Changes in the Basal Metabolic Rate of a Normal Woman
Induced by Short-Term and Long-Term Alterations
of Energy Intake

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Summary A long-term experiment was carried out to study the effects
of alterations in energy intake and meal contents on basal metabolic rate
(BMR) of a normal woman. Alterations of energy intake induced changes
in BMR and pulse rate in addition to body weight changes. Whether BMR
was expressed per whole body, per unit body weight, or per unit body
surface area, it increased progressively during long-term overeating pe-
riods, and decreased markedly during long-term undereating periods.
These results suggest that there exists 'Luxuskonsumption', or adaptive
diet-induced thermogenesis, during an overeating period and hypometab-
olism during an undereating period. BMR was affected significantly by
the menstrual cycle but not by nutrient composition when daily energy
intake was fixed at 2000 kcal for a long time.

Key Words basal metabolic rate, energy intake, overeating, undereating,
nutrient composition, pulse rate, menstrual cycle, body temperature

An increased heat production to maintain a stable body weight in the face of
increased energy intake was noted by Neumann, who named it
'Luxuskonsumption' (1). The concept has been supported recently by energy-
balance experiments carried out in rodents, in which the increment of diet-induced
thermogenesis is attributed to the brown adipose tissue (2–4). Some investigators,
however, did not observe the ability of human subjects to adapt to excess energy
intake (5, 6). Moreover, doubts have been raised as to the proposed role of the
brown adipose tissue (7, 8). The validity of Luxuskonsumption, especially in
humans, thus remains uncertain.

The conflicting results in humans seem to be partially due to heterogeneity of
subjects with respect to age, sex, body composition, food style including eating
behavior, and so on. Another problem in human studies is a difficulty in obtaining
subjects who cooperate well in over- or undereating study for a sufficiently long
period. There are reports concerning effects of long-term overeating, such as widely

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quoted experiments with prisoners (9) or with overweight people (10–13) and also of long-term undereating with malnourished children (14). The experimental conditions in these studies, however, were rather extreme, and the results presented were rather variable. We wanted to determine how the thermogenesis in an ordinarily nourished non-obese person was affected by alterations of energy intake and nutrient composition within a habitual range.

In the present study, one of the authors (J.Y.) served as a subject. She adjusted energy and nutrient contents of her meal to each experimental design, while her basal metabolic rate (BMR) was measured twice or three times a week. The duration of the study was over four years. Although we cannot immediately draw a general conclusion from our results obtained with only one subject, we emphasize that this is an appropriate way to determine small changes in BMR which might be concealed by individual variations in a mass experiment, especially when dietary and physical conditions of subjects are difficult to control.

EXPERIMENTAL

Subject. The subject was at the age of 39 to 44 years during the experiment. She had no special anamnesis, and her weight had been within the normal range with a slight tendency of underweight in her childhood and of overweight in her adolescence. Medical checks showed no evidence of health disturbance. Throughout the experiment she worked as a researcher at the laboratory on weekdays and as a housewife on weekends, usually walking over 10,000 steps per day as measured by a pedometer (MY CALORY, Yamasa Tokei Keiki Co. Ltd., Tokyo, Japan) which was occasionally set on her waist. Neither special medication nor special physical training was taken during the experimental period. The menstrual cycle was checked by basal body temperature.

Her height was 158.5 cm, and body weight varied between 48.5–61.5 kg during the present experiment.

Food intake. The subject weighed every food to be ingested by using a spring scale and calculated the energy and nutrient contents of every meal by referring to the Standard Table of Food Composition in Japan (15, 16). Energy content was adjusted by the “point” system in which one point is equivalent to 80 kcal as recommended by the Diabetic Society of Japan. To obtain as accurate contents of foodstuff as possible, she usually cooked by herself and avoided extremely manufactured products for which the composition was not shown. On inevitable occasions such as a dinner party, food contents were assessed by inspection.

