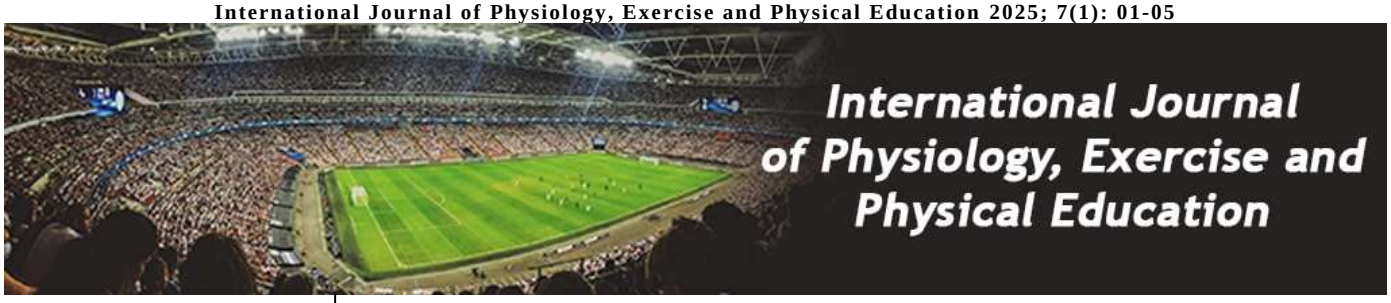

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Assessment of blood biochemical parameters in endurance swimming: Hematological biomarkers and their implications

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Abstract
This study aimed to evaluate the hematological biochemical parameters of young female athletes specializing in endurance sports, with a specific focus on their training and competitive conditions. Eight athletes, aged 12-14 years, were assessed over multiple testing periods between 2022 and 2024. Anthropometric data, including body weight (45-56.7 kg) and height (155-167.5 cm), were recorded alongside critical hematological parameters: white blood cell count (WBC), neutrophil count (NEUT#), lymphocyte count (LYMPH#), monocyte count (MONO#), eosinophil count (EO#), red blood cell count (RBC), hemoglobin (HGB), hematocrit (HCT), mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), platelet count (PLT), mean platelet volume (MPV), and plateletcrit (PCT). Key findings revealed mean values of WBC (6.33×10^9/L), RBC (4.76×10^{12}/L), HGB (13.64 g/dL), and HCT (40.54%), which fall within the normal physiological ranges for active adolescents, indicating adequate oxygen transport and recovery capacity. However, variations in PLT (mean: 376.88×10^3/μL, SD: 54.53) and MCHC (mean: 33.66 g/dL, SD: 0.85) highlight the impact of intense training loads on vascular and hematological function. Statistical distribution analysis across biomarkers showed normal variability, with elevated RBC and HGB values observed in older athletes, likely reflecting physiological adaptation to training. This research provides critical insights into the hematological profiles of youth athletes, establishing baseline data that can guide training optimization, recovery strategies, and early detection of overtraining or health risks. Further longitudinal studies are recommended to explore dynamic changes in these biomarkers over the course of athletic development.

Keywords: Blood biochemical, swimming, hematological biomarkers

Introduction
The assessment of blood biochemical parameters has become a cornerstone in sports science, particularly for evaluating the physiological status and performance capabilities of athletes. Among the diverse fields of sports, endurance disciplines such as swimming demand exceptional aerobic capacity, efficient oxygen transportation, and optimal metabolic regulation. The reliance on blood biochemical markers to monitor these physiological demands has grown exponentially due to their ability to provide quantitative insights into an athlete's health, recovery status, and adaptation to training.
Hematological Biomarkers in Endurance Sports: Key blood biomarkers, such as red blood cell count (RBC), hemoglobin concentration (HGB), hematocrit (HCT), and platelet count (PLT), play critical roles in determining oxygen-carrying capacity, vascular integrity, and recovery potential. These hematological indices are foundational in assessing an athlete's endurance capabilities, as they directly impact the efficiency of oxygen delivery and utilization, which are crucial for sustained physical performance.
Red Blood Cell Count (RBC): RBCs are integral to oxygen transport, as they contain hemoglobin, the protein responsible for binding and delivering oxygen to working muscles. High-intensity endurance activities like swimming can stimulate erythropoiesis, increasing RBC mass and enhancing oxygen delivery. However, excessive training can also lead to a decrease in RBC count due to hemolysis or iron deficiency, highlighting the need for careful monitoring (Schumacher *et al*., 2002) [5].

- **Hemoglobin (HGB):** HGB concentration is another critical parameter, as it directly correlates with the oxygen-carrying capacity of blood. Endurance training often results in an increase in HGB due to adaptive mechanisms. However, extreme exertion, particularly in swimmers exposed to hypoxic conditions, can lead to transient reductions in HGB, necessitating tailored recovery strategies (Pitsiladis *et al*., 2016) [4].
- **Hematocrit (HCT):** HCT, the proportion of red blood cells in blood volume, is a key indicator of oxygen transport efficiency. While a high HCT value can suggest improved endurance performance, excessively elevated levels may increase blood viscosity and the risk of thrombosis. Monitoring HCT changes during training and competition cycles is thus critical for balancing performance enhancement with health safety (Mujika & Padilla, 2001) [3].
- **Platelet Count (PLT):** Platelets are essential for vascular integrity and repair. Intensive swimming training, which imposes significant stress on the vascular system, may alter PLT levels. Maintaining optimal platelet function is vital for preventing vascular damage while ensuring effective recovery after training.

