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Low Energy Intake Impairs Glucose Regulation and Stamina in Japanese Young Women

Michiyo Kaneko[1*], Takehiko Kaneko[2], and Makoto Otsuki [1]

1. *Department of Home Economics, Kobe Women's University 2-1 Aoyama, Higashisuma, Suma-ku, Kobe, Hyogo Prefecture 654-8585, Japan*

2. *Department of Health and Nutrition, Wayo Women's University 2-3-1 Konodai, Ichikawa-shi, Chiba Prefecture 272-8533, Japan*

Abstract

Energy intake has been decreasing these ten years in Japan, and low energy intake is remarkable especially among young women. We attempted to show the dietary habits and physiological function including glucose tolerance and stamina for endurance-running in contemporary young Japanese women who take insufficient energy. 85 healthy women aged 20.5±1.1 years were enrolled in the present study. Subjects were categorized in two groups; Group I (n=70) with higher energy intake, and Group II (n=15) with lower energy intake than the basal metabolic rate (BMR). Actual energy intake in Group I was 1598.8±282.1 kcal/day, and it was 1019.9±127.1 kcal/day in Group II ($p<0.01$). Standard 75-g oral glucose-tolerance test was performed, and the capillary glucose value was measured at the fingertip. In Group I, glucose values at fasting, 30, 60 and 120 min were 75.0±9.1, 132.1±25.2, 120.5±27.4, 105.3±19.5 mg/dl, and those in Group II were 78.9±7.7, 155.8±26.6, 142.2±26.6, 112.3±16.0 mg/dl, respectively. The values of Group II at 30 and 60 min showed significantly high ($p< 0.01$). Stamina and the intake of protein in Group II were significantly lower than those in Group I ($p<0.05$), and muscle mass and grip strength were less in Group II than in Group I, though there was no significant difference. We indicated with these results that low skeletal muscle was considered to be responsible for the impairment of glucose regulation in Group II. This study showed that young women with low energy intake should take sufficient energy and build skeletal muscle to prevent the impairment of glucose regulation.

Corresponding author: Michiyo Kaneko, Department of Home Economics, Kobe Women's University, 2-1 Aoyama, Higashisuma, Suma-ku, Kobe, Hyogo Prefecture 654-8585, Japan. E-mail: mneko7788@hotmail.com, m-kaneko@yg.kobe-wu.ac.jp, fax: +81-78-737-2430

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Introduction

According to the statistics published by the Ministry of Health, Labour and Welfare of Japan in 2013, average energy intake of Japanese had decreased since 1995, and low energy intake has been remarkable especially among young women these ten years [1]. The energy intake by those who were 20~29 year old in 2013 was 1,628 kcal [1]. Moreover, our preliminary investigation showed that about 20% of young women were taking energy even under basal metabolic rate (BMR) because of their strong desire for thinness [2]. van Abeelen et al. reported that undernutrition in the youth caused the risk of pulmonary disease, coronary artery calcification and the higher risk of type 2 diabetes later in adulthood [3-5]. Most serious effect among these is the impairment of glucose tolerance and type 2 diabetes [6,7] which would be one of the pathogenic factors for atherosclerosis leading to mortal cardiovascular disease [8-11].

In addition, some of the young women might become pregnant in the near future and adequate nutrition is required for development of fetus. Many studies in human and animals reported that the adverse effects of prenatal malnutrition on the development of brain function, hypertension, metabolic syndrome in the adulthood [12-15]. In order to supply sufficient nutrients to the embryo, it is required for young women to have proper dietary habits and take sufficient nutrients for having healthy offspring. It is, therefore, of critical challenge for us to investigate the actual nutritional status in contemporary Japanese young women.

In the present study, we examined the dietary habits, and the effects of low energy intake on physiological function including glucose tolerance and stamina for endurance-running in young women who took insufficient energy. We hope that the results of this study would encourage young women to take sufficient nutrients and energy, and would contribute to the formulation of nutrition education policy in Japan and other countries in similar situation.

Methods

We carried out this study in accordance with the Declaration of Helsinki. This study was approved and carried out according to the guidelines of the ethics committee of human research of Kobe Women's University. Subjects gave written consent to participate in the study. This study was carried out in 2015.

Subjects and body composition

85 healthy young women aged 20.5±1.1 years were enrolled in the present study who were university students mostly from Kansai region of Japan. Body composition including muscle mass, estimated bone mass, body fat percentages were measured by impedance method (BC-716, TANITA Corp., Tokyo, Japan). Grip strength was measured by the squeeze dynamometer.

