Validation of energy intake measurements determined from observer-recorded food records and recall methods compared with the doubly labeled water method in overweight and obese individuals[1–3]

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ABSTRACT

Background: Measurements of dietary intake in obese and overweight populations are often inaccurate because food intakes are underestimated.

Objective: The purpose of this study was to evaluate the validity of the combined use of observer-recorded weighed-food records and 24-h snack recalls in estimating energy intakes in overweight and obese individuals.

Design: Subjects were 32 healthy women and 22 healthy men with mean body mass indexes (in kg/m^2) of 29.5 and 30.3, respectively. Energy intake (EI) was measured over 2 wk in a university cafeteria. No restrictions were made on meal frequency or EI. To document food consumed outside the cafeteria, 24-h snack recalls were conducted before meals. Energy expenditure (EE) was measured with the doubly labeled water (DLW) method (EE_{DLW}). Energy balance was determined by measuring body weight at the beginning and end of the 2-wk period.

Results: The mean EI in the women (10.40 ± 1.94 MJ/d) and men (14.37 ± 3.21 MJ/d) was not significantly lower than the EE_{DLW} in the women (10.86 ± 1.76 MJ/d) and men (14.14 ± 2.83 MJ/d). The mean EI represented 96.9 ± 17.0% and 103 ± 18.9% of the measured EE for women and men, respectively. There were no significant changes in weight in the group as a whole or by sex at the end of the testing period; the men lost 0.23 ± 1.58 kg and the women lost 0.25 ± 1.09 kg.

Conclusion: The combination of observer-recorded food records and 24-h snack recalls is a valid method for measuring EI in overweight and obese individuals. *Am J Clin Nutr* 2002; 75:263–7.

KEY WORDS Obesity, energy intake, doubly labeled water method, energy balance, energy expenditure, food records

INTRODUCTION

Traditionally, measurements of dietary intake have relied on self-reported data from diet histories, 24-h dietary recalls, food-frequency questionnaires, and weighed-food records. Observer-recorded food records have provided accurate measurements of dietary intakes in previous studies but often have been limited to use in controlled feeding trials in metabolic wards and thus may not reflect habitual food intakes (1, 2).

In the past decade, the measurement of energy expenditure (EE) with use of the doubly labeled water (DLW) method (EE_{DLW}) in free-living individuals has allowed researchers to investigate the validity of dietary measurements made subsequently in both lean and obese populations. However, data obtained from many studies that used self-reported dietary intake methods are limited because they lack agreement with data obtained with use of the DLW method. The lack of agreement between these 2 methods is primarily due to the underestimation of food intake by the subjects (3–10).

The largest discrepancy between self-reported energy intake (EI) and EE relative to EE_{DLW} consistently occurs in obese populations. This discrepancy is thought to occur because of systematic reporting errors. For example, obese individuals underreport their food intakes by ≈20–50% (11–14). Such reporting errors consequently confound the ability of researchers to determine habitual EIs in overweight and obese individuals.

Recently, researchers have begun to examine the extent and nature of underreporting of food intakes in obese populations. Goris et al (13) found that both undereating (a change in body mass over the recording period) and selective underrecording of food intakes accounted for 37% of underreporting in obese men. Similar conclusions were made by Heitman and Lissner (15), who found that obese men and women selectively underreport their intakes of fatty foods and foods rich in carbohydrate. Researchers have shown that as the degree of obesity increases, so does the degree of underestimation of EI (5, 13, 15–17). Because of these reporting biases, it is clear that the current methods used to collect self-reported EI data are not tenable in overweight and obese populations.

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The purpose of the present study was to evaluate the validity of observer-recorded weighed-food records in combination with 24-h snack recalls in moderately overweight individuals. To validate this method, average EIs obtained with use of the method were compared with EE_{DLW}.

SUBJECTS AND METHODS

Subjects

Fifty-four healthy subjects (*n* = 32 women and 22 men) were recruited from the participants of an ongoing, long-term (16 mo) exercise trial. The study was approved by the Advisory Committee on Human Experimentation at the University of Kansas. All subjects underwent a medical history and physical examination and were to be found free of metabolic disease. Before participation, all subjects gave informed consent after receiving an explanation of the procedures. The subjects were financially compensated for their participation.