The subject altered daily energy intake within a range between 1600 kcal (20 points) and 3200 (40 points), while taking three meals and one or two snacks a day. At least 70 g of protein were taken daily in every experimental series to minimize the loss of lean body mass. The period of each diet except for the 3200 kcal diet is described in the RESULTS. Experiments on the 3200 kcal diet were performed for only 11 days, because the subject felt too uncomfortable to continue the diet any
longer, although she experienced neither vomiting nor diarrhea.

On the day before BMR measurement, the subject took no food after lunch until supper at 7:00 p.m., which was a fixed meal of rather low energy content: 80 g of yoghurt and 79 g of biscuits (511 kcal; 11% protein, 49% fat, 40% carbohydrate with almost no dietary fiber) so that specific dynamic action would be small and the effect of the previous meal be equal in every BMR measurement.

Each series of experiments was usually repeated more than three times in four years. The results were collected regardless of season, since we did not observe any significant seasonal variation of BMR and body weight.

**BMR.** On the day of BMR measurement, the subject got up at 6:00 a.m. after sleeping for about 9 h, and came to her laboratory between 8:30 to 9:00 a.m. Her trip to work required 30 minutes walking and 40 minutes sitting in the subway. BMR measurement was carried out after she weighed herself and after lying on a bed quietly for at least 35 min in an air conditioned room (21-26°C). We confirmed in a pilot experiment that resting metabolic rate was not different whether the measurement was done after 30 min-, 60 min-, or 120-min recumbency. Three consecutive 5-min samples of expired air were collected in a Douglas bag. Oxygen and carbon dioxide were determined by means of a polarographic oxygen analyzer (RAS-31, scale range 0–25%; Analytical Instrument Co. Tokyo, Japan), and an infrared carbon dioxide analyzer (RAS-41, scale range 0–10%; Analytical Instrument Co. Tokyo, Japan), respectively. The overall calibration of these analyzers was adjusted before each experiment by infusing both helium gas and a mixture of calibrated oxygen and carbon dioxide gases. Resting metabolic rate was calculated from the volume and composition of the expired air, and the mean value of three consecutive measurements was regarded as BMR in the present study. The body surface area was obtained from the Du Bois height-weight chart.

During the collection of expired air, the pulse rate, respiration rate, and axillary and sublingual temperatures were measured by an assistant. Skin temperature was also measured on the back of the neck between the 6th and 7th cervical vertebrae, where brown adipose tissue is known to be located underneath the skin (17), and suggested to be active in thermogenesis (3). With this measurement we therefore expected to be able to detect changes of heat production, if any, caused by the brown adipose tissue.

**Analysis of results.** All results shown in the tables are expressed as mean ± SEM. The differences of mean values were statistically assessed by Student’s t test, and the difference between two proportions in paired case by McNemar’s test including χ² test.

**RESULTS**

*Short-term effects of alteration of energy intake on BMR, body weight, pulse rate, and body temperatures*

Figure 1 shows the results of a typical series of experiment in which daily

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Fig. 1. Changes of BMR induced by alteration of energy intake from 2000 kcal/day to 3200 kcal/day and then to 1600 kcal/day. ●, Body weight; □, BMR (kcal/h/body); ■, BMR (kcal/h/m²); ▽, sublingual temperature; ▲, axillary temperature; △, skin temperature of back neck; ▼, pulse rate; O, ovulation; M, menstruation.

Energy intake was increased from 2000 kcal to 3200 kcal and then decreased to 1600 kcal. Both BMR and body weight increased upon the shift to the high-calorie diet and decreased upon the shift to the low-calorie diet. The rate of BMR change per day was usually larger when energy intake was increased than when it was decreased. The BMR changes, however, were undetectable on the day following the dietary shift.

Pulse rate changed in parallel with BMR, whereas parallel change was not generally observed between BMR and temperatures measured at the back of the neck, axillary and sublingual areas as shown in Fig. 1, although the skin temperature of the back of the neck sometimes varied in association with the changes of BMR (data not shown).

