_2O, carbon dioxide production rates, and total energy expenditure were calculated as previously described (21). We reported previously the total energy expenditure values of 30 of the children from this study in an analysis of energy requirements (21).

Statistics

Variables are presented as mean ± SD. A Student's t test was used to examine misreporting of energy intake (ie, the difference between total energy intake and total energy expenditure). The relationship between the dependent variable, misreporting of energy intake and the independent variables sex and ethnicity (ie, white and Mohawk) were assessed by a two-way analysis of variance (ANOVA). Pearson r values were computed to test the simple correlations between misreporting of energy intake and the children's and parents' body-composition variables. Statistical significance was set at $P \leq 0.05$ for all tests. Statistics were computed by using *SAS* (SAS Institute, Cary, NC) and *Statplan* (The Futures Group, Washington, DC) for personal computers.

Results

Physical characteristics of the children and parents in the study are summarized in **Table 1.** A difference between sexes was found for fat mass ($P < 0.001$), and percent body fat ($P < 0.0001$). All other body-composition variables were similar for boys and girls. The Mohawk children and the white children were similar in their physical characteristics.

Total energy expenditure and total energy intake of the children by sex are given in **Table 2.** The difference between total energy intake and total energy expenditure by sex, ethnicity, and

TABLE 1
Physical characteristics of the children and parents[1]

	Children		Parents	
	Females (n = 23)	Males (n = 22)	Mothers (n = 37)	Fathers (n = 37)
Weight (kg)	20.7 ± 4.1	19.5 ± 4.1	70.4 ± 17.7	87.3 ± 18.5[2]
Height (cm)	1.12 ± 0.1	1.11 ± 0.1	1.63 ± 0.1	1.78 ± 0.1[2]
Fat-free mass (kg)	15.2 ± 2.9	16.0 ± 3.3	46.2 ± 6.3	66.7 ± 8.4[2]
Fat mass (kg)	5.5 ± 2.4	3.6 ± 1.3[3]	24.3 ± 12.1	21.0 ± 11.9
Percent body fat (%)	26.2 ± 7.1	18.4 ± 4.4[4]	32.9 ± 7.6	22.4 ± 8.7[2]

[1] $\bar{x}$ ± SD.
[2] Significantly different from mothers, $P \leq 0.05$ (Student's t test).
[3,4] Significantly different from female children (Student's t test): [3] $P < 0.01$, [4] $P < 0.0001$.

sex-by-ethnicity interaction were not statistically different as determined by two-way ANOVA. Therefore, a combined group of all the children was used for further analyses.

Mean total energy expenditure of the children was 5.74 ± 1.13 MJ/d vs a mean total energy intake by food-frequency questionnaire of 9.12 ± 2.28 MJ/d (Table 2). The difference between total energy intake and total energy expenditure was significant ($P < 0.0001$), indicating that the food-frequency questionnaire overestimated total energy intake in children by 3.39 ± 2.45 MJ/d. The range of misreporting was from an overestimation of 9.57 MJ/d to an underestimation of 1.58 MJ/d.

No correlations were found between misreporting of energy intake and the body-composition measurements of the children. Paternal percent body fat was the only body-composition variable from parental data that was significantly correlated with misreporting of energy intake ($r = 0.32$, $P = 0.03$; **Table 3**).

Discussion

We examined a semiquantitative food-frequency questionnaire (16) as a measure of total energy intake in young children by testing it against total energy expenditure measured by the doubly labeled water technique. Although the food-frequency questionnaire was originally designed to estimate relative macronutrient intake, the purpose of this study was to determine how well the food-frequency questionnaire performed in estimating total energy intake in children.

A major strength of our study is that we used total energy expenditure measured by the doubly labeled water method as the criterion method whereas previous research compared the food-frequency questionnaire against 24-h dietary recalls. Treiber et al (10) compared two 24-h dietary recalls administered 1 wk apart with a food-frequency questionnaire modified to reflect a 3-mo period and found an ≈3.10-MJ/d overestimation of total energy intake. Stein et al (9) extended the comparison of 24-h recalls and food-frequency questionnaires to a 12-mo period and found an overestimation of 4.45 MJ/d for boys and 4.58 MJ/d for girls.

