Resting energy expenditure is lower in Japanese female athletes with menstrual disorders than in eumenorrheic athletes

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Abstract Menstrual disorders are health problems in female athletes. It has also been reported that amenorrhea can lead to metabolic suppression. However, studies regarding resting energy expenditure (REE) in Japanese female athletes with menstrual disorders are lacking. The purpose of this study was to investigate whether REE was suppressed in female Japanese athletes with menstrual disorders. In total, 22 highly trained intercollegiate athletes participated in this study; and body composition, REE, thyroid and reproductive hormone levels, and nutritional intake levels were measured. Predicted REE (REEp) was calculated using two different equations based on fat-free mass (FFM) and organ-tissue mass measured by dual-energy X-ray absorptiometry (DXA). Individuals with menstrual disorders (MD group) had significantly lower height, body weight, and fat mass than those in the eumenorrheic (EU) group; however, the FFM did not differ between the groups. Both the measured REE (REEm) and REEm adjusted for FFM in the MD group were lower than those in the EU group. The REEm to REEp ratio, which indicates energy deficiency, was also lower in the MD group. In addition, although the MD group had lower triiodothyronine and progesterone levels, they were still within the normal range. Japanese female athletes with menstrual disorders may have lower REE than eumenorrheic athletes, even if thyroid and reproductive hormones are within the normal range.

Keywords energy metabolism suppression, energy deficiency, triiodothyronine, predicted REE

Introduction

Resting energy expenditure (REE) is the energy required to maintain fundamental and essential body functions at rest. Low energy intake that does not match consumption is related to energy conservation and lower REE1. A previous study reported that REE was reduced by adaptive energy suppression in malnourished patients with severe anorexia nervosa3. In addition, women with extremely low body weight due to energy deficiencies and anorexia nervosa often develop hypothalamic amenorrhea3. Therefore, energy deficiency is associated with REE reduction and menstrual abnormalities in women who do not exercise.

However, REE reduction and menstrual disorders caused by energy deficiencies can also be observed in female athletes4-6. Some female athletes wish to lose body weight to improve their performance or appearance, but severe weight reduction is associated with menstrual disorders7. Because menstrual disorders affect reproductive health and performance8,9, studies on body weight, menstrual disorders, and energy metabolism are essential for athletes. In particular, REE is related to fat-free mass (FFM), triiodothyronine (T3), estrogen, and menstrual conditions in female athletes10-12. It has been observed that amenorrheic athletes have lower body weight and T3 levels than eumenorrheic athletes, even when their energy intake does not differ significantly13,14. De Souza et al. indicated that a combined loss in body weight and T3 was associated with REE reduction in physically active women15. In addition, previous studies reported that an energy deficiency could be defined by the ratio of the measured REE (REEm) to the predicted REE (REEp) using a prediction equation16,17. It was observed that when the REE ratio was <90%, subjects had significantly lower T3 levels than those with higher REE ratios18. It is considered that T3 is lowered due to the energy deficit, and REEm is lower than REEp, resulting in a lower REE ratio. Each REE ratio can be calculated based on the REEp computed using a prediction equation16,17. However, commonly used equations are based on previous study results from individuals other than Japanese athletes. If the REEp is predicted using an equation that is not consistent with Japanese data, it may be overestimated or
underestimated\(^{(18)}\). When the REE ratios are calculated using the overestimated REEp, it is impossible to determine whether energy adaptation occurs. Taguchi et al. showed that REE can be predicted using FFM in Japanese female athletes\(^{(19)}\). In addition, Usui et al. indicated that REE could be predicted from organ-tissue mass in Japanese women\(^{(20)}\). Therefore, it is necessary to use a prediction equation for Japanese athletes. Interestingly, there was no difference in REE between lean women with a low BMI (<18.5 kg/m\(^2\)) and women with a normal BMI (18.5 - 25 kg/m\(^2\)) in Japanese eumenorrheic women\(^{(21)}\). Given that there are no previous studies on REE in Japanese athletes with menstrual disorders, it is not clear whether energy deficiency is associated with low REE in this context. In addition, no studies have compared REE and hormone status between the eumenorrheic and menstrual disorder groups in Japanese female athletes.

