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Original Article

Correlation between Hemoglobin Concentration and Oxygen Saturation Post-Exercise with Cardiorespiratory Fitness: Early Indicators for Cardiovascular Health in Young Adults

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Abstract

Background: Cardiorespiratory fitness (CRF) is an important indicator of cardiorespiratory health and a strong predictor of mortality. Several factors affect CRF, including arterial oxygen content (CaO_2), which is influenced by hemoglobin (Hb) concentration and oxygen saturation. However, the correlation between CRF and Hb remains inconclusive. This study aimed to explore the correlation between Hb concentration and oxygen saturation post-exercise with CRF, especially in young adults.

Methods: A cross-sectional study was conducted in October 2024, involving 68 medical students from a university in Jakarta, Indonesia. Consecutive stratified sampling was applied based on gender. The Global Physical Activity Questionnaire (GPAQ) and the Physical Activity Readiness Questionnaire (PAR-Q+) were used as screening tools. Hb concentration and oxygens saturation were measured using a digital hemoglobinometer and pulse oximetry, while CRF was evaluated using a 20-meter multistage test. Additional measurements included body mass index (BMI), blood pressure, and heart rate. Data were analyzed with correlation and multiple linear regression tests.

Results: The most participants were female (57.4%). Normal Hb concentration was found in 80.9% with mean Hb levels of 14.15±1.54 g/dL in males and 12.9±1.37 g/dL in females. CRF correlated positively with Hb concentration (p=0.005; r=1.13), and negatively with oxygen saturation post-exercise (p=0.005; r= -0.4). These correlations were significant in males and not in females.

Conclusions: Hb concentration and oxygen saturation post-exercise significantly correlate with CRF in males, whereas BMI and physical activity play stronger roles in females. Maintaining optimal Hb levels, preventing anemia, and promoting active lifestyles are essential strategies to support CRF, cardiovascular health, and long-term wellness.

Keywords: Cardiorespiratory fitness, exercise-induced hypoxemia, hemoglobin, physical activity, oxygen saturation.

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Introduction

Cardiorespiratory fitness (CRF) reflects the ability of the body to supply and utilize oxygen during physical activity and is closely related to aerobic metabolism and oxygen consumption (VO_2). CRF is commonly measured using maximal oxygen consumption (VO_2max), which depends on oxygen transport capacity.[1,2] VO_2max and oxygen transport capacity are affected by oxygen content (CaO_2) influenced by hemoglobin (Hb) concentration, oxygen saturation, and partial pressure of oxygen (PO2).[3,4] Hemoglobin is the main component of the oxygen transport system, with oxygen saturation reflecting the proportion of

Hb bound to oxygen.[5,6] During exercise, increased metabolic demand elevates VO_2 and decreases tissues PO_2, which can lead to oxygen desaturation after exercise or exercise-induced hypoxemia (EIH).[5,7] The EIH typically occurs during vigorous-intensity physical activity at the point of fatigue, when adenosine triphosphate (ATP) demand exceeds supply, prompting greater oxygen extraction by muscles tissue.[5,8]

According to Fick's laws, CRF is determined by cardiac output and the arteriovenous oxygen content difference (CaO_2-CvO_2).[1,9] Thus, CRF is influenced by multiple factors, including pulmonary diffusion capacity, cardiac output, oxygen transport capacity, Hb concentration, capillary density, and mitochondrial content.[1,9] Additional determinants include age, gender, genetics, smoking status, daily physical activity, body composition, nutrient intake, and certain medical conditions.[1,4] Previous studies have reported a positive correlation between Hb concentration and CRF,[3,9,10] while other studies observed a negative correlation between EIH and CRF.[3,8,11]

Despite these findings, few studies have examined the combined correlation of Hb concentration and post-exercise oxygen saturation with CRF, especially in young adults. Understanding these relationships may provide insights into early indicators of cardiovascular health. Therefore, this study aimed to explore the correlation between Hb concentration and oxygen saturation post-exercise with CRF among young adults.