The reason that the semiquantitative food-frequency questionnaire leads to an overestimation of habitual energy intake in young children is unclear. Of the possible explanations for the overestimation of energy intake, the most likely source is bias from the questionnaire. Other sources, such as instructions provided by the investigator and questionnaire analysis procedures, were controlled by the administration of a specific set of instructions and by having an independent laboratory analyze the questionnaires.

We evaluated the food-frequency questionnaire for potential sources of bias and noted that the serving sizes listed on the questionnaire were based on adult portions typically consumed rather than child portions typically consumed. We expanded on this observation by comparing the serving sizes listed on the food-frequency questionnaire with published serving size recommendations for 4–6-y-old children (22) (**Table 4**). The serving portions from the food-frequency questionnaire were on av-

TABLE 2
Reported total energy intake (TEI), total energy expenditure (TEE), and overestimation of energy intake in young children[1]

	Females (n = 23)	Males (n = 22)	Pooled subjects (n = 45)
TEI (MJ/d)	9.11 ± 2.56	9.13 ± 1.9	9.12 ± 2.28
TEE (MJ/d)	5.63 ± 1.24	5.84 ± 1.14	5.74 ± 1.13
Overestimation of TEI (MJ/d)[2]	3.49 ± 2.82	3.28 ± 1.98	3.39 ± 2.45

[1] $\bar{x}$ ± SD.
[2] TEI − TEE.

TABLE 3
Correlations between overestimation of energy intake and the children's and parent's body composition

Independent variable	Correlation coefficient
Children's weight (kg)	0.14
Children's height (cm)	0.20
Children's body mass index	−0.01
Children's fat-free mass (kg)	0.13
Children's fat mass (kg)	0.08
Children's percent body fat (%)	−0.04
Mother's percent body fat (%)	−0.01
Mother's fat mass (kg)	−0.06
Mother's fat-free mass (kg)	−0.01
Father's percent body fat (%)	0.32[1]
Father's fat mass (kg)	0.24
Father's fat-free mass (kg)	0.00

[1] $P \leq 0.05$.

TABLE 4
Comparison of serving sizes on the food-frequency questionnaire (FFQ) with suggested serving sizes for 4–6-y-old children

	Serving sizes	
Food group and selected examples	Willett et al (16) FFQ	Lowenberg's (22) suggested[1]
Milk		
Fluid milk	1 cup (237 mL)	0.5–0.75 cup [50–75]
Cheese	1 oz (28.4 g)	0.5–0.75 oz [50–75]
Yogurt	1 cup (230 g)	0.25–0.5 cup [25–50]
Fruit		
Raw	1 piece	0.5–1 piece [50–75]
Canned	0.5 cup (112 g)	0.25–0.38 cup [50–75]
Juice	4 oz (119 mL)	4 oz [100]
Vegetables, cooked	0.5 cup (98 g)	0.19–0.25 cup [38–50]
Meats		
Beef, chicken, pork	4–6 oz (114–170 g)	1–2 oz [25–33]
Egg	1	1 [100]
Grains		
Bread	1 slice	1 slice [100]
Cold cereal	1 cup (28 g)	0.5 cup [50]
Cooked cereal	1 cup (196 g)	0.5 cup [50]
Rice	1 cup (196 g)	0.5 cup [50]
Pasta	1 cup (196 g)	0.5 cup [50]
Fats		
Margarine and butter	1 tsp (4.5 g)	1 tsp [100]
Peanut butter	1 TBSP (14 g)	2 TBSP [200]

[1] Percentage of FFQ's serving size in brackets.

erage ≈25–33% greater than the suggested serving sizes for 4–6-y-old children (Table 4). A limitation of this comparison is the absence of systematic studies available on typical serving sizes of children to contrast the typical serving sizes for children with those of adults. As delineated by Block et al (23) in their report on diet questionnaire design and testing, the respondent's portion sizes for foods consumed should be determined to account for sex and age differences. Thus, a portion of the overestimation of energy intake by the food-frequency questionnaire is probably explained by the inability of the food-frequency questionnaire to account for variation in the actual portions consumed by children.

