Equilibrium Energy Intake Estimated by Dietary Energy Intake and Body Weight Changes in Young Japanese Females

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Summary To determine the energy intake (EI) required to maintain body weight (equilibrium energy intake: EEI), we investigated the relationship between calculated energy intake and body weight changes in female subjects participating in 14 human balance studies ($n=149$) conducted at the National Institute of Health and Nutrition (Tokyo). In four and a half studies ($n=43$), sweat was collected from the arm to estimate loss of minerals through sweating during exercise on a bicycle ergometer; these subjects were classified in the exercise group (Ex G). In nine and a half experiments ($n=106$) subjects did not exercise, and were classified in the sedentary group (Sed G). The relationship between dietary energy intake (EI) and body weight (BW) changes (ΔBW) was analyzed and divided by four variables: body weight (BW), lean body mass (LBM), standard body weight (SBW), and body surface area (BSA). Equilibrium energy intake (EEI) and 95% confidence interval (CI) for EEI in Ex G were 34.3 and 32.8–35.9 kcal/kg BW/d, 32.0 and 30.8–33.1 kcal/kg SBW/d, 46.3 and 44.2–48.5 kcal/kg LBM/d, and 1,200 and 1,170–1,240 kcal/m² BSA/d, respectively. EEI and 95% CI for EEI in Sed G were 34.5 and 33.9–35.1 kcal/kg BW/d, 31.4 and 30.9–32.0 kcal/kg SBW/d, 44.9 and 44.1–45.8 kcal/kg LBM/d, and 1,200 and 1,180–1,210 kcal/m² BSA/d, respectively. EEIs obtained in this study are 3 to 5% higher than estimated energy requirement (EER) for Japanese. In five out of six analyses, EER in a population (female, 18–29 y, physical activity level: 1.50) was under 95% CI of EEI obtained in this study.

Key Words equilibrium energy intake, body weight change, energy metabolism, humans

Estimated energy requirement (EER) for the Japanese is defined as energy intake (EI) required to maintain body weight (1). However, EER is actually determined by measuring energy expenditure (EE). Although the units of EI and EE are the same (kcal), they are measured differently. EI is calculated based on the weight of food consumed and its energy content as it appears in the Food Composition Tables (2). EE is determined mainly by measurement of oxygen intake.

There is no confirmation that EE and EI are the same, but the current guidelines for EI treat them as such (1). Thus, the present study sought to compare EE and EI to establish the relationship between the two.

In adults, it should be possible to determine EER using EI if EI and body weight change are significantly correlated. Therefore, in a previous study (3), we tested this relationship using data from prior human metabolic balance studies in which male subjects consumed diets with known energy content and had their body weights recorded. Although the number of the subjects was small, the relationship between EI and body weight

change was significant.

In this analysis, we sought to confirm this relationship in a larger cohort of female subjects using data from human metabolic balance studies.

SUBJECTS AND METHODS

Data for this analysis were obtained from 17 human metabolic balance studies ($n=178$) conducted by the National Institute of Health and Nutrition (Tokyo) between 1986 and 2007. Some of results in minerals and nitrogen were already reported (4–21). However, the relationship between EI and body weight change in female subjects was analyzed in this report for the first time. Three of these studies were omitted from the present analysis, two because they used male subjects, and one which did not collect skin-fold thickness data. Subjects in the remaining studies (14 experiments, $n=149$) were young females. In four and a half studies ($n=43$), sweat was collected from the arm to estimate loss of minerals through sweating during exercise using a bicycle ergometer (intensity: 1.0–1.5 kp, velocity: 50–60 rpm, duration: 30–60 min/trial, once or twice per day, with room temperature 22–29°C and humidity 40–65% RH) (4); these subjects were classified in the exercise group

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Table 1. Outline of experiments.

