Effects of Body Mass Index on Maximal Work Production Capacity and Aerobic Fitness During Incremental Exercise

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Summary

The aim of this study was to investigate the relationship between cardiopulmonary fitness as indicated by maximal work rate (Wmax) production and aerobic capacities (WAT), body mass index (BMI) and heart rate reserve. A total of 60 sedentary subjects (30 males, 30 females, aged 18-25 years) were enrolled in the study. Each subject performed an incremental exercise test (15 W/min) to the limit of tolerance on an electromagnetically-braked cycle ergometer. There was a negative correlation between increased BMI to Wmax capacity per kilogram body weight in male (r=–0.846, P=0.0001) and in female (r=–0.896, P=0.0001) subjects. In addition, WAT for each kilogram body weight also negatively correlated with increased BMI in male (r=–0.870, P=0.0001) and in females (r=–0.807, P=0.0001). The heart rate reserve correlated negatively with increasing BMI: r=–0.699, P=0.0001 (males) and r=–0.655, P=0.0001 (females).

The results of the present study have suggested that, due to the inverse correlation between BMI, Wmax capacity, aerobic fitness and heart rate reserve, it may be useful to consider BMI in establishing cardiopulmonary fitness in various subjects.

Key words

Body mass index • Exercise test • Aerobic fitness

Introduction

Exercise tests are commonly used for assessing the cardiopulmonary system functions in subjects with a different health status. It is well established that cardiopulmonary responses to exercise can be used to define pathophysiological processes that limit exercise and diagnose various diseases (Wasserman et al. 1994, Whipp et al. 1997).

A progressively increasing work rate exercise testing which provides a smoothly graded stress to the subjects is considered to be one of the most objective methods providing relevant information in impairment-disability evaluation compared to resting cardiopulmonary measurements (Wasserman et al. 1994, Whipp et al. 1997). During exercise, cardiopulmonary system functions are associated with increased metabolic demands. When the oxygen providing capacity of the cardiopulmonary system to exercising muscles falls behind their demands during high intensity exercise, increased energy demands are compensated by the anaerobic metabolism (Wasserman et al. 1994). During exercise, the metabolic transition point from aerobic to anaerobic metabolism, which is called the anaerobic threshold, is a widely used concept for determining the level of aerobic fitness, muscular strength and endurance in clinical medicine and sporting activities (Wasserman et al. 1994).
Importantly, it has been reported that reduced cardiopulmonary fitness is associated with an increased mortality rate (Lee et al. 1999, Wei et al. 1999). Reduced aerobic fitness and exercise capacity are closely related with the level of cardiopulmonary fitness and commonly observed findings in patients with high body mass index (BMI) (Rowland 1991, Reybrouck et al. 1997). A reduced aerobic fitness expressed as decreased work production capacity is an important factor affecting the energy intake to consumption ratio and leading to a positive energy balance and excess fat mass (Johnson et al. 2000). In addition, studies in young children and adolescents showed that high aerobic fitness is associated with a reduction in risk factors related to later cardiovascular system diseases (Despres et al. 1990, Young et al. 1995). Thus, it is important to determine the relation between BMI, aerobic fitness and exercise capacity in young subjects, which can be useful as a marker of cardiopulmonary system functions.

The aim of this study was to investigate the relationship between cardiopulmonary fitness as indicated by maximal work rate (Wmax) production and aerobic capacities (W_AT), the body mass index (BMI) and heart rate reserve in response to progressively increasing work rate exercise test in young sedentary male and female subjects.

Methods

Thirty male (age 20.5±0.3 years, weight 76.8±3.4 kg, height 178.4±0.9 cm, BMI 24.1±1.0 kg/m²) and 30 female (age 21.1±0.3 years, weight 66.9±2.9 kg, height 161.7±1.2 cm, BMI 25.8±1.3 kg/m²) subjects were asked to perform a cardiopulmonary exercise test. In the present study, to eliminate the age-related decline in work production capacity, the subjects’ age was limited to 18 to 25 years. The subjects had to be healthy, without known cardiac symptomatology (determined by personal history and by electrocardiography), lung disease and musculoskeletal impairment, not to be on regular medication, and to be able to complete safely a full incremental exercise test. The study was approved by the local Ethics Committee and informed consent was obtained from all subjects.

BMI was calculated as the ratio of body mass/height² (kg/m²). Body weight and height were measured, in light clothing without shoes, to the nearest 0.1 kg and 0.5 cm, respectively, before the cycling test. Body compositions were assessed using the leg-to-leg bioelectrical impedance method (Tanita Body Fat Analyzer, model TBF 300), which has been shown to provide accurate measurements (Utter et al. 1999). In female subjects, the body compositions were determined in the follicular phase of menstrual cycle to avoid water and electrolytes imbalance, which can affect the results obtained by the bioelectrical impedance method.