The question then follows as to whether the food-frequency questionnaire could be modified by adjusting the serving sizes for age and whether an appropriate correction factor could be applied so that energy intake could be accurately measured. Previous research findings in adults were inconclusive when serving sizes were adjusted on a food-frequency questionnaire. Flegal et al (24) found that participants were not aware of the specified portion sizes listed, and therefore concluded that modification of serving sizes did not improve the quality of information obtained. On the other hand, Block et al (25) found that correlations between the modified food-frequency questionnaire and 16 d of dietary record were significantly improved with the addition of age-specific portion sizes. The role of modifying serving sizes to improve the accuracy of estimating energy intake in children with the food-frequency questionnaire warrants further investigation.

Child and parental body composition were next appraised as potential factors that might influence the magnitude of the overestimation of energy intake. Studies in adults have found that energy intake is underestimated by 12% among elderly men and 24% among elderly women (26), and by 47% among young obese subjects (13). In the present study in children, we did not find any evidence of a relationship between the child's or the mother's body composition and the overestimation of energy intake by the food-frequency questionnaire. Interestingly, paternal percent body fat was the only body composition variable significantly correlated with the misreporting of energy intake ($r = 0.32$, $P = 0.03$). We conclude that body composition of the children and their parents does not appear to be a strong factor influencing the overestimation of energy intake by food-frequency questionnaire in children.

A potential limitation of this study is that energy intake and energy expenditure were measured over different time frames. Total energy expenditure was measured over 2 wk whereas food intake was estimated over the preceding year. Despite these discrepancies in measurement periods, we think that interpretation of our data is not likely affected for several reasons. First, Treiber et al (10) examined the effects of shortening the dietary intake period assessed by the food-frequency questionnaire from 1 y to 3 mo. They found that total energy intake by food-frequency questionnaire overestimated dietary intake by ≈2.51 MJ/d when compared with two 24-h recalls obtained during the same 3-mo period. Thus, limiting the dietary-recall time period may not be advantageous for obtaining accurate total energy intake. Second, in previous research on 4–6-y-old children, we found no significant correlation between age and total energy expenditure (21), suggesting that total energy expenditure and energy intake do not change markedly over the course of the year. Finally, because of energy accretion, energy intake theoretically should be greater than total energy expenditure, but the energy required for growth in children is small (estimated to be 0.084–0.126 MJ/d) (27). We estimated that energy intake would be ≈2% higher than total energy expenditure to account for the energy accretion associated with growth.

Sources of error from using the food-frequency questionnaire are most likely random in addition to systematic, as reflected in the wide range of the children's dietary intakes (4.52–13.8 MJ/d) and the wide range of misreporting of energy intake (−1.58–9.57 MJ/d). These sources of random error are linked to the ability of the mother to remember her child's dietary intake and are influenced by many factors. The mother's capacity to complete the questionnaire is affected by memory failure, nutrition knowledge, and motivation to complete the form accurately (28). Memory errors may play a large role in the disparity between estimated intake by semiquantitative food-frequency questionnaire and actual intake. Sources of memory error consist of memory failure and elaboration or confusion with current diet (28). Additionally, the inability of the parent to correctly appraise serving sizes, the perceived value of the food items to be recalled, and the fact that children tend to better remember foods liked as larger portions than foods disliked augments the amount of error (28). The amount of time the parent spent observing the child during the recalled diet period may also be reflected in the elaboration of the answers.

In conclusion, the food-frequency questionnaire overestimates total energy intake in this sample of 4–6-year-old white and Native American children by 3.39 ± 2.45 MJ/d and the systematic overestimation of energy intake by food-frequency questionnaire was not a function of sex or body composition of the children. It is unknown in what manner the overestimation occurs, thereby leaving in question the accuracy and reliability of measuring absolute energy intake by food-frequency questionnaire. Further research using total energy expenditure measurements by the doubly labeled water method to validate the food-frequency questionnaire is needed to determine the best applications of this dietary-intake methodology and to determine appropriate modifications for its use with children.

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