

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

Elizabeth Elizabeth,¹ Ignatio Rika Haryono,^{2,3} Nawanto Agung Prastowo,^{2,3}
Mariani Santosa,² Sherly Tandi Arang⁴

¹School of Medicine and Health Sciences Atma Jaya Catholic University of Indonesia

²Department of Physiology, School of Medicine and Health Sciences Atma Jaya Catholic University of Indonesia

³Atma Jaya Research and Teaching Hospital, Jakarta, Indonesia

⁴Department of Pharmacology, School of Medicine and Health Sciences Atma Jaya Catholic University of Indonesia

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 oxygen 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. The data were analyzed using 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.

Althea Medical Journal.
2025;12(3):204–210

Received: February 25, 2025

Accepted: August 30, 2025

Published: September 30, 2025

Correspondence:

Ignatio Rika Haryono,
Department of Physiology,
School of Medicine and Health
Sciences Atma Jaya Catholic
University of Indonesia,
Jl. Pluit Raya No. 2, Penjaringan,
North Jakarta 14440, Indonesia

E-mail:

ignatio.rika@atmajaya.ac.id

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 ($\text{VO}_{2\text{max}}$), which depends on oxygen transport capacity.^{1,2} $\text{VO}_{2\text{max}}$ and oxygen transport capacity are affected by oxygen content (CaO_2) influenced by hemoglobin (Hb) concentration, oxygen saturation, and partial pressure of oxygen (PO_2).^{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 muscle tissue.^{5,8}

According to Fick's laws, CRF is determined by cardiac output and the arteriovenous oxygen content difference ($\text{CaO}_2 - \text{CvO}_2$).^{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 $\alpha=5\%$ 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 assessed 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 oximeter 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 $\text{VO}_{2\text{max}}$ was calculated using the formula provided by the Ministry of Education and Culture Republic of Indonesia.¹⁵ Fitness levels ($\text{VVO}_{2\text{max}}$) were then categorized as very poor ($<29.44 \text{ mL O}_2/\text{kg}/\text{min}$), poor (29.14 to 37.65 $\text{mL O}_2/\text{kg}/\text{min}$), moderate (37.66 to 46.06 $\text{mL O}_2/\text{kg}/\text{min}$), good (46.07 to 54.49 $\text{mL O}_2/\text{kg}/\text{min}$), and excellent ($\geq 54.5 \text{ mL O}_2/\text{kg}/\text{min}$) for males; whereas very poor ($<23.22 \text{ mL O}_2/\text{kg}/\text{min}$), poor (23.22 to 27.94 $\text{mL O}_2/\text{kg}/\text{min}$), moderate (27.95 to 33.66 $\text{mL O}_2/\text{kg}/\text{min}$), good (33.67 to 39.4 $\text{mL O}_2/\text{kg}/\text{min}$), and excellent ($\geq 39.41 \text{ mL O}_2/\text{kg}/\text{min}$) for females.¹⁵ Hb concentration was classified as normal and low based on gender, with normal values 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

Table 1 VO₂max, Hemoglobin Concentration, and Physical Activity of Young Adults by Gender

Characteristic	Male (n=29)		Female (n=39)		Total n (%)	p-value
	n	(%)	n	(%)		
VO ₂ max						
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, VO₂max = maximal oxygen uptake, Hb = Hemoglobin concentration

of moderate activity was multiplied by 4 metabolic equivalents (METs) and vigorous 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/m²) compared to females (23.73±4.89 kg/m²) 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 Subject Characteristics and Correlation with VO₂max

Characteristic	Male (n=29)		Female (n=39)		Total Mean±SD
	Mean±SD	p	Mean±SD	p	
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 ₂ max (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

