






Original article (short paper)

Fat mass is negatively associated with the physiological ability of tissue to consume oxygen

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Abstract — Aims: To describe the relationship between variables related to body composition and peak oxygen uptake ($\dot{V}O_2$ peak) and to verify whether fat mass can affect these relationships. **Methods:** Eighty participants underwent cardiopulmonary exercise testing to measure $\dot{V}O_2$ peak and a body composition assessment to measure fat mass, fat free mass (FFM), and total body mass (BM). **Results:** There were significant relationships between $\dot{V}O_2$ peak relative to FFM (fat free mass) (mL/kgFFM/min) and absolute fat mass (kg) ($r=-0.50$, $p<0.001$) and relative fat mass (%) ($r=-0.56$, $p<0.001$). Absolute $\dot{V}O_2$ peak (L/min) had a high positive relationship with FFM ($r=0.83$, $p<0.0001$); the relationship between $\dot{V}O_2$ peak (L/min) and FFM remained high and positive even when accounting for absolute fat mass (kg) ($r=0.83$, $p<0.001$). $\dot{V}O_2$ peak relative to total body mass (mL/kgBM/min) showed a high negative relationship with relative fat mass (%) ($r=-0.89$, $p<0.001$) and a positive relationship with fat free mass (kg) ($r=0.57$, $p<0.001$), which did not change when accounting for fat mass (kg) ($r=0.56$, $p<0.001$). **Conclusion:** These data indicate that the physiological ability of tissue to consume oxygen ($\dot{V}O_2$ peak in mL/kgFFM/min) is negatively associated with fat mass. Moreover, the individual's cardiorespiratory capacity to transport oxygen for working muscles ($\dot{V}O_2$ peak in L/min) is strongly related to absolute FFM, and this association is not affected by fat mass. Finally, a better body mass composition (high FFM and low fat mass) is important for aerobic physical fitness ($\dot{V}O_2$ peak in mL/kgBM/min) and improved physiological ability of tissue to consume oxygen ($\dot{V}O_2$ peak in mL/kgFFM/min).

Keywords: aerobic physical fitness; body composition; peak oxygen uptake; obesity; fat free mass.

Introduction

According to the World Health Organization (WHO), 39% of adults aged 18 years and over were overweight in 2016, and 13% were obese¹. This number, which is increasing exponentially worldwide, has been strongly associated with physical inactivity¹. Globally, around 31% of adults (men 28% and women 34%) aged 15 years and over were insufficiently active in 2008. As a consequence, approximately 3.2 million deaths each year are attributable to insufficient physical activity².

A sedentary lifestyle and obesity are public health issues because they are thought to be important risk factors for several noncommunicable diseases, such as cardiovascular diseases and type 2 diabetes mellitus³. However, there is currently no consensus about whether obesity and a sedentary lifestyle are related or whether they are actually independent risk factors. Several previous studies aimed to verify the relationship between obesity and physical fitness. Their results revealed lower cardiorespiratory fitness for obese than for thinner subjects for several different populations⁴⁻¹⁰. However, contradictory results about the relationship between fat body mass and physical fitness were found in the literature^{4,11}.

Aerobic physical fitness levels have traditionally been assessed by maximal oxygen uptake ($\dot{V}O_2$ max) and can be defined as the

highest rate at which oxygen can be taken up, transported, and utilized by the body during maximal exercise¹². Furthermore, $\dot{V}O_2$ max can be used as a means for identifying physiological impairments and as prognostic data for several types of heart disease¹³. Achieving a clear plateau in oxygen uptake ($\dot{V}O_2$) during cardiopulmonary exercise testing has traditionally been used as the best evidence of $\dot{V}O_2$ max. However, in clinical testing situations, a clear plateau may not be detected. Consequently, peak oxygen uptake ($\dot{V}O_2$ peak) is often used as an estimate for $\dot{V}O_2$ max. For practical purposes, $\dot{V}O_2$ max and $\dot{V}O_2$ peak are used interchangeably¹³.

In order to compare different individuals, $\dot{V}O_2$ max/peak is usually expressed relative to total body mass (BM) (in mL/kgBM/min), and when comparing exercise tolerance, this representation should be used¹⁴. Specifically, when $\dot{V}O_2$ max/peak is used in clinical situations, it should be presented relative to fat free mass (FFM) (in mL/kgFFM/min), as this better reflects the physiological ability of the tissue to consume oxygen¹¹.