The subjects were requested not to eat a heavy meal or smoke at least 2 h before the test and also refrain from taking any drug, or caffeine for a period of 12 h before the test. After becoming familiar with the testing equipment, a symptom limited maximal exercise test was performed by each subject to assess cardiopulmonary and metabolic functional capacity.

Each subject performed an incremental ramp test (Whipp et al. 1981) using a calibrated electromagnetically braked cycle ergometer (LODE, Groningen, The Netherlands). The exercise test began with a warm-up of 4 min at 20 W. Pedaling speed remained between 50-70, generally 60 rpm throughout the test, and the work rate was increased by 15 W every minute with a work rate controller until the subjects could no longer continue to maintain the work rate. The cycle ergometer power was reduced abruptly again to 20 W and the subjects continued to cycle for a further 4 min.

Throughout the test, the heart rate was measured and recorded continuously at 5-second intervals using the Polar heart watch; these data were later downloaded to a computer for analysis. Heart rate reserve was estimated from the difference between heart rate at Wmax and at rest. Oxygen uptake in response to the progressively increasing work rate exercise test was estimated indirectly (Wasserman and Whipp 1975).

During exercise, minute ventilation (V̇E, l/min, at body temperature saturated with water vapor at ambient pressure, BTPS) was measured with a spirometer (Pony, Cosmed). Aerobic fitness was assessed by determining the work rate at the anaerobic threshold (W_AT). During exercise, anaerobic threshold was estimated non-invasively using a close relationship V̇E and metabolism (Hollmann 1985).

Data were expressed as mean ± S.E.M. For statistical comparison between the males and females Student’s t-test was used. P<0.05 was accepted as significant. Correlation analysis was performed by using Pearson correlation test to analyze the correlation between BMI and Wmax and W_AT capacities for each kilogram body weight (Wmax/BW and W_AT/BW) and heart rate reserve.
Results

Wmax and $W_{\text{AT}}$ were found to be 208±5 W and 120±2 W for male and 121±3 W and 75±1 W for female subjects, respectively (Table 1). The work rate at the anaerobic threshold to Wmax ratio was 58% in male and 61% in female (Table 1). Estimated peak VO₂ for each kilogram body weight was found to be 36.60±1.2 ml/min/kg in male and 27.85±1.2 ml/min/kg in female subjects (Table 1).

Table 1. The mean (±S.E.M.) values and ranges for maximal work rate production capacity (Wmax), work rate at the anaerobic threshold ($W_{\text{AT}}$), percentage of anaerobic threshold to maximal work rate production capacity (%$\text{W}_{\text{AT}}$), maximal work rate production capacity for each kilogram body weight ($W_{\text{max}}$/$\text{BW}$), aerobic work rate production capacity for each kilogram body weight ($W_{\text{AT}}$/$\text{BW}$) and estimated peak oxygen uptake (VO₂peak) for each kilogram body weight in male and female subjects

<table>
<thead>
<tr>
<th></th>
<th>Wmax (W)</th>
<th>$W_{\text{AT}}$ (W)</th>
<th>%$\text{W}_{\text{AT}}$</th>
<th>Wmax/$\text{BW}$ (W/kg)</th>
<th>$W_{\text{AT}}$/$\text{BW}$ (W/kg)</th>
<th>VO₂peak (ml/min/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>208±5</td>
<td>120±2</td>
<td>%58</td>
<td>2.845±0.11</td>
<td>1.649±0.06</td>
<td>36.60±1.2</td>
</tr>
<tr>
<td>Ranges</td>
<td>(140-260)</td>
<td>(85-150)</td>
<td>(51-76)</td>
<td>(1.102-3.769)</td>
<td>(0.669-2.192)</td>
<td>(21.99-46.19)</td>
</tr>
<tr>
<td>Female</td>
<td>121±3*</td>
<td>75±1*</td>
<td>%61</td>
<td>1.947±0.11*</td>
<td>1.209±0.06*</td>
<td>27.85±1.2*</td>
</tr>
<tr>
<td>Ranges</td>
<td>(60-165)</td>
<td>(55-100)</td>
<td>(51-71)</td>
<td>(0.636-3.139)</td>
<td>(0.748-2.093)†</td>
<td>(13.83-41.02)</td>
</tr>
</tbody>
</table>

* significantly different from the male subjects, † anaerobic threshold was not detected in a female subject

As illustrated in Figure 1, there was a negative linear relationship between increased BMI and Wmax/BW and also increased BMI and $W_{\text{AT}}$/BW in both male and female subjects. Wmax/BW and $W_{\text{AT}}$/BW were found to be 2.845±0.11 W/kg and 1.649±0.06 W/kg in male subjects but 1.947±0.11 W/kg and 1.209±0.06 in female subjects (Table 1).