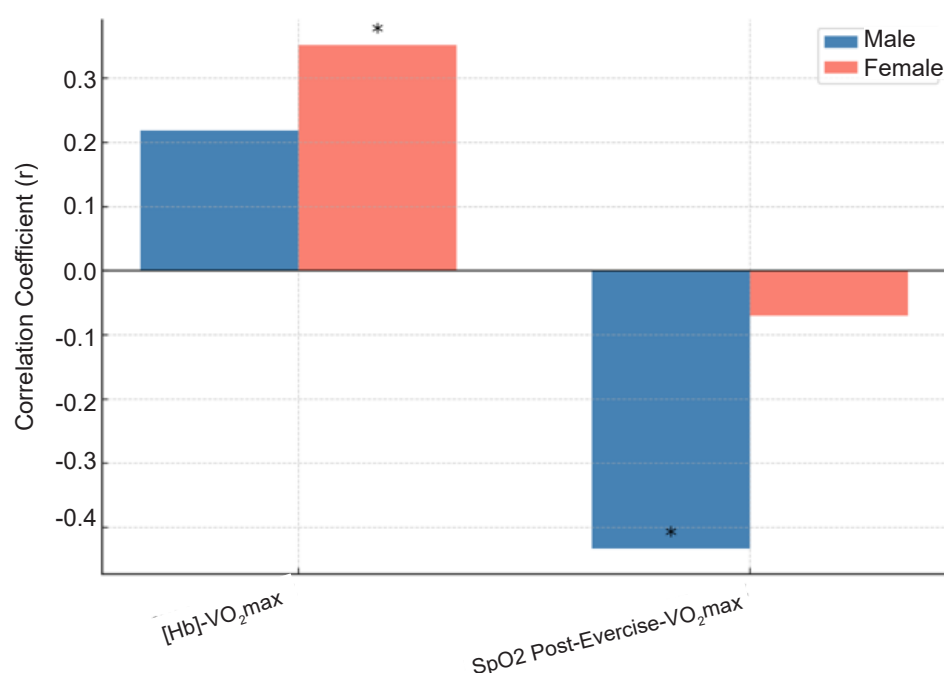


Figure 1 Correlation Between Hemoglobin Concentration [Hb] and Oxygen Saturation (SpO₂) Post-Exercise with VO₂max

(Table 2).

Correlation analysis further showed a weak 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 no 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, SpO₂ = 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, CaO_2 will decrease, 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 males 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 ($\text{CaO}_2 - \text{CvO}_2$). This difference is influenced by CaO_2 and Hb concentration, which determine oxygen transport.^{5,9} Oxygen transportation is influenced by CaO_2 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 be due to physiological differences between males and females. In general, females 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 CRF variation. Higher cardiac output increases oxygen delivery to muscles during exercise, while greater pulmonary capacity enhances 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.

References

1. Raghuveer G, Hartz J, Lubans DR, Takken T, Wiltz J, Mietus-Snyder M, et al. Cardiorespiratory fitness in youth- an important marker of health: a scientific statement from the American Heart Association. *Circulation*. 2020;142(7):e101-18. doi: 10.1161/CIR.0000000000000866.
2. Franklin BA, Wedig IJ, Sallis RE, Lavie CJ, Elmer SJ. Physical activity and cardiorespiratory fitness as modulators of health outcomes. *Mayo Clin Proc*. 2023;98(2):316-31. doi: 10.1016/j.mayocp.2022.09.011.
3. Goodrich J, Ryan B, Byrnes W. The influence of oxygen saturation on the relationship between hemoglobin mass and VO_2max . *Sports Med Int Open*. 2018;2(4):E98-104. doi: 10.1055/a-0655-7207.
4. Riebe D, Ehrman JK, Liguori G, Magal M. ACSM's guidelines for exercise testing and prescription. 10th ed. Philadelphia: Wolters Kluwer; 2018.
5. Dunn J-OC, Mythen MG, Grocott MP. Physiology of oxygen transport. *BJA Educ*. 2016;16(10):341-8. doi: 10.1093/bjaed/mkw012.
6. Hafen BB, Sharma S. Oxygen saturation. In: StatPearls [Internet]. Treasure Island (FL): StatPearls; 2022 [Cited 2024 May 5]. Available from: <https://www.ncbi.nlm.nih.gov/books/NBK525974/>.
7. Eroğlu H, Okyaz B, Türkçapar Ü. The effect of acute aerobical exercise on arterial blood oxygen saturation of athletes. *J Educ Train Stud* 2018;6(9a):74-9. doi: 10.11114/jets.v6i9a.3562.
8. Martín-Escudero P, Cabanas AM, Fuentes-Ferrer M, Galindo-Canales M. Oxygen saturation behavior by pulse oximetry in female athletes: breaking myths. *Biosensors (Basel)* 2021;11(10):391. doi: 10.3390/bios11100391.
9. Otto JM, Montgomery HE, Richards T. Haemoglobin concentration and mass as determinants of exercise performance and of surgical outcome. *Extrem Physiol Med* 2013;2(1):33. doi: 10.1186/2046-7648-2-33.
10. Tsai KZ, Lai SW, Hsieh CJ, Lin CS, Lin YP, Tsai SC, et al. Association between mild anemia and physical fitness in a military male cohort: the CHIEF study. *Sci Rep*. 2019;9(1):11165. doi: 10.1038/s41598-019-47625-3.
11. Gaston AF, Durand F, Roca E, Doucende G, Hapkova I, Subirats E. Exercise-induced hypoxaemia developed at sea-level influences responses to exercise at moderate altitude. *PLoS One*. 2016;11(9):e0161819. doi: 10.1371/journal.pone.0161819.
12. Warburton DER, Bredin SSD, Jamnik VK, Gledhill N. International launch of the PAR-Q+ AND ePARmed-X+ validation of the PAR-Q+ and ePARmed-X+. *Health & Fitness Journal of Canada*. 2011;4(2):38-46. doi: <https://doi.org/10.14288/hfjc.v4i2.151>.
13. World Health Organization. Global physical activity questionnaire analysis guide (GPAQ) [Internet]. 2021. [Cited 2024 May 24]. Available from: <https://www.who.int/publications/m/item/global-physical-activity-questionnaire>.
14. Ho CC, Lee PF, Xu S, Hung CT, Su YJ, Lin CF, et al. Associations between cigarette smoking status and health-related physical fitness performance in male Taiwanese adults. *Front Public Health*. 2022;10:880572. doi: 10.3389/fpubh.2022.880572.
15. Ministry of Education and Culture of the Republic of Indonesia. TKSI: Beep test [Internet]. [Cited 2024 May 9]; Available from: <https://tksi.kemdikbud.go.id/>
16. Karakochuk CD, Hess SY, Moorthy D, Namaste S, Parker ME, Rappaport AI, et al. Measurement and interpretation of hemoglobin concentration in clinical and field settings: a narrative review. *Ann N Y Acad Sci* 2019;1450(1):126-46. doi: 10.1111/nyas.14003.
17. Ashok P, Kharche JS, Raju R, Godbole G. Metabolic equivalent task assessment for physical activity in medical students. *Natl J Physiol Pharm Pharmacol*. 2017;7(3):236-239. doi: 10.5455/njppp.2017.7.0825604092016
18. Monyeki MA, Veldsman T, Coetzee B, Sparks M, Moss SJ, Pienaar C, Swanepoel M, et al. Relationships between iron status and selected physical fitness components of South African Adolescents: the PAHL-study. *Children (Basel)*. 2024;11(6):659. doi: 10.3390/children11060659.
19. Toivo K, Kannus P, Kokko S, Alanko L, Heinonen OJ, Korpelainen R, et al. Haemoglobin, iron status and lung function of adolescents participating in organised sports in the Finnish Health Promoting

