Gender difference in maximal fat oxidation relative to fat free mass by dual energy X-ray absorptiometry in prepubertal children

原　　著

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Key words: fat free mass, gender, exercise

〔Abstract〕 The exercise intensity that elicits the maximal rate of fat oxidation is effective in the reduction of fat mass in children. Differences in fat metabolism between men and women can be attributed to the effect of sex hormones; however, little is known regarding the differences in the maximal rate of fat oxidation between prepubertal boys and girls. This study aimed to compare the maximal rate of fat oxidation in boys and girls relative to body composition by dual energy X-ray absorptiometry. Twenty eight children (17 boys, 11 girls; age, 6-12 years) participated in this study. Fat free mass was measured using dual energy X-ray absorptiometry following body weight and height measurement. Peak oxygen uptake and maximal rate of fat oxidation were determined using a graded exercise test on a treadmill. Body weight, height and body mass index were not significantly different between boys and girls. Boys had significantly higher fat free mass than girls ($P<0.05$). Peak oxygen uptake relative to fat free mass was higher in boys than in girls ($P<0.01$), but the maximal rate of fat oxidation relative to fat free mass and exercise intensity at which the maximal rate of fat oxidation is elicited were not significantly different between boys and girls. Maximal rate of fat oxidation relative to fat free mass was not influenced by gender in prepubertal children.

Introduction

Obesity is the most prevalent nutritional disorder among children and adolescents in industrialized countries[1,2], and represents a risk factor for development of metabolic complications such as insulin resistance, diabetes, hypertension and ischemic heart disease[3]. Excess weight in children is generally caused by lower physical activity, unhealthy eating patterns or a combination of both. Physical activity potentially plays a central role in the prevention of obesity and attenuation of diabetes and cardiovascular disease risks[4]. Thus, it is necessary to develop physical activity programs designed to reduce fat mass.

The exercise intensity that elicits the maximal rate of fat oxidation (MFO) is referred to as Fatmax and is potentially effective in reduction of fat mass and risk of metabolic diseases in children[5,6]. Fatmax can be reached at low to moderate exercise intensities [range: 33-65% of maximal oxygen uptake ($\dot{V}O_2max$)] in adults[7,8], which means that it can be safely achieved by most individuals[9]. Moreover, exercise training at the Fatmax is better than eucaloric interval training at increasing insulin sensitivity[10]. However, there are few studies that investigated Fatmax and MFO in prepu-

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bertal children. It is necessary to clarify what factor affects Fatmax and MFO in prepubertal children for applying exercise training at Fatmax to exercise prescriptions.

In adults, gender is one of the predictors of fat oxidation rate during exercise, and women have a higher MFO than men[11]. The differences in fat metabolism between men and women are partially attributed to the effect of sex hormones[12]. However, the effect of gender on fat oxidation during exercise in prepubertal children is unclear. Indeed, previous studies conducted on MFO in children reported contradictory results and had several limitations. Lazzer et al. have shown that MFO were higher in boys than in girls; however, fat oxidation rates were not divided by body mass or fat free mass (FFM)[6]. Moreover, the studies suggesting that there is no difference in the MFO relative to FFM between boys and girls used skinfold thickness to determine FFM[13,14]. Because FFM is a better representation of metabolically active tissues and MFO is positively correlated with FFM[15], it is important that FFM is measured accurately. Although, the skinfold method has a limitation in that the error of estimation increases with increase in body fat[16], dual energy X-ray absorptiometry (DXA) provides a reliable and accurate estimate of whole body composition in children[17]. Therefore, the purpose of this study was to compare the MFO, relative to FFM measured using DXA, in prepubertal boys and girls during a graded exercise test.

Methods

Participants

Twenty eight children (17 boys and 11 girls, age: 6-12 years) participated in this study. The maturational level of the participants was assessed using the Tanner scale[18]. All children were less than Tanner stage 2. The participants did not include any athletes. All participants were free of pathologic conditions and current medication and supplement use. The participants and their guardians received a verbal and written description of the study and all gave their informed consent for participation prior to testing. This study followed the Declaration of Helsinki and was approved by the institutional ethics committee.

