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Correlation of Body Fat and VO_2max with Markers of Metabolic Health

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Authors' Contribution

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ABSTRACT

Background: Cardiorespiratory fitness (CRF), an indicator of physical fitness, is paramount to predicting cardiovascular and metabolic health. Of various indicators of CRF, maximal oxygen uptake (VO_2max) is the best. Percentage of body fat and lipid profile are two important indicators of an individual's metabolic function. Dyslipidemia and excess body fat are known to increase cardiometabolic risk and decrease aerobic capacity. The interaction of body fat and aerobic fitness, as measured by VO_2max, along with other metabolic parameters, determines long-term health outcomes and identifies modifiable health targets. **Methodology:** This cross-sectional study conducted at the Department of Endocrinology and Medicine, King Edward Medical University, Lahore, from February to May, 2025 included 221 apparently healthy adults aged 18-65 years. The participant's anthropometric data was collected i.e. BMI, body fat percentage, and waist circumference. VO_2max was calculated using the formula based on resting heart rate and age. Metabolic markers were fasting triglycerides and high-density lipoprotein (HDL). SPSS version 25.0, was used for data analysis. Relationship of variables was tested using Pearson correlation, multiple linear regression, and one-way ANOVA taking p-value of 0.05 as significant. **Results:** Participants included 221 adults (49.8% males) with a mean age of 36.8 ± 9.4 years and mean BMI of 28.6 ± 4.9 kg/m^2. VO_2max showed strong negative correlations with body fat percentage ($r = -0.518$, $p < 0.001$), BMI ($r = -0.406$, $p < 0.001$), and waist circumference ($r = -0.387$, $p < 0.001$). HDL correlated positively with VO_2max ($r = +0.285$, $p = 0.001$), while triglycerides were inversely related ($r = -0.214$, $p = 0.003$). Regression analysis identified body fat, BMI, and HDL as significant predictors, explaining 47% of VO_2max variability. VO_2max declined significantly across BMI categories ($p < 0.001$), confirming that excess body mass compromises aerobic fitness. **Conclusion:** The findings indicate that increased body fat and dyslipidemia are strongly associated with reduced cardiorespiratory fitness. Body fat percentage, BMI, and HDL emerged as key determinants of VO_2max, highlighting the integrated role of adiposity and metabolic status in predicting aerobic performance. These results highlight the importance of weight management and aerobic conditioning in improving metabolic health and reducing cardiovascular risk.

INTRODUCTION

Cardiorespiratory fitness (CRF) is the capacity of the circulatory and respiratory systems to provide oxygen for prolonged physical activity and is considered as one independent determinant of cardiovascular and metabolic health outcomes [1]. The most accepted measure of CRF and overall physiological performance continues to be maximal oxygen uptake (VO_2max). Low levels of VO_2max are correlated to increased cardiovascular morbidity and mortality regardless of the presence of other risk factors [2, 3].

Obesity and high body fat percentage significantly impact on reduced aerobic efficiency due to increased pressure on the heart and decreased the oxygen transport capacity. This relationship has been explored in several studies [4]. Studies have established that age, resting heart rate, and body mass index are reliable predictors of VO_2max, while studies have documented a comprehensive inverse relationship between fat mass and aerobic capacity for both males and females [5]. Likewise, a considerable meta-analysis on cardiorespiratory fitness, BMI, and mortality underscored that low VO_2max value individuals had an increased risk of death due to cardiovascular disease and all-cause mortality [6].

Body composition, particularly body fat percentage and waist circumference, directly influences oxygen utilization, muscle efficiency, and energy metabolism. Moreover, metabolic markers such as triglycerides and HDL cholesterol further shape aerobic performance [7, 8]. High triglyceride concentrations and low HDL levels have been linked to insulin resistance, endothelial dysfunction, and impaired oxygen delivery, which collectively reduce VO_2max . These interconnections suggest that VO_2max not only reflects cardiovascular endurance but also provides an indirect assessment of overall metabolic health.

This study was conducted to explore the correlation between body fat percentage and VO_2max and to determine their association with metabolic markers such as triglycerides and HDL in apparently healthy adults. The rationale behind this investigation was to evaluate whether changes in adiposity and lipid profile are sufficient to predict variations in aerobic capacity. Establishing these associations may assist clinicians and exercise physiologists in developing early preventive strategies targeting metabolic health through body composition management and aerobic conditioning.