Consequently, the purpose of this study was to investigate whether REE is low in Japanese female athletes with menstrual disorders. It was hypothesized that female Japanese athletes with menstrual disorders would have lower REE than eumenorrheic athletes due to lower levels of reproductive and metabolic hormones.

**Materials and methods**

**Subjects**

Highly trained collegiate athletes on national competition levels were recruited via fliers, and the research group provided an oral explanation of the study protocol and objectives to the respondents. A total of 113 subjects completed a screening questionnaire and interviews, and only 23 satisfied the inclusion and exclusion criteria. The inclusion criteria of the present study were as follows: expressed willingness to participate, age 18–30 years, not using medications that would alter metabolic or sex hormone concentrations, not currently trying to lose or gain any body weight, maintained a stable weight for at least 2 months, non-smoker, not pregnant; not using hormonal contraceptives, and not using any form of hormone therapy for at least 6 months. The exclusion criteria included gynecological treatment for menstrual disorders. None of the enrolled subjects exhibited anemia or lipid metabolism abnormalities, and none had a history of eating disorders. Written informed consent was obtained from all subjects. All study procedures were approved by the Ethics Review Committee on Research with Human Subjects of Waseda University (application number 2015-304), and the study was conducted in accordance with the Declaration of Helsinki. Ultimately, 22 female collegiate athletes participated in this study (soccer, n = 9; lacrosse, n = 9; swimming, n = 4).

The ovulation of the subjects was determined by urinary testing of the luteinizing hormone (LH) surge using ovulation test kits every day from 17 days before the scheduled day of menstruation until the onset of menstruation (Dotest, ROHTO Pharmaceutical Co., Ltd., Osaka, Japan). Subjects were considered eumenorrheic if menses occurred at regular intervals of 25–38 days, oligomenorrheic if menses occurred at irregular intervals of 39–90 days, and amenorrheic if they failed to menstruate for a minimum of 3 consecutive months\(^{(22)}\). These menstrual cycles were confirmed by questionnaires before the measurements and interviews during the measurements. Oligomenorrheic (n=8) and amenorrheic (n=2) subjects were allocated to the menstrual disorder (MD) group (n=10). All eumenorrheic subjects (n=12) were allocated to the eumenorrheic (EU) group.

**Body composition**

After overnight fasting, body weight was measured to the nearest 50 g using an electronic scale (UC-321; A&D Co., Ltd., Tokyo, Japan), and height was measured to the nearest 0.1 cm using a stadiometer (YG-200; Yagami Inc., Tokyo, Japan). Body mass index was also calculated for each subject. Subjects measured body weight and recorded their physical condition every day.

A dual-energy X-ray absorptiometry (DXA) (Hologic Delphi A; Hologic Inc., Marlborough, MA, USA) was used to measure body fat percentage, bone mineral content, and lean soft tissue mass to calculate organ tissue mass. FFM was calculated from the morning fasting body weight and body fat percentage measured using DXA.

**Measurement of resting energy expenditure**

The REEm was assessed during the early follicular phase (2–7 days after confirmation of bleeding) of each menstrual cycle in eumenorrheic and oligomenorrheic subjects after overnight fasting. Amenorrheic subjects were assessed at any given time. The day before the measurement, we instructed the subjects not to eat or drink anything other than water after 9:00 pm. On the day of the measurement, the subjects were asked to come to the measurement site slowly without running from home and were kept at rest for at least 30 min after arriving. REE was measured by indirect calorimetry using the Douglas bag technique in a room adjusted to approximately 22 °C to 24 °C\(^{(19)}\). The subjects were instructed to remain awake, quiet, and still before and throughout the measurement. After 30 min of rest, two 10-min samples of expired gas were collected in bags. Oxygen and carbon dioxide concentrations were analyzed using an expiration gas analyzer (AE100i; Minato Medical Science Co., Ltd., Osaka, Japan). The volume of expired air was determined using a dry gas volume meter (DC-5A; Shinagawa, Tokyo, Japan). The measurements were repeated until the coefficient of variation (CV) of the REE measured twice was less than 5% and the average of the two values was used in the analysis (mean CV, 2.1%). REEm was calculated using Weir’s equation\(^{(23)}\).
**Prediction of resting energy expenditure**