Physical characteristics and body composition

All participants arrived at the laboratory in the morning after an overnight fast (＞12 h). Body mass was measured on a digital balance to the nearest 0.1kg, wearing only leggings and underwear, and height was measured on a stadiometer to the nearest 0.1cm. Body mass index was calculated as body weight in kg・(height in m)$^{-2}$. Bone mineral content, total fat mass, lean mass was measured using DXA (Delphi A-QDR, Hologic Inc., Bedford, MA, USA; Version 12.4: 3 Pediatric Whole body). FFM was calculated adding bone mineral content and lean mass. The estimated coefficient of validation for DXA measurements from test-retest analysis was determined to be ＜1%.

Exercise tests and cardiopulmonary analysis.

After the DXA measurements in the fasting state, the participants essentially ate a carbohydrate-rich snack (approximately 200 kcal) around noon for continuation of the measurements because they could not tolerate the hunger. Participants performed a graded exercise test to exhaustion on a treadmill (MAT-2700, Fukuda Denshi, Japan) to determine $\dot{V}O_2$peak and Fatmax. We confirmed the validity of short-time testing for determination of the exercise intensity that elicits MFO compared to steady-state exercise[19]. The graded exercise test was started at 1 km・h^{-1} and 0% slope, and the speed and slope of the treadmill were increased every minute, by approximately 1 metabolic equivalent, until participants were exhausted[20,21]. During the exercise, a 12-lead electrocardiogram was recorded electronically (Stress Test System ML-6500, Fukuda Denshi, Japan), and heart rates were derived from the RR interval. Pulmonary gas exchange (oxygen uptake [$\dot{V}O_2$], carbon dioxide output [$\dot{V}CO_2$], and respiratory exchange ratio [RER]) were determined breath-by-breath using a

Table 1　Physical characteristics of participants.

	Boys	Girls
Age (years)	9.4 ± 1.7	8.0 ± 1.5*
Height (cm)	138.0 ± 10.5	130.4 ± 13.9
Body mass (kg)	38.3 ± 9.1	32.6 ± 12.4
Body mass index (kg・m^{-2})	19.6 ± 3.4	18.5 ± 3.2
Fat mass (kg)	11.7 ± 6.1	10.6 ± 6.2
Percentage of fat mass (%)	29.4 ± 10.1	30.4 ± 8.9
Fat free mass (kg)	26.5 ± 5.4	22.0 ± 6.7

All values are expressed as mean ± standard deviation. *indicates a significant difference between boys and girls ($P < 0.05$).

gas analyser (AE-300S, Minato Medical Science, Osaka, Japan). Maximal effort was considered to have been reached if the participants demonstrated a plateau in $\dot{V}O_2$, i.e., change in $\dot{V}O_2 < 2.1$ ml・kg^{-1}・min^{-1} over the final successive stages of the test or if at least 2 of the following secondary criteria were achieved: the highest heart rate reached 95% of age-predicted maximal heart rate (220 - age), the highest RER was > 1.05, and the participant demonstrated clear subjective symptoms of fatigue[13]. Fat oxidation rates were determined from oxygen and carbon dioxide values recorded 30 s moving average using the following equation[22]: fat oxidation (g・min^{-1}) = 1.67 × $\dot{V}O_2$ (l・min^{-1}) − 1.67 × $\dot{V}CO_2$ (l・min^{-1}). This equation assumes a negligible urinary nitrogen excretion rate and CO_2 production from lactic acid buffering. The highest recorded 30 s moving average $\dot{V}O_2$ and fat oxidation rates during the exercise test was determined as $\dot{V}O_2$peak and MFO. Fatmax was defined as the exercise intensity ($\dot{V}O_2$) at which the fat oxidation rate was maximal. $\dot{V}O_2$peak and MFO were divided by body mass or FFM for these adjustments.

Statistical analyses

Data are expressed as mean ± SD, if not otherwise stated. Non-paired t-test was used to compare physical characteristics, body composition, and cardiopulmonary data between boys and girls. The Pearson correlation coefficient was determined to evaluate the relationships between body mass and body composition (fat free mass, fat mass and percentage of fat mass) and between body composition and cardiopulmonary data. SPSS Statistics 21.0 software (SPSS, Tokyo, Japan) was used for statistical analysis. Significance was defined as $P < 0.05$.