It is possible that the confusion surrounding the proper expression of $\dot{V}O_2$ max/peak contributes to the conflicting results regarding the relationship between body composition and $\dot{V}O_2$ max/peak. In overweight and obese adults, this relationship may present some peculiarities. Overweight and obese people are characterized by high fat mass percentage, which is a negative

point for $\dot{V}O_2max/peak$ relative to BM, but not necessarily for expressed in absolute values (L/min). This is because higher fat free mass, a metabolically active tissue, is also expected for overweight and obese people and may contribute to higher absolute $\dot{V}O_2max/peak$ values¹¹. On the other hand, it is not known if a high fat mass can prejudice the ability of the fat free mass to consume oxygen.

To the best of our knowledge, no data are available about the relationship between body composition and different ways to express $\dot{V}O_2max/peak$ (absolute, relative to BM or relative to FFM). Therefore, the main aim of this study was to describe the relationship between total body mass and body composition (body fat mass and fat free mass in absolute and relative values) and $\dot{V}O_2peak$ in individuals with different body mass index (BMI) and to verify whether the level of individual fat mass is able to affect these relationships. We hypothesized that absolute values for $\dot{V}O_2peak$ (L/min) will have a significant relationship with absolute fat free mass, but $\dot{V}O_2peak$ relative to BM (mL/kgBM/min) will not, and will instead show a stronger relationship with fat mass. We also hypothesized that higher fat mass will impair the relationship between $\dot{V}O_2peak$ and FFM and will also be negatively associated with the physiological ability of the tissue to consume oxygen. These data may be helpful for better understanding the factors associated with aerobic physical fitness in lean and overweight or obese populations and to aid evaluation of these populations.

Methods

Participants

Adults of both sexes, 18-66 years old, were invited to take part in this study. Participants were recruited through advertisements that were posted on social networks and at a medical school. Inclusion criteria were: body mass index (BMI) > 20 and <42 kg/m², plus no history of neurological, cognitive, orthopedic, respiratory, or endocrine disease (except obesity). BMI was calculated by dividing body mass by height squared (kg/m²). Subjects were classified according to BMI by using the following criteria: a BMI < 25 kg/m² indicates lean subjects, while BMI ≥ 25 kg/m² indicates overweight subjects, and a BMI ≥ 30 kg/m² indicates obese subjects¹. Between July 2013 and December 2014, 136 subjects were assessed for study eligibility by medical assessment that included a medical history questionnaire and a medical examination. Fifty-six individuals were excluded after application of the inclusion criteria. Eighty subjects participated in this study, the subjects presented the following characteristics: age: 47.4±10.3 years old; body mass: 82.2±14.3 kg; height: 164.2±8.7 cm; BMI: 30.5±5.0 kg/m²; fat mass: 42.0±12.3 %; fat mass: 33.4±12.4 kg and fat free mass: 44.8±10.6 kg. According to BMI criteria, 12 subjects were classified as lean, 36 were classified as overweight and 32 were classified as obese. Figure 1 illustrates flow chart showing participant selection.

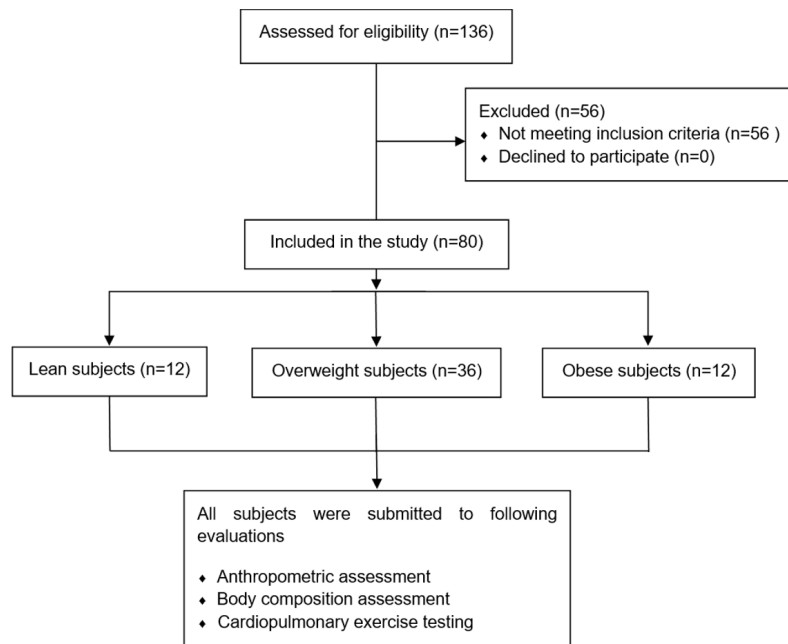


Figure 1. Flow chart for selection of study participants.

