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＜研究報告＞

The relation between menstrual disturbance and basal metabolic rate in Japanese female athletes

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Abstract

The purpose of the present study was to examine whether menstrual disturbances in Japanese female athletes is accompanied by a reduced basal metabolic rate (BMR). Seventy young female volunteers, classified into three groups according to their menstrual states, eumenorrheic athletes, EU, n = 44 ; oligomenorrheic/amenorrheic athletes, OA, n = 18 ; and eumenorrheic untrained subjects, EC, n = 8 ; participated in the present study. The BMR was measured by an indirect calorimetry. The body fat mass (FM) and percent of body fat mass (%FM) were estimated by using air displacement method. The dietary intakes were determined from 3-day foods records with photographic intelligence. Serum triiodothyronine (T_3), estradiol, hemoglobin, iron, and ferritin concentrations were also assessed. The maximal oxygen uptake and resting heart rate (HR) were measured in EU and OA groups. There was no significant difference in BMR among EU, OA and EC groups : 28.3 ± 3.2 kcal/kg LBM/day in EU ; 27.3 ± 3.4 kcal/kg LBM/day in OA ; 27.5 ± 2.5 kcal/kg LBM/day in EC, respectively. However, the level of T_3, %FM and resting HR were significantly lower in OA group than those in EU and EC groups, whereas other variables including energy intake, macronutrient composition, and dietary restriction were almost identical among three groups. These data suggested that the menstrual dysfunction in Japanese young athletes is not directly associated with the lower BMR but the fall of thyroid hormone may contribute to the abnormal menstruation in athletes.

Key words: female athletes, BMR, body composition, thyroid hormone, energy intake

Introduction

Menstrual disturbances associated with exercise are reported in active women and athletes who participate in physical activity ranging from recreational to strenuous exercise training. Amenorrhea, which involves complete follicular and luteal suppression, is the most severe menstrual disturbance observed in trained

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athletes ; other more subtle and less sever disturbances such as oligomenorrheic menstruation are also observed in athletes. The incidence rate of these menstrual disturbances was high in sports that emphasize thin physique, like long-distance running and gymnastics (ACSM 1997).

Although the exact mechanism underlying these menstrual disturbances remains unclear, the impact of energetic stress and its key components, energy intake, energy expenditure, and energy balance, are likely involved. Previous studies (Myerson et al., 1997 ; Lebenstedt et al., 1999) found that athletes with menstrual dysfunction showed a lower basal metabolic rate (BMR) and less body fat as compared to active controls with regular menstruation. Our previous study (Taguchi et al., 2001 and 2002) also found that oligomenorrheic and amenorrheic distance runners had a lower BMR level than eumenorrheic runners and sedentary controls with regular menstruation, suggesting that a reduced BMR plays an important role in the menstrual disturbances. However, it was unclear in these studies whether the lower BMR in oligomenorrheic and amenorrheic athletes is linked with menstrual dysfunction or different physical fitness level. For this reason, it is necessary to verify whether menstrual abnormality in Japanese female athletes is accompanied by a lower BMR. In addition, menstrual abnormality in athletes is also reported to have a correlation with several factors such as body composition (Sjödin et al., 1996 ; Sparti. et al., 1997), energy intake (Nelson et al., 1986 ; Kaiserauer et al., 1989 ; Harber, 2004), energy balance (Deuck et al., 1990 ; Loucks et al., 1998), and hormonal states (Loucks et al., 1992 and 1994). Specifically, circulating thyroid hormone levels (T_3 and T_4) have been suggested to be important regulators of cellular metabolism and energy expenditure. Indeed, several studies reported that serum level of thyroid hormone T_3 and T_4 were reduced in female athletes with amenorrhea and low caloric intake as compared with athletes with regular menstrual cycles and age-matched controls (Marcus et al., 1985). From these considerations, we examined whether menstrual dysfunction in Japanese athletes is associated with a lower BMR.

Methods

Subjects.

Seventy female volunteers participated in this study. The experimental procedures were explained in details, and informed consent was obtained from each subject. The study protocol was approved by the institutional ethical committee review board in Japan Women's College of Physical Education for use of human subjects in confirmation with the declaration of Helsinki. Subject's menstrual status was assessed with a questionnaire, and 44 athletes were classified as eumenorrheic athletes (EU) who has regularly menstruating cycle. 18 athletes were classified as oligomenorrheic athletes who has two or three menstrual cycles in the previous year, and amenorrheic athletes (OA) who has been absent of menstruation. In the present study, eumenorrheic, oligomenorrheic and amenorrheic female collegiate athletes who participated in various sports such as track and field events, swimming, rowing, fencing, volleyball, basketball, soft-tennis, table tennis, rugby, rhythmic gymnastics, cheer leading were recruited. In addition, 8 women were classified as eumenorrheic untrained controls (EC) who has regularly menstrual cycles.