Results

Physical characteristics of participants

The physical characteristics of boys and girls are shown in **Table 1**. Boys were older than girls (t(26) = 2.254, $P < 0.05$), but all children were less than Tanner stage 2. Body mass, height, and body mass index were not significantly different between boys and girls [t(26) = 1.397, $P = 0.17$; t(26) = 1.643, $P = 0.11$; and t(26) = 0.837, $P = 0.41$, respectively]. Moreover, Fat mass, percentage of fat mass and FFM were not significantly different between boys and girls [t(26) = 0.482, $P = 0.63$; t(26) = − 0.27, $P = 0.79$; and t(26) = 1.970, $P = 0.06$, respectively]. Body mass was correlated with FFM (r = 0.870; $P < 0.001$, **Figure 1**), fat mass (r = 0.863; $P < 0.001$) and percentage of fat mass (r = 0.556; $P < 0.01$).

Cardiopulmonary data

Cardiopulmonary data during the graded exercise test are shown in **Table 2**. $\dot{V}O_2$peak relative to body mass and FFM was higher in boys than in girls (t(26) = 2.215, $P < 0.05$, t(26) = 3.546, $P < 0.01$, respectively), and exercise time was longer in boys than in girls (t(26) = 2.104, $P < 0.05$). The peak values of heart rate and RER during exercise were not significantly different between boys and girls [t(26) = 1.022, $P = 0.32$ and t(26) = 1.136, $P = 0.27$, respectively]. MFO relative to body mass and FFM and Fatmax were not significantly different between boys and girls [t(26) = − 1.178, $P =$

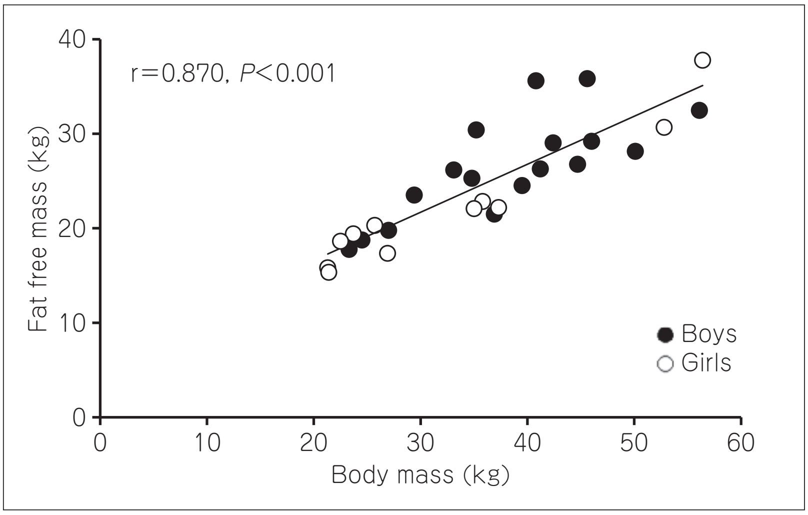

Figure 1 The relationship between body mass and fat free mass in boys and girls.

Table 2 Cardiopulmonary data during the graded exercise test.

	Boys	Girls
$\dot{V}O_2$peak (ml・min^{-1})	1416.8 ± 337.9	1025.8 ± 349.2**
$\dot{V}O_2$peak (ml・kg^{-1}・min^{-1})	37.7 ± 7.7	32.1 ± 4.5*
$\dot{V}O_2$peak relative to FFM (ml・kg FFM^{-1}・min^{-1})	53.2 ± 5.4	46.2 ± 4.5**
Heart rate peak (beats・min^{-1})	187.3 ± 12.2	182.5 ± 12.3
RER peak	1.15 ± 0.09	1.11 ± 0.13
Exercise time (sec)	621.2 ± 77.8	559.1 ± 73.8*
Maximal rate of fat oxidation (mg・min^{-1})	211.0 ± 95.7	215.9 ± 115.3
Maximal rate of fat oxidation relative to FFM (mg・kg FFM^{-1}・min^{-1})	8.0 ± 3.6	9.6 ± 4.0
Fatmax (%$\dot{V}O_2$peak)	44.7 ± 12.0	51.2 ± 8.6

All values are expressed as mean ± standard deviation. $\dot{V}O_2$peak, peak oxygen uptake; RER, respiratory exchange ratio; FFM, fat free mass; Fatmax, exercise intensity of the maximal rate of fat oxidation. *and ** indicate significant differences between boys and girls ($P<0.05$ and $P<0.01$, respectively).

