

Correlation of Hemoglobin Levels with VO₂ Max in Adolescent Basketball Athletes

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Abstract: Hemoglobin serves as a key determinant in oxygen transport to peripheral tissues, thereby directly influencing aerobic capacity, typically assessed via maximal oxygen uptake (VO₂ Max). In basketball, a sport characterized by a unique integration of aerobic and anaerobic demands, maintaining optimal hemoglobin concentration is critical for sustaining high-level performance. This study aimed to examine the association between hemoglobin concentration and VO₂ Max in competitive basketball athletes. A quantitative correlational design with a cross-sectional approach was employed. Twenty basketball athletes (12 male, 8 female), aged 19–23 years, were recruited through purposive sampling. Hemoglobin concentration was assessed using digital hematology analysis, while VO₂ Max was estimated through the Multistage Fitness Test. Data were analyzed using Pearson's product-moment correlation with a significance threshold of $p < 0.05$. The mean hemoglobin concentration was 14.73 ± 1.27 g/dL, and the mean VO₂ Max was 51.89 ± 5.32 mL·kg⁻¹·min⁻¹. Statistical analysis demonstrated an exceptionally strong positive correlation between hemoglobin concentration and VO₂ Max ($r = 0.993$, $p < 0.001$), indicating that higher hemoglobin levels are closely linked to enhanced aerobic capacity. These findings underscore the pivotal role of hemoglobin monitoring in athlete fitness evaluation and suggest its potential utility as a biomarker for targeted performance optimization strategies in basketball.

Keywords: basket, hemoglobin, VO₂ Max.

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INTRODUCTION

Aerobic physical capacity is a key component of athletic performance, particularly in basketball, which requires a combination of strength, speed, endurance, and cardiorespiratory resilience. One of the most widely used physiological parameters to assess aerobic capacity is maximal oxygen uptake (VO₂ Max). VO₂ Max reflects the body's maximal capacity to absorb, transport, and utilize oxygen during intense physical activity, thereby serving as a critical indicator in evaluating an athlete's cardiorespiratory fitness level (Rahmawati, et. al. 2021).

Among the various factors influencing VO₂ Max, hemoglobin concentration plays a pivotal role. Hemoglobin is a protein within red blood cells responsible for binding and transporting oxygen from the lungs to body tissues. Adequate hemoglobin concentration enables efficient oxygen transport, thereby supporting muscle performance during strenuous physical exercise. Previous studies have demonstrated that higher hemoglobin levels are positively correlated with increased VO₂ Max, primarily due to the enhanced oxygen-carrying capacity of the blood (Pradana, 2022).

Basketball athletes, as a population group with high metabolic demands and intensive training schedules, are at risk of experiencing fluctuations in hemoglobin levels due to training stress, environmental adaptation, and nutritional status. A decline in hemoglobin concentration may lead to reduced aerobic capacity and premature fatigue, ultimately affecting competitive performance. Therefore, monitoring hematological parameters, including hemoglobin, constitutes a crucial aspect of athlete development and performance management (Wati, 2021).

Although the relationship between hemoglobin and VO₂ Max has been extensively investigated in endurance athletes such as long-distance runners and cyclists, studies involving basketball players remain limited, particularly within local populations and individuals of productive age. Given the unique characteristics of basketball, which demands a simultaneous combination of aerobic and anaerobic activities, a deeper understanding of the role of hemoglobin in supporting aerobic capacity in basketball athletes is essential. Accordingly, this study aims to analyze the relationship between hemoglobin concentration and VO₂ Max in basketball players, thereby providing scientific contributions to the development of training programs and the monitoring of athletes' physical performance (Utami dan Amani, 2023).