Figure 2 shows the extents of change in both BMR and body weight within one to two weeks after alteration of energy intake. The rate of change in BMR was greater than that in body weight, whether BMR was expressed per whole body, per unit body weight, or per unit body surface area (21–29%, 15–26%, or 19–29% vs. 3–5% upon shift from 1600 kcal/day to 3200 kcal/day).
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Long-term effects of energy intake level on BMR, body weight, pulse rate, and body temperatures

Figure 3 shows BMR levels when energy intake was fixed at various levels for more than three weeks. On the 1600 kcal diet both BMR and body weight were still decreasing even six weeks after dietary shift; the rate of decrease in BMR per whole body exceeded that of body weight when calculated from the slope obtained by linear least-square regression, e.g., 0.4% /day vs. 0.06% /day during 35–47 days in a typical experimental series. The mean value of BMR was larger on the 2800 kcal diet than that on the 1600 kcal diet by 41.1% on whole body level, 27.4% on unit weight basis, or 35.6% on unit surface area basis, while the difference in mean values of body weight was only 11.0%. The results shown in Fig. 3 clearly indicate that BMR is substantially affected by energy intake levels, higher BMR being induced by high calorie diet and lower BMR by low calorie diet, and that the change of BMR far exceeds the change of body weight.

Figure 4 shows the relationship between body weight and BMR after long-term fixed diets of various energy levels, indicating that the level of BMR correlated well with body weight except for the results obtained with the 1600 diet (the three points in parentheses). The exception may be related to the fact that body weight was still decreasing on that diet at the time of BMR measurements. Figure 5 shows that BMR also correlates well with the pulse rate. On the other hand, no correlation was found between BMR and body temperature measured at either the back of the neck.
Fig. 3. Long-term effects of energy intake on BMR during postovulation periods. Every result was obtained from three to fourteen weeks after the changes of energy intake. Means ± SEM were shown for each experimental diet, with numbers of experiments in parentheses. ○, BMR (kcal/h/m²); □, BMR (kcal/h/body); ●, body weight (kg).

Fig. 4. Relationship between body weight and BMR after long-term fixed diets. Data were collected from the experiments of Fig. 3. Circles in parentheses represent values obtained with 1600 kcal/day diet. A regression line (y = 1.1x − 29.9, r = 0.555, p < 0.02) was obtained when all mean values of BMR on Fig. 3 were plotted against mean values of body weight, and another (y = 1.1x − 28.6, r = 0.814, p < 0.001) when three results during more than the 61-day period on the 1600 kcal/day diet shown in parentheses were excluded.
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Fig. 5. Relationship between BMR and pulse rate. Mean values of pulse rate were plotted against BMR. Regression line: \( y = 0.63x + 22.8 \), \( r = 0.879 \), \( p < 0.001 \).

Table 1. Effects of alteration of nutrient composition on basal metabolic rate.

| Exp. No. | Diet | Menstrual period (n) | Body weight (kg) | BMR/h (kcal/body) | BMR/h (kcal/m²) | BMR/h (kcal/kg) | Pulse rate (beats/min) |
|----------|------|----------------------|------------------|-------------------|----------------|----------------|------------------------|
| 1        | Hp   | Pre (4)              | 51.1 ± 0.1       | 40.4 ± 1.7        | 26.9 ± 1.1     | 0.790 ± 0.033  | 48.2 ± 0.4             |
|          |      | Post (7)             | 51.1 ± 0.2       | 42.7 ± 0.6        | 28.3 ± 0.4     | 0.835 ± 0.011  | 50.3 ± 0.9             |
|          | Hf   | Pre (6)              | 51.4 ± 0.5       | 42.6 ± 1.3        | 28.3 ± 0.8     | 0.828 ± 0.020  | 48.6 ± 0.6             |
|          |      | Post (5)             | 51.1 ± 0.6       | 44.4 ± 1.1        | 29.4 ± 0.6     | 0.869 ± 0.012  | 48.8 ± 1.1             |
|          | Hc   | Pre (7)              | 51.7 ± 0.3       | 42.2 ± 0.6        | 28.0 ± 0.4     | 0.818 ± 0.014  | 48.4 ± 1.0             |
|          |      | Post (5)             | 51.0 ± 0.1       | 44.5 ± 0.2        | 29.6 ± 0.1     | 0.873 ± 0.004  | 50.9 ± 1.7             |
| 2        | Hp   | Pre (3)              | 53.2 ± 0.3       | 49.8 ± 0.5        | 32.5 ± 0.2     | 0.939 ± 0.007  | 53.2 ± 0.9             |
|          | Hf   | Pre (3)              | 52.6 ± 0.3       | 43.6 ± 2.3        | 27.8 ± 1.6     | 0.830 ± 0.046  | 48.8 ± 1.6             |
|          | Hc   | Pre (3)              | 53.2 ± 0.1       | 46.0 ± 0.4        | 30.0 ± 0.3     | 0.864 ± 0.008  | 48.3 ± 0.4             |