Experiment No.	Subject			Duration (d)	Dietary intake			
	Gender	Ex. G	Sed. G		Energy (kcal)	Protein (g)	Lipid (g)	Carbohydrate (g)
1	F	12		8	1,557	75	66	167
2	F	8		15	1,729	78	48	244
3	F	8		12	1,930	87	57	263
4	F	8		8	1,712	69	47	251
5	F	7	2	8	1,815	76	53	253
6	F		12	10	1,636	65	64	195
7	F		12	8	1,922	66	68	258
8	F		11	8	1,906	66	68	254
9	F		12	8	1,633	59	41	253
10	F		11	8	1,647	61	45	244
11	F		10	8	1,638	55	46	249
12	F		11	12	1,906	73	43	303
13	F		12	8	1,659	62	45	245
14	F		13	8	1,804	32	5	393
Total		43	106					

Table 2. Physical characteristics of subjects.

Items		Exercise group	Sedentary group	Independent <i>t</i> -test
Number		43	106	
Age	(y)	20.1±0.6	20.1±1.6	NS
Body height (H)	(cm)	159.4±1.4	158.6±14.4	NS
Initial body weight (i-BW)	(kg)	52.71±5.31	51.94±1.59	NS
Final body weight (f-BW)	(kg)	52.25±5.22	51.85±4.98	NS
Body weight change ($\Delta W/d$)	(g/d)	-44±29	0±0	NS
Body mass index (BMI)	(kg/m ²)	20.7±0.4	20.3±1.6	NS
Standard body weight (SBW)	(kg)	56.0±1.0	56.4±4.0	NS
Lean body mass (LBM)	(kg)	39.6±0.5	39.8±0.1	NS
Body surface area (BSA)	(m ²)	1.49±0.02	1.48±0.38	NS

(Ex G). In nine and a half experiments ($n=106$) no exercise was performed, and these subjects were classified in the sedentary group (Sed G). During all the metabolic studies, subjects were asked to be sedentary except for the physical exercise scheduled in the experiments. An outline of experiments performed is shown in Table 1.

For each experiment, all subjects gave written informed consent. All studies in the present analysis were carried out according to the rules of the Helsinki Declaration. The ethical committee of the National Institute of Health and Nutrition, established in 1990, approved all studies. All studies were carried out in the Humanities Ward of the National Institute of Health and Nutrition.

Physical characteristics of the subjects are shown in Table 2.

In this study, the relationship between dietary energy intake (EI) and body weight (BW) changes (ΔBW) was determined and divided by four parameters: body weight (BW), lean body mass (LBM), standard body weight (SBW), and body surface area (BSA); thus, the results of

this study may be generalized to obese or lean subjects. BW is initial body weight in the morning after an overnight fast on the first day of the balance period (Table 3). LBM was calculated using BW and body fat percentage, which was estimated based on body density (BD) using the method of Keys and Brozek (22). BD was determined at the beginning of the study using the formula of Nagamine (23), based on skin-fold thickness (back of upper arm and sub-scapula) of the non-dominant arm measured using EIKEN skin-fold calipers (24). SBW was calculated using average height in meters in the morning throughout the balance period using the following formula: $SBW=22 \times (\text{height: m})^2$ (kg) as proposed by the Japan Society for the Study of Obesity (JASSO) (25). BSA was calculated using BW and height by the method of Fujimoto et al. (26).

Each metabolic study consisted of three phases: pre-balance (adaptation), balance, and post-balance. In the pre-balance period (2–4 d), subjects were given an experimental diet in order to adapt it to their needs and to the needs of the study. When the diet was not suitable

Table 3. Sample experimental design (No. 14, Table 1).

(1) Total schedule

Experimental day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Period	Pre-balance (Adaptation)			Balance study (Step 1)						(Step 2)			Post-balance (Completion)		
Dietary menu No.	A	3	4	1	2	3	4	1	2	3	4	1	2	3	A
Height		○	○	○	○	○	○	○	○	○	○	○	○	○	○
Weight		○	○	○	○	○	○	○	○	○	○	○	○	○	○
Skin fold thickness			○												
Initial body weight							Final body weight								

(2) Daily schedule

6:00	8:30	12:30	18:30	22:00
Get up	Breakfast	Lunch	Supper	Lights-out
Excretion Height Weight Blood pressure (Blood)	Excretion	Laboratory assistant	Laboratory assistant	Excretion Height Weight Blood pressure (Skin fold thickness)

Each metabolic study consists of three phases of periods, namely, pre-balance (adaptation), balance and post-balance.