METHOD

This study employed a quantitative approach with a correlational design, aiming to examine the relationship between hemoglobin levels and VO₂ Max values among basketball athletes. A cross-sectional design was applied, in which hemoglobin and VO₂ Max data were collected simultaneously at a single measurement point. The research was conducted at Old School Makassar over a four-week period, with sampling and measurements carried out on the Old School Arena basketball court. The study population consisted of all active basketball athletes affiliated with the Old School Makassar club, aged 16–20 years, in good health, and free from injury or illness during the research period. Sampling was performed using accidental sampling, with inclusion criteria including: (1) being an active athlete who had trained regularly for at least the past six months, (2) not consuming supplements or medications that could influence hemoglobin levels, and (3) willingness to comply with all research procedures. A total of 20 athletes (13 males and 7 females) were included as participants, based on availability and eligibility.

Hemoglobin levels were measured using a photometric method with a Digital Hemoglobin Analyzer. Capillary blood samples were obtained from the fingertip after proper sterilization. All measurements were conducted in the morning under light fasting conditions to minimize fluctuations in hemoglobin concentration due to food intake or dehydration. VO₂ Max was assessed using the validated Multistage Fitness Test (bleep test), a widely accepted field method for estimating aerobic capacity. During the test, athletes were instructed to run back and forth over a 20-meter distance in synchronization with beep signals, continuing until exhaustion or failure to maintain the required pace. VO₂ Max values were estimated based on the achieved level and total distance covered, using predictive equations standardized by the American College of Sports Medicine (ACSM). Data analysis was performed using SPSS version 25. Normality was first tested with the Shapiro–Wilk Test. For normally distributed data, the relationship between hemoglobin levels and VO₂ Max was analyzed using Pearson’s correlation, while Spearman’s correlation was applied if the data were not normally distributed. Statistical significance was set at $p < 0.05$.

RESULT

The measurement of hemoglobin levels in 20 basketball athletes demonstrated values ranging from 12.7 to 16.5 g/dL. Most male athletes presented hemoglobin concentrations within the range of 14.7–16.5 g/dL, with the highest value recorded in athlete A18 (16.5 g/dL) and the lowest in athlete A07 (14.7 g/dL). In contrast, female athletes generally exhibited lower hemoglobin levels, ranging between 12.7 and 13.6 g/dL, with the minimum value observed in athlete A12 (12.7 g/dL) and the maximum in athlete A04 (13.6 g/dL). Overall, these findings indicate that the majority of athletes fall within the normal hemoglobin reference range for their respective age and sex categories, with minor inter-individual variations likely influenced by physiological factors, hydration status, and physical fitness condition. The detailed measurement results are presented in the table below.

Table 1. Hemoglobin Concentration Measurements in Adolescent Basketball Athletes

No	Kode Atlet	Jenis Kelamin	Usia (tahun)	Hb (g/dL)
1	A01	Male	20	16.2
2	A02	Male	22	15.7
3	A03	Male	21	14.9
4	A04	Female	20	13.6
5	A05	Male	23	15.3
6	A06	Female	22	12.9
7	A07	Male	19	14.7
8	A08	Male	21	16.0
9	A09	Female	20	13.2
10	A10	Male	20	15.8
11	A11	Male	23	16.4
12	A12	Female	22	12.7

No	Kode Atlet	Jenis Kelamin	Usia (tahun)	Hb (g/dL)
13	A13	Male	21	15.1
14	A14	Female	19	13.5
15	A15	Male	20	14.8
16	A16	Male	22	15.6
17	A17	Female	21	13.4
18	A18	Male	20	16.5
19	A19	Female	23	13.0
20	A20	Male	21	15.2

The measurement of VO₂ Max in 20 basketball athletes revealed values ranging from 43.8 to 60.5 mL/kg/min. Male athletes generally exhibited higher VO₂ Max levels, within the range of 50.3–60.5 mL/kg/min, with the highest value observed in athlete A18 (60.5 mL/kg/min) and the lowest in athlete A07 (50.3 mL/kg/min). In contrast, female athletes demonstrated relatively lower values, ranging between 43.8 and 47.1 mL/kg/min, with the maximum recorded in athlete A04 (47.1 mL/kg/min) and the minimum in athlete A12 (43.8 mL/kg/min). Overall, these findings indicate that most athletes fall within the category of good to very good cardiorespiratory fitness, according to VO₂ Max reference standards based on age and sex. Nonetheless, individual variations were observed, which may be influenced by training levels, aerobic capacity, and physiological factors. The detailed measurement results are presented in the following table.