Basal metabolic rate.

All eumenorrheic subjects were tested during the follicular phase of their menstrual cycle.

After an overnight fasting at our accommodation facility, the subjects were awakened at 6 a.m. and the basal metabolic rate (BMR) was measured by indirect calorimetry. Subjects remained awake in a supine position at a comfortable room temperature (23–25℃). After 30-min habituation period with musk, expired gas was collected in Douglas bag for 10-min, and oxygen consumption and carbon dioxide production were analyzed by using AE-300 SRC (Minato medical science, Tokyo). BMR was then calculated from the average of the 10-min using the Weir's equation (Weir, 1949).

Body composition.

Body weight (BW) and body composition were measured by air displacement method using BOD POD system (LMI Inc. Carifornia). Percent of body fat (%BF) was calculated using the equation of Brożek et al. (1963), and fat mass (FM) and lean body mass (LBM) were estimated based on the two-compartment model.

Dietary survey.

Energy and nutrient intakes were determined from 3-day foods records and photographic intelligence. A registered dietitian (RD) instructed recording technique to the subjects before investigation. The RDs were fed to analyze all diets for energy and nutrient intakes using conventional software (Wellness 21, Top Business System, Okayama) which was made by using the Standard Tables of Food Composition in Japan (2005). Screening of disordered eating was performed by Eating Attitude Test (EAT 26).

Blood analysis.

Venous blood samples were taken after the measurement of BMR to analyze hemoglobin (Hb), serum iron (Fe), and serum ferritin (Fr) concentrations, as well as serum triiodothyronine (T_3) and estradiol (E_2) level. Hb was determined by SLS-Hb assay, Fe was determined by Nitroso-PSAP assay. Fr was determined by chemiluminescent enzyme immunoassay (CLEIA), T3 and E2 were determined by electro chemiluminescence immunoassay (ECLIA).

Aerobic fitness test.

Maximal oxygen consumption ($\dot{V}o_2max$) was determined by the use of a computerized system (AE-300 SRC, Minato medical science, Tokyo) with continuously monitoring fraction of oxygen and carbon dioxide during graded-exercise lead to exhaustion.

Statistics.

Data were analyzed by one-way analysis of variance (ANOVA) techniques and dependent Student's t-test. Sheffe's post hoc analysis were used to determine the location of the difference when significance was obtained with the ANOVA test. SPSS package (Ver. 14.0) was used for the statistical analysis in this study. The level of statistical significance was set at $p < 0.05$. All data are expressed as the means ± standard deviation (SD).

Results

Table 1 shows the characteristics of subjects. The values in all variables were similar among EU, OA and EC groups except for %BF and resting HR. The level of %BF and resting HR were significantly lower in EU and OA than those in EC. However, FM of the two athlete groups was not different from that of EC group. EAT 26 score was the same level among the three groups, and all of subjects did not have disordered dietary habits. The levels of $\dot{V}o_2max$ and athletic career were almost identical between EU and OA groups.

Table 2 shows the nutritional intakes of the subjects. Energy intake, protein, fat and carbohydrate intakes were not different among three groups.

Table 1 Characteristics in three groups

	Athletes		Untrained
	EU (n = 44)	OA (n = 18)	EC (n = 8)
Age (yr)	20.0 ± 1.1	20.3 ± 1.7	21.3 ± 1.5
Height (cm)	161.4 ± 5.4	164.6 ± 6.7	159.8 ± 5.6
Weight (kg)	55.9 ± 5.2	55.9 ± 8.1	56.5 ± 4.1
Body fat (%)	19.9 ± 3.8 *	18.1 ± 5.2 *	24.1 ± 4.1
Fat mass (kg)	11.1 ± 2.6	10.4 ± 4.2	13.8 ± 3.5
Lean body mass (kg)	44.8 ± 3.8	45.5 ± 5.0	42.7 ± 4.1
Resting HR (bpm)	50.3 ± 5.1 *	47.4 ± 6.7 *	59.1 ± 8.0
Body temperature (℃)	35.8 ± 0.5	35.8 ± 0.3	35.6 ± 0.5
EAT26 score	10.8 ± 5.7	9.6 ± 5.5	7.3 ± 1.8
$V_{O_2}max$ (ml/kg/min)	37.2 ± 3.6	38.6 ± 6.7	—
Athletic career (yr)	8.5 ± 5.2	9.5 ± 3.1	—

Values are mean ± SD.
EU, eumenorrheic athletes ; OA, oligomenorrheic/amenorrheic athletes ; EC, eumenorrheic untrained control.
* : Significant difference from EC group at $p < 0.05$.