In the pre-balance period (2–4 d), the subject consumed the experimental diet to adapt it to subjects' dietary and investigators' experimental requirements.

Duration of the balance period ranged from 8 to 15 d.

In the post balance period, the balance study was completed.

Table 3 is an experimental protocol.

for the subject, for example, if it contained more food than subjects could eat, the menu was adjusted. Duration of the balance period ranged from 8 to 15 d. In the post-balance period, the balance study was complete. Table 3 shows the experimental protocol (No. 14, Table 1).

Metabolic studies used to evaluate nutritional balance, in which subjects have to eat all food supplied and maintain a set schedule, have the potential to be stressful for the subjects. However, the results of one experiment (No. 13, Table 1) showed that participation in the metabolic study had almost no effect on subjects' subjective fatigue (16) or immunoglobulin levels (17).

Dietary menus were designed by a registered dietician (NK) so as to meet dietary allowances in Japan (27), except for the experiments involving special diets, for which food composition tables were used (28, 29). All menus calculated using older food composition tables (28) were re-calculated using new food composition tables (29) for this analysis.

Subjects were required to consume all of the diet. They were allowed no other food, but could drink as much ion-free water as they wanted. The weight of the water consumed was measured and recorded.

During metabolic studies, subjects spent their daily life according to the set schedule, ate all the diet supplied, and were asked to be sedentary except for the physical exercise scheduled in the experiments (Table 3).

Body weight measurements. In all experiments, subjects had their body weight measured (10 g sensitivity) with no clothes on after emptying the bladder every morning immediately after getting up.

Determination of initial body weight (i-BW) and final body weight (f-BW). Initial body weight (i-BW) was designated as body weight in the morning on the first day of the balance study, and final body weight (f-BW) as that on the day following termination of the balance study (Table 3). We did not use body weight data from the pre- and post-balance periods, due to potential body weight fluctuation caused by body water shifts, changes in intestinal contents, and other factors.

Basal metabolic rate (BMR) during experiments (Nos. 9–14, Table 1). Basal metabolic rate (BMR) during experiments (Nos. 9–14, Table 1) was measured using a Douglas bag and mass spectrometry. Some of these results were previously reported elsewhere (18, 19).

Total energy expenditure (TEE) during the balance period (No. 8, Table 1). Total energy expenditure during one of the experiments (No. 8, Table 1) was measured using the doubly labeled water method. Details of this study were previously reported elsewhere (20, 21).

Data analysis and statistics. Data are shown as means $\pm$ SD. The relationship between dietary energy intake (EI) and body weight change (Δ BW) was examined by simple linear regression analysis or analysis of covariance after dividing by the four parameters using Stat View-J 5.0. Physical characteristics in the Ex and Sed groups, and EEI divided by LBM in sedentary male and female subjects were compared using independent *t*-tests.

RESULTS

Characteristics of subjects in the two groups

Characteristics of subjects in the two groups were not

Fig. 1. Relationship between dietary energy intake and body weight change. The relationship between dietary energy intake (EI) and body weight change (ΔBW) was examined by simple linear regression analysis after dividing by (A) body weight (BW), (B) standard body weight (SBW), (C) lean body mass (LBM), and (D) body surface area (BSA), in both the exercise group (Ex G) and the sedentary group (Sed G). The regression equation, coefficient of determination (r^2), 95% confidence interval (CI) for EEI, and results of analysis of covariance (AC: p) are shown in each figure.

significantly different (independent t -test, Table 2).

Relationship between energy intake (EI) and body weight changes (ΔBW)

The relationship between EI and ΔBW divided by the four parameters is shown in Fig. 1.