Body weight and composition

Subjects reported to the Energy Balance Laboratory between 0700 and 0900 and were weighed before breakfast after they had attempted to void their bladders. Body weights were recorded with a digital scale accurate to ±0.1 kg while the subjects were wearing standardized gym shorts, T-shirts, and no shoes or socks. Body fat was estimated with the use of hydrostatic weighing, and underwater weight was recorded to the nearest 25 g. Residual volume was measured in duplicate with the use of the method of Wilmore et al (18) immediately before body density was measured. Body density was calculated with the use of the equation of Goldman and Buskirk (19), and percentage body fat was calculated with the equation of Brozek et al (20).

Resting metabolic rate

All subjects refrained from exercise for 48 h before testing began to eliminate any residual effects of the most recent exercise session on resting metabolic rate (RMR) (21–23). Before each RMR measurement, subjects were transported to the laboratory in a motorized vehicle. After entering the laboratory, the subjects rested supine for 20 min. RMR was then measured with a ventilated canopy hood system and a SensorMedics 2900 metabolic cart (SensorMedics, Yorba Linda, CA). The oxygen and carbon dioxide analyzers were calibrated with gases of known concentration before each test, and the flow meter was calibrated with a 3-L syringe. Each measurement of RMR required a minimum of 30 min. The test was continued until at least three 5-min blocks of steady state measurements were obtained. The measurements obtained in these 5-min blocks were then averaged to obtain the RMR. A valid metabolic steady state was defined as <10% fluctuation in minute ventilation and oxygen consumption and <5% fluctuation in the respiratory quotient over a 5-min period.

Observed and weighed-food records and recall methods

All subjects consumed meals at a university cafeteria for 2 wk. The cafeteria features a food court where different stations offer specialized items such as stir-fry, pasta, salads, sandwiches, pizza, and grilled foods. Subjects could typically choose from 8 to 10 entrées at each meal. The cafeteria was open for a total of 9.5 h on weekdays and 5.5 h (for brunch and dinner) on the weekend. Subjects were not required to eat a predetermined number of meals but were encouraged to maintain their usual meal pattern. The research staff weighed all the foods selected by the subjects with a balance (OHOUS Scout Balance; Cynmar Corp, Carlinville, IL). The EI for each subject was calculated by subtracting the energy content of plate waste from the initial energy content of each food and beverage item. The weights of the food and beverage items were recorded to the nearest 0.1 g. When necessary, subjects were allowed to choose foods for consumption outside the cafeteria, but were asked to return all food waste (eg, apple cores and partially eaten food) to the cafeteria the next day for measurement. Before the data were collected, all research personnel were tested to ensure that they could reliably determine EIs from plate waste and the recall instruments. Reliability was excellent (intraclass correlation > 0.95, $P < 0.05$).

Dietary recalls (for approximately the previous 12 h) were conducted each morning during the assessment period to document any food or beverage intakes outside the cafeteria. Before the lunch and dinner meals, the research staff questioned subjects about any snacks or beverages consumed between meals.

A registered dietitian reviewed all food records obtained during the testing period. Energy and nutrient intakes were calculated with the use of a food database (FOOD PROCESSOR, version 7.1; ESHA Research, Salem, OR). Vendor product information, recipes, and cooking methods for all foods and beverages served at the cafeteria were entered into the database.

Measurement of total energy expenditure with the doubly labeled water method

Subjects reported to the Energy Balance Laboratory between 0800 and 0900 after an overnight fast. Baseline urine specimens were collected from each subject before they drank a mixed solution containing ≈0.10 g ^2H_2O/kg body wt and 0.15 g $H_2{}^{18}O$/kg body wt and then a rinse solution of 100 mL tap water. After isotope administration, the subjects were free to engage in their usual daily activities. On day 1, the subjects were required to return to the laboratory 4–6 h after isotope administration to provide urine specimens; on subsequent study days, urine from the second void of the day was saved for isotopic analyses.

