Relationship between Body Composition and Cardiorespiratory Fitness in Japanese Junior High School Boys and Girls

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This study attempted to evaluate the influence of body composition on cardiorespiratory fitness as represented by maximal oxygen uptake (\(\dot{V}O_{2\max}\)) in junior high school boys and girls. The subjects were judged apparently healthy. Measurements of \(\dot{V}O_{2\max}\) during an incremental treadmill exercise testing as well as measurements of body composition were compared between obese boys and girls, 12 to 15 years old, and age-and height-matched nonobese boys and girls. Analyses of the data revealed that statistically significant (\(P<0.01\)) mean differences between the obese and nonobese groups were observed for body mass (BM), percentage body fat, and body fat content. Fat-free mass (FFM) of obese boys was significantly larger than nonobese boys. There were significant differences between obese and nonobese groups irrespective of sex, when \(\dot{V}O_{2\max}\) was expressed as milliliters of oxygen per kilogram of BM per minute. In contrast, no significant group differences were found in \(\dot{V}O_{2\max}\) expressed as ml per kg of FFM per min. No significant differences existed either for absolute \(\dot{V}O_{2\max}\) between the obese girls and the nonobese girls due almost entirely to the similarity in FFM between these two groups. Significant correlations were found both in boys (\(r = -0.742\)) and girls (\(r = -0.843\)) between \(\dot{V}O_{2\max}\) (ml/kg BM/min) and percentage body fat, thereby indicating the striking effects of excess body fat. These results in the present study support the general belief that obesity accentuates exercise intolerance and low aerobic capacity.


Key words: Fat-free mass, Obesity, Maximal oxygen uptake

INTRODUCTION

Among many elements of physical fitness, endurance or cardiorespiratory fitness is considered most important in regard to the incidence of coronary heart disease (CHD). Traditionally, the cardiorespiratory fitness has been evaluated by the amount of oxygen (\(O_2\)) that can be taken up by the working muscles during maximal exercise (Taylor et al., 1955). It is a well-established fact that oxygen uptake (\(\dot{V}O_2\)) increases with running speed up to a critical velocity beyond which no further increase in \(\dot{V}O_2\) takes place, even though the individual is still able to increase his/her speed of running. The rate of \(\dot{V}O_2\) at which this “flattening” or “levelling-off” in \(\dot{V}O_2\) occurs is called the maximal oxygen uptake and usually expressed as \(\dot{V}O_{2\max}\) (Kemper and Verschuer, 1985). Thus, the determination of \(\dot{V}O_{2\max}\) is essential even in evaluating an individual's capacity to perform aerobic work (Astrand, 1960).

Since \(\dot{V}O_{2\max}\) and anaerobic threshold are influenced largely by factors such as pulmonary ventilation, pulmonary diffusion, cardiac output or \(O_2\) and \(CO_2\) transport via blood, cardiac functioning, vascularization, oxygen utilization by the working muscles, and physical condition of the involved muscles, it can be the single best measure of the functional capacity of the cardiorespiratory systems as a unit. In general, \(\dot{V}O_{2\max}\) is significantly related
to age, gender, exercise habits, cardiovascular clinical status, and to a lesser extent to heredity (Klis-
soutras, 1971; Bouchard and Lortie, 1984; Fagard et
al., 1991). Of these factors, age, sex, and heredity are
the factors that cannot be altered. In contrast, exer-
cise habits and cardiovascular clinical status as well
as obesity are factors that can be altered relatively
easily.

Clinical manifestations of cardiovascular risk factors appear only later in life, but risk-related behavior patterns for CHD have their origins in childhood and adolescence (Tell and Vellar, 1988). There is ample evidence to support the view that physical activity habits contribute to the increase in the cardiorespiratory fitness and influence serum lipid characteristics as well as body composition, and hence its continuation may be beneficial in the secondary protection against cardiovascular disease or to minimize the potential development of these risk factors even among children.

Giving evidence to the development of multiple risk factors at an early age, Gilliam et al. (1977) suggested the use of diet modification and pre-
scribed physical activity be studied as one possible means of CHD intervention. Obesity and a family history of heart disease were found to be the two most frequently occurring risk factors (Gilliam et al., 1977). Obesity is to a large extent the result of reduced physical activity with the maintenance of an abundant diet. It is of interest that the cardiorespiratory fitness is closely related to the individual's reported activity level.

