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Energy Intake Deficiency Promotes Bone Resorption and Energy Metabolism Suppression in Japanese Male Endurance Runners: A Pilot Study

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Abstract

It has been reported that male athletes face increased risk for low energy availability and resulting health consequences similar to female athletes. The present study aimed to reveal the energy status of Japanese male runners and to examine the association between energy deficiency and physiological characteristics such as energy metabolism, bone health, and hormonal status. Six male collegiate long-distance runners during a training season participated in this study. Energy intake (EI) was assessed using 3-day dietary records with food pictures. Exercise energy expenditure (EEE) was determined by the HR-VO_2 method. Body composition and bone status were measured by dual-energy X-ray absorptiometry. Energy availability (EA) was calculated by subtraction of EEE from EI and normalized by fat-free mass (FFM). Energy balance (EB) was calculated EI minus estimated total energy expenditure (TEE). Resting energy expenditure (REE) was measured by indirect calorimetry using the Douglas bag technique, and blood sampling was conducted to assess hormonal status. The mean EA of the subjects was 18.9 ± 6.8 kcal/kg FFM/day, and severe negative EB (range: −1444 ~ −722 kcal/d) was observed. REE of four runners was suppressed, and moreover, bone resorption was promoted in all subjects. The data in our study suggested that energy deficiency could promote bone resorption and energy metabolism suppression in Japanese male endurance runners. Additional short- and long-term studies are needed to clarify the health risks caused by energy deficiency in male athletes and explore strategies to prevent health problems related to energy deficiency in long-distance runners.

Keywords

energy availability, energy deficiency, resting energy expenditure, bone resorption, male athletes

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Long distance competitions such as marathon and "ekiden" (a long-distance relay race) are very popular in Japan. Therefore, there is a strong tendency in Japan to run long distances from a young age. It has been reported that runners who practice long-distance running have frequent stress fractures. Sports doctors have warned against daily training with overruns to avoid stress fractures and other health problems (Nattiv, 2000; Torii, 2006). Previous study (Barrack et al., 2017) reported that male adolescent endurance runners whose weekly running mileage was 14.4 ± 2.0 km have lower body weights and lower spine BMD Z-score values than nonrunner athletes. The Medical Committee of the Japan Association of Athletics Federations (JAAF) reported that the average running mileage of male high-school runners was more than 30 km per week (https://www.jaaf.or.jp/about/resist/medical/). Due to longer running mileage, Japanese

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runners who have been running since adolescence were hypothesized to likely have bone injuries or other health problems. Since the energy expenditure of athletes increases with their daily training, adequate energy intake is a primary concern in most athletes (Burke, 2001). To prevent runner's injuries, Tahara et al. (2018) pointed out that it is necessary to reduce the amount of exercise and take energy from a proper diet. However, the relationship between energy status and physical conditions including bone status in Japanese runners has not been clarified.

As recognized in the Relative Energy Deficiency in Sport (Mountjoy et al., 2014), energy availability (EA) is used as a key element to the underlying determinants of energy inadequate status. EA is calculated as energy intake (EI) minus exercise energy expenditure (EEE), normalized to fat-free mass (FFM) per day (Loucks & Thuma, 2003; Nattive et al., 2007). It is known that if the energy intake is insufficient, EA decreases and the state of relative energy deficiency occurs in athletes. The condition where EA falls below 30 kcal/kg FFM/day is defined as low energy availability (LEA; Manore et al., 2007). It has been reported that LEA exerts physical effects, such as impaired reproductive function (Gibbs et al., 2013; Reed et al., 2015), metabolic rate (Gibbs et al., 2011; Melin et al., 2015), bone health (Nattiv, 2000; Papageorgiou et al., 2017), and eating disorders and/or disordered eating (Gibbs et al., 2011) in female athletes.

Since 2014, it has been reported that male athletes face increased risk for LEA and resulting health consequences similar to those in female athletes (Mountjoy et al., 2014; Tenforde et al., 2016), such as hypogonadism (Heikura et al., 2018; Hooper et al., 2017), low bone mineral density (Viner et al., 2015), and eating disorders (Devrim et al., 2018). The updated consensus statement (Mountjoy et al., 2018) mentioned that LEA occurs when there is a mismatch between energy intake (EI) and exercise energy expenditure (EEE) in daily training or competition. Previous studies reported that male endurance athletes, including long distance runners, were in negative energy balance (EB) (Fudge et al., 2006; Torstviet et al., 2018). Motonaga et al. (2006) reported that the total energy intake was lower than the total energy expenditure (TEE) among sub-elite male long-distance runners with high EEE. EI in another study of Japanese male elite athletes, including runners (Tatsuta et al., 2012), was almost equivalent to Motonaga et al.'s result, but EA, bone status, and reproductive hormone level were not reported in these studies. Because Japanese male runners have been training since they were young, there is a high probability that the energy status of the body is getting lower and that they might have health problems related to low energy status.