METHODOLOGY

This study is a cross-sectional observational study which took place over six weeks in the Departments of Endocrinology and Medicine at King Edward Medical University and its teaching hospitals in Lahore from February to May, 2025. The purpose of the study was to assess the association of body fat percentage and maximal oxygen uptake (VO_2max) in relation to some markers of metabolic health in healthy adults. The research protocol was approved by the Institutional Review Board at King Edward Medical University (Reference No. 169/RC/KEMU). The objectives of the study and the nature of the processes were explained to the subjects, assuring them of confidentiality, and consent was obtained in writing.

A total of 221 participants were included in the study. The sample size was initially estimated between 150 and 200 based on feasibility, but recruitment continued until complete data were collected for 221 individuals. A non-probability consecutive sampling method was used to enroll participants who fulfilled the inclusion criteria and provided informed consent. Individuals of both sexes, aged between 18 and 65 years, and apparently healthy were included. Participants with known systemic illnesses or on medications that could affect metabolic parameters were excluded. The exclusion criteria comprised diabetes mellitus, hypertension, dyslipidemia, chronic liver or kidney disease, ischemic heart disease, congestive cardiac failure, pregnancy, lactation, and malignancy. These restrictions ensured that the sample represented a physiologically healthy population without confounding metabolic disorders.

Each participant's anthropometry and biochemistry was assessed. Sex and age of participants were recorded, and all measurements were stratified by gender during analysis. For the assessment participants were weighed and measured without shoes and in light clothing. Standing height was measured in cm without shoes. Body mass index (BMI) was calculated as weight in kg/height in m^2. Waist circumference was measured in cm midway between the lower costal margin and iliac crest with a non-stretchable tape. The percentage of body fat was assess using bioelectrical impedance analysis (BIA) through an OMRON BF-508. Since electrical impedance provides an indirect but relatively dependable measure of total body fat, it gives a fair approximation of total body fat. The estimate of VO_2 max through age and resting heart provides a reasonable cardiorespiratory assessment without physical strain or exertion. This measure of heart capacity provides an index of maximal oxygen uptake [9, 10].

Fasting venous blood samples were collected to evaluate triglycerides and high-density lipoprotein (HDL) cholesterol levels and to assess metabolites. These parameters were taken as determinants of metabolic health to establish the correlation with each VO_2max and the adiposity indices. All results were recorded on a predesigned proforma and verified for completeness prior to being entered into the database.

Statistical analysis was performed using IBM SPSS version 25. Quantitative variables such as age, BMI, body fat percentage, waist circumference, triglycerides, HDL, and VO_2max were expressed as mean ± standard deviation. Independent samples t-tests were used to compare mean values between males and females. The association between VO_2max and other continuous variables was determined by Pearson's correlation coefficient. A multiple linear regression model was constructed to identify independent predictors of VO_2max. Participants were further grouped according to BMI categories, and the differences in mean VO_2max across these groups were analyzed by one-way ANOVA, followed by Tukey's post hoc test. A p-value of less than 0.05 was considered statistically significant.

RESULTS

A total of 221 adults took part in the study, with 110 males (49.8%) and 111 females (50.2%). The mean age was 36.8 ± 9.4 years, with no significant difference between sexes. Overall, participants were overweight (BMI 28.6 ± 4.9 kg/m^2). Females had a higher BMI than males (29.3 ± 5.0 vs. 27.9 ± 4.8 kg/m^2; p = 0.032). Body fat levels were markedly greater in females (38.9 ± 6.8%) compared with males (28.4 ± 6.1%; p = 0.001). The detailed demographic and anthropometric characteristics of the study participants are presented in Table 1.

Waist measurements were higher in males (99.8 ± 11.5 cm vs. 93.1 ± 12.2 cm; p = 0.021). Mean VO_2max was 34.6 ± 5.8 ml/kg/min, with males showing better aerobic capacity than females (36.9 ± 5.6 vs. 32.4 ± 5.4 ml/kg/min; p = 0.037). While triglyceride levels were slightly higher in males, this difference was not significant (p = 0.064). HDL cholesterol was significantly higher among females (p = 0.041). In summary, participants generally exhibited excess body weight, with clear sex-specific differences in body composition, aerobic fitness, and lipid profile.