Consequently, it is meaningful to assess cardiorespi-

Table 1 Physical characteristics of subjects

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Age (yr)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Fat (%)</th>
<th>Fat (kg)</th>
<th>FFM (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boys</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non obese</td>
<td>14</td>
<td>13.4±0.8</td>
<td>162.8±5.7</td>
<td>48.6±6.4</td>
<td>12.4±3.3</td>
<td>6.1±2.1</td>
<td>42.4±4.9</td>
</tr>
<tr>
<td>Obese</td>
<td>7</td>
<td>13.6±0.5</td>
<td>166.5±7.3</td>
<td>80.3±13.6##</td>
<td>29.0±3.7##</td>
<td>23.5±6.3##</td>
<td>56.7±8.1##</td>
</tr>
<tr>
<td>Girls</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non obese</td>
<td>10</td>
<td>13.2±1.0</td>
<td>155.9±2.2</td>
<td>44.2±4.8</td>
<td>18.0±5.2</td>
<td>8.2±3.1</td>
<td>36.0±2.6</td>
</tr>
<tr>
<td>Obese</td>
<td>6</td>
<td>13.7±0.5</td>
<td>155.4±3.2</td>
<td>53.7±7.2##</td>
<td>29.2±3.9##</td>
<td>15.9±4.1##</td>
<td>37.9±3.8 NS</td>
</tr>
</tbody>
</table>

## p<0.01, NS: Not significantly different from non-obese group.

spiratory fitness of any individual and the relation-
ship between fitness and the degree of obesity. The
present study was conducted (1) to assess the rela-
tionship between body composition and cardiorespi-

METHODS

Subjects

Thirty-seven apparently healthy junior high school boys and girls (boys : 21, girls : 16), aged 12
-15 yr, were recruited for this study from one public school in Osaka City. Upon arrival at the labora-
tory, physical examination, resting electrocardio-
gram recording and blood pressure measurement
were performed. All the subjects were judged appar-
ently healthy, since they were taking no medication and were free from cardiovascular and/or pulmo-
nary disease at the time of the study. The parents of all the subjects gave consent after being thoroughly informed of the purpose, requirements, and proce-
dures of this study.

The subjects were assigned to one of two groups
by gender: obese groups (7 boys or 6 girls) and nonobese groups (14 boys or 10 girls), according to the method of Buskirk (1974) and Huenemann et al. (1966). That is, boys with a body fat content of 20.0% or greater (as determined by underwater weighing), and girls with a body fat content of 25.0% or greater were arbitrarily considered obese. A description of some physical characteristics of the
subjects appears in Table 1.

The tests of body composition and maximal aerobic capacity were conducted at the Exercise Physiology Laboratory of Osaka Prefectural College of Nursing. Environmental conditions were kept almost uniform throughout all experimental protocols.

Assessment of body composition

Body composition was estimated in the fasting state from underwater weighing (hydrodensitometry) in a stainless steel tank (1.0×0.8×1.1m) in which a swing seat (0.6×0.45×0.3m) was suspended from a four-strain guage system (Sojahoh Keisoh, TR215K, Osaka, Japan). The recording of underwater weight was initiated immediately after bubbles stopped coming from the subject. The underwater weight was the average of the heaviest values that were reproduced two or three times among 5 to 10 measurements.

Residual lung volume (RV) was measured inside the water tank immediately prior to the measurement of underwater weight by a closed-circuit helium-dilution method with FRC Computer System (Fukuda Sangyo, COMF-100). Measurements were conducted while the subject was immersed to the neck level and in the same posture as during the underwater trials. Body density (Db) expressed as g/cm³ was calculated from the following equation:

\[ Db = \frac{BMa - BMw - t}{Dw - (RV + VGI)} \]

where BMa = body mass in air, BMw = body mass in water, t = tare weight, Dw = density of water, and VGI = the volume of gas trapped in the gastrointestinal tract, sinuses, etc. (i.e., c.a. 100ml). Percentage body fat (%BF) was derived from Db according to the formula described by Brozek et al. (1963). Fat-free mass (FFM) was calculated as the difference between BM and fat mass (FM), where FM equaled BM times %BF.