The REEp based on FFM (REEp FFM) was calculated using the following prediction equation developed for Japanese athletes\(^{18}\):

\[
\text{REEp FFM} = 27.5 \times \text{FFM (kg)} + 5
\]

Bone mass (BM), adipose tissue mass (AT), skeletal muscle mass (SM), and residual mass (RM) were estimated using values obtained from DXA according to a previously published method\(^{20}\).

\[
\begin{align*}
\text{BM (kg)} &= \text{bone mineral content (g)} \times 1.85/1000 \\
\text{AT (kg)} &= \text{FM (kg)} \times 1.18 \\
\text{SM (kg)} &= 1.13 \times \text{lean soft tissue (kg)} - 0.02 \times \text{age (years)} + 0.97 \\
\text{RM (kg)} &= \text{body weight} - (\text{BM} + \text{AT} + \text{SM})
\end{align*}
\]

Bone mass (BM), adipose tissue mass (AT), skeletal muscle mass (SM), and residual mass (RM) were estimated using values obtained from DXA according to a previously published method\(^{20}\).

The REEp from organ tissue (REEp organ tissue) was calculated using the sum of the four body components and the corresponding tissue respiration rate as follows\(^{19,24}\):

\[
\text{REEp organ tissue} = 2.3 \text{BM} + 4.5 \text{AT} + 13 \text{SM} + 54 \text{RM}
\]

The REEm to REEp FFM ratio (REE ratio FFM) and the REEm to REEp organ tissue ratio (REE ratio organ tissue) were calculated as an indicator of energy deficiencies.

**Blood analysis**

Venous blood samples were collected after morning fasting to analyze serum T\(_3\), estradiol (E\(_2\)), insulin-like growth factor 1 (IGF-1), LH, follicle stimulating hormone (FSH), and progesterone (P\(_4\)) concentrations. T\(_3\), E\(_2\), LH, FSH, and P\(_4\) levels were measured using chemiluminescence immunoassays, and IGF-1 was measured using an immunoradiometric assay. All blood parameters were analyzed by LSI Medience Corporation (Tokyo, Japan). Blood samples of eumenorrheic and oligomenorrheic subjects were collected during the early menstrual phase, and those of amenorrheic subjects were collected on an arbitrary day during a regular training period.

**Dietary survey**

Subjects completed 3-day weighed food records using a food scale, and digital photographs of their meals were also obtained. Photographs were taken using a digital camera or the subject’s smartphone. A registered dietitian, one of the authors of this study (KM), provided instructions on weighing their food and recording the amounts. After the experiment, a registered dietitian reviewed the food diary with the subjects. Energy and macronutrient intake were calculated using a dietary software (Excel Eiyoukun; Kenpakusha, Japan) based on the standard table of food composition in Japan (Seventh Revised Edition)\(^{25}\).

**Statistical analyses**

Data are expressed as the mean ± standard deviation. SPSS version 26.0 (IBM SPSS, IBM Japan, Tokyo) was used for statistical analysis. Normality was assessed using the Shapiro-Wilk test. For normally distributed variables, Student’s t-test was used to compare the MD and EU groups. The Mann-Whitney U test was used to identify differences in data that were not normally distributed (age, exercise duration, and P\(_4\)). Analysis of covariance was used to identify differences in REEm between the groups after adjustment for FFM. Statistical significance was set at \(p < 0.05\).