0.25; t(26) = −1.041, $P = 0.31$; and t(26) = −1.541, $P = 0.14$, respectively, **Figure 2**].

Relationship between body composition and cardiopulmonary data

MFO relative to FFM was correlated with body mass index (r = 0.593; $P<0.01$), percent fat (r = 0.759; $P<0.001$, **Figure 3**), and fat mass (r = 0.571; $P<0.01$). The absolute MFO was correlated with fat mass (r = 0.809; $P<0.001$). There was no relationship between MFO and $\dot{V}O_2$peak relative to FFM (r = −0.158; $P = 0.42$).

Discussion

The main finding from the present study was that Fatmax and MFO relative to FFM were not different between boys and girls. Although previous studies suggested no difference in the MFO between boys and girls, fat oxidation in these studies was not divided by FFM measured by DXA[6,13,14] in spite of the relationship between FFM and fat oxidation[15]. In addition, although fat oxidation can also be attributed to aerobic capacity such as $\dot{V}O_2$max in adults[15], the present results showed no relationship between MFO and $\dot{V}O_2$peak in prepubertal children. In prepubertal children, aerobic capacity may not be a key factor for determining the MFO. The present study suggests that MFO relative to FFM was not influenced by gender in prepubertal children.

Two possible mechanisms may help explain the results of this study. First, participants in the present study were not influenced by sex hor-

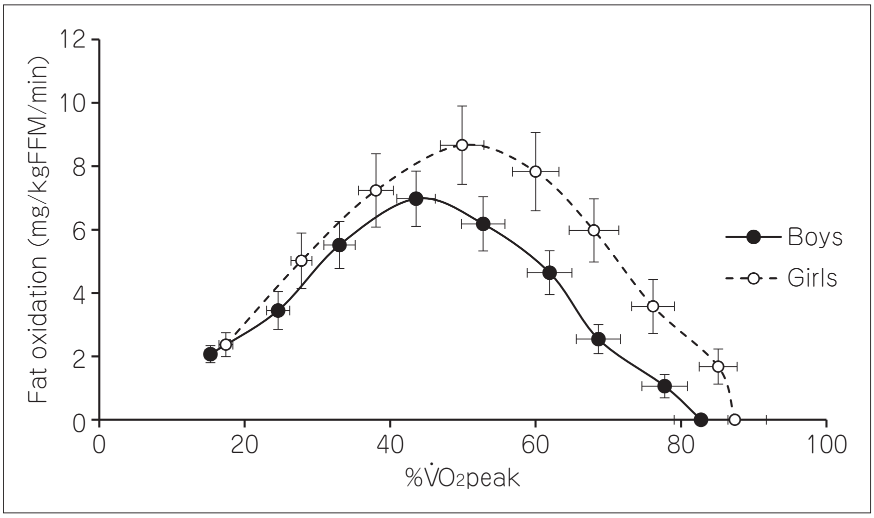

Figure 2 The relationship between fat oxidation rate and exercise intensity expressed as a percentage of V̇O_2peak in boys and girls. Values are expressed as mean±standard error.