Assessment of maximal aerobic capacity

\( \dot{V}O_{2\text{max}} \) was determined using a motorized treadmill protocol consisting of jogging and running. Following the warm-up period of 2-3min, the subject started at a level grade and a speed of 100m/min. After 3 min of walking at 0%, the treadmill speed was increased by 10m/min until the subject could no longer continue. Open circuit calorimetry was used for data collection during the progressive exercise test. Expired gases were analyzed for \( O_2 \) and \( CO_2 \) fractions, using a paramagnetic \( O_2 \) analyzer and an infrared \( CO_2 \) analyzer (Mijnhardt OX-4). These gas analyzers were calibrated against gases of known concentration prior to and after each test. Ventilatory volume and gas concentration were converted into electronic signals, which were then transmitted to the electronic microprocessor system. Standard equations were used to calculate \( \dot{V}O_2 \), carbon dioxide output (\( \dot{V}CO_2 \)), respiratory exchange ratio (RER), and other derivatives.

Throughout the test, the electrocardiogram (ECG) was monitored telemetrically with an ECG telemetry transmitter (LX-3100, Fukuda Denshi) and an electrocardiograph (DS-502, Fukuda Denshi) by use of the CM5 lead placement, which is considered the most sensitive for ST segment changes. ECGs were recorded with a pen recorder (Recti-Horiz 8K-23, San-ei) at the paper speed of 25mm/s during the last 15 s of each minute. Heart rate (HR) was determined from the number of R-R interval. All subjects were verbally encouraged by test administrators to provide a true maximal effort.

The criteria for attainment of \( \dot{V}O_{2\text{max}} \) were 1) an increase in \( \dot{V}O_2 \) of less than 150ml/min with increases in work rate, 2) the highest HR measured at the end of exercise being >90% of the HR\(_{\text{max}} \) set for the subject’s age (i.e., 220-age), and 3) the highest RER in the expiratory air during the final stage of the incremental exercise being >1.0. In this study, \( \dot{V}O_{2\text{max}} \) was accepted only when two of the three criteria were met.

Expression of maximal oxygen uptake

Although \( \dot{V}O_{2\text{max}} \) is a universally accepted meas-
ure to indicate state and change in cardiorespiratory fitness, how to express VO$_{2\text{max}}$ in relation to body size is still a subject for discussion. The relation between VO$_{2\text{max}}$ and body size is of considerable significance in growth and training studies on boys and girls. VO$_{2\text{max}}$ is, in general, expressed not only in absolute values (i.e., liters per minute) but also in relation to BM, FFM or height squared. In the current study, we present our data in relation to BM and FFM as well as in absolute terms.

**Statistical analyses**

Values are expressed as mean and SD unless otherwise indicated. The Pearson product-moment coefficient was used to establish the correlation between variables. Student’s unpaired t-test was applied to determine statistical differences between the obese and nonobese groups. Although the t-test was utilized to evaluate the difference between two means, we assumed that the variances of the two samples were equal. When equality of variances was not fulfilled by F-test, Welch’s method was applied. Statistical significance was only accepted when P values were less than 0.01 in all analyses.

**RESULTS**

The age, height, BM, and body composition variables for the subjects are presented in Table 1. Results of unpaired t-test indicated that statistically significant (P < 0.01) group mean differences between the obese and the nonobese were observed for BM, %BF, and absolute BF. FFM significantly differed only in boys; i.e., the obese group had larger values than the nonobese group. There were no significant differences in age and height between the obese group and the nonobese group irrespective of sex.

The maximal values for the VO$_2$ and HR measured during treadmill exercise are listed in Table 2. The three criteria for attaining VO$_{2\text{max}}$ were met in most subjects, and all subjects reported here fulfilled at least two of the three criteria.

As for the boys, the absolute value of VO$_{2\text{max}}$ was significantly (P < 0.01) larger in the obese group than in the nonobese. When VO$_{2\text{max}}$ was expressed as milliliters (ml) per kilogram (kg) of BM per minute, significant group mean differences were found; however, no differences existed in HR$_{\text{max}}$ and VO$_{2\text{max}}$ that was expressed as ml per kg of FFM per min. As for the girls, significant group mean differences were found only in VO$_{2\text{max}}$ expressed as ml per kg of BM per min. Mean (±SD) values of VO$_{2\text{max}}$ expressed as ml per kg of BM per min for the nonobese groups were 52.0±4.4 (boys) and 44.5±6.7 (girls). HR$_{\text{max}}$ values for all groups with the exception of the obese boy group averaged higher than 200 bpm.