**Results**

The characteristics of the subjects included in this study are listed in Table 1. The height, body weight, and body fat percentage were lower in the MD group than in the EU group (\(p < 0.05\)); however, there was no significant difference in FFM between the groups. The energy status of the subjects is listed in Table 2. The daily energy, carbohydrate, protein, and fat intake levels did not differ significantly between the two groups. REEm in the MD group was significantly lower than that in the EU group (\(p = 0.001\)). After REEm was adjusted for FFM, it was still significantly lower in the MD group (\(p = 0.001\)). REEp FFM in the MD group was significantly lower than that in the EU group (\(p < 0.05\)). REEp FFM and REEp organ tissue were similar in both groups (\(p = 0.276\) and 0.304, respectively); however, REE ratio FFM and REE ratio organ tissue were lower in the MD group (\(p = 0.042\) and \(p = 0.050\), respectively). In addition, there was a significant difference between REEm and REEp FFM or REEm and REEp organ tissue in the MD group, but not in the EU group. Thyroid and reproductive hormone levels are shown in Table 3. T\(_3\), FSH, and P\(_4\) levels were significantly lower in the MD group than in the EU group (\(p < 0.05\)).

**Discussion**

The primary finding of this study was that female athletes with menstrual disorders had lower REEm than those from the EU group, even after adjusting for FFM. To our knowledge, this is the first study exploring the relationship between REE and menstrual disorders in Japanese female athletes. A previous study comparing amenorrhea and normal menstruation in Japanese female athletes showed that fatigue fractures occurred more frequently in the amenorrhea group, but there are no papers mentioning REEm\(^{26}\). The majority of reports on REE and energy deficiency or menstrual disorders are focused on white women. In white female athletes, the reported REEs were approximately 30 kcal/kg FFM/day\(^{27}\); in contrast, Japanese women had an REE of approximately 27.5 kcal/kg FFM/day\(^{18}\). Because of possible racial differences, data from Japan are required. It has been reported that amenorrhea is more common in esthetic and endurance athletes due to severe weight loss during competition\(^{26}\). We decided to examine menstrual disorders in athletes who are considered less likely to experience excessive weight loss for the sake of competition. Therefore, most of the subjects in this study were soccer and lacrosse players. The
Table 1. Characteristics of subjects.

<table>
<thead>
<tr>
<th></th>
<th>All</th>
<th>EU (n = 12)</th>
<th>MD (n = 10)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>19.9 ± 1.1</td>
<td>20.2 ± 1.1</td>
<td>19.6 ± 1.1</td>
<td>0.180</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>161.5 ± 5.7</td>
<td>163.7 ± 5.3</td>
<td>158.9 ± 5.4</td>
<td>0.047</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>55.1 ± 5.2</td>
<td>57.5 ± 4.2</td>
<td>52.1 ± 4.9</td>
<td>0.013</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>21.1 ± 1.4</td>
<td>21.5 ± 1.4</td>
<td>20.6 ± 1.2</td>
<td>0.150</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>20.0 ± 3.8</td>
<td>22.1 ± 3.2</td>
<td>17.6 ± 3.0</td>
<td>0.003</td>
</tr>
<tr>
<td>Fat mass (kg)</td>
<td>11.1 ± 2.8</td>
<td>12.7 ± 2.4</td>
<td>9.2 ± 1.7</td>
<td>0.001</td>
</tr>
<tr>
<td>Fat-free mass (kg)</td>
<td>44.0 ± 3.7</td>
<td>44.8 ± 3.0</td>
<td>43.0 ± 4.3</td>
<td>0.276</td>
</tr>
<tr>
<td>Skeletal muscle mass (kg)</td>
<td>21.4 ± 1.8</td>
<td>21.7 ± 1.7</td>
<td>21.2 ± 2.0</td>
<td>0.532</td>
</tr>
<tr>
<td>Residual mass (kg)</td>
<td>17.1 ± 1.8</td>
<td>17.3 ± 1.6</td>
<td>16.8 ± 2.0</td>
<td>0.499</td>
</tr>
<tr>
<td>Age at menarche (yrs)</td>
<td>12.6 ± 1.6</td>
<td>12.2 ± 1.8</td>
<td>13.1 ± 1.1</td>
<td>0.153</td>
</tr>
<tr>
<td>Exercise duration (h/day)</td>
<td>2.7 ± 0.7</td>
<td>2.6 ± 0.7</td>
<td>2.9 ± 0.7</td>
<td>0.353</td>
</tr>
</tbody>
</table>