Measurement of vascular age

Vascular aging was evaluated by the second derivative of photoplethysmogram (SDPTG) at fingertip [16-18]. The subject put the right forefinger on the devise for about 20 seconds. The machine, the BC Checker Ver.10.00 (Future Wave, Inc., Tokyo, Japan), measured the amount of light absorbed by hemoglobin reflecting blood flow, and analyzed SDPTG wave form of the fingertip which reflects arterial stiffness. The machine showed the vascular age.

Glucose-tolerance test

Standard 75-g oral glucose-tolerance test (OGTT) was performed at the fingertip, and capillary glucose values were measured at fasting without any food for 10 hours before measurement, and 30, 60, and 120 min followed by drinking of 75g glucose in 225 ml water.

Nutrition intake

Brief-type self-administered diet history questionnaire (BDHQ) was conducted for analyzing food and energy intakes [19-21]. The subjects were requested to answer the questionnaires which contain the kinds of food, amount and the frequency the subjects had for the previous one month of the investigation. 4 page sheets filled by each subject were sent to the EBN JAPAN (DHQ Support Center, Tokyo, Japan) which analyzed energy intake, nutrient intake, kind of food and amount of food for one month.

Stamina test

Stamina was estimated by the method developed by Shindo in Japan [22]. Subjects were walking or running at the speed of 4 stages from 40 sec/100m to 85 sec/100m. At the stage of each speed, subjects were running for about 4 minutes constantly, and then counted the pulse rate for 15 seconds just after stopping. After subjects counted pulse rate at each speed, they plotted 4 dots on the special graph sheets made by Shindo with the speed in the vertical direction and pulse rate in the lateral direction. We made the regression line on each graph, and evaluated the speed (sec/100m) at 125 pulse rate/min equivalent to 50% VO_2max for 20 year old persons. By carrying out this test, called "simplified Stamina-Test", we estimated the subjects' stamina. Low speed at 125 pulse rate/min was considered low stamina.

Statistical analysis

Food groups and nutritional values were compared between the two groups. Two-tailed student's t-test, followed by the F-test checking variance, was performed. Statistical analysis in OGTT was carried out by the simple main effect at each time point followed by the two way ANOVA of the repeated measure general linear model. Post-hoc analysis was performed by Bonferroni using the software of SPSS. $p<0.05$ was considered significant difference.

Results

Energy intake

15 subjects out of 85 participants (17.6%) were taking energy under BMR calculated by Harris-Benedict Equation. Subjects were categorized in two groups; Group I (20.5±1.2 years old, n=70) with higher energy intake, and Group II (20.5±1.0 years old, n=15) with lower energy intake than BMR. As shown in Table 1, actual energy intake in Group I was 1598.8±282.1 kcal/day, and it was 1019.9±127.1 kcal/day in Group II, and there was significant difference ($p<0.001$). However, the BMR value calculated by Harris-Benedict Equation in each group was 1290.1±80.4 kcal/day in Group I, 1282.0±48.7 kcal/day in Group II, and there was no significant difference. The body mass indexes (BMI) of both groups (Group I; 20.7±2.7 kg/m2, Group I; 21.1±1.2 kg/m2) were in the normal range and there was no significant difference between the two groups.

Glucose metabolism

Standard 75-g oral glucose-tolerance test was performed, and the glucose values at the fingertip were measured at fasting, and 30, 60, and 120 min after glucose loading (Fig.1). The blood glucose level at 30 min in Group II was significantly higher than that in Group I (155.8±26.6 mg/dl vs 132.1±25.2 mg/dl, $p=0.002$) showing the steep increase of blood glucose level from the fasting level in Group II. At 60 min, it was also significantly higher in Group II than in Group I (142.2±26.6 mg/dl vs 120.5±27.4 mg/dl, $p=0.007$). On the other hand, blood glucose values at fasting in both groups (78.9±7.7 mg/dl vs 75.0±9.1 mg/dl) were similar. The value in Group II at 120 min post-loading was 112.3±16.0 mg/dl and 105.3±19.5 mg/dl in Group I.