Table 1

Demographic and Anthropometric Characteristics of Study Participants (n = 221)

Variable	Mean ± SD (All)	Mean ± SD (Males, n=110)	Mean ± SD (Females, n=111)	p-value
Sex (%)	221 (100 %)	110 (49.8%)	111 (50.2%)	

Age (years)	36.8 ± 9.4	37.2 ± 9.1	36.4 ± 9.7	0.184
BMI (kg/m²)	28.6 ± 4.9	27.9 ± 4.8	29.3 ± 5.0	0.032*
Body Fat (%)	33.7 ± 7.9	28.4 ± 6.1	38.9 ± 6.8	0.001**
Waist Circumference (cm)	96.4 ± 12.1	99.8 ± 11.5	93.1 ± 12.2	0.021*
VO_2max (ml/kg/min)	34.6 ± 5.8	36.9 ± 5.6	32.4 ± 5.4	0.037*
Triglycerides (mg/dL)	158.3 ± 67.2	165.7 ± 69.4	151.0 ± 64.8	0.064
HDL (mg/dL)	38.9 ± 8.5	37.2 ± 7.9	40.6 ± 9.0	0.041*

*p < 0.05; **p < 0.01

Correlation analysis showed multiple variables' relation with VO_2max. Body fat percentage revealed the strongest inverse correlation with VO_2max ($r = -0.518$, $p < 0.001$), then followed BMI ($r = -0.406$, $p < 0.001$) and waist circumference ($r = -0.387$, $p < 0.001$).

This indicates that study participants with more fat tissue had more poorly developed cardiorespiratory fitness. In addition, age revealed a moderate negative correlation ($r = -0.321$, $p = 0.001$), and this correlation most likely reflects a physiological decline of aerobic capacity with advancing age.

Lipid parameters also demonstrated significant associations. While VO_2max and triglycerides had inverse correlation ($r = -0.214$, $p = 0.003$), VO_2max and HDL had positive correlation ($r = +0.285$, $p = 0.001$). These results, therefore, suggest that more positive (aerobic) capacity, and consequently better metabolic health, is associated with more favorable lipid profile.

Table 2

Correlation of VO_2max with and Anthropometric & Metabolic Variables

Variable	Pearson's r	p-value	Interpretation
Age	−0.321	0.001**	VO_2max decreases with age
BMI	−0.406	0.000**	Higher BMI linked to lower VO_2max
Body Fat (%)	−0.518	0.000**	Strong inverse correlation
Waist Circumference	−0.387	0.000**	Significant negative association
Triglycerides (mg/dL)	−0.214	0.003**	Mild inverse correlation
HDL (mg/dL)	+0.285	0.001**	Positive correlation with VO_2max

To determine independent predictors of VO_2max a multiple linear regression analysis was conducted. The model was significant ($p < 0.001$) and accounted for 47% of the total variance (Adjusted $R^2 = 0.47$). Among the predictors, body fat percentage ($\beta = -0.232$, $p < 0.001$) and BMI ($\beta = -0.197$, $p < 0.001$) were the strongest negative predictors of cardiorespiratory fitness. Age negatively contributed ($\beta = -0.143$, $p < 0.001$) and confirmed that aerobic capacity declines steadily with advancing years. On the other hand, HDL cholesterol had a strong positive effect ($\beta = +0.154$, $p = 0.007$) and triglycerides had a small significant negative effect ($\beta = -0.045$, $p = 0.013$). The results highlight that regardless of age and sex, body fatness and the lipid profile are major predictors of aerobic capacity.

Table 3

Multiple Linear Regression Predicting VO_2max

Predictor	β Coefficient	Standard Error	t-value	p-value	Interpretation
Constant	51.302	2.491	20.60	0.000	—
Age (years)	−0.143	0.036	−3.97	0.000**	Negative predictor
BMI (kg/m²)	−0.197	0.048	−4.10	0.000**	Strong inverse effect
Body Fat (%)	−0.232	0.062	−3.74	0.000**	Major determinant
HDL (mg/dL)	+0.154	0.056	+2.75	0.007**	Positive predictor
Triglycerides (mg/dL)	−0.045	0.018	−2.51	0.013*	Mild inverse effect

Model Summary:

$R = 0.69$; $R^2 = 0.48$; Adjusted $R^2 = 0.47$; $F(5, 215) = 36.4$; $p < 0.001$.

The World Health Organization (WHO) classifications set the BMI boundaries for the normal weight (18.5–24.9 kg/m²), overweight (25–29.9 kg/m²), and obese (≥30 kg/m²) categories. Mean values of VO_2max are seen to decrease within each successive BMI range classification. Highest VO_2max was attained by the normal weight group (39.1ml/kg/min); in overweight group, VO_2max declined to 34.5ml/kg/min and in the obese group to 30.2ml/kg/min. Highly significant differences ($p<0.001$) within the groups was confirmed by ANOVA and differences in subgroups were shown by post hoc (Tukey) comparisions. It can therefore, be concluded, greater body weight relates to increase reduced aerobic capacity.