Values represent the mean ± SD. BMI: body mass index; EU: eumenorrheic group; MD: menstrual disorders group; Skeletal muscle mass = 1.13 × Lean soft tissue (kg) -0.02 × age (years) + 0.97; Residual mass = Body weight – (BM + AT + SM).

Table 2. Energy status of subjects.

<table>
<thead>
<tr>
<th></th>
<th>EU</th>
<th>MD</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy intake (kcal/day)</td>
<td>1,882 ± 394</td>
<td>1,816 ± 337</td>
<td>0.679</td>
</tr>
<tr>
<td>REEm (kcal/day)</td>
<td>1,244 ± 100</td>
<td>1,057 ± 120</td>
<td>0.001</td>
</tr>
<tr>
<td>REEm adj FFM (kcal/day)</td>
<td>1,239 ± 32</td>
<td>1,062 ± 36</td>
<td>0.001</td>
</tr>
<tr>
<td>REEm / FFM (kcal/kg/day)</td>
<td>27.8 ± 1.9</td>
<td>24.8 ± 3.8</td>
<td>0.042</td>
</tr>
<tr>
<td>REEp FFM (kcal/day)</td>
<td>1,237 ± 82</td>
<td>1,187 ± 119*</td>
<td>0.276</td>
</tr>
<tr>
<td>REE ratio FFM</td>
<td>1.01 ± 0.07</td>
<td>0.90 ± 0.14</td>
<td>0.042</td>
</tr>
<tr>
<td>REEp organ tissue (kcal/day)</td>
<td>1,296 ± 107</td>
<td>1,240 ± 134*</td>
<td>0.304</td>
</tr>
<tr>
<td>REE ratio organ tissue</td>
<td>0.96 ± 0.07</td>
<td>0.86 ± 0.13</td>
<td>0.050</td>
</tr>
</tbody>
</table>

Values represent the mean ± SD. EU: Eumenorrheic group; MD: Menstrual disorders group; REEm: measured resting energy expenditure; REEm adj FFM: measured resting energy expenditure adjusted for fat-free mass; REEp organ tissue: predicted resting energy expenditure by organ tissue mass; REEp FFM: predicted resting energy expenditure by fat-free mass; * vs. REEm (p < 0.05).
height and weight of the subjects in this study exceeded the averages of the National Health and Nutrition Survey in Japan (Height was 157.5 cm and weight was 52.0 kg), but their BMI was close to the mean of the National Health and Nutrition Survey (20.2 for 15-19 years old and 21.0 for 20-29 years old)\(^2\). Although the subjects were athletes, their physiques were not markedly different from those of women who do not exercise regularly.