Zero-order correlations between VO$_{2\text{max}}$ and body composition variables calculated for each gender are presented in Table 3. In the correlational analyses, the data for the obese and nonobese groups were pooled. The FFM had a significant correlation

### Table 2: Maximal oxygen uptake and maximal heart rate of subjects

<table>
<thead>
<tr>
<th></th>
<th>n (l/min)</th>
<th>VO$_{2\text{max}}$ (ml/kg BW/min) (1)</th>
<th>VO$_{2\text{max}}$ (ml/kg FFM/min) (2)</th>
<th>HR$_{\text{max}}$ (bpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boys</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non obese</td>
<td>14</td>
<td>2.5±0.3</td>
<td>52.0±4.4</td>
<td>59.0±4.7</td>
</tr>
<tr>
<td>Obese</td>
<td>7</td>
<td>3.3±0.7*</td>
<td>40.8±3.8*</td>
<td>57.5±4.6</td>
</tr>
<tr>
<td>Girls</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non obese</td>
<td>10</td>
<td>2.0±0.2</td>
<td>44.5±6.7</td>
<td>54.3±7.2</td>
</tr>
<tr>
<td>Obese</td>
<td>6</td>
<td>1.9±0.2</td>
<td>35.8±2.6*</td>
<td>50.4±2.7</td>
</tr>
</tbody>
</table>

(1) VO$_{2\text{max}}$ per weight
(2) VO$_{2\text{max}}$ per fat free mass
* p < 0.01
Table 3 Correlation matrices among body composition and VO_{max}

<table>
<thead>
<tr>
<th></th>
<th>Boys</th>
<th>Girls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>0.971</td>
<td>0.789</td>
</tr>
<tr>
<td>Fat (kg)</td>
<td>0.872</td>
<td>0.771</td>
</tr>
<tr>
<td>FFM (kg)</td>
<td>0.923</td>
<td>-0.619</td>
</tr>
<tr>
<td>VO_{max} (l/min)</td>
<td>-0.333</td>
<td>0.354</td>
</tr>
<tr>
<td>VO_{max} (ml/kg BW/min)</td>
<td>0.658</td>
<td></td>
</tr>
<tr>
<td>VO_{max} (ml/kg FFM/min)</td>
<td>0.858</td>
<td></td>
</tr>
</tbody>
</table>

1): VO_{max} per weight, 2): VO_{max} per fat free mass

Fig. 1 Relationship between fat-free mass and maximal oxygen uptake

Fig. 2 Relationship between percentage body fat and maximal oxygen uptake
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(\(r = 0.923\)) to absolute \(\dot{V}O_{2\text{max}}\) in boys, while no significant correlations were obtained between FFM and any of the three \(\dot{V}O_{2\text{max}}\) variables in girls. The variable that correlated highest with %BF was \(\dot{V}O_{2\text{max}}\) expressed as ml per kg of BM per min: \(r = -0.843\) for boys and \(r = -0.742\) for girls.

Depicted in Figures 1 and 2 are the individual data points for FFM and absolute \(\dot{V}O_{2\text{max}}\) and for %BF and \(\dot{V}O_{2\text{max}}\) expressed as ml per kg of BM per min, respectively.

**DISCUSSION**

The current study examined (1) the relationship of body composition and \(\dot{V}O_{2\text{max}}\) of 12- to 15-yr-old boys and girls, and (2) the differences in \(\dot{V}O_{2\text{max}}\) between obese and nonobese groups. The \(\dot{V}O_{2\text{max}}\) has been widely accepted as a criterion for the assessment of physical fitness, especially cardiorespiratory fitness. \(\dot{V}O_{2\text{max}}\) is a measure of the functional limit of the cardiorespiratory system and the single most valid index of maximal exercise capacity. In addition, the bulk of research on animals and humans indicates that regular physical activity may contribute to protection from CHD in a variety of beneficial ways.

Depending on the aim of the study, \(\dot{V}O_{2\text{max}}\) has been expressed either as liters per min (Buskirk and Taylor, 1957; Welch et al., 1958; Davies et al., 1972; Kitagawa et al., 1974; Kitagawa et al., 1977; Kitagawa and Miyashita, 1981; Cooper et al., 1984) or as ml per kg per min. The latter expression is separated into ml per kg of BM per min (Buskirk and Taylor, 1957; Welch et al., 1958; Kitagawa et al., 1974; Kitagawa et al., 1977; Kitagawa and Miyashita, 1981; Tanaka et al., 1984; Tanaka et al., 1985) and ml per kg of FFM per min (Buskirk and Taylor, 1957; Welch et al., 1958; Kitagawa et al., 1974; Kitagawa et al., 1977; Kitagawa and Miyashita, 1981).