The aim of the present study was to reveal the energy status of Japanese male runners, and to examine the association between energy deficiency and physiological characteristics such as energy metabolism, bone health, and hormonal status.

Materials and Methods

Subjects

Six healthy, male collegiate long-distance runners (19–21 years old) were recruited to participate in this study. All subjects belonged to the track and field team in a university, and the measurement period was during their regular training season. None of the subjects were taking any medications or smoking. Subjects were given oral and written descriptions of the study, and written informed consent was obtained from all participants prior to study enrolment. The study was approved by the Human Research Committee of Waseda University for the use of human subjects following the Declaration of Helsinki (2018-082).

Energy Intake

Three-day dietary records with photographic intelligence methods were used to ascertain each subject's energy and nutrient intake levels. The subjects were asked to record the consumed contents in as much detail as possible on the dietary record form and to weigh foods using a food scale. The subjects also took a photograph of each meal with a smartphone camera. After finishing their 3-day dietary records, the subjects were interviewed by a sports dietitian, who is a coauthor of this study (KM). Energy and nutrient intake levels were calculated using nutrient calculation software that conformed to the Standard Tables of Food Composition in Japan (Wellness 21, Top Business System; Okayama, Japan).

Exercise Energy Expenditure

Prior to EEE measurement, a multistage exercise tolerance test was conducted and the maximum volume of oxygen consumption (VO_2 max) was measured using a cycle ergometer (Aerobike 75XL, Combi Wellness; Tokyo, Japan). After 5 min rest, the load was increased from 120 W by 30 W every 3 min, and exercise was continued until exhaustion. Oxygen uptake during exercise was continuously measured using a gas analyzer (AE-301S, Minato Medical Science; Tokyo, Japan), and heart rate (HR) was continuously measured by an HR monitor (Polar H7, Polar Electro Japan; Tokyo, Japan). The subjects were asked to indicate their rating of perceived exertion (RPE) using a Japanese version of the Borg scale (Borg, 1982) at the end of each stage. The judgment criteria for exhaustion was determined as when the subject presented with 3 or more of the following:

RPE ≧19, HR ≧ (220 – age), unable to continue exercise at the instructed load, respiratory exchange ratio ≧1.1, or observation of VO_2 leveling off. The maximum VO_2 obtained at that point was set as the VO_2max, and the maximum HR was set as HRmax. Then, an HR–VO_2 relational expression was created for each individual subject.

Next, during 3-day training sessions, the subjects wore an HR monitor (Polar Electro Japan). Oxygen uptake was estimated by applying the mean HR per minute to an individual's HR–VO_2 relational expression, and energy expenditure during exercise was obtained. The net EEE was calculated by subtracting basal metabolism during exercise.

Measurement of Resting Energy Expenditure

Subjects came to the laboratory at 7:00 am by car after fasting for 10–12 hr, except for drinking water. At the laboratory, subjects rested in the supine position for at least 30 min in a comfortable room temperature (23–25°C), and a face mask was put on. Subjects gave 2 samples of expired air collected in Douglas bags for a duration of 10 min each, and the mean value was used for the analysis (CV = 2.1%). An oxygen and carbon dioxide analyzer (AE-100i, Minato Medical Science) was used to analyze the rate of oxygen consumption and carbon dioxide production. The volume of expired air was determined using a dry gas volume meter (DC-5A, Shinagawa; Tokyo, Japan). Gas exchange results were converted to REE (kcal/day) using Weir's equation (Weir, 1949).

