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Short Communication

Metabolic Response to Short-Term 4-Day Energy Restriction in a Controlled Study

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Abstract

Objectives: Metabolic rate is affected not solely by diet but also by environmental characteristics such as climate and seasonal changes in day length. In the present study, we conducted a controlled study in which we observed metabolic response to short-term energy restriction (ER).

Materials and Methods: Thirty-two subjects were divided randomly into a slight ER group and a moderate ER group. The energy intake per day for slight ER vs moderate ER was 1462 kcal vs 1114 kcal. During the 4-day study periods, the same daily timetable, which consists of nutrition, exercise, sleeping and others, was imposed on both groups. The same environment was also provided to both groups.

Results: After the 4-day ER, significant decreases in body weight and basal metabolic rate (BMR) were shown in both groups. The decrease in body weight was 2% of the baseline level in both groups, and the decreases in the BMR were 6% of baseline levels in the slight ER group and 13% in the moderate ER group. The decrease in BMR in the moderate ER group was significantly larger than that in the slight ER group.

Conclusions: In a controlled study of short-term ER, we observed a significant decrease in BMR. There was a positive association between the degree of ER and the reduction in BMR. Reductions in BMR were greater than those in body weight. It, thus, appears that the minimization of weight loss is due to dramatic decreases in BMR. This suggests the existence of metabolic resistance against ER.

Key words: calorie restriction, controlled study, energy expenditure, human, nutrition

Introduction

Little is known about metabolic adaptations to nutritional stress, and many scientists doubt that such adaptations exist (1). Energy expenditure (EE) has been reported to vary among human populations. For example, people living in cold regions have a high basal metabolic rate (BMR) (2). On the other hand, the tropical population has a low BMR, and the Food and Agriculture Organization/World Health Organization/United Nations University equations for predicting BMR from body weight substantially overestimate BMR of people living in the tropics by an average of 8% (3). It remains unclear whether such differences in BMR are, for the most part, genetically determined as the result of long-term adaptation to environmental factors, or due to short-term functional acclimatization (4).

In clinical trials for the treatment of obesity or diabetes mellitus, several researchers have concluded that dietary energy restriction (ER) depresses the resting metabolic rate (5–7). Furthermore, it has been reported that reductions in resting metabolic rate exceed decreases anticipated with the achievement of a lower body weight (8). Taylor and Keys showed, in a Minnesota experiment, that 6 months of severe ER leads to a marked reduction in EE in 32 lean men (9). In an observation study, Leibel et al. reported that body weight is maintained with

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compensatory changes in EE as a "metabolic resistance" (10). Weyer et al. also reported that such a response occured in sustained ER in the Biosphere 2 experiment (11). Recently, Friedlander et al. reported that the minimization of weight loss occurs with decreasing EE during 3 weeks of ER (12).

It has been suggested that BMR is affected not solely by diet but also by many factors such as climate, seasonal changes, daily timetable, sleeping, and physical activity (1, 13, 14). However, in previous studies, these factors were not controlled. Therefore, to clarify the existence of "metabolic resistance" to reduced body weight, a well-controlled study is needed. In the present investigation, we conducted a controlled study and demonstrated metabolic resistance to reduced body weight during short-term ER.

Materials and Methods

The study was approved by both the Ethical Committee of Kansai Medical University and the Ethical Committee of Hamamatsu University School of Medicine. The study was conducted at the Autobacs Osaka Kenko Center, an institute for occupational health education (Autobacs Seven Co., Ltd., Japan), where a 6-day health education program was offered. Participants in each period of the program number 2 to 7 persons, and they stay at the dormitory of the Autobacs Osaka Kenko Center during the program.

Subjects of this study were selected from among the participants of the education programs carried out from November 2003 to January 2005. In total, 32 male adults, whose BMR could be measured in the program, were the subjects of the present study (slight ER; 15 men, moderate ER; 17 men). The diet offered during the program was randomly chosen between a slight ER menu and a moderate ER menu. The mean energy intake of the 32 subjects at the baseline, according to food-frequency questionnaires (FFQs), was 1990 kcal/day. The subjects were asked to fill out a one-week food record before the program. Registered dieticians interviewed the subjects to confirm their answers to the FFQ using food models. Energy intake was calculated using Excel Eiyokun Ver. 3 (KENPAKUSHA, Tokyo, Japan) (15).