Tabel 2. VO₂ Max Measurement in Adolescent Basketball Athletes

No	Kode Atlet	Jenis Kelamin	Usia (tahun)	VO ₂ Max (mL/kg/ menit)
1	A01	Male	20	58.2
2	A02	Male	22	55.9
3	A03	Male	21	51.4
4	A04	Female	20	47.1
5	A05	Male	23	54.7
6	A06	Female	22	44.5
7	A07	Male	19	50.3
8	A08	Male	21	57.5
9	A09	Female	20	46.0
10	A10	Male	20	56.1
11	A11	Male	23	59.3
12	A12	Male	22	43.8
13	A13	Female	21	53.2
14	A14	Male	19	46.9
15	A15	Male	20	51.7

16	A16	Female	22	55.0
17	A17	Male	21	46.2
18	A18	Female	20	60.5
19	A19	Male	23	45.4
20	A20	Male	21	54.0

Descriptive analysis revealed that the mean hemoglobin concentration among the 20 basketball athletes was 14.73 g/dL with a standard deviation of 1.27 g/dL, indicating inter-individual variation in hemoglobin levels within the group. Meanwhile, the mean VO₂ Max was recorded at 51.89 mL/kg/min with a standard deviation of 5.32 mL/kg/min, reflecting differences in aerobic capacity across the measured athletes. The results of the multivariate test are presented in the following table.

Tabel 3. Multivariate Analysis Result

No.	Variabel	Mean	Std. Deviation	Minimum	Maximum
1	Hemoglobin	14.7250	1.26943	12.70	16.50
2	VO ₂ Max	51.8850	5.32010	43.80	60.50

The correlation analysis demonstrated a very strong and positive association between hemoglobin levels and VO₂ Max among basketball athletes, with a Pearson correlation coefficient of $r = 0.993$ and a significance level of $p = 0.000$ ($p < 0.01$). This indicates that higher hemoglobin concentrations are closely related to higher VO₂ Max values in athletes. The near-perfect strength of this relationship suggests that hemoglobin plays a critical role in supporting aerobic capacity in the athletes included in this study. The table below presents the correlation results between hemoglobin levels and VO₂ Max.

Tabel 4. Correlation Analysis Result

		Hemoglobin	VO2 Max
Hemoglobin	Pearson Correlation	1	.993**
	Sig. (2-tailed)		.000
	N	20	20
VO2_Max	Pearson Correlation	.993**	1
	Sig. (2-tailed)	.000	
	N	20	20

** . Correlation is significant at the 0.01 level (2-tailed).

DISCUSSION

The findings of this study revealed a very strong and significant relationship between hemoglobin levels and VO₂ Max in basketball athletes, with a Pearson correlation coefficient of $r = 0.993$ and a significance level of $p < 0.01$. This result indicates that an increase in hemoglobin concentration tends to be accompanied by an improvement in aerobic capacity, as reflected by higher VO₂ Max values. Physiologically, this relationship can be explained by the role of hemoglobin as the primary oxygen-transporting molecule in the blood. Hemoglobin within erythrocytes binds oxygen in the

lungs and delivers it to body tissues, including skeletal muscles actively engaged during intense physical activity. A higher hemoglobin concentration enhances the oxygen-carrying capacity of the blood, thereby improving the body's ability to generate energy aerobically (Webb, et. al. 2023).