The experiments 1 and 2 were carried out with an interval of more than 3 months, during which period the subject took other diets including a 3200 kcal diet. Results are shown as means ± SEM of the number of observations in parentheses carried out in each experimental series 25 to 60 days after dietary shift. The diets were all of 2000 kcal and approximately composed of the following nutrients: Hp, high-protein diet containing 140 g of protein and 50 g of fat; Hf, high-fat diet containing 70 g of protein and 100 g of fat; Hc, high-carbohydrate diet containing 70 g of protein and 25–30 g of fat. The remaining part of the energy in each group was supplied by carbohydrate. Pre, preovulation; Post, postovulation. There is no significant difference in BMR between different diets when compared between the same menstrual period (\( p > 0.01 \)).
Effects of alteration in nutrient composition and of menstrual cycle on BMR

Long-term diets with an equal energy level (2000 kcal/day) showed a similar effect on BMR irrespective of nutrient composition (Table 1). Sublingual temperature at the time of BMR measurement was higher during postovulation than during preovulation (data are not shown. McNemar’s test in the experiment 1 of Table 1, \( n = 34, p < 0.01 \)), and BMR values were lower during prevulation period than during postovulation period (data are not shown. McNemar’s test in the experiment 1 of Table 1, \( n = 34, p < 0.05 \)).

DISCUSSION

BMR defined in the present experiment is, in a strict sense, the resting metabolic rate in a fasting state, and is presumably somewhat higher than the real BMR. The BMR values, however, can be compared with each other, since the condition was the same among every experimental series throughout the study. The period on each diet was sufficiently long so that possible over- or under-estimation of energy and nutrient contents in daily meals, which could result from the general approximation method used in the present study, was expected to be cancelled. The subject made no conscious alteration in the routine of her life, took daily at least 1600 kcal of energy and more than 70 g of protein, and had neither habitual diarrhea nor vomiting. Accordingly, we presume that she did not have a considerably large gain or loss of lean body mass during the experimental period.

In the present experiment, significant changes of BMR were observed upon the alteration of energy intake by as few as 400 kcal/day, irrespective of nutrient composition. This result leads to the conclusion that whether BMR was expressed per whole body, per unit body weight, or per unit body surface area, it varied substantially depending on energy intake, and that the change was independent of nutrient composition at least within such a habitual range as in the present study.

The BMR change, however, was never observed within one day after diet change in the present experiment. Dauncey (18) has, however, shown a significant increase of the resting metabolic rate measured in the morning 14 h after overfeeding of only one day. The last meal, if it is high calorie, may have an influence on BMR due to continuing specific dynamic action. In fact, we also observed a marked increase in BMR during both the overeating and the undereating periods when the subject took a 2044 kcal supper, four times as large as the usual pre-test supper, on the day before BMR measurement. Dauncey’s result might be attributable to a prolonged influence of specific dynamic action, whereas our result was not much affected by supper on the preceding day because of its low energy content.