Body Composition and stamina test

Table 2 shows stamina for endurance-running in the two groups. Running speed at 125 pulse rate/min in Group I was 56.0±8.9 sec/100m, and the speed in

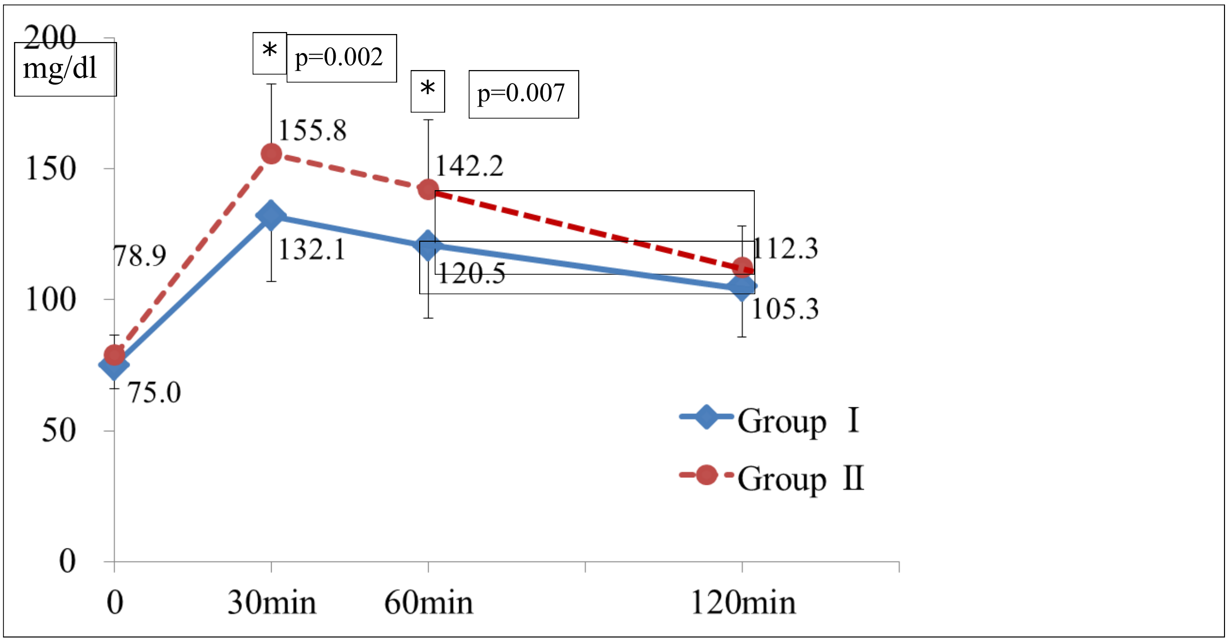

Figure 1: Glucose values at fingertip measured at fasting and 30, 60, 120min after glucose loading.

Values are mean ± S.D.
*: Significant difference between two groups (p <0.05)

Table 1: Age, body mass index (BMI), actual energy intake and basal metabolic rate (BMR) calculated Harris-Benedict Equation

	Group I n=70			Group II n=15		
Age	20.5	±	1.2	20.5	±	1
BMI (kg/m^2)	20.7	±	2.7	21.1	±	1.2
Energy intake (kcal/day)	1598.8	±	282.1	1019.9	±	127.1*
Basal metabolic rate (kcal/day)	1290.1	±	80.4	1282	±	48.7

Values are mean ± S.D.
Group I: energy intake was higher than BMR calculated Harris-Benedict Equation
Group II: energy intake was lower than BMR calculated Harris-Benedict Equation
*: Significant difference between two groups (p <0.05)
BMI; body mass index
BMR; basal metabolic rate

Table 2: Muscle mass, estimated bone mass, body fat percentage, grip strength, stamina for running and vascular age.

	Group 1			Group 2		
Muscle (kg)	35.2	±	2.9	34.7	±	2.5
Estimated bone mass (kg)	2.12	±	0.29	2.06	±	0.24
Body fat percentage (%)	27.8	±	5.2	28.7	±	2.5
Grip strength (kgw)	26.4	±	4.2	24	±	3.4
Stamina (sec/100m)	56.0	±	8.9	61.8	±	11.8*
Vascular age	20.1	±	0.6	20.0	±	0

Group II was 61.8±11.8 sec/100m which was significantly slower than that in Group I ($p<0.05$). This result means that stamina in Group I was significantly stronger than in Group II. There was no significant difference between the two groups in grip strength (26.4±4.2 kgw vs 24.0±3.4 kgw), and in muscle mass (35.2±2.9 kg vs 34.7±2.5 kg). Estimated bone mass and body fat percentage in both groups were similar. Vascular ages in both groups were almost the same.