These findings are consistent with the statement of Samodra, et. al. (2022), who emphasized that total hemoglobin mass (tHb-mass) is one of the primary determinants of VO_2 Max. In high-intensity sports such as basketball, adequate hemoglobin levels are crucial to support the increased oxygen demand during physical activity. Similarly, Wulandari, et. al. (2022) highlighted that an elevation in hemoglobin concentration can enhance VO_2 Max through an increase in arterial oxygen content, thereby improving oxygen availability in muscle tissues during training or competition. Basketball is characterized as an intermittent sport that combines both aerobic and anaerobic demands, where players frequently engage in short sprints, jumps, and rapid movements, interspersed with periods of moderate-intensity activity. Such conditions require a high cardiorespiratory capacity for athletes to sustain optimal performance throughout the game. VO_2 Max, which reflects the maximal capacity of the body to utilize oxygen, is therefore considered a key indicator of an athlete's aerobic fitness. Conversely, reduced hemoglobin levels impair oxygen transport capacity, limiting oxygen supply to skeletal muscles, leading to decreased endurance and earlier onset of fatigue.

Hemoglobin is the primary oxygen-transport protein in red blood cells, responsible for distributing oxygen from the lungs to body tissues, including skeletal muscles. During high-intensity physical activities such as basketball, the oxygen demand of muscles increases markedly to support aerobic energy metabolism. Aerobic capacity, as reflected in VO_2 Max, depends on the efficiency of the cardiovascular and respiratory systems in delivering oxygen, as well as the ability of muscle tissues to utilize it. From a metabolic perspective, higher hemoglobin levels enhance the blood's oxygen-carrying capacity. Oxygen bound to hemoglobin is subsequently released to muscle tissues according to metabolic demands, mediated through the hemoglobin–oxygen dissociation curve. Greater oxygen availability in tissues optimizes oxidative phosphorylation within the mitochondria, the primary pathway for aerobic ATP production. Adequate ATP supply is essential to sustain repeated muscle contractions with high efficiency, thereby supporting greater physical endurance and higher VO_2 Max (Hariyanti, et. al. 2020).

Furthermore, optimal hemoglobin levels facilitate faster metabolic recovery by reducing lactate accumulation. This occurs because sufficient oxygen availability allows pyruvate, the end product of glycolysis, to enter the Krebs cycle and electron transport chain, thereby promoting ATP production predominantly through aerobic rather than anaerobic pathways. Conversely, low hemoglobin levels restrict oxygen delivery, increase reliance on anaerobic metabolism, accelerate muscle fatigue, and reduce VO_2 Max. Theoretically, hemoglobin is not merely a determinant of oxygen transport capacity but also a key factor in optimizing aerobic energy metabolism within muscles. The positive relationship between hemoglobin and VO_2 Max observed in this study is consistent with the fundamental principles of exercise physiology, whereby adequate oxygen availability enhances aerobic metabolic efficiency, supports physical performance, and delays fatigue during high-intensity activity (Hardiansyah, et. al. 2024).