The participants were informed about the study's purpose and experimental procedures, and all gave informed written consent before taking part. All experimental procedures were approved by the Human Research Ethics Committee (protocol number 215.154) of the University and are in accordance with the Declaration of Helsinki.

Cardiopulmonary exercise testing

Participants were submitted to a cardiopulmonary exercise test on a motorized treadmill (Inbrasport, ATL, Porto Alegre, Brazil) with individualized ramp protocol to measure $\dot{V}O_2peak$. An individual, subjective level of exertion was obtained using

the Borg scale¹⁵. During the cardiopulmonary exercise testing, ventilation and expired gases were measured breath by breath using a metabolic analyzer (Quark, Rome, Italy). For analysis, mean values were calculated every 20 seconds for each variable. Calibration procedures for the metabolic analyzer were performed according to the manufacturer's guidelines before each test. The highest $\dot{V}O_2$ measured at the cessation of exercise was called $\dot{V}O_2 peak$ because none of the participants reached the criteria for $\dot{V}O_2 max$ ¹⁶.

Body composition

Body composition was assessed by dual-energy X-ray absorptiometry (DXA, software version 12.3, Lunar DPX, Madison, WI). The variables analyzed were: FFM in absolute values (kg) and relative to BM (%), fat mass in absolute values (kg) and relative to total body mass (%), and total body mass (kg). This method has been previously demonstrated to be reliable and valid¹⁷.

Statistical analyses

The statistical analyses were performed using the Statistica software (version 6.0, Statsoft Inc., Tulsa, Oklahoma, USA). Data were expressed as mean and standard deviation (SD). All variables had a normal distribution according to the Kolmogorov-Smirnov normality test, and exhibited homogeneous variability on the Levene test. One-way ANOVA was used to assess differences between lean, overweight and obese groups. When significant interactions were present, Newman-Keuls post-hoc procedures were used to identify the specific differences.

Pearson's correlation coefficients between $\dot{V}O_2 peak$ and body mass composition were calculated taking into account the volunteer's age. To this end, the pool of participants from the three groups was used. Pearson's correlation coefficients between $\dot{V}O_2 peak$ and fat free mass (kg) were also calculated taking into account the fat mass (kg). Correlations below 0.49 are described as poor; those from 0.50 to 0.69 are described as "moderate"; those from 0.70 to 0.89 are described as "high," and those 0.9 and above are described as "very high"¹⁸. The level of significance was set at 0.05 for all statistical procedures.

Results

The treadmill performance of the participants is shown in Table 1. All participants finished the test without intercurrent.

Table 2 presents Pearson coefficient correlations between $\dot{V}O_2 peak$ and total body mass (kg), absolute fat mass (kg), fat free mass (kg) and relative fat mass (%). Absolute fat mass (kg) ($r=-0.52$, $p<0.001$), fat free mass (kg) ($r=0.83$, $p<0.001$) and relative fat mass (%) ($r=-0.75$, $p<0.001$) showed significant correlation with absolute values for $\dot{V}O_2 peak$ (L/min) (Table 2). When the relationship between $\dot{V}O_2 peak$ (L/min) and fat free mass (kg) was analyzed taking into account the fat mass (kg), the correlation was also classified as high ($r=0.83$, $p<0.001$) (Table 3). We found that $\dot{V}O_2 peak$ expressed relative to BM (mL/kgBM/min) presented a significant and negative correlation with BM (kg) ($r=-0.37$, $p=0.001$), relative fat mass (%) ($r=-0.89$, $p<0.001$) and absolute fat mass (kg) ($r=-0.80$, $p<0.001$). Moreover, $\dot{V}O_2 peak$ expressed relative to BM (mL/kgBM/min) also presented a significant but positive correlation with fat free mass (kg) ($r=0.57$, $p<0.001$), which was not affected when absolute fat mass (kg) was taking into account (Table 3). As $\dot{V}O_2 peak$ expressed relative to BM (mL/kgBM/min), expressed relative to FFM (mL/kgFFM/min) presented significant and negative correlation with BM (kg) ($r=-0.25$, $p=0.026$), absolute fat mass (kg) ($r=-0.50$, $p<0.001$) and relative fat mass (%) ($r=-0.56$, $p<0.001$) as showed in Table 2.

Table 1. Results obtained from cardiopulmonary exercise test (n=80).