- Sports Club Study. *BMJ Open Sport Exerc Med.* 2020;6(1):e000804. doi: 10.1136/bmjsem-2020-000804.
20. Rineau E, Gueguen N, Procaccio V, Geneviève F, Reynier P, Henrion D, Lasocki S. Iron deficiency without anemia decreases physical endurance and mitochondrial complex I activity of oxidative skeletal muscle in the mouse. *Nutrients* 2021;13(4):1056. doi: 10.3390/nu13041056.
 21. Kacker S, Saini R, Jangid N, Sorout J, Zenab A, Bishnoi P. Maximal aerobic capacity (VO₂max): a comprehensive overview. *Medical Science of Ukraine (MSU).* 2024;20(2):12–20. doi: 10.32345/2664-4738.2.2024.02.
 22. Littleton SW, Tulaimat A. The effects of obesity on lung volumes and oxygenation. *Respir Med.* 2017;124:15–20. doi: 10.1016/j.rmed.2017.01.004.
 23. Triwianti T, Cahyati WH, Rahayu SR. Factors affecting hemoglobin levels in prospective female donors in Semarang Blood Centre. *Public Health Perspectives Journal.* 2022;7(1):49–60. <https://journal.unnes.ac.id/nju/phpj/article/view/34038>.
 24. St Pierre SR, Peirlinck M, Kuhl E. Sex matters: a comprehensive comparison of female and male hearts. *Front Physiol* 2022;13:831179. doi: 10.3389/fphys.2022.831179.
 25. Besson T, Macchi R, Rossi J, Morio CYM, Kunimasa Y, Nicol C, et al. Sex differences in endurance running. *Sports Med.* 2022;52(6):1235–57. doi: 10.1007/s40279-022-01651-w.
 26. Parry-Williams G, Sharma S. The effects of endurance exercise on the heart: panacea or poison? *Nat Rev Cardiol* 2020;17(7):402–412. doi: 10.1038/s41569-020-0354-3.
 27. Hughes DC, Ellefsen S, Baar K. Adaptations to endurance and strength training. *Cold Spring Harb Perspect Med* 2018;8(6):a029769. doi: 10.1101/cshperspect.a029769.
 28. Billingsley HE, Buono MG Del, Canada JM, Kim Y, Damonte JI, Trankle CR, et al. Sarcopenic obesity is associated with reduced cardiorespiratory fitness compared with nonsarcopenic obesity in patients with heart failure with reduced ejection fraction. *Circ Heart Fail* 2022;15(10):e009518. doi: 10.1161/CIRCHEARTFAILURE.122.009518.