学 位 論 文

Relationship between peak oxygen uptake and regional body composition in Japanese subjects

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Original article

Relationship between peak oxygen uptake and regional body composition in Japanese subjects

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Abstract

Purpose: To investigate the link between peak oxygen uptake and regional body composition by dual energy X-ray absorptiometry (DEXA) in Japanese subjects.
Methods: A total of 93 men (42.2 ± 12.3 years old) and 106 women (43.5 ± 12.3 years old) were enrolled in this cross-sectional investigation study. Peak oxygen uptake was measured by the breath-by-breath method. Regional body composition i.e., body fat mass, lean body mass, and body fat percentage was evaluated using DEXA. In addition, metabolic risk parameters were also evaluated.
Results: Peak oxygen uptake was 37.6 ± 8.7 mL/kg/min in men and 31.1 ± 6.4 mL/kg/min in women, and decreased with age in both genders. Peak oxygen uptake was significantly correlated with total body fat percentage (men: $r = -0.684$, $p < 0.0001$; women: $r = -0.681$, $p < 0.0001$). These associations remained even after adjusting for age and total lean body mass. However, peak work rate was positively and significantly correlated with leg lean body mass.
Conclusion: Peak oxygen uptake was closely correlated with total body fat percentage in both genders. Aerobic exercise as well as leg resistance training might be useful for improving peak oxygen uptake in Japanese subjects.

Keywords: Dual energy X-ray absorptiometry (DEXA); Japanese; Leg muscle mass; Peak oxygen uptake; Regional body composition

1. Introduction

It is well-known that regular physical activity increases high density lipoprotein (HDL) cholesterol and reduces triglycerides, resting blood pressure, fasting blood sugar, abdominal fat accumulation, and insulin responses to an oral glucose challenge test.[1–5] Sandvik et al.[6] reported that physical fitness was a graded, independent, long-term predictor of mortality from cardiovascular causes in healthy, middle-aged men. Sawada et al.[7] showed that low cardiorespiratory fitness was associated with cancer mortality in Japanese men.[7] In addition, there are some studies demonstrating changes in aerobic exercise level with aging in Japanese subjects.[8,9]

Maximal oxygen uptake is generally considered an accurate and reliable parameter. In the Exercise and Physical Activity Reference for Health Promotion 2006, established by the Ministry of Health, Labour and Welfare of Japan in 2006, maximal oxygen uptake was considered to be the most significant element of physical fitness related to health

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promotion, and the recommended reference value for maximal oxygen uptake to prevent lifestyle-related disease was reported.[10]

The ventilatory threshold (VT), which is defined as the upper limit of aerobic exercise, is also thought to serve as a standard for exercise recommended reference value.[11] We have previously reported that the VT was negatively correlated with total body fat percentage.[12] However, the link between peak oxygen uptake and regional body composition using dual energy X-ray absorptiometry (DEXA) still remains unknown. Therefore, in this study, we evaluated the relationship between peak oxygen uptake and regional body composition in Japanese subjects.

2. Methods

2.1. Subjects

We enrolled 93 men (42.2 ± 12.3 years old) and 106 women (43.5 ± 12.3 years old) who met the following criteria: (1) wanted to volunteer in this cross-sectional investigation study at Okayama Southern Institute of Health; (2) had received anthropometric and peak oxygen uptake measurements and body composition measurements by using DEXA; (3) received no medications for diabetes, hypertension, and/or dyslipidemia; and (4) provided written informed consent (Table 1).

Ethical approval for the study was obtained from the Ethical Committee of Okayama Health Foundation.

2.2. Anthropometric and body composition measurements

Anthropometric and body compositions were evaluated based on the following parameters: height, body weight, abdominal circumference, hip circumference, and body composition. The abdominal circumference was measured at the umbilicus, and the hip was measured at the widest circumference over the trochanters in standing subjects after a normal exhalation.[13] The body composition was measured by DEXA (QDR4500, Hologic Inc., Waltham, MA, USA), which is accepted as an accurate standard.[14] The DEXA measurement consisted of a whole body scan using an array

Table 1
Clinical characteristics of enrolled subjects.