Estimation of Energy Balance and Energy Availability

Diet-induced thermogenesis (DIT) was predicted by 10% of EI, and nonexercise activity thermogenesis (NEAT) was measured by a 3-axis accelerometer (HJA-750C, Omron Healthcare; Kyoto, Japan). TEE was predicted as following:

$$\text{TEE}\left(\text{kcal / day}\right) = \text{REEm} + \text{DIT} + \text{EEE} + \text{NEAT}$$

Finally, EB was calculated by subtraction of TEE from EI as following:

$$\text{EB}\left(\text{kcal / day}\right) = \text{EI}\left(\text{kcal / day}\right) - \text{TEE (kcal / day)}$$

EA for given days was quantified as:

$$\left(\text{EI}\left(\text{kcals}\right) - \text{Net EEE}\left(\text{kcals}\right)\right) / \text{fat - free mass}\left(\text{FFM}\right)\text{(kg)}$$

EA was calculated for 3 exercise days, and the average EA was used as the EA of each subject.

Body Composition Measurement, REE Prediction, and REE Ratio

Body height was measured at rest by a stadiometer (YL-65, Yamagi; Nagoya, Japan). Body weights were measured to within 50 g using a digital weighing scale (UC-321, A&D; Tokyo, Japan) under morning fasting conditions. The body mass index (BMI) was calculated by dividing body weight by the square of height. The percentage of fat (% body fat), appendicular lean soft tissue (ALST), bone mineral content (BMC), and bone mineral density (BMD) of the whole body were measured by dual-energy X-ray absorptiometry (DXA) (QDR-4500 DXA Scanner, Hologic; Marlborough, MA). FFM was calculated based on body weight and body fat percentage. Organ tissue level assessment was conducted using the method used in previous studies (Hayes et al., 2002; Taguchi et al., 2011; Usui et al., 2012). The entire body was categorized into four component tissue masses of bone mass (BM), adipose tissue (AT), skeletal muscle (SM), and residual mass (RM) based on the obtained DXA measurements. The specific resting metabolic rate of the four compartments was assumed from previously reported data [bone (2.3 kcal/kg), AT (4.5 kcal/kg), skeletal muscle (13 kcal/kg), and residual mass (54 kcal/kg)] (Elia, 1992). The predicted REE (REEp) was calculated using the following prediction model;

$$\text{REEp} = 2.3\text{BM} + 4.5\text{AT} + 13\text{SM} + 54\text{RM}$$

The REE ratio was calculated as measurement of resting energy expenditure (REEm) divided by REEp. If the REE ratio was <0.90, it was determined that REE was suppressed (De Souza et al., 2008; Melin et al., 2015).

Blood Testing

Venous blood samples were collected while in a fasting state. Triiodothyronine (T_3), insulin-like growth factor (IGF-1), and insulin as metabolic hormones, and luteinizing hormone (LH), estradiol (E_2), and testosterone (TES) as reproductive hormone were analyzed. T_3, E_2, TES, and LH were determined by a chemiluminescent immunoassay (CLIA). IGF-1 was measured by an electrochemiluminescent immunoassay (ECLIA). To evaluate bone status, specific bone remodeling biochemical markers [bone-specific alkaline phosphatase (BAP) and N-telopeptide of type I collagen (NTX)] were measured, and serum 25-hydroxyvitamin D fraction [25(OH)D] concentrations were analyzed. BAP was determined by a

Table 1. Body Composition, Physical Characteristics, and Training Status of the Subjects.

	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	Sub 6	Mean
Height (cm)	175.0	172.0	168.0	169.5	171.0	174.5	171.7 ± 2.8
Body weight (kg)	58.3	54.0	59.6	56.5	55.0	55.4	56.4 ± 2.1
BMI (kg/m^2)	19.0	18.3	21.1	19.7	18.8	18.2	19.2 ± 1.1
Body fat (%)	9.1	9.4	12.4	8.7	8.5	9.0	9.5 ± 1.4
FFM (kg)	53.0	48.9	52.2	51.6	50.3	50.4	51.0 ± 1.5
VO_2max (ml/kg/BW)	61.1	59.2	58.2	56.6	59.8	57.0	58.6 ± 1.7
Running distance (km/wk)	121.0	108.8	142.8	115.5	122.5	182.8	132.2 ± 27.3
Training start age (yrs)	10	12	12	8	9	15	11 ± 3
Athletic history (yrs)	8.8	6.7	6.7	10.8	11.7	4.7	8.2 ± 2.7

Note. Mean data are presented as mean ± SD; BMI, body mass index; FFM, fat-free mass; BW, body weight; VO_2max, maximal oxygen uptake.

chemiluminescent enzyme immunoassay (CLEIA) and NTX was measured by an enzyme immunoassay (EIA). 25(OH) D fraction concentrations were measured by liquid chromatography-tandem mass spectrometry (LC-MS/MS). All blood parameters were analyzed by LSI Medience (Tokyo, Japan).