Methods

This cross-sectional study was conducted in October 2024 among medical students at the School of Medicine and Health Sciences, Atma Jaya Catholic University of Indonesia. Consecutive stratified sampling was applied based on gender. The sample size was calculated with α=5% and 10% precision. Ethical approval was obtained from the Ethics Committee of Atma Jaya Catholic University of Indonesia (Approval No. 10/08/KEP-FKIKUAJ/2024). Written informed consent was obtained from all participants.

Screening was carried out using the Global Physical Activity Questionnaire (GPAQ) and the Physical Activity Readiness Questionnaire (PAR-Q+), both of which were validated instruments.[12,13] The GPAQ, developed by the World Health Organization (WHO), was used to exclude individuals with inactive or light-intensity physical activity and to identify those with moderate or vigorous activity.[13] The PAR-Q+ was a self-administered questionnaire that assess an individual's health condition for safe participation in intense physical activity. This tool consisted of yes/no questions on medical history and current symptoms, where any 'yes' response indicates potential health risk requiring medical clearance.[12] Participants were excluded if they had a history of cardiovascular disease, such as heart failure, angina pectoris, or blood clots, as well as chronic obstructive pulmonary disease, type II diabetes mellitus, recent illness, or recent blood transfusion within eight weeks. Additional exclusion criteria included resting oxygen saturation <95%, smoking status, caffeine consumption within 24 hours before the test, or the use of nail polish, which may interfere with pulse oximetry readings.[1,6,14] In brief, PAR-Q+ questionnaire was used to exclude subjects from this study. These measures were applied to ensure participant safety and minimize confounding from underlying health conditions.

Participants who met the inclusion and exclusion criteria underwent several measurements. Body weight was measured using a digital scale, height using a wireless stadiometer, blood pressure with an automatic blood pressure monitor, heart rate and oxygen saturation using a pulse oximetry, and hemoglobin (Hb) concentration with a digital hemoglobinometer. All instruments used had been tested for validity and reliability. Furthermore, CRF was assessed using the 20-meter multistage shuttle run test (beep test), and VO_2max of was calculated using the formula provided by the Ministry of Education and Culture Republic of Indonesia.[15] Fitness levels (VVO_2max) were then categorized as very poor (<29.44 mL O_2/kg/min), poor (29.14 to 37.65 mL O_2/kg/min), moderate (37.66 to 46.06 mL O_2/kg/min), good (46.07 to 54.49 mL O_2/kg/min), and excellent (>=54.5 mL O_2/kg/min) for males; whereas very poor (<23.22 ml O_2/kg/min), poor (23.22 to 27.94 ml O_2/kg/min), moderate (27.95 to 33.66 ml O_2/kg/min), good (33.67 to 39.4 ml O2/kg/min), and excellent (>= 39.41 ml O2/kg/min) for females.[15] Hb concentration was classified as normal and low based on gender, with normal value ranging from 12 to 16 g/dL in females and 13 to 18 g/dL in males.[16] Physical activity was further categorized into light, moderate, and vigorous intensity using the GPAQ scoring protocol. In this approach, the duration of moderate activity was multiplied by 4 metabolic equivalents (METs) and vigorous

Table 1 VO_2max, Hemoglobin Concentration, and Physical Activity of Young Adults by Gender

Characteristic	Male (n=29)		Female (n=39)		Total n (%)	p-value
	n	(%)	n	(%)		
VO_2max						
Very poor	19	(82.6)	4	(17.4)	23 (33.8)	0.001*
Poor	9	(22.5)	31	(77.5)	40 (58.8)	
Moderate	1	(20)	4	(80)	5 (7.4)	
Hb concentration						
Low	5	(38.5)	8	(61.5)	13 (19.1)	0.219
Normal	24	(43.6)	31	(56.4)	55 (80.8)	
Physical activity						
Moderate	22	(44.9)	31	(55.1)	49 (72.1)	0.022*
Vigorous	7	(36.8)	8	(63.2)	19 (27.9)	
Total	29	(42.6)	39	(57.4)	68 (100)	