The absolute \(\dot{V}O_{2\text{max}}\) values may be one of the best indices of an individual’s cardiorespiratory fitness to transport oxygen to working muscles (Taylor et al., 1955). In addition, the absolute \(\dot{V}O_{2\text{max}}\) values are useful when changes in maximal aerobic capacity of boys and girls are assessed during the period from prepuberty to adolescence (Yamaji, 1992). However, \(\dot{V}O_{2\text{max}}\) values should be expressed as ml per kg of BM per min when they are used to examine the capacity to perform exhausting work (Buskirk and Taylor, 1957). \(\dot{V}O_{2\text{max}}\) values expressed as ml per kg of FFM should be used when we examine the performance of the cardiorespiratory system (Buskirk and Taylor, 1957).

Cooper et al. (1984) reported significant positive correlations between BM and absolute \(\dot{V}O_{2\text{max}}\) among children ranging in age from 6 to 17 years. This may suggest that absolute \(\dot{V}O_{2\text{max}}\) values of obese children are higher than those of nonobese children. Buskirk and Taylor (1957), Kitagawa and Miyashita (1981), and Welch et al. (1958) observed no statistically significant differences in absolute \(\dot{V}O_{2\text{max}}\) values between the obese and nonobese groups. Similar results were obtained in girls of the current study. In the present study, however, the absolute \(\dot{V}O_{2\text{max}}\) values of boys were significantly higher for the obese group than for the nonobese group. According to Forbes and Lewis (1956), the human skeletal muscle accounted for about 50% of FFM. Further, since the skeletal muscle is an active tissue which consumes much oxygen during activity, the differences in boys between the present study and the study of Kitagawa and Miyashita (1981) were presumably attributed to differences in the amount of FFM (particularly skeletal muscle). There were small differences in FFM between the obese and nonobese groups in the study of Kitagawa and Miyashita (1981), while the FFM of boys was significantly higher in the obese group than in the nonobese group in the present study (Table 1). However, as reported by Kitagawa and Miyashita (1981), no significant difference was noted in the FFM of girls between the two groups. This may be the reason why no significant difference was noted in the absolute \(\dot{V}O_{2\text{max}}\) value. In the present study,
the relationship between the body composition and \( \dot{V}O_{2\text{max}} \) was also investigated in obese and nonobese subjects that were pooled. As a result, FFM was found significantly correlated with the absolute \( \dot{V}O_{2\text{max}} \) value \((r=0.923)\) in boys. Since FFM was high and so was \( \dot{V}O_{2\text{max}} \) in the obese group as shown in Fig. 1, it was suggested that the oxygen transport system to the skeletal muscle was excellent regardless of the amount of body fat in persons with more FFM or skeletal muscle. Similar results were obtained in studies of Buskirk and Taylor (1957; \( r=0.85 \)), Davies et al. (1972; Boy: \( r=0.89 \), Girl: \( r=0.85 \)), and Kitagawa and Miyashita (1981; nonobese: \( r=0.824 \), obese: \( r=0.962 \)). On the contrary, \( \dot{V}O_{2\text{max}} \) (l/min) was not necessarily high in the obese girls, although their FFM was high. The reason for this discrepancy is obscured, and more detailed research is necessary.

Welch et al. (1958) and Kitagawa and Miyashita (1981) have reported that \( \dot{V}O_{2\text{max}} \) expressed as ml per kg of BM is significantly lower in the obese group than in the nonobese group. The same tendency was seen in the present study (Fig. 2). As suggested by Buskirk and Taylor (1957) and Kitagawa and Miyashita (1981), an excessive amount of body fat appears to exert an unfavorable burden on cardiac function, particularly during exhausting exercise.

In summary, the influence of body composition on \( \dot{V}O_{2\text{max}} \) was clearly demonstrated in a young, apparently healthy population. One interesting finding was that significant correlations existed both in boys \((r=-0.742)\) and girls \((r=-0.843)\) between \( \dot{V}O_{2\text{max}} \) (ml/kg BM/min) and percentage body fat. Thus, the effects of excess body fat are striking. These observations in the current study support the general belief that obesity accentuates exercise intolerance and low maximal aerobic capacity. The fact that FFM showed a very high correlation \((r=0.923)\) to absolute \( \dot{V}O_{2\text{max}} \) (l/min) only in boys was another interesting finding, while no significant relationship was found in girls. Accordingly, no significant differences in absolute \( \dot{V}O_{2\text{max}} \) existed between the obese girls and the nonobese girls. This was considered due almost entirely to the lack of difference in FFM between these two girl groups.

REFERENCES


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(Received November 10, 1993)
(Accepted April 5, 1994)