	Men (n = 93)			Women (n = 106)		
	Mean ± SD	Minimum	Maximum	Mean ± SD	Minimum	Maximum
Age (year)	42.2 ± 12.3	21.0	68.0	43.5 ± 12.3	22.0	69.0
Height (cm)	169.7 ± 5.5	158.1	187.3	158.3 ± 5.3	148.5	175.1
Body weight (kg)	66.3 ± 8.2	50.3	95.7	52.7 ± 6.9	35.3	72.4
Body mass index (kg/m^2)	23.0 ± 2.6	17.9	32.3	21.1 ± 2.9	13.3	31.3
Abdominal circumference (cm)	81.1 ± 7.8	67.9	104.9	75.3 ± 8.7	61.5	95.7
Hip circumference (cm)	93.9 ± 4.8	83.6	110.5	90.3 ± 5.0	76.9	108.5
Peak oxygen uptake (mL/kg/min)	37.6 ± 8.7	16.5	58.4	31.1 ± 6.4	17.6	49.8
Peak work rate (watt)	204.4 ± 47.6	91.0	354.0	144.8 ± 28.7	80.0	243.0
Peak heart rate (beat/min)	181.3 ± 21.6	106.0	230.0	175.0 ± 14.7	136.0	206.0
Body fat mass (right arm) (g)	710.2 ± 252.5	268.2	1637.8	864.0 ± 291.2	149.1	1771.4
Body fat mass (left arm) (g)	664.7 ± 238.7	243.9	1692.0	841.6 ± 297.8	126.7	1878.1
Body fat mass (trunk) (g)	6400.9 ± 2839.7	2222.8	16,050.5	6175.5 ± 2775.2	1145.5	13,400.7
Body fat mass (right leg) (g)	2152.7 ± 741.7	906.5	4138.7	2807.3 ± 730.1	456.1	4893.2
Body fat mass (left leg) (g)	2172.5 ± 797.5	929.5	5465.5	2786.4 ± 753.6	551.4	5626.8
Body fat mass (head) (g)	1001.0 ± 79.8	814.5	1249.9	858.0 ± 66.6	691.8	1040.9
Body fat mass (total) (g)	13,069.6 ± 4586.2	5568.7	27,070.2	14,305.0 ± 4398.9	3165.9	26,443.1
Lean body mass (right arm) (g)	3075.1 ± 418.9	2404.6	5409.9	1908.1 ± 242.0	1442.7	2723.3
Lean body mass (left arm) (g)	2863.1 ± 454.4	2142.7	5736.9	1758.9 ± 220.6	1242.2	2384.5
Lean body mass (trunk) (g)	25,209.1 ± 2654.0	20,201.8	36,261.1	19,421.5 ± 2170.9	15,434.7	29,905.0
Lean body mass (right leg) (g)	9136.0 ± 1145.8	6856.3	12,622.4	6453.7 ± 768.1	4742.3	8117.1
Lean body mass (left leg) (g)	9095.7 ± 1175.4	6642.9	13,425.0	6363.4 ± 785.2	4842.3	8038.1
Lean body mass (head) (g)	4035.2 ± 450.7	3230.4	7049.1	3503.0 ± 268.9	2841.8	4100.5
Lean body mass (total) (g)	53,374.2 ± 5585.0	42,399.2	75,288.3	39,323.8 ± 3846.3	31,045.8	48,256.8
Body fat percentage (right arm) (%)	18.5 ± 5.2	8.9	30.4	30.6 ± 7.2	8.4	45.9
Body fat percentage (left arm) (%)	18.7 ± 5.3	8.6	31.8	31.6 ± 7.5	7.6	49.2
Body fat percentage (trunk) (%)	19.7 ± 6.7	7.9	37.0	23.4 ± 7.5	6.4	40.6
Body fat percentage (right leg) (%)	18.9 ± 5.2	8.5	30.4	30.0 ± 5.5	7.6	44.3
Body fat percentage (left leg) (%)	18.9 ± 5.1	8.6	30.4	30.0 ± 5.3	9.0	43.3
Body fat percentage (head) (%)	20.0 ± 0.4	19.2	21.1	19.7 ± 0.5	18.3	21.3
Body fat percentage (total) (%)	19.4 ± 5.3	9.2	32.4	26.2 ± 5.7	8.5	37.7
Systolic blood pressure (mmHg)	127.7 ± 14.3	101.0	180.0	116.7 ± 14.1	92.0	162.0
Diastolic blood pressure (mmHg)	78.8 ± 9.4	56.0	111.0	71.3 ± 10.6	52.0	96.0
Triglyceride (mg/dL)	98.7 ± 54.1	33.0	308.0	68.7 ± 32.9	26.0	200.0
High density lipoprotein cholesterol (mg/dL)	58.6 ± 16.9	31.0	149.0	68.8 ± 13.3	42.0	103.0
Blood glucose (mg/dL)	93.7 ± 10.4	73.0	146.0	88.8 ± 9.5	59.0	133.0
Insulin (μU/mL)	5.4 ± 3.9	0.7	28.2	4.3 ± 2.1	0.6	16.1
Homeostasis model assessment index	1.3 ± 1.1	0.2	7.2	1.0 ± 0.5	0.9	4.0