1) Relationship between EI and ΔBW divided by body weight (BW) (Fig. 1A). EI and ΔBW divided by BW were significantly correlated in both the Ex ($r^2 = 0.142$, $p < 0.001$) and Sed ($r^2 = 0.324$, $p < 0.001$) groups. Equilibrium energy intake (EEI) and 95% confidence interval (CI) for EEI were 34.3 and 32.8–35.9 kcal/kg BW/d (96–105% of the intercept), respectively, in Ex G, and 34.5 and 33.9–35.1 kcal/kg BW/d (98–102% of the intercept), respectively, in Sed G. EEIs in both groups were nearly the same, but in analysis of covariance, the slope for Ex G was significantly different from that for Sed G ($p = 0.0279$).

2) Relationship between EI and ΔBW divided by standard body weight (SBW) (Fig. 1B). EI and ΔBW divided by SBW were also significantly correlated in both Ex G ($r^2 = 0.172$, $p < 0.001$) and Sed G ($r^2 = 0.116$, $p < 0.001$). EEI and 95% CI for EEI were 32.0 and 30.8–33.1 kcal/kg SBW/d (96–103% of the intercept), respectively, for Ex G, and 31.4 and 30.9–32.0 kcal/kg SBW/d (98–102% of the intercept), respectively, for Sed G. EEIs in both groups were nearly the same, and in analysis of covariance, the slope for Ex G was not significantly different from that for Sed G ($p = 0.7225$).

3) Relationship between EI and ΔBW divided by lean body mass (LBM) (Fig. 1C). EI and ΔBW divided by LBM were also significantly correlated in both Ex G

($r^2 = 0.084$, $p < 0.001$) and Sed G ($r^2 = 0.260$, $p < 0.001$). EEI and 95% CI for EEI were 46.3 and 44.2–48.5 kcal/kg LBM/d (95–105% of the intercept), respectively, in Ex G, and 44.9 and 44.1–45.8 kcal/kg LBM/d (98–102% of the intercept), respectively, in Sed G. EEIs in both groups were nearly the same, but in analysis of covariance, the slope for Ex G was significantly different from that for Sed G ($p = 0.0243$).

4) Relationship between EI and ΔBW divided by body surface area (BSA) (Fig. 1D). EI and ΔBW divided by BSA were also significantly correlated in both Ex G ($r^2 = 0.223$, $p < 0.001$) and Sed G ($r^2 = 0.252$, $p < 0.001$). EEI and 95% CI for EEI were 1,200 and 1,170–1,240 kcal/m² BSA/d (97–103% of the intercept), respectively, for Ex G, and 1,200 and 1,180–1,210 kcal/m² BSA/d (99–101% of the intercept), respectively, for Sed G. EEIs in both groups were nearly the same, and in analysis of covariance, the slope for Ex G was not significantly different from that for Sed G.

In the four analyses, significant differences were not observed in equilibrium energy intake (EEI) between exercise (Ex) and sedentary (Sed) groups.

Comparison of equilibrium energy intake (EEI) and estimated energy requirements (EERs) in the Dietary Reference Intakes (DRIs) (2010) (1)

The results of this study were compared with EERs from the DRIs (2010) using the standard height and weight at physical activity levels (PLA) of 1.50 and 1.75 from the DRIs (females 18–29 y: 158.0 cm, 50.6 kg) (Table 4). EEI (1,724–1,756 kcal/d) was 103–105% of EER {PAL I (1.50): 1,677 kcal/d}, or 88–90% of EER

Table 4. Comparison between EEI in this report and EER in DRI in the case of typical women.

Group	Parameter divided	EEI/parameter		Unit	Size of typical women ¹	EEI (kcal/d)		EER (kcal/d) ⁴
		Intercept	95% CI			Intercept	95% CI	
Exercise group	Body weight (BW) ¹	34.3	32.8–35.9	kcal/kg BW/d	50.6 kg	1,735	(1,660–1,827)	for both exercise and sedentary groups 1,677 (PAL I: 1.50) 1,957 (PAL II: 1.75)
	Standard body weight (SBW) ²	32.0	30.8–33.1	kcal/kg SBW/d	54.9 kg	1,756	(1,690–1,817)	
	Body surface area (BSA) ³	1,205	1,166–1,244	kcal/m ² BSA/d	1.455 m ²	1,753	(1,697–1,810)	
Sedentary group	Body weight (BW) ¹	34.5	33.9–35.1	kcal/kg BW/d	50.6 kg	1,746	(1,710–1,776)	
	Standard body weight (SBW) ²	31.4	30.9–32.0	kcal/kg SBW/d	54.9 kg	1,724	(1,696–1,757)	
	Body surface area (BSA) ³	1,196	1,180–1,210	kcal/m ² BSA/d	1.455 m ²	1,741	(1,716–1,766)	