Meanwhile, it is commonly believed that BMR of women displays a periodicity.
Table 2. Daily energy balance during overeating period.

| Description                                      | Value |
|--------------------------------------------------|-------|
| Excess energy intake (kcal)                      | 800   |
| Body weight gain (g)                             | 87    |
| Energy deposited as fat (kcal) (a)               | 626   |
| Increase in specific dynamic action (kcal) (b)   | 80    |
| Increase in BMR (kcal) (c)                       | 102   |
| Storage plus excess energy output (kcal) (d)     | 808   |

Results are shown as means of data from two experimental series, in which after long-term feeding of the 2000 kcal diet at a constant body weight energy intake was increased to 2800 kcal for 30 and 37 days. Based on the assumption that fat represented 80% of body weight gain. 10% of the excess energy intake. Average BMR during overeating period minus average BMR during the last 1 week on the 2000 kcal diet. Sum of (a), (b), and (c).

coinciding with the stage of menstrual cycle: lower BMR before ovulation and higher BMR after ovulation. Incompatible results, however, have been reported: some subjects showed no difference in BMR during the menstrual cycle (19, 20). In our short-term experiments, BMR changed upon alteration of energy intake independently of menstrual cycle. On the other hand, in the long-term experiment in which energy intake was fixed to 2000 kcal/day and daily variations in BMR were eliminated by statistical treatment, BMR was shown to be significantly higher during postovulation period than during preovulation period. This means that the change in BMR occurring in conjunction with the menstrual cycle was smaller than that induced by alteration of energy intake by 400 kcal/day.

Although it is rather difficult to assess exactly an ideal energy intake level for maintaining an energy balance of a subject, daily energy intake of 2800 kcal or more appears to be in excess for the present subject. The increase in BMR upon overeating was observed not only when expressed per whole body but also when expressed per unit body weight or per unit body surface area, eliminating the possibility that the BMR increase was simply attributed to an increased energy for maintaining increased body weight. We presume the existence of some mechanism in the human body for dissipating excess energy, like the brown adipose tissue in cafeteria-fed rats (3), though we could not find any relationship between BMR and the skin temperature of the back of the neck in the present experiment. On the other hand, the 1600 kcal diet must have been insufficient for the present subject, because both BMR and the body weight kept decreasing and a prolongation of menstrual period was observed after 2–3 months on the diet. This suggests that there also exists some mechanism for adaptation to undereating.

The results obtained in the present study indicate that an excess or a deficient energy intake would not produce an expected amount of gain or loss of body weight, since the adaptive changes in BMR occur on the changes of energy intake. We tried to calculate the energy balance during the overeating period (Table 2). In two series of similar long-term experiments, daily energy intake was increased from...
2000 kcal to 2800 kcal. Since a constant body weight had been maintained on a 2000 kcal diet, a 2800 kcal diet should have resulted in daily energy excess of 800 kcal. Daily energy deposited as fat during the overeating period was estimated to be 626 kcal from the body weight gain, assuming that fat represented 80% of the weight gain. The increase in specific dynamic action was estimated to be 10% of excess energy intake (80 kcal). The amount of BMR increase actually observed was 102 kcal. Thus the total amount of storage plus excess energy output was estimated to be 808 kcal, which roughly agreed with the excess energy intake. Although the increase in BMR (Luxuskonsumtion) corresponded to only a small fraction (13%) of excess energy intake compared with observation in rodents (3), it seemed to make some contribution to lowering the amount of fat deposition.

Elevation of absolute energy expenditure in obese subjects was observed by many workers, but BMR expressed per kilogram of body weight, per body surface area, or per kilogram of fat-free mass, was low or normal in some obese subjects compared with that in lean subjects (13, 21, 22). Furthermore, Kashiwazaki et al. (23) have recently reported that the resting metabolic rate per unit of fat-free mass was not significantly different between obese and normal weight female subjects, although individual variation was quite large. It is conceivable that the extent of change in BMR upon alteration of energy intake is different among individuals, even when expressed per unit of fat-free mass, and that subjects who have a weak capacity to increase BMR in response to overeating have a tendency to become obese, compared with subjects who have a strong capacity. Further experiments are needed to examine that possibility.

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