Table 2 Energy and macronutrient intakes in three groups

		Athletes		Untrained
		EU	OA	EC
Energy	(kcal/day)	2076 ± 488	2013 ± 556	1645 ± 241
	(kcal/kg BW/day)	37.4 ± 9.2	36.4 ± 8.9	30.2 ± 7.0
	(kcal/kg LBM/day)	46.6 ± 11.0	44.0 ± 10.0	39.5 ± 8.0
Protein	(g/day)	67.2 ± 19.8	68.8 ± 21.7	54.9 ± 7.3
	(g/kg BW/day)	1.2 ± 0.4	1.2 ± 0.4	1.0 ± 0.2
	(g/kg LBM/day)	1.5 ± 0.5	1.5 ± 0.5	1.3 ± 0.3
Fat	(g/day)	66.3 ± 18.5	64.5 ± 8.1	52.9 ± 13.8
	(energy %)	28.7 ± 5.0	29.1 ± 4.7	28.6 ± 6.2
Carbohydrate	(g/day)	296.6 ± 75.1	286.6 ± 87.4	237.5 ± 47.1
	(g/kg BW/day)	5.3 ± 1.34	5.1 ± 1.4	4.3 ± 1.2
	(g/kg LBM/day)	6.6 ± 1.7	6.3 ± 1.6	5.6 ± 1.3

Values are mean ± SD. BW, body weight ; LBM, Lean body mass ; EU, eumenorrheic athletes ; OA, oligomenorrheic/amenorrheic athletes ; EC, eumenorrheic untrained control.

Table 3 shows the detail in blood biochemical analysis. Serum T_3 concentration in OA group was significantly lower than that in EU ($p<0.05$) and EC ($p<0.01$) groups, whereas serum E_2 and variables in anemia markers were similar among three groups.

Table 4 shows the BMRs in three groups. These were significant differences among three groups in terms of kcal/day, kcal/kg BW/day, and kcal/kg LBM/day, respectively.

Discussion

Major findings in the present study were (1) that, BMR was not different among the three groups, despite of detectable differences in menstrual status ; and (2) that, T_3 in OA group was significantly lower than that in EU and EC

Table 3 Blood biochemical parameters in three groups

	Athletes		Untrained
	EU	OA	EC
T_3 (ng/ml)	1.02 ± 0.10	0.91 ± 0.14* †	1.07 ± 0.17
E_2 (pg/ml)	73 ± 51	68 ± 89	68 ± 71
Anemia markers			
RBC (× 10^4/μl)	446 ± 28	440 ± 31	454 ± 24
Hb (g/dl)	13.1 ± 0.9	13.3 ± 1.0	13.1 ± 0.7
Ht (%)	41.0 ± 3.0	41.7 ± 3.1	41.8 ± 1.9
Serum iron (μg/dl)	123 ± 54	107 ± 38	90 ± 33
Ferritin (ng/ml)	28 ± 17	32 ± 21	21 ± 17

Values are mean ± SD.
EU, eumenorrheic athletes ; OA, oligomenorrheic/amenorrheic athletes ; EC, eumenorrheic untrained control.
T_3 : triiodothyronine, E_2 : estradiol, RBC : red blood cell, Hb : hemoglobin, Ht : hematocrit.
* : significant differrence from EC group at $p < 0.01$. † : significant differrence from Eu group at $p < 0.05$.

Table 4 Basal metabolic rate in three groups

	Athletes		Untrained
	EU	OA	EC
BMR (kcal/day)	1263 ± 185	1236 ± 163	1178 ± 150
(kcal/kg BW/day)	22.7 ± 2.7	22.4 ± 3.3	20.9 ± 2.3
(kcal/kg LBM/day)	28.3 ± 3.2	27.3 ± 3.4	27.5 ± 2.5

Values are mean ± SD. BMR : Basal metabolic rate.
EU, eumenorrheic athletes ; OA, oligomenorrheic/amenorrheic athletes ; EC, eumenorrheic untrained control.

groups. These data do not support the consept that athletes with menstrual disorder have a lower BMR. Our results are inconsistent with the previous studies (Myerson et al., 1991 ; Lebenstedt et al., 1999) reported that athletes with menstrual dysfunction have lower BMR. Myerson et al. (1991) found that amenorrheic high mileage runners seem to have a less adequate diet than eumenorrheic runners, but appear to maintain energy balance and stable body weight through a reduction in RMR. Myerson et al. limited their investigation to amenorrheic athletes with higher aerobic fitness level ($\dot{V}O_2max$) than that of our study, whereas close to half athletes in OA group in the present study were oligomenorrhea.