beam.[15] The subjects removed all metal objects, and were positioned in the supine position with their hands placed on either side of the body and their legs held 10 cm apart according to the specifications of the manufacturer. All scans were analyzed according to the manufacturer's instructions.[16] Body fat mass, lean body mass, body fat percentage of the entire body and specific regions, i.e., the right arm, left arm, trunk, right leg, left leg, and head, were manually and automatically calculated according to the instrument.

2.3. *Exercise testing*

Peak oxygen uptake was measured using a maximal graded exercise test with bicycle ergometers (Excalibur V2.0, Lode BV, Groningen, Netherlands). The initial work load was 30–60 w, and the work rate was increased thereafter by 15 w/min until the subject could not maintain the required pedaling frequency (60 rpm).[17] During the latter stages of the test, each subject was verbally encouraged by the test operators to give their maximal effort. In addition, an ECG was monitored continuously while recording the heart rate (HR). The expired gas was collected, and the rates of oxygen consumption (VO_2) and carbon dioxide production (VCO_2) were measured breath-by-breath using a cardiopulmonary gas exchange system (Oxycon Alpha, Mijnhrdt B.V., Netherlands). The achievement of peak oxygen uptake was accepted if the following two conditions were met: the subject's maximal HR was >95% of the age-predicted maximal HR (220 − age), and the VO_2 curve showed a leveling off. In addition, the observed maximal work rate during the testing was used for this analysis.

2.4. *Blood pressure (BP) measurements at rest*

Resting systolic and diastolic BP (SBP and DBP) were measured indirectly using a mercury sphygmomanometer placed on the right arm of the seated participant after at least 15 min of rest.

2.5. *Blood sampling and assays*

After the subjects fasted overnight for 10–12 h, blood samples were collected in order to determine the levels of HDL cholesterol, triglycerides (L Type Wako Triglyceride H, Wako Chemical, Osaka, Japan), insulin and blood glucose. Serum insulin was measured by immunoradiometric assay (IRMA) using INSULIN RIABEAD (DAINABOT, Tokyo, Japan). Blood glucose was measured by the glucose-oxidant method. The insulin resistance was evaluated using the homeostasis model assessment, the Homeostasis model assessment (HOMA) index (fasting plasma glucose (mg/dL) × fasting serum insulin (μU/mL)/405), according to the method developed by Matthews et al.[18]

2.6. *Statistical analysis*

All data are expressed as means ± SD values. The sample sizes of all parameters were thought to be sufficient and had a normal distribution, and hence Pearson's correlation coefficients were calculated and used to test the significance of the linear relationship between continuous parameters: where $p < 0.05$ was considered statistically significant. However, in the relationship between the peak oxygen uptake and regional body composition, and between the work rate and regional body composition, a $p < 0.007$ ($0.05/7 \approx 0.007$) was considered statistically significant after the Bonferroni correction. Multiple regression analysis was also used to adjust for confounding factors, and $p < 0.05$ was considered statistically significant.

3. Results

The measurements of parameters are summarized in Table 1. The peak oxygen uptake in enrolled subjects was 37.6 ± 8.7 mL/kg/min in men, and 31.1 ± 6.4 mL/kg/min in women. The total body fat percentage using DEXA was 19.4% ± 5.3% in men and 26.2% ± 5.7% in women (Table 1).

We investigated the age-related changes in peak oxygen uptake. The peak oxygen uptake was significantly and negatively correlated with age (men: $r = -0.500$, $p < 0.0001$; women: $r = -0.486$, $p < 0.0001$).

The simple correlation analysis between peak oxygen uptake and anthropometric, body composition parameters using DEXA was evaluated (Table 2). In men, peak oxygen uptake was negatively correlated with abdominal

Table 2
Simple correlation analysis between peak oxygen uptake and body composition parameters.