Variable	Subjects (n=80)
Absolute $\dot{V}O_2 peak$ (L/min)	2.5±0.9
Relative to total body mass $\dot{V}O_2 peak$ (mL/kgBM/min)	31.6±12.7
Relative to FFM $\dot{V}O_2 peak$ (mL/kgFFM/min)	55.5±11.0
HRmax (bpm)	161.4±18.3
HRmax (% predicted)	92.8±9.1
$\dot{V}CO_2/\dot{V}O_2$	1.04±0.1

$\dot{V}O_2 peak$: peak oxygen uptake. FFM: fat free mass. HRmax: maximum heart rate. $\dot{V}CO_2/\dot{V}O_2$: respiratory exchange ratio.

Table 2. Pearson coefficient correlation values between $\dot{V}O_2 peak$ and body composition variables (n=80).

Variables	$\dot{V}O_2 peak$ (L/min)	p value	$\dot{V}O_2 peak$ (ml/kgBM/min)	p value	$\dot{V}O_2 peak$ (ml/kgFFM/min)	p value
Total body mass (kg)	0.09	0.421	-0.37*	0.001	-0.25*	0.026
Fat mass (kg)	-0.52*	<0.001	-0.80*	<0.001	-0.50*	<0.001
Fat free mass (kg)	0.83*	<0.001	0.57*	<0.001	0.33*	0.003
Fat mass (%)	-0.75*	<0.001	-0.89*	<0.001	-0.56*	<0.001

$\dot{V}O_2 peak$: peak oxygen uptake. FFM: fat free mass. *significant correlation.

Table 3. Pearson coefficient correlation values between $\dot{V}O_2 peak$ and body composition variables (n=80) analyzed taking into account the fat mass.

Variables	$\dot{V}O_2 peak$ (L/min)	p value	$\dot{V}O_2 peak$ (ml/kgBM/min)	p value	$\dot{V}O_2 peak$ (ml/kgFFM/min)	p value
Total body mass (kg)	0.81*	p<0.001	0.44*	p<0.001	-0.03	p=0.80
Fat mass (kg)	-		-		-	
Fat free mass (kg)	0.83*	p<0.001	0.56*	p<0.001	-0.29*	p=0.01
Fat mass (%)	-0.81*	p<0.001	-0.67*	p<0.001	0.27*	p=0.02

$\dot{V}O_2 peak$: peak oxygen uptake. FFM: fat free mass. *significant correlation.

Discussion

Given that no data are available about the relationship between body composition and different ways to express $\dot{V}O_2 max/peak$ (absolute, relative to BM, or relative to FFM) in individuals with different BMI, the main aim of the present study was to verify the relationship between body composition and $\dot{V}O_2 peak$ values expressed in different ways. The aim was also to verify if the level of fat mass can affect these relationships. As was hypothesized, the most relevant finding is that the fat mass (in kg or in %) negatively affected the highest rate at which oxygen can be used by an individual to perform muscular work ($\dot{V}O_2 peak$ in L/min) as well as physical fitness ($\dot{V}O_2 peak$ in mL/kgBM/min) and the physiological ability of the tissue to consume oxygen ($\dot{V}O_2 peak$ in ml/kgFFM/min). This finding suggests that the level of fat mass affects exercise tolerance and the muscular capacity to consume oxygen. Furthermore, individuals presenting higher fat free mass also presented the better $\dot{V}O_2 peak$ values (absolute, relative to total body mass, and relative to fat free mass) assessed in this study. However, contrary to our initial hypothesis, higher fat mass did not impair the relationship between $\dot{V}O_2 peak$ and FFM, in other words, fat mass is negatively associated with $\dot{V}O_2 peak$, however it did not impair the relationship between $\dot{V}O_2 peak$ and FFM. The high positive relationship ($r=0.83$) between FFM (kg) and $\dot{V}O_2 peak$ (L/min) values confirms our initial hypothesis and corroborates the importance of FFM for $\dot{V}O_2 peak$. In the same direction, the relationship between FFM (kg) and $\dot{V}O_2 peak$ (L/min) values was not modified when fat mass (kg) was taken into account. These data were expected since FFM demands a greater amount of oxygen than other tissues in the body. On the other hand, Chatterjee, Bandyopadhyay¹⁹ showed higher absolute $\dot{V}O_2 max$ in obese boys than in non-obese boys with similar levels of physical fitness; this may be explained by a higher muscle mass in the obese volunteers, but the authors did not present these data. In the present study, fat mass was negatively associated with $\dot{V}O_2 peak$ (L/min) however, it is unlikely that this association has a causal relationship. Considering that our individuals with higher fat mass also have lower FFM, it is possible that $\dot{V}O_2 peak$ (L/min) presented a significant association with the percentage of fat mass, because individuals with higher fat mass also have less FFM, and lean mass can impair $\dot{V}O_2 peak$ (L/min). As such, the lack of change in Pearson correlation between $\dot{V}O_2 peak$ (L/min) and FFM (kg) when fat mass (kg)

was taken into account suggests that fat mass has no harmful effect on the maximal rate at which oxygen can be used by an individual.