Detailed information on the procedures followed for specimen analysis and subsequent data analysis were described previously by Jones et al (24). Briefly, isotopic enrichment in the urine samples was determined with use of a VG Optima isotope ratio mass spectrometer (VG Isotech, Middlewich, United Kingdom). Total daily EE was estimated with the use of Elia's equation (25):

$$\text{Total EE (MJ/d)} = (15.48/\text{RQ} + 5.55) \times r\text{CO}_2\ (\text{L/d}) \quad (1)$$

where rCO_2 is the rate of carbon dioxide production.

Statistics

PC-SAS (SAS Institute Inc, Cary, NC) was used for the statistical analysis. Means and SDs were calculated for all dependent measures. We conducted a linear, forward stepwise regression to determine whether we could predict EE. To be included in the model, the variable needed to load at the $P < 0.05$ level. A dependent *t* test was calculated to determine differences between EE and EI and to compare changes in body mass. Additionally, a Bland and Altman plot (26) was used to assess agreement between EI and EE. To examine the possibility that a change in

TABLE 1
Baseline characteristics of the subjects[1]

	Women (n = 32)	Men (n = 22)
Age (y)	22.1 ± 4.3	22.7 ± 3.8
Weight (kg)	80.7 ± 9.7	97.5 ± 10.4[2]
BMI (kg/m²)	29.5 ± 2.8	30.3 ± 2.9
Fat-free mass (kg)	50.8 ± 5.3	69.9 ± 5.9[2]
Fat mass (kg)	29.9 ± 6.5	27.6 ± 6.3
Percentage body fat (%)	36.8 ± 4.7	28.1 ± 4.1[2]
RMR (MJ)	6.62 ± 0.82	8.65 ± 0.86[2]

[1] $\bar{x}$ ± SD. RMR, resting metabolic rate.
[2] Significantly different from women, $P < 0.05$.

weight influenced the difference between EI and EE, a linear regression analysis was performed

$$EB = B_o + B_1 \times Wt_{ch} \quad (2)$$

where EB is the difference between EE and EI, B_o is the intercept, and Wt_{ch} is the weight change.

RESULTS

The physical characteristics of the subjects at baseline are shown in **Table 1**. The ethnicity of the subjects was as follows: 81% white, 10% African American, 5% Asian, 2% Native American, and 2% Hispanic. The mean age of the subjects was 22.4 y. The women were overweight [body mass index (BMI; in kg/m²) = 29.5] and the men were obese (BMI = 30.3) by clinical definition (27). All subjects had excess body fat as indicated by hydrostatic weighing.

Mean EI, total daily EE_{DLW}, mean EI expressed as a percentage of EE (EI/EE × 100), EE/RMR, and EI/RMR are shown in **Table 2** for men and women. There was good agreement between estimates of mean EI and mean EE_{DLW} (12.02 ± 3.18 MJ compared with 12.19 ± 2.76 MJ, respectively). The mean EI represented 99.4 ± 17.9% of the measured EE, although individual differences ranged from −37.3% to 44.2%. In the women, EI was slightly underestimated in most and the average EI/EE was 96.9 ± 17.0%. The men had a positive EI/EE (103.0 ± 18.9%); however, EI/EE was equally divided above and below the EE value.

Individual differences between reported EI and EE in women and men ranged from −38.4% to 38.8% and from −30.2% to 44.1%, respectively. The correlation between reported EI and EE was 0.71 (**Figure 1**). The differences between EI and EE in men and women, as a function of average EIs and EEs, are shown in **Figure 2**. The mean difference was calculated to obtain relative bias for the group estimate, and the limits of agreement (±2 SDs of the difference) indicate the scatter of individual differences. The mean difference between the 2 measurements was −0.18 MJ/d. The 95% CI for the bias for EI ranged from −0.80 to 0.46 MJ/d, which indicated good agreement at the group level. However, the limits of agreement for individuals was large (range: 4.45 to −4.64 MJ/d), which indicated a wide scattering of differences for under- and overreporting of EI. Individual differences tended to increase as absolute energy values increased, which confirms the likelihood that subjects who eat more tend to have greater day-to-day variation in food intake. This tendency is shown for men in Figure 2.