	Men (n = 93)		Women (n = 106)	
	r	p	r	p
Age (year)	−0.500	**< 0.0001**	−0.486	**< 0.0001**
Height (cm)	0.169	0.1052	0.226	**0.0058**
Body weight (kg)	−0.224	0.0311	−0.318	**0.0009**
Body mass index (kg/m^2)	−0.341	**0.0008**	−0.432	**< 0.0001**
Abdominal circumference (cm)	−0.592	**< 0.0001**	−0.575	**< 0.0001**
Hip circumference (cm)	−0.254	0.0139	−0.336	**0.0004**
Body fat mass (right arm) (g)	−0.640	**< 0.0001**	−0.587	**< 0.0001**
Body fat mass (left arm) (g)	−0.636	**< 0.0001**	−0.554	**< 0.0001**
Body fat mass (trunk) (g)	−0.623	**< 0.0001**	−0.635	**< 0.0001**
Body fat mass (right leg) (g)	−0.503	**< 0.0001**	−0.416	**< 0.0001**
Body fat mass (left leg) (g)	−0.489	**< 0.0001**	−0.393	**< 0.0001**
Body fat mass (head) (g)	−0.250	0.0154	−0.219	0.0243
Body fat mass (total) (g)	−0.618	**< 0.0001**	−0.615	**< 0.0001**
Lean body mass (right arm) (g)	0.076	0.4709	0.110	0.2628
Lean body mass (left arm) (g)	0.073	0.4863	0.066	0.5045
Lean body mass (trunk) (g)	0.147	0.1587	0.095	0.3334
Lean body mass (right leg) (g)	0.311	**0.0024**	0.242	0.0123
Lean body mass (left leg) (g)	0.341	**0.0008**	0.234	0.0159
Lean body mass (head) (g)	−0.115	0.2708	−0.033	0.7398
Lean body mass (total) (g)	0.214	0.0399	0.163	0.0954
Body fat percentage (right arm) (%)	−0.682	**< 0.0001**	−0.612	**< 0.0001**
Body fat percentage (left arm) (%)	−0.677	**< 0.0001**	−0.569	**< 0.0001**
Body fat percentage (trunk) (%)	−0.661	**< 0.0001**	−0.686	**< 0.0001**
Body fat percentage (right leg) (%)	−0.608	**< 0.0001**	−0.510	**< 0.0001**
Body fat percentage (left leg) (%)	−0.618	**< 0.0001**	−0.522	**< 0.0001**
Body fat percentage (head) (%)	−0.592	**< 0.0001**	−0.468	**< 0.0001**
Body fat percentage (total) (%)	−0.684	**< 0.0001**	−0.681	**< 0.0001**

Note: p values in bold mean significant correlations.

circumference, body fat mass (except for head fat mass) and body fat percentage. The correlation coefficient between peak oxygen uptake and total body fat percentage was the highest among the parameters tested ($r = -0.684$, $p < 0.0001$) (Fig. 1A). In women, peak oxygen uptake was also negatively correlated with body mass index, abdominal circumference, body fat mass (except for head), and body fat percentage. The correlation coefficient between peak oxygen uptake and total body fat percentage was also the highest ($r = -0.681$, $p < 0.0001$) among the parameters (Fig. 1B). Next, we performed multiple regression analysis, and used peak oxygen uptake as dependent variable and age, total body fat percentage and total lean body mass as independent variables to adjust for confounding factors. The relationships between peak oxygen uptake and total body fat percentage were still significant even after adjusting for age and total lean body mass in both genders (standard correlation coefficients (β) of total body fat percentage (%) were −0.637 in men ($p < 0.0001$) and −0.587 in women ($p < 0.0001$)).

We also investigated the relationship between the work rate and body composition parameters (Table 3). The work rate was positively correlated with lean body mass (trunk, right arm, left arm, right leg, left leg, and total) in men. The work rate was also negatively correlated with body fat percentage in men. The correlation coefficient between the work rate and left leg lean body mass ($r = 0.610$, $p < 0.0001$) was the highest. In women, the work rate was positively correlated with height and lean body mass (except head). The work rate was negatively correlated with body fat percentage (right arm, trunk, and total). The correlation coefficient between work rate and right leg lean body mass ($r = 0.629$, $p < 0.0001$) was the highest among the variables.

Finally, the peak oxygen uptake was weakly correlated with triglyceride levels ($r = -0.393$, $p < 0.0001$), HDL cholesterol ($r = 0.227$, $p = 0.0288$), blood glucose ($r = -0.317$, $p = 0.0020$), insulin ($r = -0.231$, $p = 0.0258$), and the HOMA index ($r = -0.249$, $p = 0.0160$) in men. In women, peak oxygen uptake was also weakly correlated with SBP ($r = -0.281$, $p = 0.0035$), DBP ($r = -0.198$, $p = 0.0422$), triglyceride ($r = -0.357$, $p = 0.0002$), blood glucose ($r = -0.309$, $p = 0.0013$), insulin ($r = -0.391$, $p < 0.0001$), and the HOMA index ($r = -0.403$, $p < 0.0001$).