Note: *p-value<0.05, VO_2max = maximal oxygen uptake, Hb = Hemoglobin concentration

activity by 8 METs. The total weekly MET-minutes were then calculated, and participants were categorized into light (<600 MET-min/week), moderate (600–2999 MET-min/week), or vigorous (≥3000 MET-min/week) physical activity.[13,17]

All data were analyzed using the STATA. The Shapiro–Wilk test was applied to assess normality. Normally distributed data were analyzed using Pearson's correlation, while non-normally distributed data were analyzed using Spearman's correlation and the Mann–Whitney U test. Variables with p<0.25 were further analyzed using multiple linear regression to identify independent predictors of CRF..

Results

A total of 68 students participated in this study, consisting of 29 males (42.6%) and 39 females (57.4%). Low hemoglobin concentration was detected in 13 students (19.1%), of whom 8 (61.5%) were female. Interestingly, females demonstrated better cardiorespiratory fitness (CRF) compared to males. Bivariate analysis showed significant correlations between CRF and physical activity (p=0.022) as well as between CRF and gender (p=0.001), as shown in Table 1.

The mean Hb concentration was 14.15±1.54 g/dL in males and 12.9±1.37 g/dL in females. Body mass index (BMI) was significantly higher in males (25.6±5.89 kg/m^2) compared to females (23.73±4.89 kg/m^2) and showed a significant correlation with CRF (p=0.024). In males, diastolic blood pressure was also significantly correlated with CRF (p=0.039). Furthermore, exercise-induced hypoxemia (EIH) was observed, reflected by post-exercise oxygen desaturation, which correlated with CRF in males (p=0.019). In females, a significant correlation was found between hemoglobin concentration and CRF (p=0.027) (Table 2).

Correlation analysis further showed a weak

Table 2 Subject Characteristics and Correlation with VO_2max

Characteristic	Male (n=29)		Female (n=39)		Total
	Mean±SD	p	Mean±SD	p	Mean±SD
Age (years old)	20.1±1.5	0.601	19.67±1.32	0.756	19.85±1.4
BMI (kg/m^2)	25.6±5.89*	0.003*	23.73±4.89*	0.024*	24.53±5.38
Systolic blood pressure (mmHg)	116.6±10.85**	0.234**	103.78±13.04	0.270	109.25±13.66**
Diastolic blood pressure (mmHg)	72.6±7.28*	0.039*	70.5±7.27	0.388	71.4±7.3
HR (beats/min)	85.38±10.11	0.802	88.44±10.68	0.405	87.13±10.48
HR after multistage test (%)(beats/min)	169.76±15.83	0.377	165.87±14.7**	0.177**	167.52±15.2**
SpO_2 pre-exercise (%)	97.34±1.17	0.392	97.87±0.89**	0.133	97.6±1
SpO_2 post -exercise (%)	93.45±4.21*	0.019*	95.28±3.1	0.673	94.5±3.7
Hb concentration (g/dL)	14.15±1.54	0.254	12.9±1.37*	0.027*	13.4±1.6
VO_2max (mL O_2/kg/min)	24.78±4.12		21±3.14		22.61±4.03

Note: *p-value <0.05, **p-value <0.25, SD= Standard deviation, VO2max = maximal oxygen uptake, BMI = Body mass index, HR= Heart rate, Hb = Hemoglobin, SpO2 = oxygen saturation