Screening for Eating Disorders

The Eating Attitudes Test (EAT-26) was used to screen for symptoms and concerns characteristic of eating disorders (ED). Each subject completed the test alone before starting measurements. A score over 20 corresponded to risk for ED (Garner et al., 1982).

Statistical Analysis

All measurement data were shown individually and mean values were presented as mean ± standard deviation (SD). No other statistical analyses were used in this study.

Results

Individual and mean values for body composition, physical characteristics, and training status are presented in Table 1. Individual and mean values for nutritional, metabolic, and bone characteristics and reproductive hormones are presented in Table 2. All subjects had been running since a young age (11 ± 3 years). The subject's EIs (2,380–2,673 kcal/day) were lower than their TEEs (3,308–4,518 kcal/day), and negative EB (range: −1,845 ~−722 kcal/day, average: −1,444 ± 396 kcal/day) was observed in all subjects. EA levels were very low (18.9 ± 6.8 kcal/kg FFM/day), and the EA of five out of six runners were below the cut-off value (<30 kcal/kg FFM/day). The REE ratio of Subjects 1 (0.85) and 3 (0.89) were below 0.90, where the REE was suppressed and bone resorption was promoted, which was classified as a trend toward low bone mineral density (Z-score < −1). Subject 4's REE was suppressed (REE ratio = 0.87) and bone resolution was promoted (Z-score was −0.9). The REE of Subjects 2 and 5 were not suppressed. The Z-score of Subject 2 was −1.5 and −0.9 in Subject 5, and they were classified as trending toward low bone mineral density. Since the REE ratio of Subject 6 was 0.88, REE was suppressed. The BMD Z-score of Subject 6 was normal, but bone resolution was promoted as NTX was elevated above the reference value (9.5–17.7 nmol/L). The testosterone levels of Subjects 4 and 6 were lower but within the reference value. The concentrations of E_2 in all subjects, except Subject 5, were below the normal range (19–51 pg/ml). The concentration of serum vitamin D in all subjects (17.3–23.2 ng/ml) was below the recommended concentrations for athletes (Mountjoy et al., 2014).

Discussion

Male collegiate long-distance runners were found to have a far lower EI in contrast to their TEE and were severely energy deficient. The energy deficiency may be related to disorders of physiological functions, such as REE suppression, bone resorption, and hormonal disturbance, even though the degrees of health problems in each individual runner were different. This is the first study to examine energy deficiency and its relationship with physiological factors in Japanese male endurance runners.

EB and EA as indicators of energy deficiency were used in this study. All runners had negative EB (−1845 ~−722 kcal/day). This is consistent with the results of previous studies (Motonaga et al., 2006; Vogt et al., 2005). According to a systematic review of endurance athletes across a training season, male athletes have a greater discrepancy between EI and TEE than that of female athletes (Heydenreich et al., 2017). The measurements in the present study were conducted during a regular training season, and no runners were undergoing weight loss. The EAT 26 scores for ED screening were

Table 2. Nutritional, Metabolic, and Bone Characteristics, and Reproductive Hormones of the Subjects.