The same health education program, which consists of lectures regarding nutrition, exercise, smoking, sleeping, and others, was conducted in the same facility for both the slight ER group and the moderate ER group. Thus, the daily timetable and the environment, such as room temperature, exercise, sleeping, climate, season, and nutritional intake without energy were the same for both groups.

Diets imposed on slight ER groups vs moderate ER groups were prepared to include 1462 vs 1114 (kcal/day) of energy, 238.1 vs 163.0 (g/day) of carbohydrates, 31.7 vs 30.8 (g/day) of lipids, 60.0 vs 54.4 (g/day) of protein, 26.3 vs 25.7 (g/day) of dietary fiber, 897 vs 892 (mg/day) of calcium, 17.1 vs 16.3 (mg/day) of iron, 1468 vs 1468 (μg/day) of retinol, 110 vs 110 (mg/day) of vitamin C, and 9.6 vs 9.4 (mg/day) in vitamin E. Energy and nutrients were calculated using Excel Eiyokun Ver. 3. Participants were informed of their energy intake at the end of the educational program.

Subjects were familiarized with the measurements of body movements, body temperature, BMR, pulse rate, blood pressure, height, and body weight on Day 1. From Day 2 to Day 5, body movements were recorded using an accelerometer (Calorie Counter e-style, SUZUKEN, Nagoya, Japan). Complete records for body movements were obtained from 13 men in the slight ER group and 14 men in the moderate ER group.

In the morning of days 2 and 6, BMR, pulse rate, systolic blood pressure, and diastolic blood pressure, were measured by medical doctors and nurses. For measurements of blood pressure, an automated device (BP-103i II, Colin Corporation, Komaki, Japan) was used. Blood samples were obtained in the morning of days 2 and 6 by medical doctors and nurses, and serum variables were measured by SRL, Inc (Tokyo, Japan). The numbers of subjects who gave consent to sample their blood were 14 men in the slight ER group and 13 men in the moderate ER group among all subjects. Body temperature, height, and body weight were measured by individual subjects. Body temperature was measured in bed using an axilla thermometer. Body mass index (kg/m^2) was also calculated by dividing the weight (kg) by the height (m) squared.

BMR was measured under controlled conditions in accordance with a previous report (16). The measurement was carried out between 06:00 and 07:00, immediately after wake up, 11 h after the last meal. The subjects lay quietly on a bed, and the BMR and respiratory quotient were measured by indirect calorimetry (AR-1 TYPE-3, ARCO SYSTEM, Kashiwa, Japan), monitoring of oxygen consumption, and carbon dioxide production.

Data are expressed as mean±standard deviation. Mann-Whitney's U test was used for comparison of the data of the slight ER group and the moderate ER group. Wilcoxon signed-ranks test was used for the analysis of the baseline and follow-up levels of the variables measured. Values of $p<0.05$ were considered significant. All statistical analyses were performed using SPSS Base 11.5J for Windows (SPSS Inc., Chicago, IL).

Results

Table 1 shows the baseline levels of variables. Variables for both the slight ER group and the moderate ER group showed the same levels. From day 2 to day 5, there was no significant difference in body movements between the slight ER group and the moderate ER group. It was 292±54 kcal/day for the slight ER group, and 267±68 kcal/day for the moderate ER group.

As show in Table 2, significant decreases in body weight and body mass index were observed in both the slight and moderate ER groups after 4 days of ER. The decrease in body weight was 2% of baseline levels in both groups. Blood pressure, pulse rate, body temperature, and serum cholesterol in both groups showed no significant change. A significant decrease in serum concentrations of triglycerides was observed in both groups.

Table 3 shows the change in energy metabolism in response to ER. In the slight ER group, BMR showed a significant decrease from day 2 to day 6. In the moderate ER group, significant decreases were shown in BMR, BMR per body weight, and respiratory quotient. In addition, decreases in

Table 1 Baseline levels of variables

	Slight ER group (n=15)	Moderate ER group (n=17)
Age (year)	38.8±10.1	39.6±12.8
Height (cm)	172.7±6.5	171.5±6.4
Body weight (kg)	70.2±6.2	70.2±12.5
Body mass index (kg/m^2)	23.6±1.9	23.9±4.0
Systolic blood pressure (mmHg)	116±14	115±17
Diastolic blood pressure (mmHg)	72±12	69±11
Pulse rate (/min)	61±7	58±8
Body temperature (°C)	35.8±0.3	35.9±0.5
BMR (kcal)	1221±208	1228±196
BMR per body weight (kcal/kg)	17.5±3.1	17.7±2.7
Respiratory quotient	0.88±0.05	0.90±0.08
	Slight ER group (n=14)	Moderate ER group (n=13)
Total cholesterol (mg/dl)	205±34	192±37
LDL cholesterol (mg/dl)	131±26	115±35
HDL cholesterol (mg/dl)	50±9	54±13
Triglyceride (mg/dl)	146±92	126±67

ER; energy restriction, n; number, BMR; basal metabolic rate, LDL; low-density lipoprotein, HDL; high-density lipoprotein. BMR and respiratory quotient were obtained by indirect calorimetry. Data are expressed as mean±standard deviation. There was no significant difference between the slight ER group and the moderate ER group.