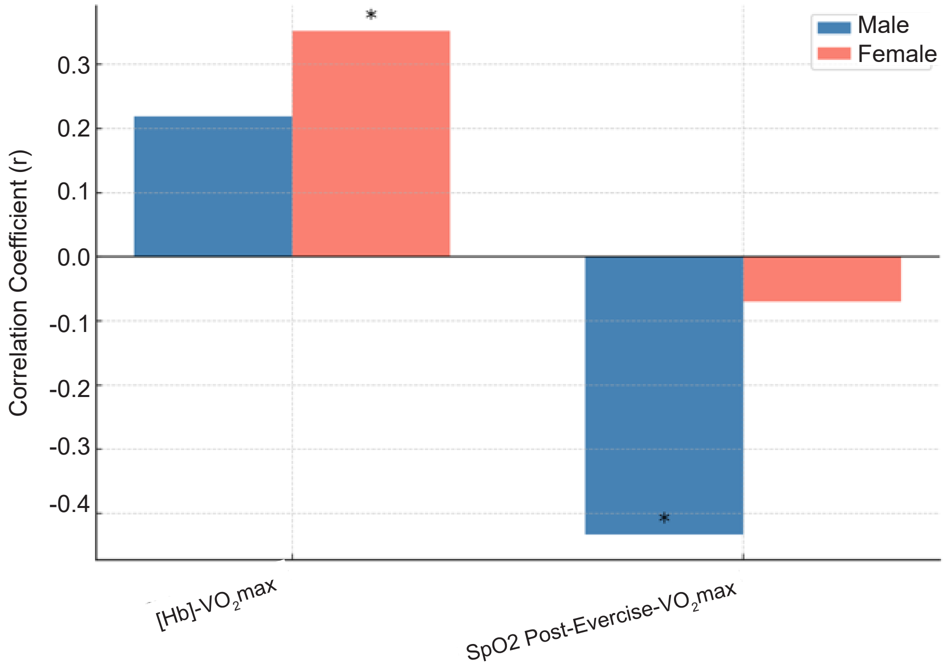

Figure 1 Correlation Between Hemoglobin Concentration [Hb] and Oxygen Saturation (SpO_2) Post-Exercise with VO_2max

positive correlation between Hb concentration and CRF in females (p=0.027, coefficient 0.352), and a moderate negative correlation between oxygen saturation post-exercise and CRF in males (p=0.019, coefficient -0.433) (Figure 1).

Furthermore, the multivariate analysis showed that in males, hemoglobin concentrations (p=0.005), oxygen saturation post-exercise (p=0.005), BMI (p=0.001), and diastolic blood pressure (p=0.012) were significant predictors of CRF (Table 3). However, there was not significant correlation between hemoglobin concentration (p=0.333) or oxygen saturation post-exercise (p=0.822) and CRF in females, although BMI (p=0.018) and physical activity (p=0.033) were significant (Table 3).

Discussion

This study has explored the correlation between Hb concentration and oxygen saturation post-exercise with CRF among young adults, revealing a weak positive correlation between Hb concentration and CRF

Table 3 Multivariate Analysis of Factors Associated with Cardiorespiratory Fitness (CRF)

Variable	Male (n=29)			Female (n=39)			Total (n=68)		
	Coef.	p	R2	Coef.	p	R2	Coef.	p	R2
Gender							-2.354	0.01*	
Hb concentration	1.13	0.005*		0.621	0.09		0.825	0.004*	
SpO_2				0.493	0.333				
SpO_2 post-exercise	-0.4	0.005*		0.033	0.822		-0.228	0.037*	
BMI	-0.383	0.001*		-0.231	0.018*		-0.306	0.000*	
Systolic blood pressure	0.103	0.146					0.036	0.301	
Diastolic blood pressure	-0.266	0.012*							
Physical activity				2663	0.033*		1.217	0.190	
HR after multistage test				0.023	0.480		0.012	0.642	
			0.6422			0.3868			0.5164

Note: *p-value <0.05, Hb= Hemoglobin , BMI= Body mass index, HR= Heart rate, SpO_2 = oxygen saturation in females. These results are in accordance with previous studies.[3,10,18,19] Interestingly, anemia of mild to severe degree has been shown to reduce CRF.[10,18,20] When the Hb concentration is low, CaO2 will decreases, leading to. reduced oxygen transport and diminished CRF. Low Hb concentration may also impair pulmonary diffusion capacity, lower circulating blood volume, and reduce stroke volume, and cardiac output.[10,20] Additionally, this study has found that more females than male had low Hb concentration, which may reflect their greater susceptibility to anemia due to menstrual blood loss and hormonal factors.