There were no significant changes in weight in the group as a whole or by sex at the end of the 14-d testing period (**Table 3**). The men and women lost a similar amount of weight over the 14-d testing period, suggesting that they underate during this time. Weight fluctuations were larger on an individual level than

TABLE 2
Comparison of measured energy intake (EI) and energy expenditure (EE) determined with the doubly labeled water method[1]

	Women (n = 32)	Men (n = 22)
EI (MJ/d)	10.40 ± 1.94	14.37 ± 3.21[2]
EE (MJ/d)	10.86 ± 1.76	14.14 ± 2.83[2]
EI − EE (MJ)	−0.44 ± 1.86	0.22 ± 2.85
EI/EE (%)[3]	96.9 ± 17.0	103.0 ± 18.9
EE/RMR	1.65 ± 0.25	1.63 ± 0.31
EI/RMR	1.59 ± 0.35	1.65 ± 0.30

[1] $\bar{x}$ ± SD. RMR, resting metabolic rate.
[2] Significantly different from women, $P < 0.05$.
[3] EE/EI × 100.

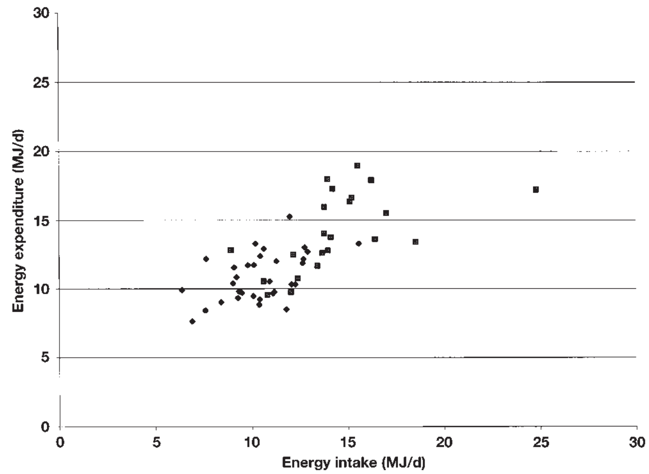

FIGURE 1. Relation between energy expenditure measured with use of the doubly labeled water method and energy intake in women (◆) and men (■). Linear regression line: energy intake (MJ) = 0.812 × energy expenditure (MJ/d) + 2.12; $r = 0.71$, $P < 0.001$.

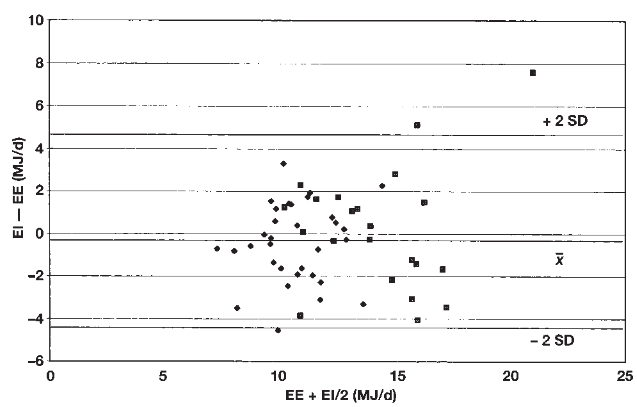

FIGURE 2. Individual differences between energy intake (EI) and energy expenditure (EE) measured with use of the doubly labeled water method plotted against the mean of the measurements of EI and EE in women (◆) and men (■). Lines are drawn to indicate the means ± SDs.

TABLE 3
Weight and weight changes during administration of doubly labeled water[1]

	Women (n = 32)	Men (n = 22)
	kg	
Beginning weight (day 0)	81.27 ± 9.67	98.32 ± 10.03[2]
Ending weight (day 14)	81.02 ± 9.52	98.09 ± 10.69[2]
14-d Change in weight	−0.25 ± 1.09	−0.23 ± 1.58

[1] $\bar{x}$ ± SD.
[2] Significantly different from women, $P < 0.05$.

by group, ranging from 2.49 to −4.01 kg in men and from 1.56 to −2.29 kg in women. After adjustment for weight changes, the test for the intercept equal to zero was insignificant for both the group as a whole and for men and women individually.