Nutrient intake

In spite of the fact that Group I had significantly higher intake of protein (57.2±12.0 g/day), fat (50.3±10.5 g/day) and carbohydrate (218.9±55.9 g/day) than Group II (36.5±8.6 g/day, 32.5±9.5 g/day, 136.8±24.7 g/day, respectively), the balance of energy taken from protein, fat and carbohydrate was similar (Fig.2). Intake of all the other nutrients, minerals, saturated fatty acid, monosaturated fatty acid, polysaturated fatty acid, n-3 fatty acid, n-6 fatty acid, cholesterol and dietary fiber in Group I showed significantly higher than those in Group II ($p<0.05$) (Table 3).

Food intake

Table 4 shows the amount of food in each group. Group I had a significantly higher intake ($p< 0.05$) of cereals (Group I; 370.3±148.9 g/day, Group II ; 229.1±84.8 g/day), green and yellow vegetables(Group I; 91.4±71.5 g/day, Group II; 49.1±30.4 g/day), other

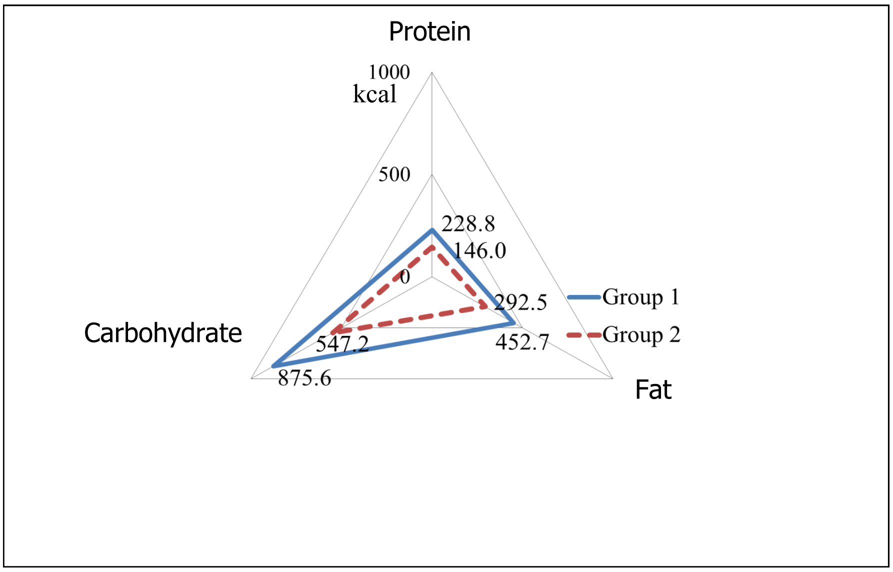

Figure 2: The balance of energy intake from protein, fat and carbohydrate

Table 3: Nutrient intake in both groups.

	Group 1			Group 2		
Protein (g/day)	57.2	±	12.0	36.5	±	8.6*
Fat (g/day)	50.3	±	10.5	32.5	±	9.5*
Carbohydrate (g/day)	218.9	±	55.9	136.8	±	24.7*
Mineral (g/day)	14.0	±	3.0	9.4	±	2.0*
Saturated fatty acid (g/day)	14.2	±	3.7	9.6	±	3.6*
Monounsaturated fatty acid (g/day)	18.2	±	4.0	11.6	±	3.4*
Poly unsaturated fatty acid (g/day)	11.5	±	2.7	7.2	±	1.9*
n-3 fatty acid (g/day)	2.1	±	0.6	1.2	±	0.4*
n-6 fatty acid (g/day)	9.3	±	2.1	5.9	±	1.6*
Cholesterol (mg/day)	359.0	±	104.7	242.5	±	101.4*
Dietary fiber (g/day)	9.5	±	3.6	5.9	±	2.0*

Values are mean ± S.D.
*: Significant difference between two groups ($p < 0.05$)

Table 4: Intake of food groups in both groups.

	Group 1			Group 2		
Cereals (g/day)	370.3	±	148.9	229.1	±	84.8*
Tubers (g/day)	42.6	±	44.1	34.3	±	30.5
Green and yellow vegetables (g/day)	91.4	±	71.5	49.1	±	30.4*
Other vegetables (g/day)	137.2	±	74.3	75.9	±	43.0*
Oils and fats (g/day)	10.6	±	4.0	6.8	±	3.3*
Beans (g/day)	42.1	±	34.7	26.2	±	23.6
Seafood (g/day)	51.8	±	27.9	25.9	±	18.4*
Meats (g/day)	67.6	±	29.4	44.1	±	18.3*
Eggs (g/day)	41.4	±	20.1	29.8	±	19.8*
Dairy (g/day)	118.6	±	94.3	105	±	73.0
Fruits (g/day)	79.1	±	60.7	45.8	±	27.5*
Sugar (g/day)	4.3	±	3.7	3.2	±	2.5
Sweets (g/day)	46.6	±	31.0	27.4	±	15.7*