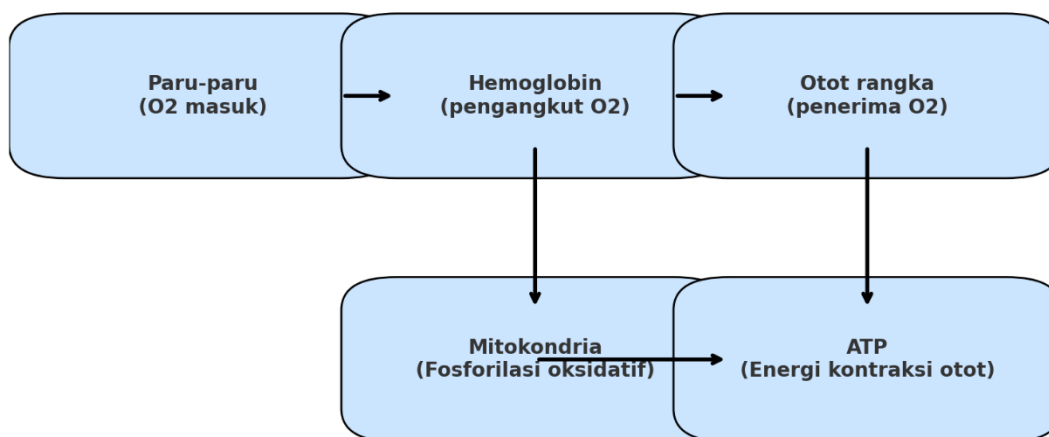


Figure 1. Schematic Representation of Oxygen Energy Metabolism Pathway

As illustrated in Figure 1, oxygen enters the body through the lungs, is transported by hemoglobin in the blood, and subsequently delivered to the skeletal muscles. Within the muscle cells, oxygen is directed to the mitochondria, where it undergoes oxidative phosphorylation to produce ATP, which serves as the primary energy source for muscle contraction.

Based on the findings of this study, the mean hemoglobin concentration among the athletes was 14.73 g/dL, ranging from 12.7 to 16.5 g/dL, which generally falls within the normal reference range according to clinical laboratory standards for athletes aged 18–25 years. Male athletes demonstrated higher hemoglobin levels compared to their female counterparts, consistent with the literature indicating that this difference is influenced by androgenic hormones (testosterone), which stimulate erythropoiesis. The average VO_2 Max was recorded at 51.89 mL/kg/min, with a range of 43.8–60.5 mL/kg/min, suggesting that most athletes possess aerobic capacity within the good to very good categories. The near-perfect correlation ($r > 0.99$) observed in this study indicates that hemoglobin concentration is one of the key physiological factors influencing VO_2 Max in basketball athletes. Nonetheless, it is important to recognize that VO_2 Max is not solely determined by hemoglobin, but also by other factors such as cardiac output, muscle capillary density, mitochondrial oxidative enzyme activity, hydration status, and training strategies. Despite these considerations, the findings reinforce the argument that monitoring hemoglobin concentration may serve as a valuable early indicator in evaluating the fitness level and competitive readiness of athletes (Risma, et. al. 2024).

This study also provides practical implications for coaches and sports medical practitioners. Routine monitoring of hemoglobin levels may be incorporated as part of periodic health assessments for athletes, particularly prior to competitions. If hemoglobin concentrations are found to be below the optimal threshold, timely interventions can be implemented, such as improving the intake of iron, vitamin B12, and folic acid through appropriate dietary adjustments or supplementation. This is critical because deficiencies in these nutrients can impair hemoglobin synthesis and ultimately reduce aerobic capacity. Moreover, proper training load management plays a crucial role in maintaining hemoglobin stability, as excessive training without adequate recovery may decrease hemoglobin levels through mechanisms such as hemolysis caused by physical impact or oxidative stress (Rahmawati, et. al. 2021).

The findings of this study are consistent with those of Tangkudung, et. al. (2024), who reported that in team-sport athletes, an increase of 1 g/dL in hemoglobin concentration significantly enhances VO₂ Max. Similarly, research by Pradana (2022) on soccer players demonstrated that higher hemoglobin levels were associated with improved long-distance running performance and greater total distance covered during matches. These observations indicate that the positive effect of hemoglobin on aerobic capacity is not limited to endurance sports but is also relevant to intermittent sports such as basketball. Nevertheless, several limitations of this study should be acknowledged, including the relatively small sample size (n = 20) and its cross-sectional design, which precludes establishing direct causality. Furthermore, external factors such as hydration status, psychological stress, and training conditions in the days preceding data collection may have influenced the measurements. Future studies with larger sample sizes, longitudinal designs, and tighter control of confounding variables are warranted to strengthen these findings.

Overall, this study confirms that hemoglobin is a key physiological indicator closely associated with VO₂ Max in basketball athletes. Maintaining hemoglobin concentrations at optimal levels may serve as an important strategy in athlete development programs to support maximal physical performance on the court. Regular physiological evaluations, including hemoglobin assessment and VO₂ Max measurement, could be integrated as essential components of athlete fitness and health management (Wati, 2021).