DISCUSSION

Previous research clearly indicates a significant and systematic underestimation of food intake by overweight and obese subjects asked to recall or record their food intakes (11–14). As a consequence, it is particularly important that reliable methods be developed to accurately estimate EIs in these at-risk populations. In the present study, the DLW method was used as a biomarker of the validity of EIs derived from observer-recorded weighed-food records and 24-h snack recalls in overweight and obese populations. The results indicate that EIs determined with these methods were in excellent agreement with mean EE_{DLW} values. For the group as a whole, the measured EI was 99.4 ± 17.9% of the EE. Although there was close agreement at the group level, EI measured by an observer still presents problems of precision as indicated by the large scattering of differences on an individual level. Clearly, some subjects in the present study underate or overate. The easy access to food provided in the cafeteria environment and the invasive nature of food weighing must be considered factors in the individual variation observed.

The correlation coefficient between EI and measured EE in the present study was 0.71 and the regression coefficient for the slope of the line relating EI to EE was 0.81. In a previous validation study that used food records and the DLW method, weak agreement (r = 0.45) was shown (10). In a larger study that compared EI with estimated EE for weight maintenance, Mertz et al (28) found a correlation coefficient of 0.61, whereas de Vries (29) et al found a more robust correlation coefficient of 0.85, representing an EI that was ≈10% lower than the energy requirement for the experiment.

On average, both the men and women lost weight over the 14-d study period, suggesting a change in food consumption patterns. Undereating may have been a factor that was not readily shown by measurement of EI. Sixty-two percent of the women lost weight, which suggests undereating rather than underreporting of snack and other food intakes. However, as one might expect because of random chance, an equal number of men also lost and gained weight during the testing period. Because EI slightly exceeded EE in men, it is likely that some of the men overreported their snack and food intakes outside the cafeteria. It is feasible that the bagged lunches and snacks taken for consumption outside the cafeteria were not eaten entirely, but were reported as such to lessen the burden of having to return the food waste. Subjects consumed, on average, 20.1% of their total daily food intake outside of the cafeteria, which increased the potential for under- and overreporting of food intakes. Although the change in weight on day 14 was not significantly different from that on day 0 in the group as a whole, there were large individual differences in weight losses and gains. It appears that in the present study, as shown by others (4, 13), the act of measuring food intake alters an individual's behavior and, therefore, food intake.

Some subjects reported limitations in food selection and availability. The cafeteria was not open continuously; however, food service began at 0700 and ended at 0730 on weekdays to accommodate the students'schedules. Most of our subjects enjoyed the cafeteria setting and ate there throughout the school year. By allowing our subjects to snack or eat late meals outside of the cafeteria, we thought we were better able to capture habitual EIs. Additionally, the high degree of researcher contact and familiarity may have lessened some selective underreporting. In a study by Poppitt et al (2), the primary food selectively underreported was high-carbohydrate snacks in both obese and nonobese woman eating an ad libitum diet in a metabolic facility. However, Goris et al (13) found no relation between snack intake and selective underreporting in obese subjects.

The DLW method has been extensively validated (30–34) and provides a high level of accuracy and precision. However, work by Ravussin et al (35) suggests that the more obese the subject, the greater the likelihood that the DLW method will underrepresent EE. Because our subjects represented the lower end of clinical obesity, we doubted that EE_{DLW} would be underestimated in our obese subjects. Additionally, the mean EE of our subjects was similar to that obtained in other studies that evaluated overweight and obese female subjects (36–38). On average, the women in our study required 10.86 ± 1.76 MJ/d. Fogelholm et al (36), who studied older women with similar BMIs, found mean energy requirements to be only 0.60 MJ/d lower than those of our subjects. The average ratio of EE to BMI for the men in our study (0.47) agreed well with the ratio calculated (0.49) with the data reported by Goris et al (13) for obese men. In our study, the men and women had a total EE of ≈1.6 × RMR. Prentice et al (14) found that, on average, free-living overweight women have a total EE of 1.5 × basal metabolic rate, whereas Bandini et al (11) reported a total EE of ≈1.7 × basal metabolic rate for obese adolescents.

This study showed that the combined use of observer-recorded weighed-food records and 24-h snack recalls is a valid method for capturing food intake in an overweight group of individuals. However, caution must be taken when evaluating these data on an individual level because of the lack of precision shown. The methods described herein provide a means for capturing habitual EIs in a group of individuals who are more likely to underreport or undereat during examination periods.

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