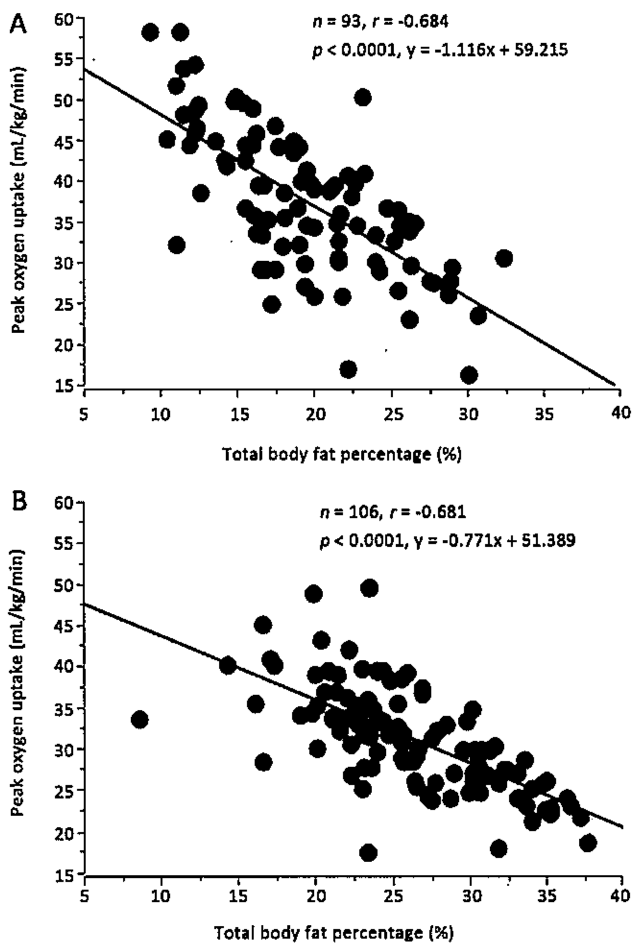

Fig. 1. Simple correlation analysis between peak oxygen uptake and total body fat percentage using DEXA in men (A) and women (B).

Table 3
Simple correlation analysis between work rate and body composition parameters.

	Men (n = 93)		Women (n = 106)	
	r	p	r	p
Age (year)	−0.513	**< 0.0001**	−0.520	**< 0.0001**
Height (cm)	0.383	**0.0002**	0.403	**< 0.0001**
Body weight (kg)	0.146	0.1634	0.163	0.0947
Body mass index (kg/m^2)	−0.070	0.5034	−0.039	0.6881
Abdominal circumference (cm)	−0.353	**0.0005**	−0.248	0.0103
Hip circumference (cm)	0.084	0.4235	0.107	0.2751
Body fat mass (right arm) (g)	−0.394	**< 0.0001**	−0.247	0.0106
Body fat mass (left arm) (g)	−0.390	**0.0001**	−0.198	0.0415
Body fat mass (trunk) (g)	−0.398	**< 0.0001**	−0.323	**0.0007**
Body fat mass (right leg) (g)	−0.235	0.0235	−0.048	0.6270
Body fat mass (left leg) (g)	−0.233	0.0245	−0.034	0.7311
Body fat mass (head) (g)	−0.007	0.9505	0.079	0.4182
Body fat mass (total) (g)	−0.362	**0.0004**	−0.249	0.0100
Lean body mass (right arm) (g)	0.330	**0.0013**	0.512	**< 0.0001**
Lean body mass (left arm) (g)	0.332	**0.0012**	0.427	**< 0.0001**
Lean body mass (trunk) (g)	0.454	**< 0.0001**	0.467	**< 0.0001**
Lean body mass (right leg) (g)	0.582	**< 0.0001**	0.629	**< 0.0001**
Lean body mass (left leg) (g)	0.610	**< 0.0001**	0.616	**< 0.0001**
Lean body mass (head) (g)	0.003	0.9761	0.209	0.0316
Lean body mass (total) (g)	0.522	**< 0.0001**	0.577	**< 0.0001**
Body fat percentage (right arm) (%)	−0.525	**< 0.0001**	−0.420	**< 0.0001**
Body fat percentage (left arm) (%)	−0.530	**< 0.0001**	−0.350	**0.0002**
Body fat percentage (trunk) (%)	−0.504	**< 0.0001**	−0.450	**< 0.0001**
Body fat percentage (right leg) (%)	−0.443	**< 0.0001**	−0.306	**0.0014**
Body fat percentage (left leg) (%)	−0.460	**< 0.0001**	−0.318	**0.0009**
Body fat percentage (head) (%)	−0.446	**< 0.0001**	−0.325	**0.0007**
Body fat percentage (total) (%)	−0.518	**< 0.0001**	−0.434	**< 0.0001**