Lebenstedt et al. (1999) also found that low RMR are associated with menstrual cycle disturbances in athletes. In this previous study, food restraint score of athletes with menstrual disorders was significantly higher than that of athletes with normal menstrual cycles. Myerson et al. also found that EAT 26 score of amenorrheic runners was significantly higher than eumenorrheic runners and controls (A>E, C). Conversely, we were not able to detect a significantly different score of EAT 26 test between OA and EU groups ; furthermore, the score was low value.

Therefore, the discrepancy between present study and previous study may be due to some factors including extent of menstrual abnormality, athletic fitness level, and dietary restraint.

Since thyroid hormones is known to increase resting energy expenditure in humans, the lower T_3 concentration in female athletes has been observed. In the present study, T_3 concentration of OA group was significantly lower than that of EU ($p<0.05$) and EC ($p<0.01$) groups (EC≧EU>OA), despite serum T_3 concentration of each subject kept within a normal range. In the previous studies (Myerson et al., 1991 ; Loucks and Heath, 1994 ; Zanker and Swaine, 1997), thyroid hormone levels were in the low-to-normal range, and lower than those in regularly menstruating subjects in amenorrheic athletes. Our results are consistent with the previous studies. Onur et al. (2005) reported that an increase in plasma T_3 of 1.8 pmol/L increased REE by about 0.5 MJ/day (119 kcal/day) as a curative effect for the patients with anorexia nervosa. Loucks and Heath (1994) showed the suppression of T_3 production occurred at a threshold of energy availability (total energy expenditure minus thermic effect of activity) between 19.0 and 25.0 kcal/kg LBM/day. They concluded that T_3 levels fell when energy intake was reduced to 800 kcal/day if carbohydrate content was <200 kcal/day, but when energy intake was reduced to 600 kcal/day or less, T_3 level fell regardless of carbohydrate content. In the present study, athletes did not follow a restrictive diet, thus, energy and carbohydrate intake levels of OA group were not below the above data.

Energy and macronutrient intakes were not different among the three groups in the present study. These data are consist with the previous investigations (Myerson et al., 1991, Reading et al., 2002). Energy intake of EU and OA athletes were 37.4 ± 9.2 and 36.4 ± 8.9 kcal/kg BW/day, respectively. Estimated energy requirement (EER) by Dietary Reference Intakes for Japanese (2005) set up 35–40 kcal/kg BW/day. Our data was comparable level with EER of non-athletic healthy individuals.

Kurzer and Calloway (1986) demonstrated that severe restriction of energy intake (40 to 17 kcal/kg BW/day) caused anovulatory and amenorrhea during observation period. They concluded that inadequacy of energy intake would also be a factor of amenorrhea. If athletes had restricted dietary habit, T_3 concentration would have decreased, consequently, BMR might be depressed. Therefore, low T_3 level in OA group might be a possible involvement of reduced BMR when linked with some kind of another factors such as energy deficiency.

Incidentally, the athletes (EU and OA) had significantly lower %BF and resting HR than the untrained controls (EC) in the present study. These were the same result to the previous study (Kaiserauer et al., 1989 ; Wilmore et al., 1992). No significant differences were observed in the athletic career, and the frequency of exercise training (averagely 2–3 hours per day, 5–6 times per week) during a recent years in EU and OA groups. Lower %BF and resting HR than EC will be brought on by inclement physical activity in the athlete groups.

Because of %BF did not differ significantly between EU and OA groups, it appears that %BF have no direct relation with menstrual status in this study. However, %BF and FM in OA was rather low than EU. Zanker and Swain (1998) showed that %BF were significant difference among the three groups of athletes (Amenorrheic < Oligomenorrheic < Eumenorrheic). Generally, the less %BF and/or low FM were known as determinant factors of menstrual dysfunction in female athletes, which could be associated with reduction of resting energy metabolism, hormone imbalance and eating disorders (Myerson et al., 1991 ; ACSM, 1997). Taguchi et al. (2006) reported that lower BMR involved with lower BF and %BF. Deuck et al. (1996) showed that increased %BF (from 8.2% to 14.4%) was nonpharmacological treatment which can contribute to reestablishing menstrual cyclicity in amenorrheic athletes. Further examination including duration of menstrual disturbance and energy balance is needed to clarify the relation between body composition, menstrual states and BMR in Japanese female athletes.

In conclusion, the menstrual dysfunction in Japanese young athletes is not directly associated with the lower BMR but the fall of thyroid hormone may contribute to the abnormal menstruation in athletes.

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