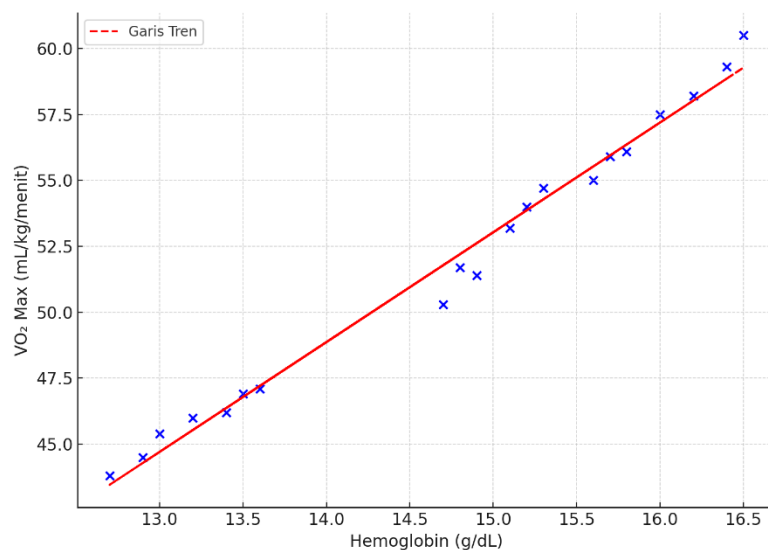


Figure 2. Scatter Plot of the Relationship Between Hemoglobin Levels and VO₂ Max

The scatter plot illustrates the relationship between hemoglobin levels and VO₂ Max in 20 basketball athletes. Each point on the graph represents an individual athlete, with the horizontal axis indicating hemoglobin concentration and the vertical axis representing the measured VO₂ Max value. The distribution pattern of the data points clearly demonstrates an upward slope from the lower left to the upper right, indicating a strong positive relationship between the two variables. Higher hemoglobin levels are associated with higher VO₂ Max values among the athletes. This positive correlation is further supported by the red dashed trend line, which represents the results of simple linear regression modeling. The steep positive slope of the line suggests that even small

changes in hemoglobin concentration may have a considerable impact on the improvement of VO₂ Max (Mancera-Soto, et. al. 2022).

Athletes with hemoglobin levels around 12.7–13.5 g/dL tended to have a VO₂ Max below 47 mL/kg/min, whereas those with hemoglobin levels above 16 g/dL achieved VO₂ Max values exceeding 58 mL/kg/min. The close clustering of data points around the trend line further indicates that the relationship between the two variables is consistent, with very few outliers. This finding is in line with the statistical test results showing a Pearson correlation coefficient of $r = 0.993$ ($p < 0.01$), indicating an almost perfect association. Physiologically, this relationship is logical since hemoglobin serves as the key molecule responsible for transporting oxygen from the lungs to skeletal muscle. Higher hemoglobin concentrations enhance the oxygen-carrying capacity of the blood, thereby improving the body's ability to generate aerobic energy. In basketball, which combines both aerobic and anaerobic activities, high aerobic capacity reflected by VO₂ Max is essential for sustaining performance throughout the game. Furthermore, the scatter plot not only provides a visual confirmation of the statistical analysis but also highlights the biological relevance of the association between hemoglobin and VO₂ Max. Such visualization may serve as an effective scientific communication tool to demonstrate to coaches, athletes, and sports health practitioners that monitoring hemoglobin concentration can be an important indicator for assessing fitness and performance in athletes (Rahmawati, et. al. 2021).

CONCLUSION

This study demonstrates a very strong and significant association between hemoglobin concentration and VO₂ Max in basketball athletes. Higher hemoglobin levels were associated with greater aerobic capacity, as reflected by the nearly perfect positive correlation ($r = 0.993$; $p < 0.001$). These findings underscore the critical role of hemoglobin in supporting the oxygen transport system, which directly influences athletes' aerobic performance. Therefore, monitoring hemoglobin concentration may serve as an important physiological indicator in fitness evaluation and as a basis for developing performance enhancement strategies, particularly in basketball, where both aerobic and anaerobic demands are substantial.

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