Table 2 Change in variables from day 2 to day 6

	Slight ER group (n=15)	Moderate ER group (n=17)
Body weight (kg)	–1.48±0.52*	–1.43±1.02*
Body mass index (kg/m^2)	–0.58±0.23*	–0.54±0.37*
Systolic blood pressure (mmHg)	–3.40±10.16	–0.53±9.02
Diastolic blood pressure (mmHg)	–3.13±6.55	–0.18±4.97
Pulse rate (/min)	–1.00±5.37	0.53±3.68
Body temperature (°C)	0.03±0.39	0.03±0.37
	Slight ER group (n=14)	Moderate ER group (n=13)
Serum total cholesterol (mg/dl)	–0.57±20.03	–0.85±16.99
Serum LDL-cholesterol (mg/dl)	4.21±23.32	7.08±14.60
Serum HDL-cholesterol (mg/dl)	0.57±6.96	–2.15±5.66
Serum triglyceride (mg/dl)	–46.5±111.1*	–41.3±51.5*

ER; energy restriction, n; number, LDL; low-density lipoprotein, HDL; high-density lipoprotein. Data are expressed as mean±standard deviation. There was no significant difference between the slight ER group and the moderate ER group. * Decreases in variables were evaluated to be significant by the Wilcoxon signed-ranks test.

Table 3 Changes in energy metabolism from day 2 to day 6

	Slight ER group (n=15)	Moderate ER group (n=17)
BMR (kcal)	–69.4±101.5*	–154.0±65.5*†
BMR per body weight (kcal/kg)	–0.66±1.54	–1.95±1.21*†
Respiratory quotient	–0.037±0.072	–0.048±0.067*

ER; energy restriction, n; number, BMR; basal metabolic rate. BMR was obtained by indirect calorimetry, monitoring of oxygen consumption, and carbon dioxide production. Data are expressed as mean±standard deviation. * Decreases in variables were evaluated to be significant by the Wilcoxon signed-ranks test. † Decreases in variables of the moderate ER group were significantly larger than those of the slight ER group by the Mann-Whitney's U test.

BMR and BMR per body weight in the moderate ER group were significantly larger than those in the slight ER group. Decreases in BMR were 6% of baseline levels in the slight ER group and 13% in the moderate ER group.

Discussion

It has been acknowledged that metabolic rate is affected not only by diet but also by environmental characteristics such as climate and seasonal changes in day length (13, 14). However, previous studies on EE during a restricted diet were not well controlled. In the present study, subjects were divided randomly, and baseline levels of variables were the same between the slight ER and moderate ER groups. In addition, factors such as daily timetable, room temperature, climate, season, exercise, and sleeping were controlled. Furthermore, nutritional elements other than energy were also the same between the two groups. Therefore, the present study was well controlled.

With short-term ER, there were no marked changes in blood pressure, pulse rate, body temperature, or serum cholesterol in either group. Body weight in both groups showed a small but significant decrease with short-term ER. Decreases in body weight were 2% of baseline levels in both groups. In contrast, BMR showed a large decrease. Decreases in BMR were 6% of baseline levels in the slight ER group and 13% in the moderate ER group. On the basis of previous studies of human starvation, it has been suggested that weight loss is accompanied by a decrease in BMR greater than that which can be accounted for by the changes in body weight and composition, and that the maintenance of a reduced body weight is associated with compensatory changes in EE (10). This suggestion is consistent with the minimization of changes of variables and the dramatic BMR reduction in our short-term ER.

In a controlled study of 4-day short-term ER, BMR and respiratory quotient decreased significantly. There was a positive association between the degree of ER and the reduction in BMR. In addition, changes in BMR were larger than those in body weight and other variables measured. It is considered that this dramatic response of the BMR acts as a metabolic resistance to minimize the reduction in body weight.

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