¹ Dietary Reference Intakes for the Japanese, 2010 (1).² (Height: m)² × 22 (25).³ The method of Fujimoto et al. (26).⁴ EER = BMR (22.1 kcal/kg BW/d) × {Physical activity level (PAL)} (1).

{PAL II (1.75): 1,957 kcal/d}.

In five out of six comparisons between EER and EEIs, EER was less than lower limits of 95% CI of EEIs. EEIs for Ex and Sed groups obtained using body surface area (BSA) as parameter, were 4.53% and 3.82% higher than EER, respectively.

Gender differences in EEIs

Equilibrium energy intakes (EEIs) divided by kg LBM for sedentary young females obtained in this study were compared with those for sedentary young males obtained in the previous study (3).

EEIs divided by kg LBM for sedentary young females in this study (44.9 kcal/kg LBM/d) were significantly lower than those for sedentary young males (46.2 kcal/kg LBM/d) (2) ($p=0.0016$).

DISCUSSION

This is the first report on equilibrium energy intake (EEI) in young females. The authors believe the sample size of this analysis is sufficiently large to determine EEI. *Relationship between energy intake (EI) and body weight changes (ΔBW)*

In the four analyses, significant differences were not observed in equilibrium energy intake (EEI) between exercise (Ex) and sedentary (Sed) groups. The reason is not clear, but exercise in this study might not have affected daily energy expenditure. We speculated that subjects of Ex G reduced energy consumption after exercise, and compensated for additional energy consumption during exercise to decrease body temperature to the normal levels. Further experiments are needed to clarify this phenomenon.

Ninety-five percent confidence intervals (95% CI) of the intercepts obtained by dividing by the four parameters ranged between 95–105% and 99–101% of the intercepts for the Ex and Sed groups, respectively. Although the 95% CI for the Ex G was slightly wider than that for the Sed G, the error ranges of equilibrium energy intake (EEI) obtained in this analysis were very narrow. The authors believe the reliability of EEI in the present study is very high.

EEI for typical Japanese women (18–29 y, 158.0 cm, 50.6 kg) was calculated using data from the Ex and Sed groups divided by body weight (BW), standard body weight (SBW), and body surface area (BSA), and ranged from 1,735–1,756 in Ex G and 1,724–1,746 kcal/d in Sed G. EEIs obtained by the three methods were nearly the same in the Ex and Sed groups. This indicates that any of these three methods can be applied to estimate EEIs for females in any other age group. However, the difference between males and females in EEI divided by LBM suggests that further analysis is needed to be able to apply this method to males.

Comparison of EEI in this analysis and estimated energy requirement (EER) in the dietary reference intake (DRI) (1)

EEIs in the Ex and Sed groups in this analysis were nearly the same (34.3 and 34.5 kcal/kg BW/d, respectively) and were 1.55 and 1.56 times the standard basic metabolic ratio proposed by the DRI (22.1 kcal/kg BW/d) (1), and 1.57 and 1.58 times the basic met-

abolic ratio measured in some subjects in this analysis (21.9 kcal/kg BW/d) (Nos. 9–11, Table 1) (18, 19). In five out of six comparisons between EER and EEIs, EER was less than the lower limits of 95% CI of EEIs. EEIs for Ex and Sed groups obtained using body surface area (BSA) as a parameter were 4.53% and 3.82% higher than EER, respectively (Table 4).