Furthermore, exercise-induced hypoxemia (EIH) has occurred in this study, with a moderate negative correlation found between EIH and CRF in males, similar to other studies.[3,21] EIH occurs during vigorous exercise as metabolic demand increases, leading to elevated VO_2 and reduced PO_2 in the tissues. This results in a rise in PCO_2, hydrogen ions, blood acidity, and 2,3-DPG levels in hemoglobin. During exercise, lactate accumulation and increased body temperature further enhance oxygen utilization, resulting in post-exercise desaturation.[5–7] EIH may affect CRF directly, through fatigue of the working muscles, or indirectly by reducing CaO_2.[8] Interestingly, EIH has been reported to occur more frequently in trained individuals than in untrained ones.[11]

A correlation has been shown between hemoglobin concentration and oxygen saturation with CRF in males. This can be explained by Fick's law, which states that CRF depends on cardiac output and the arteriovenous oxygen content difference (CaO_2-CvO_2). This difference is influenced by CaO_2 and Hb concentration, which determine oxygen transport.[5,9] Oxygen transportation is influenced by CaO2 and cardiac output. CaO_2 is affected by hemoglobin concentration, oxygen saturation and PO_2.[5] There is also a positive correlation between hemoglobin concentration and CRF. Since hemoglobin is the principal carrier of oxygen, higher hemoglobin levels increase oxygen transport capacity.[9] Conversely, low hemoglobin levels reduce oxygen delivery, lowering CRF.[10,20] When VO_2 increases during exercise, greater oxygen utilization by the tissues occurs, which contributes to oxygen desaturation.[5,6] This explains the negative correlation between EIH and CRF.

In this study, BMI had a stronger influence on CRF than Hb concentration and oxygen saturation. Males had a higher mean BMI than females, with values in the overweight to obese range. Obesity impairs pulmonary function, alters glucose metabolism, and reduces oxygen exchange, all of which negatively affect CRF.[1,22] In females, CRF correlated more strongly with BMI and physical activity than with hematological parameters. This may due to physiological differences between males and females. Female generally have lower Hb concentrations, smaller lung and cardiac capacity, lower muscle mass and higher body fat mass compared with males. These factors contribute to lower CRF in females and suggest the need for interventions that target cardiovascular and musculoskeletal adaptations rather than focusing solely on hematological parameter.[23–25] Despite a positive correlation between hemoglobin concentration and CRF, CRF is also determined by cardiac output, ventilator capacity, and muscular oxygen utilization.[1,5] Regular moderate-to-vigorous physical activity can induce cardiovascular adaptations such as increased blood volume, higher cardiac output, mitochondrial efficiency, and angiogenesis, thereby improving oxygen transport and utilization.[2,26,27] Body composition, especially muscle mass, also influences blood flow and cardiac output, further increasing CRF.[28]

This study has several limitations. Potential confounding factors influencing CRF, such as direct measurements of cardiac output, ventilation capacity, or muscle oxygen utilization were not measured. Although hemoglobin concentration contributes to oxygen transport, CRF is shaped by multiple physiological mechanisms. Without measuring these variables, it is difficult to determine the exact contribution of hemoglobin to CRFvariation. Higher cardiac output increases oxygen delivery to muscles during exercise, while greater pulmonary capacity enhance oxygen uptake and carbon dioxide clearance.. Thus, future research should include these variables to provide a more comprehensive understanding of CRF determinants.

In conclusion, this study demonstrates that Hb concentration and oxygen saturation post-exercise are correlated with CRF, particularly in males. Oxygen transport is an important determinant of CRF, but other factors, including BMI, physical activity, and diastolic blood pressure also play significant roles.

Maintaining optimal Hb concentration and oxygen saturation supports better CRF, improving the body's ability to deliver and utilize oxygen during physical activity. These findings reinforce CRF as a key indicator of cardiovascular health and overall wellness, emphasizing the importance of promoting healthy lifestyle behaviors to prevent disease and support long-term health in young adults.

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