The MD group exhibited lower P\(_4\) levels than the EU group. While P\(_4\) does not affect food intake and body weight, it has been suggested that it may affect appetite\(^3\). Although further investigations are needed to confirm these effects, the low P\(_4\) level found among women from the MD group in this study may be related to low REEm by causing continuous lower food intake due to reduced appetite\(^3\). The MD group also exhibited lower LH than the EU group, but in normal range. According to the anovulation classification advocated by the World Health Organization, normogonadotropic anovulation belongs to group 2; that is, individuals in this category are in a state of anovulation, but their FSH and LH concentrations are normal\(^4\). Estrogen status can be assessed using the progesterin challenge test, which is based on estrogen secretion\(^5\). Withdrawal bleeding after the progesterin challenge indicates sufficient estrogen exposure. However, amenorrhea due to low estrogen levels is indicated by bleeding that occurs after the combined estrogen/progesterin test. Individuals with menstrual disorders exhibit decreased progesterone secretion, but stable estrogen secretion, and both estrogen and progesterone secretion are reduced in severe stage menstrual disorders. In the present study, the MD group exhibited lower FSH and P\(_4\) levels than the EU group; however, both parameters remained within the normal ranges in both groups. Furthermore, there was no significant difference in the E\(_2\) levels between the two groups. Therefore, the MD group subjects appeared to have menstrual disorders with reproductive hormone levels in the normal range.

Runners with amenorrhea exhibited lower REE, E\(_2\), and P\(_4\) than runners with eumenorrhea, despite no difference in their mean energy intake and body weight\(^6\). Singhal et al. reported that oligoamenorrheic young athletes had lower REE than eumenorrheic subjects\(^7\). Similarly, in our study, subjects from the MD group had lower REEm and P\(_4\) levels than those from the EU group. However, there were only two (10%) amenorrheic athletes in the MD group, and reproductive hormone levels of the athletes except for one athlete in the MD group were also within the normal range. In addition, oligomenorrheic subjects in the MD group were measured 2-7 days after the onset of menstruation in the present study. Therefore, no difference in E\(_2\) and LH was observed between the MD and EU groups. A previous study also showed that there was no difference in daily ovarian steroid excretion in subjects with a menstrual disorder and low REE ratio\(^8\). This indicates that E\(_2\) and LH did not affect the REE ratio in the present study. In contrast, one of the amenorrheic subjects had T\(_3\) and LH values below the reference values, and the REE ratio was also below 0.9. It is possible that low T\(_3\) may have influenced the low REE ratio, and that low LH may have been related to amenorrhea. For Japanese female athletes, REEm levels were low when menstrual disorders were present, even if reproductive hormone levels were not within the abnormal range.

Melin et al. reported that 24 elite endurance athletes with menstrual disorders had lower T\(_3\) and REE than eumenorrheic athletes\(^9\). Thyroid hormones play a significant role in diverse processes related to metabolism\(^4\), high T\(_3\) levels induce increasing energy expenditure\(^9\), and it modulates energy expenditure by central and peripheral

### Table 3. Thyroid and reproductive hormone levels of subjects.

<table>
<thead>
<tr>
<th></th>
<th>EU</th>
<th>MD</th>
<th>p value</th>
<th>Normal range</th>
</tr>
</thead>
<tbody>
<tr>
<td>T(_3) (ng/mL)</td>
<td>1.03 ± 0.09</td>
<td>0.83 ± 0.14</td>
<td>0.002</td>
<td>0.80–1.60</td>
</tr>
<tr>
<td>E(_2) (pg/mL)</td>
<td>49 ± 18</td>
<td>46 ± 18</td>
<td>0.736</td>
<td>19–226</td>
</tr>
<tr>
<td>IGF-1 (ng/mL)</td>
<td>232 ± 56</td>
<td>211 ± 37</td>
<td>0.318</td>
<td>175–499*</td>
</tr>
<tr>
<td>LH (mIU/mL)</td>
<td>3.82 ± 1.20</td>
<td>3.28 ± 1.30</td>
<td>0.332</td>
<td>1.76–10.24</td>
</tr>
<tr>
<td>FSH (mIU/mL)</td>
<td>5.58 ± 0.75</td>
<td>4.84 ± 0.85</td>
<td>0.045</td>
<td>3.01–14.72</td>
</tr>
<tr>
<td>P(_4) (ng/mL)</td>
<td>0.4 ± 0.2</td>
<td>0.2 ± 0.0</td>
<td>0.001</td>
<td>&lt; 0.4</td>
</tr>
</tbody>
</table>

Values represent the mean ± SD. E\(_2\): estradiol; EU: eumenorrheic group; MD: menstrual disorders group; FSH: follicle-stimulating hormone; IGF-1: insulin-like growth factor-1; LH: luteinizing hormone; P\(_4\): progesterone; T\(_3\): triiodothyronine.