	Sub 1	Sub 2	Sub 3	Sub 4	Sub 5	Sub 6	Mean	Clinical normal value
Nutritional characteristics								
EI (kcal/d)	2,586	2,382	2,380	2,488	2,385	2,673	2,482 ± 124	
Protein (g/kg BW)	1.9	1.9	1.9	1.6	1.5	2.5	1.9 ± 0.3	
Fat (g/kg BW)	1.5	1.5	1.1	1.5	1.3	1.4	1.4 ± 0.2	
CHO (g/kg BW)	5.7	5.8	5.6	5.9	6.2	6.3	5.9 ± 0.3	
Ca (mg/d)	858	844	1229	589	569	1033	855 ± 253	
Fe (mg/d)	9.5	7.9	9.7	10.5	9.9	9.6	9.5 ± 0.9	
EAT 26 (point)	2	1	7	14	11	5	7 ± 5	<20
Metabolic characteristics								
EEE (kcal/d)	924	1,385	1,442	1,711	1,539	2,095	1,516 ± 386	
TEE (kcal/day)	3,308	3,679	3,927	4,139	3,989	4,518	3,927 ± 411	
EB (kcal/d)	−722	−1,297	−1,547	−1,650	−1,604	−1,845	−1,444 ± 396	
EA (kcal/kg FFM/d)	31.4	20.4	18.0	15.1	16.8	11.5	18.9 ± 6.8	>30
REEm (kcal/d)	1,350	1,351	1,337	1,340	1,387	1,296	1,344 ± 29	
REEm (kcal/kg FFM/d)	25.7	27.6	25.6	26	27.6	25.7	26.4 ± 1.0	
REEp (kcal/d)	1,591	1,404	1,498	1,536	1,438	1,467	1,489 ± 68	
REE ratio	0.85	0.96	0.89	0.87	0.96	0.88	0.90 ± 0.05	
T_3 (ng/dl)	104	122	100	101	119	77	104 ± 16	58–159
IGF-1 (ng/ml)	162	246	145	204	271	179	201 ± 49	139–501
Bone characteristics								
Total BMD (g/cm^2)	1.047	1.059	1.110	1.097	1.086	1.140	1.090 ± 0.034	
Z-score	−1.7	−1.5	−1.4	−0.9	−0.9	−0.1	−1.1 ± 0.6	> −1.0
BAP (μg/L)	17.5	24.5	13.7	11.3	25.4	14.9	17.9 ± 5.8	3.7–20.9
NTX (nmol/L)	19.8	25.1	38.4	28.8	23.6	35.1	28.5 ± 7.1	9.5–17.7
25(OH)D (ng/ml)	23.1	17.3	21.6	23.2	22.8	19.6	21.3 ± 2.4	32–52[a]
Reproductive hormones								
LH (mIU/ml)	5.19	2.64	2.98	2.01	2.72	2.27	3.00 ± 1.10	0.79–5.72
E_2 (pg/ml)	17	16	18	18	28	<10	18 ± 6	19–51
TES (ng/ml)	8.4	5.71	5.23	3.98	6.13	2.78	5.37 ± 1.93	1.92–8.84

Note. Mean data are presented as mean ± SD. EI, energy intake; CHO, carbohydrate; BW, body weight; EAT26, eating attitude test 26; EEE, exercise energy expenditure; TEE, total energy expenditure; EB, energy balance; EA, energy availability; REEm, measured resting energy expenditure; REEp, predicted resting energy expenditure; T_3, triiodothyronine; IGF-1, insulin-like growth factor 1; FFM, fat-free mass; BMD, bone mineral density; BAP, bone-specific alkaline phosphatase; NTX, N-telopeptide of type I collagen; 25(OH)D, serum 25-hydroxyvitamin D; LH, luteinizing hormone; E_2, estradiol; TES, testosterone. a, recommendation from RED-S (Mountjoy et al., 2014).

extremely low, and none of the subjects in this study were at risk for ED. EI estimation was carried out very carefully, and thus the energy intake statuses of the subjects in this study are considered to be low. Since the mean EEE exceeded 1,500 kcal/day, the EA of the subjects were extremely low. In previous studies of male endurance athletes, including long-distance runners, the EA of low testosterone groups were 21 kcal/kg FFM/day (Heikura et al., 2016), and 27.2 kcal/kg FFM/day (Hooper et al., 2017). The average EA in the present study was lower than those athletes. In the present study, five out of six athletes were classified as having LEA. In addition, the EA of male athletes in this study was lower than that of Japanese female athletes (30.1 ± 11.6 kcal/kg FFM/day) (Taguchi et al., 2018). The cause of lower EB and EA in this study may be due to a mixture of lower energy intake and higher exercise volume. Vogt et al. (2005) reported that the cyclists on a negative EB reduced their BW over 6 days; however, the actual weight loss over the 6-day observation period was lower than that expected. BW was monitored in this study and hardly changed in a week, including the measurement period. This is probably due to metabolic depression caused by chronic daily low energy intake (Koehler et al., 2017). However, the possibility that an underestimation of EI from the dietary survey affected the result cannot be ignored.

The average REEm in this study (26.4 kcal/kg FFM/day) was lower than the previously reported REE of Japanese male athletes (Oshima et al., 2011, 2013; Taguchi & Oshima, 2015; Tatsuta et al., 2012). For predicting REE in this study, a tissue-organ level prediction model using data obtained from DXA was used. Adaptive thermogenesis is considered to be the result of down-regulation of cellular thermogenesis (Koehler et al., 2017), and REE ratio can be used to assess metabolic suppression. The average ratio in the present study was 0.91, which was very close to the threshold of 0.90 (De Souza et al., 2008; Melin et al., 2015). The ratios of four out of six athletes were below 0.90, and the REE of four subjects in this study was metabolically suppressed. This result is consistent with previous studies which showed that many male endurance athletes had metabolic depression (Torstveit et al., 2018).