Table 4

Comparison of VO_2max Across BMI Categories

BMI Category	n	Mean VO_2max (ml/kg/min)	SD	p-value (ANOVA)
Normal (18.5–24.9)	44	39.1	4.3	
Overweight (25–29.9)	96	34.5	4.9	
Obese (≥30)	81	30.2	5.1	**0.000**

Post hoc (Tukey): All pairwise comparisons significant at $p < 0.05$.

To summarize, the study found strong inverse relationships between cardiorespiratory fitness and BMI, body fat percentage, and waist circumference, all measures of adiposity.

VO_2max positively relates to HDL cholesterol and negatively to triglycerides, as expected. Adiposity and lipid measures were found to explain almost 50% of the variation in VO_2max according to the fitted regression model. Moreover, participants classified as obese had significantly lower VO_2max than those of normal weight, further proving the negative impact of excess body fat on aerobic fitness and general metabolic health.

DISCUSSION

The results from the present study indicate a strong negative association between body fat percentage and VO_2max, whereby high levels of body adiposity are associated with a lower level of cardiorespiratory fitness. The study population consisted of overweight adults with significantly higher body fat in females, which may explain sex-related differences observed in aerobic capacity.. This finding is consistent with past studies showing that excess body fat decreases aerobic fitness. Other studies have reported findings consistent with the present study showing the inverse relationship between fat mass and VO_2max for both men and women, suggesting that body composition is an important factor for aerobic fitness [11, 12]. Current findings are consistent with the findings of studies which showed that high BMI and adiposity are separate risk factors for poor cardiorespiratory fitness and increased cardiovascular risk [13, 14].

This study's findings about the negative association between VO_2max and BMI, waist circumference, and triglyceride values strengthen the claim that fatty tissue and lipid deficiency undermining metabolic efficiency, along with dyslipidememia, are poorly coexisting metabolic conditions. More body fat might decrease the metabolically active fat-free mass enough to hinder the transportation and utilization of oxygen, possibly as an adaptation wherein excess weight high in fatty tissue increases the demand placed on the circulatory system, thus reducing the person's aerobic capabilities. The established relationship between HDL and VO_2max can be correlated to the research [15, 16]. HDL presence in the bloodstream, CRF, and aerobic capacity can be positively related to good metabolic health.

The study's regression analysis indicates that body fat percentage, BMI, and HDL are notable predictors of VO_2max and account for almost half of its variance. This is in line with the studies where age, resting heart rate, and body mass index could estimate VO_2max in healthy adults [17-19]. The powerful strength of the associations presented here further strengthens the assertion, indicating that the incorporative structural (body composition) and biochemical (lipid profile) factors work simultaneously to determine aerobic capacity.

Comparison of VO_2max values across BMI categories demonstrates a distinct, graded decline among the different weight classifications from normal weight to obese. This finding corresponds with the results reported by studies as well as the study of HRV-VO_2max determinants (2020) which states that the presence of higher levels of body fat is related to lower levels of autonomic flexibility and poor cardiovascular efficiency [20-22]. This, in turn, may indicate a potential decline of endurance with excess body fat due to lower mitochondrial density, a less efficient endurance capacity, and/or more impaired substrate utilization within the fat encumbered individual.

From a public health perspective, these findings highlight the interaction between health metabolism and the fitness of metabolism. The relationship between VO_2max and triglycerides, where VO_2max and triglycerides have an inverse relationship, and other scenarios where VO_2max and HDL have direct relationships show the significance of VO_2max. Aerobic capacity is primarily protective against cardiometabolic disorders. Promoting the combined benefits of weight loss and aerobic exercise may help improve cardiorespiratory and lipid metabolic dysfunction. The indirect estimation of VO_2max, through noninvasive techniques of resting heart rate and body composition analysis, may provide a practical approach for the initial identification of a person with high metabolic risk.

Reflecting on the present results, this study reinforces the concept that maintaining an optimal body composition is vital for preserving cardiovascular and metabolic health. The data suggest that moderate improvements in physical activity and fitness can have measurable effects on metabolic markers, even in apparently healthy adults. These outcomes provide a foundation for preventive interventions targeting both obesity and sedentary lifestyle as modifiable determinants of disease risk.

CONCLUSION

In conclusion, this study demonstrated that VO2max and hence cardiorespiratory fitness is closely linked to metabolic health with BMI, WC, body fat and HDL being its major predictors. Improving physical activity and maintaining healthy body composition may therefore serve as effective strategies to enhance both cardiovascular endurance and metabolic well-being.

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