Note: p values in bold mean significant correlations.

4. Discussion

Ohta et al.[8] reported that maximal oxygen uptake was significantly decreased with age in 832 apparently healthy subjects, and could be represented by the single regression line:

y (maximal oxygen uptake: mL/kg/min) $= 46.6 - 0.36 \times$ age ($r = -0.447$) in men and $y = 35.3 - 0.23 \times$ age ($r = -0.407$) in women. Miura[9] reported that oxygen uptake at VT was significantly correlated with age (men: $r = -0.626$, women: $r = -0.578$) in 610 Japanese subjects. The age-related decrease of the VT was observed in previous studies on Japanese subjects not taking any medications.[12] In this study, the age-related decrease in peak oxygen uptake was also noted as per previous studies in Japanese subjects not taking any medications. The mean values obtained from this study also promise to be quite useful in reference databases for evaluating aerobic exercise levels defined by peak oxygen uptake in Japanese subjects.

In some literature, a relationship between aerobic exercise level and body composition has been reported. Watanabe et al.[19] reported that maximal oxygen uptake was significantly and negatively correlated with body fat percentage in a small sample of 21 boys and 16 girls. Sanada et al.[20] showed that the VT was significantly correlated with thigh skeletal muscle mass (men: $r = 0.58$, women: $r = 0.47$) in 1463 Japanese men and women. Yu et al.[21] also measured symptom-limited maximal oxygen uptake, and body composition using an impedance technique, and reported that physical activity was an important determinant of the age-related decline in maximal oxygen uptake in Hong Kong Chinese. In patients with chronic heart failure, skeletal muscle mass was strongly predictive of maximal oxygen uptake at baseline and after exercise training.[22] In this study, peak oxygen uptake was significantly and negatively correlated with total body fat percentage using DEXA in apparently healthy Japanese men and women. In addition, peak oxygen uptake was weakly correlated with metabolic risk parameters.

We have previously proved the link between the VT and leg strength per body weight in Japanese women in a cross-sectional study.[23] In a longitudinal study, an increase in leg strength per body weight was associated with improving metabolic syndrome and abdominal circumference in Japanese men.[24] It was speculated to be difficult for subjects with a smaller leg lean body mass to support the entire their body weight, and also difficult for those subjects with less leg lean body mass to carry out aerobic exercise, i.e., walking and jogging. In addition, peak oxygen uptake was also linked to total body fat percentage. It is well-known that fat is stored for energy, whereas muscle are the main engines that use energy. However, when aerobic exercise reached certain level, it starts to burn fat. Taken together, although aerobic exercise has been advocated as the most suitable activity for reducing body fat percentage and increasing aerobic exercise levels, such as peak oxygen uptake, it is important for subjects with smaller leg lean body mass to maintain or maximize the lean body mass of their lower limbs, as well as to carry out aerobic exercise, to reduce fat mass and increase peak oxygen uptake, thus resulting in improved metabolic risk factors in Japanese subjects.

Potential limitations still remain in this study. First, our study was a cross-sectional but not a longitudinal study. Second, 93 men and 106 women in our study voluntarily underwent measurements: they were therefore more likely to be health-conscious as compared with the average person. Third, we could not show a clear mechanism between body fat percentage and peak oxygen uptake. However, it seems reasonable to suggest that promoting aerobic exercise as well as resistance training of the lower limb might result in improved peak oxygen uptake and metabolic risk factors in some Japanese subjects. To show this, further prospective and larger sample size studies are urgently required in the Japanese population.

5. Conclusion

In this study, we accurately evaluated the relationship between peak oxygen uptake and regional body composition using DEXA in Japanese subjects for the first time. The total body fat percentage was closely correlated to peak oxygen uptake, even after adjusting for confounding factors in both genders. In addition, work rate was positively correlated with lower lean body mass.

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