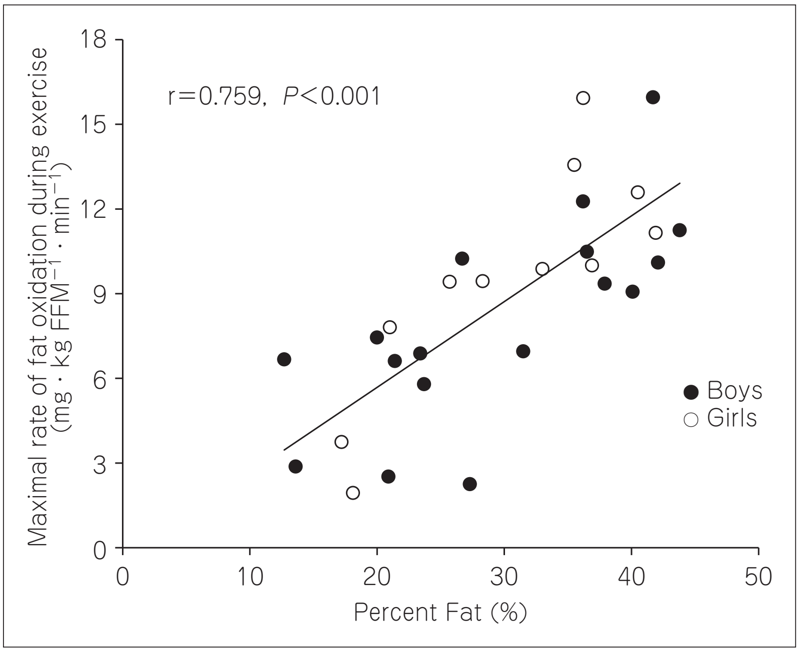

Figure 3 The correlation between the maximal rate of fat oxidation during exercise expressed relative to fat-free mass and percentage of fat mass. FFM, fat free mass.

mones. Although women have shown a higher MFO than men due to ovarian hormones[12], the present results indicated similar fat oxidation between boys and girls as they were in the prepubertal period. Second, MFO in prepubertal children may be related to fat mass rather than gender. We found the relationship between fat mass and MFO in prepubertal children. In previous studies on adults, body fatness was not a predictor of the MFO[15]. Previous studies have reported that the concentration of plasma free fatty acids in obese children was higher than in normal weight children[23], and that increased free fatty acids contribute to greater fat oxidation during exercise[24]. In addition, fat mass was positively related to fat oxidation at rest in prepubertal children[25]. The present results also suggested that fat mass is positively correlated with the MFO in prepubertal children.

This is the first data to show that MFO relative to FFM by DXA was not influenced by gender in Japanese prepubertal children. Although previous studies have also revealed similar results about MFO between boys and girls, skinfold thickness was used to determine FFM[13,14]. The skinfold method has a limitation in that the error of estimation increases with increase in body fat[16]. The present study showed highly accurate results by golden standard method for body fat as DXA. In addition, considering the results of **Figure 1** which showed the individual variation of FFM with increasing body mass, FFM could be suitable index for calculation of accurate MFO. This is the original study to examine the effects of gender on MFO in Japanese prepubertal children, and the emphasis of the present study was on examination of these effects after dividing by FFM using DXA in all prepubertal children.

This study had limitations that need to be recognized. Firstly, we did not conduct biochemical measurements and biopsies. Catecholamine responses during exercise play a key role in fat oxidation[26] and the proportion of muscle fibre type contributes to fat oxidation[27]. In addition, the measurement of sex hormones could support the present data. Therefore, these measurements may be helpful in investigating the underlying mechanisms of fat oxidation in prepubertal children. Secondly, participants essentially consumed a snack 1-3 hours prior to exercise testing as they were not able to continue with the experimentation because of hunger. It is known that a pre-exercise meal reduces fat oxidation during exercise[28]. However, the snack provided was approximately 200 kcal, and previous studies in adults have suggested no effect or minor effects of snack feeding on substrate metabolism 30 minutes to 3.5 hours prior to exercise[29,30]. Moreover, there is no study that has investigated the effects of pre-exercise snack feeding on substrate metabolism in prepubertal children. Therefore, the pre-exercise snack feeding can be considered to have a negligible effect on fat oxidation during exercise.

Conclusions

In conclusion, the present study demonstrated that MFO relative to FFM by DXA was not influenced by gender in prepubertal children. These results may be important for development of physical activity programs designed to optimize fat oxidation rates and to reduce fat mass in prepubertal children.

Conflicts of Interest

There are no conflicts of interest to declare.

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原　著

思春期前の子どもにおける最大脂質酸化量の性差
―二重エネルギー X 線吸収法で求めた除脂肪体重による補正―

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キー・ワード：除脂肪量，男女差，運動

〔要旨〕　二重エネルギー X 線吸収法により求めた除脂肪量を用いて最大脂質酸化量を補正し, 思春期前の子どもにおける性差を検討した. 28 名の子ども（男児 17 名, 女児 11 名, 6–12 歳）を対象に, 多段階漸増運動負荷試験により最大酸素摂取量，最大脂質酸化量を測定した．その結果，身長および体重に性差はないものの，除脂肪量は男児が女児より有意に高値を示した．除脂肪量で補正した最大酸素摂取量は男児で女児より有意に高値を示したが，除脂肪量で補正した最大脂質酸化量およびその運動強度に性差はなかった. 除脂肪量で補正した最大脂質酸化量は思春期前の子どもにおいて性差がないことが示唆された.