*Normal range for 20-year-old women.
The $T_3$ level is associated with REE; therefore, an increase in $T_3$ levels could explain an increase in REE. FFM is considered the strongest determinant of REE; however, the effect of $T_3$ levels on REE is independent of FFM. The athletes in the MD group in this study exhibited lower REEm and $T_3$ than those in the EU group, even when their FFM was equal, as seen in previous studies. This result indicates that a low level of $T_3$ is one of the causes of low REEm in the MD group.

Two equations were used to predict REEp in this study. There was no difference between REEm and REEp in the EU group. This indicates that the prediction equations used were able to predict REE in Japanese female athletes. The REE ratio has recently been used in sports science to search for energy deficiencies. De Souza et al. indicated that it was difficult to assess energy deficiencies due to the under-reporting of energy intake and energy expenditure variability; therefore, they considered the REE ratio a more reliable measure for assessing energy deficiencies. These data indicated that the REEm may be low due to energy deficiencies in individuals from the MD group; conversely, the data did not indicate that REEm was low in EU group individuals. However, there was no significant difference in energy intake between the two groups in this study. Menstrual disorders are continuously affected by ongoing energy intake; thus, differences between the two groups in the study may have existed previously. In addition, both the MD group and the EU group included almost the same number of subjects in each sport. The energy intake was not significantly different due to no different exercise durations between the two groups.

Athletes in the MD group had lower REEm, but it did not result in a significant difference in FFM. Koehler et al. reported that the REE for women with exercise-associated amenorrhea was significantly lower than for women with DXA-predicted REE. They concluded that REE suppression in women with amenorrhea results from reduced metabolic activity at the tissue level. In this study, REEm was significantly lower than REEp in organ tissue in the MD group, as previously reported. In addition, there was no significant difference in the SM and RM between the groups. SM and RM include tissues with high metabolic activity. These results indicate that the tissue compartments with high metabolic activity were not low in the MD group. Although we did not measure the metabolic activity of tissues in this study, it is possible that low REEm could be caused by alterations in the metabolic activity of tissues even if FFM was not low.

The present study had several limitations. Athletes in the MD group were not subdivided into oligomer and amenorrhea groups. It was difficult to recruit subjects with menstrual issues because few had amenorrhea. In a previous study of Japanese female athletes, 5.3% had secondary amenorrhea. In the present study, the percentage of athletes with amenorrhea was 4.4%, but most received medical treatment. Therefore, few athletes matched the required criteria in this study. Nonetheless, the present study indicated that energy metabolism was influenced by menstrual conditions, even when reproductive hormone levels were within the normal range. Moreover, we could not investigate the previous energy balance or energy metabolism of the subjects. Menstrual disorders could have been influenced by a previous energy deficiency, but there were no practical methods to informatively investigate such previous energy intake or any other previous condition.

In conclusion, REEm was low in Japanese female athletes who exhibited menstrual disorders, even when their hormone levels were not within the abnormal range. For female athletes, normal menstruation and sufficient energy intake are important for maintaining health and prolonging their performance. If they have menstruation problems, even if hormone levels are within the normal range, their energy intake and REE should be monitored. Further research is required to determine the effects of continuous energy deficiency and REE in conjunction with other health issues; therefore, longitudinal studies should be performed.

Acknowledgements

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Conflict of Interests

The authors declare no conflict of interests regarding the publication of this article.

Author Contributions

MT and KM conceptualized the study design and protocol. KM, MG, and ST collected data. AN and ST interpreted the data. MT and KM drafted the manuscript. All authors critically reviewed, revised, and approved the manuscript.

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