Values are mean ± S.D.
*: Significant difference between two groups ($p < 0.05$)

vegetables (Group I; 137.2±74.3 g/day, Group II ; 75.9±43.0 g/day), oils and fats (Group I;10.6±4.0 g/day, Group II ; 6.8±3.3 g/day), seafood (Group I; 51.8±27.9 g/day, Group II ; 25.9±18.4 g/day), meats (Group I; 67.6±29.4 g/day, Group II ; 44.1±18.3 g/day), eggs (Group I; 41.4±20.1 g/day, Group II ; 29.8±19.8 g/day), fruits (Group I; 79.1±60.7 g/day, Group II ; 45.8±27.5 g/day) and sweets (Group I; 46.6±31.0 g/day, Group II ; 27.4±15.7 g/day). There was no significant difference between the two groups in the intake of tubers, beans, dairy and sugar.

Discussion

We showed that 17.6% of subjects in this study were taking extremely low energy even under BMR. In spite of taking very low energy in Group II, they showed normal range of BMI. This phenomenon could be explained by two reasons. Firstly, the amount of physical activities of the subjects in Group II might have been low. Secondary, the subjects in Group II in the normal range of BMI were trying to reduce weight by lowering food intakes with strong desire for thinness. If they would continue the dietary habits of low energy intake for a long time, BMI would be lower and the subjects in Group II would definitely become slender. We would emphasize that some serious problems are hidden behind normal BMI. Low BMI would have higher risk of having low weight birth babies [23, 24], and their glucose regulation would be impaired in their adulthood leading to type 2 diabetes [25, 26]. These reports suggested that young women should have adequate dietary habits and sufficient energy for healthy offspring.

Very serious physiological problem with very low energy intake is the impairment of glucose regulation. In general, the definition of diabetes is that glucose level at 120 min after glucose loading is over 200 mg/dl. In our results, glucose level measured at 120 min in Group II was 112.3 mg/dl. However, blood glucose levels of Group II at 30 and 60 min after glucose loading were significantly high showing steep increase from 78.9 mg/dl at fasting to 155.8 mg/dl at 30 min. Some reports have shown that the large fluctuation of blood glucose level impaired endothelial function and the acute glucose fluctuations triggered oxidative stress leading to endothelial cell apoptosis more severe than even stable hyperglycemia [27-29]. It was also reported that the swings in blood glucose level accelerated atherogenesis [30]. These reports suggested that young women with low energy intake in our study might have the higher risk of atherosclerosis leading to mortal cardiovascular disease in their later lives [8-11].

Our result showed that stamina for endurance-running was significantly low in Group II. It indicated that subjects in Group II did not have much enough muscle for endurance in running. Actually muscle mass and grip strength were slightly less in Group II. Generally speaking in elderly individuals, low skeletal muscle, occasionally caused by less intake of protein [31,32], would be mainly responsible for postprandial glucose disposal and would be also associated with insulin resistance leading to type 2 diabetes [33,34]. Therefore, low skeletal muscle, sarcopenia in older ages, was significantly associated with type 2 diabetes [35,36]. In our study, subjects were not older persons but young women of 20.5±1.1 years. But still we could assume that the impairment of glucose regulation in Group II was because of the insufficiency of skeletal muscle for the consumption of glucose after glucose loading just the same as shown in sarcopenia in elderly. Less skeletal muscle in Group II could be considered the reason for the blood glucose level at 30 and 60 min to be significantly high.

Concerning the dietary habits, the intake of all kinds of nutrients in Group II was significantly less than in Group I. The major problem is the deficiency of protein from meats, seafood and eggs which would lead to low skeletal muscle mass [31, 32]. We need to measure skeletal muscle mass and function using leg dynamometer to confirm this hypothesis in the next study.

Since vascular age in both groups were almost same as their actual age, it can be considered that atherosclerosis in Group II was not progressed. However, the big fluctuation of blood glucose level shown in Group II posed the higher risk of atherosclerosis leading to mortal cardiovascular disease [8-11]. This study showed that young women with low energy intake should take sufficient energy and build skeletal muscle to prevent the impairment of glucose regulation.

Conclusion

Our study showed that 17.6% of young women who participated in this study were taking energy even under BMR. The subjects with low energy intake impaired glucose regulation and their stamina was significantly low. The impairment of glucose regulation could be considered to be due to less energy intake.

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