Thus, in this group, EEI is quantitatively 3 to 5% higher than EER for individuals with low physical activity levels (PAL: 1.50). The reason of this difference is not clear, but we assume EEI is 3–5% higher than EER or EER is estimated lower than the actual EER in this group. Further investigation is needed to clarify this difference between EEI and EER.

Relationship between EI and total energy expenditure (TEE)

Ebine (20) measured total energy expenditure (TEE) using the doubly-labeled water method during a balance study (No. 8, Table 1). However, although EI was the same in each subject, TEE and Δ BW differed among subjects, and the relationship between EI and TEE was not clear.

Ebine et al. (21) also investigated the relationship between EI and TEE when body weight was unchanged in 10 post-graduate students, and found that EI and TEE were nearly equivalent. This supports the idea that EER in the DRI and EEI are nearly quantitatively equivalent. However, in this study, EEI was higher than EER, although the difference was small.

Differences in the slope of the regression equations between EI and Δ BW in the Ex and Sed groups

We found a significant difference in the slope of the regression equations between EI and Δ BW in Ex and Sed groups when divided by BW and LBM. The slope of the equation for Sed G was higher than that for Ex G. This means that excessive or insufficient energy intake resulted in a larger Δ BW in Sed G subjects than in Ex G subjects. Although the reason for this difference is not clear, when the EI is lower than EEI under sedentary conditions, lean body mass is primarily lost rather than body fat, and weight loss is greater than under high exercise conditions. This may explain the fact that this difference in slope disappeared when Δ BW was divided by SBW or BSA when LBM was not taken into consideration. Further studies are required to clarify the reason for this difference in the slopes of the regression equations between the two groups.

Gender differences in EEI

Among adults, males have higher metabolic rates than females (30). This sex difference has been primarily attributed to individual differences in fat-free mass (FFM), which is the major determinant of resting energy expenditure (REE). However, 24 h energy expenditure (total energy expenditure, TEE) and REE measured in a respiratory chamber were higher in males than in females even after adjusting for differences in body composition, age, and activity (30). These data provided evidence for an influence of gender on energy expenditure independent of sex differences in FFM.

EEIs divided by kg LBM for sedentary young females in this study (44.9 kcal/kg LBM/d) were lower than

those for sedentary young males (46.2 kcal/kg LBM/d) (2). This suggests that gender influences energy metabolism. Further studies are required to clarify the reason for this gender difference in EEI.

Finally, as was described in “Subjects and Methods,” we did not use body weight data from the pre- and post-balance periods, due to potential body weight fluctuation caused by body water shifts, changes in intestinal contents, and other factors. This might be effective in bringing out the clear relationship between energy intake and body weight change.

CONCLUSION

The relationship between dietary energy intake (EI) and body weight (BW) changes (Δ BW) was analyzed in 149 young Japanese females sub-divided into exercise (Ex G: $n=43$) and sedentary (Sed G: $n=106$) groups. Equilibrium energy intake (EEI) was divided by four parameters: body weight (BW), lean body mass (LBM), standard body weight (SBW), and body surface area (BSA).

EI and Δ BW were significantly correlated in both the Ex and Sed groups divided by each of the four parameters.

EEI and 95% confidence interval (CI) for EEI in Ex G were 34.3 and 32.8–35.9 kcal/kg BW/d, 32.0 and 30.8–33.1 kcal/kg SBW/d, 46.3 and 44.2–48.5 kcal/kg LBM/d, 1,200 and 1,170–1,240 kcal/m² BSA/d, respectively.

EEI and 95% CI for EEI in Sed G were 34.5 and 33.9–35.1 kcal/kg BW/d, 31.4 and 30.9–32.0 kcal/kg SBW/d, 44.9 and 44.1–45.8 kcal/kg LBM/d, 1,200 and 1,180–1,210 kcal/m² BSA/d, respectively.

Although 95% CIs for the Ex group were slightly wider than for the Sed group, the error ranges of EEI obtained in this analysis were very narrow. Thus, we believe that the reliability of EEI is very high.

The lower limits of 95% CI of EEI is higher than EER for low physical activity levels (PAL: 1.50) in five out of six analyses.

Exercise in this study might not affect daily energy expenditure.

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