Fig. 2. The mean heart rate response to the progressively increasing work rate exercise tests: at rest, at the 20 W cycling, at the anaerobic threshold, and at maximal exercise performance, respectively: for the male (o) and female (Δ) subjects.

The heart rate responses to the incremental exercise test are shown in Figure 2. Females had higher heart rate values at the 20 W cycling compared to the males: 123.4±3.1 beat/min vs. 105.7±2.2 beat/min, and
lower heart rate value at the Wmax 178.5±2.5 beat/min vs. 191.5±1.9 beat/min (Fig. 2).

The mean heart rate reserve was 111.8±2.6 beats in male and 95.3±2.3 beats in female subjects. There was a positive linear correlation between the heart rate reserve and Wmax/BW in male (r=0.593, P=0.0005) and in female (r=0.697, P=0.0001) subjects (Fig. 3). However, the heart rate reserve decreased linearly with increasing BMI in male (r=–0.699, P=0.0001) and female (r=–0.655, P=0.0001) subjects (Fig. 4).

![Fig. 3. The heart rate reserve and maximal work rate production capacity per kilogram body weight (Wmax/BW) for male (o) and female (V) subjects.](image1)

![Fig. 4. The heart rate reserve and body mass index (BMI) for male (o) and female (V) subjects.](image2)

While Wmax capacity was not affected by the body weight and height in the male group, we have found a negative correlation between body weight and Wmax capacity (r=–0.417, P=0.02) and a positive correlation (r=0.567, R=0.001) between height and Wmax capacity in the female group. Interestingly, age had a positive effect on Wmax capacity in the males (r=0.443, P=0.01) but a negative effect on Wmax capacity in the females (r=–0.431, P=0.01). However, $W_{AT}$ showed no significant correlation with any of the variables in either males or females.

**Discussion**

In the present study, it was found that aerobic power indicated by Wmax and $W_{AT}$ production capacities per kilogram body weight negatively correlated with an increased BMI. Work capacity with regard to the body weight ratio can be useful in determination of work capacity and also aerobic fitness when measurement of VO$_2$ is not available (Gulmans et al. 1997, Rump et al. 2002).

Decreased physical work capacity is a common finding in patients with obesity which describes the condition of BMI greater than 30 kg/m$^2$ due to excess body fat mass (Rowland 1991, Reybrouck et al. 1997). In addition, a markedly low work production capacity has also been reported in underweight subjects (i.e. BMI lower than 17 kg/m$^2$) (Satanarayana et al. 1977, Desai et al. 1984).

During exercise, skeletal muscles, the heart and the O$_2$-carrying capacity of the blood have significant effects on work production capacity. The systematically
reduced exercise capacity could be linked with a reduced O$_2$ supply to the active muscles. In patients with obesity, increase in type II muscle fibers decrease in type I muscle fibers (Kissebah and Krakower 1994) may also have an important effect on reduced work capacity. Furthermore, work capacity has been shown to be affected by various factors, including age (Sallis 1993, Yang et al. 1999), genes and environment (Bouchard and Shephard 1994) and height (Farazdaghi and Wohlfart 2001).

During exercise, it is generally accepted that heart rate increases in an almost linear manner with increasing work rate. A progressively decline in maximal heart rate in relation to the age is reported and this is suggested to be independent of gender or training status (Wiebe et al. 1999). However, this was not the case in our study groups in which the age of subjects varied between 18 to 25 years. There was a progressive decrease in heart rate reserve with increasing BMI in male and female subjects. A reduced cardiac performance during progressive work rate exercise in obese subjects has been reported (Salvadori et al. 1999). Left ventricular dimensions are enlarged in obese subjects (Nakajima et al. 1989, Alaud-din et al. 1990), which results in a reduced ventricular contractility at rest and during exercise in obese patients. In addition, elevated myocardial oxidative stress has been reported in patients with obesity (Vincent et al. 1999).

As expected, both W$_{max}$ capacity and W$_{AT}$ were systematically low in female subjects compared to male subjects. It has been well established that women have a smaller blood volume and heart size than men when expressed relative to body mass or fat-free mass (Mitchell et al. 1992). Furthermore, women have lower hemoglobin concentration and arterial O$_2$ content (Mitchell et al. 1992) and this has an important effect on aerobic power (Howley et al. 1995). However, the metabolic transition point (indicating aerobic power) was present on average in 58 % of male and in 61 % of female W$_{max}$ capacities which was not significantly different between the groups. These values are in accordance with the results of other investigations in which it was found that the mean anaerobic threshold for normal subjects ranged between 35 % to 80 % of W$_{max}$ capacity (Hansen et al. 1984, Whipp 1994).

As a result, W$_{max}$ and aerobic work production capacities with regard to the body weight are inversely correlated with BMI and also with heart rate reserve. Thus, it may be useful to consider a strategy to increase aerobic fitness in subjects with high BMI to prevent further increases in body weight and reduction of cardiopulmonary fitness.

References


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