T_3 is associated with energy metabolism, and it has been reported that the REE of amenorrheic female athletes was low in association with a low T_3 level (Loucks & Collister, 1993). The T_3 levels of all subjects in this study were within the normal range. The previous intervention study by Koehler et al. (2016) indicated that low EA (EA = 15 kcal/kg FFM/day) in exercising men was not associated with changes in metabolic hormones like T_3 and IGF-1. Heikura et al. (2018) found that T_3 in the low EA group (average EA: 21) of elite distance athletes was not significantly different from the moderate EA group (average EA: 37). Unlike female athletes, a change in metabolic hormones in male athletes may render them less susceptible to LEA. In addition, FFM alone explained 68% of the variance in REE of Japanese male athletes by multiple regression analysis (Oshima et al., 2013), while T_3 explains 7.8% of the variance. Because of the small number of athletes in this study, grouping was not possible, and the impact of physique on REE was not clear. Further studies on the impact of energy deficiency and hormonal changes on REE will be needed in Japanese male athletes.

The American College of Sports Medicine has defined low BMD as a Z-score between −1.0 and −2.0 with risk factors for fracture in athletes (Nattiv et al., 2007). In the previous study, total BMD Z-score of three runners was less than −1, and −0.9 in two runners. In addition, NTX in all subjects was higher than the standard value (9.5–17.7 nmol/L), which indicates that bone resorption was promoted, and all runners were at risk of low bone mineral density. Several previous studies of male runners showed mean BMDs from 1.14 to 1.32 g/cm^2 (Fredericson et al., 2007; Hind et al., 2006; Stewart & Hannan, 2000), which are higher than that of this study. EI and EA were not measured in these studies. Continued LEA has been shown to reduce bone density in both male and female athletes (Holtzman and Ackerman, 2019). The BMD in the previous study of elite distance athletes was 1.3 g/cm^2, even though the mean EA was 21 kcal/kg FFM/day, which was classified as LEA (Heikura et al., 2018). The average EA in the present study was lower than that in the previous study.

According to the reports of the Medical Committee of the JAAF, athletes who started training from a young age before entering college are more likely to have a stress fracture. Moreover, runners trained for longer distances have a higher prevalence of bone injuries or problems, such as stress fractures, than short-distance runners. It is also reported that few athletes keep a well-balanced nutrition intake from their diet. All of the runners in the present study were trained from a young age (8–15 years old).

The influence of nutrient intake (i.e., calcium, vitamin D) may also be a factor affecting low BMD in this study. The mean calcium intake in this study was 855 mg, which is about half of the recommended intake level of athletes to optimize bone health with LEA (ACSM, 2016). In addition, serum 25(OH) D concentrations in this study were at insufficient levels and two subjects were deficient in serum vitamin D. A previous study reported that cyclists with low blood vitamin D levels have low BMD (Keay et al., 2018). The high risk of bone resorption in the present study is associated with a continued lower intake of nutrients attributed to the energy deficiency status. When EI is low, not only do EA and EB decrease, but calcium and vitamin D levels do as well. It can be said that chronic energy and nutrient deficiencies stimulates bone resorption and is related to bone health in Japanese male athletes.

Since serum estradiol (E_2) plays a critical role in maintaining normal BMD in males, Ackerman et al. (2012) suggested that E_2 levels predict BMD in male athletes. Interestingly, E_2 levels in all subjects were below the reference range (<19 pg/ml) in the present study, and showed lower levels compared to the previous study. Further research regarding the impact of reproductive hormones on the increased number of cases of Japanese male athletes is undergoing.

The strength of the present study was that the acquisition of detailed data using highly accurate measurement methods. The limitations were short measurement durations with a small sample size, and a lack of comparisons between groups. We believe that further studies in this interesting and novel area focusing on male athletes are needed. Since Asian countries have totally different dietary habits from Western countries, it is difficult to evaluate EI and EA accuracy due to diet complexities. Therefore, it is necessary to clarify the impact of energy deficiency on physical conditions using cautious methods of EI evaluation.

Conclusion

The present study suggests that energy deficiency could promote bone resorption and energy metabolism suppression in Japanese male endurance runners. Additional short- and long-term studies are needed to clarify the health risks caused by energy deficiency in male athletes and explore strategies to prevent health problems related to energy deficiency in long-distance runners in this ethnic group.

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