In order to compare different individuals, with different fat mass, $\dot{V}O_2 max/peak$ is commonly presented relative to BM (ml/kgBM/min)¹¹. Our data showed significant high negative relationship between (ml/kgBM/min) and fat mass percentage ($r=-0.89$) or absolute fat mass ($r=-0.80$), and these data were in accordance with previous data ($r=-0.83$ to -0.40)⁵⁻¹⁰; this indicates that poor body composition implies poor aerobic physical fitness, or, in others words, poor exercise tolerance. Physical fitness is a set of measurable health and skill-related attributes that include cardiorespiratory fitness, muscular strength and endurance, body composition and flexibility, balance, agility, reaction time and power²⁰. Barry, Baruth, Beets, Durstine, Liu, Blair²¹ conducted a meta-analysis to quantify the joint association of cardiorespiratory fitness and weight status on mortality from all causes and found that the unfit individuals, those who present lower $\dot{V}O_2 max$ (mL/kgBM/min), had twice the risk of mortality regardless of BMI. Moreover, overweight and obese individuals had similar mortality risks as normal weight-fit individuals. These results suggest not only that obesity and low fitness levels should be considered independent entities, but also that physical activity programs (mainly strength training) which improve FFM and, consequently, oxygen consumption capacity should be promoted. Indeed, in terms of minimizing the risk of mortality, improving oxygen consumption capacity was more important than simply initiating a program to reduce body mass²¹.

In order to evaluate the physiological ability of the tissue to uptake oxygen, the $\dot{V}O_2 peak$ values should be expressed relative to FFM (ml/kgFFM/min)¹¹. In fact, when the relationship between this variable and body composition was evaluated, significant associations were detected for fat mass (in kg or in %) and FFM. Previous studies have argued that obese individuals have fat mass infiltration within the skeletal muscle, which may compromise the contractile component of the muscle, impairing strength development^{22,23}. Our data expand this view; the data suggest that higher fat mass was associated with diminished physiological ability of the tissue to uptake oxygen. Conversely, Goran, Fields, Hunter, Herd, Weinsier¹¹ found contradictory results. These authors did not find a significant association between $\dot{V}O_2 max$ (ml/kgFFM/min) and fat mass; however, they studied children, and it is possible that children's physiological capacity for oxygen consumption is different from adults'.

In summary, cardiorespiratory performance, exercise tolerance, and physiological ability of the tissue to uptake oxygen varied according to body composition.

The practical implication of this study is that physical activity programs that improve FFM and reduce fat mass should be considered for obese people. Such programs improve oxygen uptake capacity and prevent the fat mass from impairing the physiological ability of the tissue to uptake oxygen. This matter is very important because there is an inverse relationship between $\dot{V}O_2$ max/peak and mortality from all causes; the relationship was independent of gender and persisted after adjustment for traditional cardiovascular disease (CVD) risk factors (e.g., age, blood cholesterol, blood pressure, obesity, smoking status, family history, blood glucose and type 2 diabetes)²⁴. More recently, Kavanagh et al.²⁵ showed among women referred for cardiac rehabilitation, those with higher $\dot{V}O_2$ peak presented a decrease in mortality by about 50%. In addition, these same authors showed that an increase in $\dot{V}O_2$ peak of 1ml/kg/min was associated with a decrease in cardiac mortality of about 10%.

Conclusion

The physiological ability of tissue to consume oxygen ($\dot{V}O_2$ peak in mL/kgFFM/min) is lower when an individual presents higher fat mass (in kg or in %). The individual's cardiorespiratory capacity to transport oxygen for working muscles ($\dot{V}O_2$ peak in L/min) is highly associated with absolute FFM, and this association is not affected by the level of individual fat mass. Finally, aerobic physical fitness ($\dot{V}O_2$ peak in mL/kgBM/min) is highly associated with fat mass (negatively) and with FFM (positively).

Limitation of the study

In the present study, participants were submitted to a cardiopulmonary exercise test to measure $\dot{V}O_2$ peak, however, skeletal muscle capacity to consume oxygen was not measured, therefore caution should be taken with the interpretation of the results.

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