In addition to oxygen transport, hematological biomarkers provide insights into an athlete's immune status. The white blood cell count (WBC) is a primary marker of immune function. Prolonged and intensive training in swimming can suppress immune function, as evidenced by a reduction in WBC levels, increasing susceptibility to infections. Conversely, elevated WBC levels may indicate inflammation or overtraining syndrome, both of which can impair performance (Gleeson, 2002) [1]. Swimming presents unique physiological challenges that differentiate it from other endurance sports. These include prolonged exposure to water, thermoregulation issues, and frequent hypoxic conditions. These factors influence blood volume and plasma composition, which can lead to hemodilution and alter the interpretation of hematological indices. For example, the aquatic environment promotes a redistribution of blood flow, which may temporarily decrease RBC and HGB levels, masking true erythropoietic adaptations (Pendergast *et al*., 2011) [6].

Longitudinal analysis of hematological biomarkers provides valuable insights into an athlete's response to training and competition. Studies have shown that consistent monitoring of RBC mass, HGB, and HCT can predict endurance performance and identify early signs of overtraining or maladaptation. For instance, a sustained increase in RBC mass and HGB is strongly associated with enhanced performance, while deviations from baseline values often precede declines in fitness (Schumacher *et al*., 2002) [5].

Despite the advancements in understanding hematological biomarkers, gaps remain in their application to sport-specific contexts. Swimming, as an endurance discipline, requires tailored approaches to monitoring due to its environmental and physiological distinctiveness. Future research should focus on establishing sport-specific reference ranges for key biomarkers, considering factors such as gender, age, and training intensity. Additionally, integrating hematological data with other physiological and biomechanical parameters could provide a more comprehensive understanding of performance and recovery dynamics (Lippi *et al*., 2009) [2]. The assessment of blood biochemical parameters, particularly hematological biomarkers, is indispensable in endurance sports like swimming. These biomarkers provide critical insights into oxygen transport, immune function, and recovery status, all of which are pivotal for optimal performance. By addressing the unique challenges posed by swimming and advancing research on sport-specific adaptations, the field can enhance the precision of training methodologies and promote the long-term health of athletes.

Method

This cross-sectional study included eight female swimmers aged 12-14 years (mean: 13 years), with body weights ranging from 45 to 56.7 kg and heights from 155 to 167.5 cm. Blood samples were collected in the early morning, prior to any physical activity or food intake, to ensure accurate measurement of hematological parameters. Sampling was conducted at the beginning of centralized training periods as determined by the Sports Authority of Viet Nam. All analyses were performed at the Medic Medical Center using an automated hematology analyzer to measure key parameters, including WBC, NEUT#, LYMPH#, RBC, HGB, HCT, and PLT. The study followed ethical guidelines, with informed consent obtained from guardians, and aimed to establish baseline hematological profiles for young swimmers under controlled conditions.

Results

The table below summarizes the hematological parameters measured across all athletes:

RBC	HGB	HCT	PLT	WBC	NEUT#	LYMPH#	MONO#
8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
4.76	13.64	40.54	376.88	6.33	2.89	2.79	0.5
0.18	0.63	1.99	54.53	0.98	0.84	0.52	0.18
4.47	12.6	38.1	294.0	5.1	1.4	2.02	0.27
4.62	13.4	39.48	346.75	5.69	2.45	2.49	0.44
4.8	13.55	40.4	371.0	6.23	2.96	2.73	0.48
4.9	13.78	41.25	407.75	6.84	3.43	3.21	0.5
4.93	14.7	44.1	461.0	7.99	4.07	3.53	0.89

Visual Comparisons of Hematological Parameters

The bar chart below compares the RBC, HGB, HCT, PLT levels of anonymized athletes:

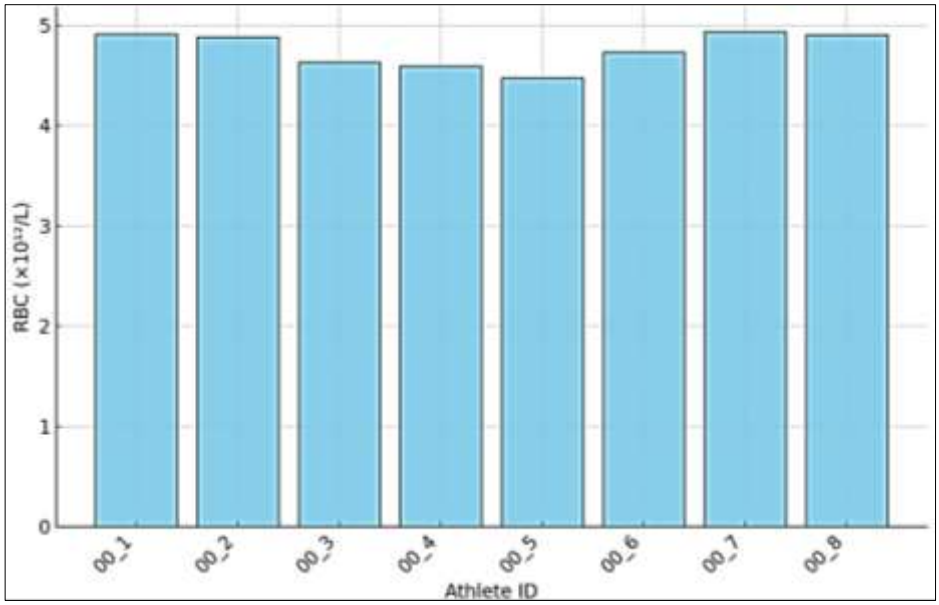

Fig 1: RBC levels among athletes (Anonymized by ID)

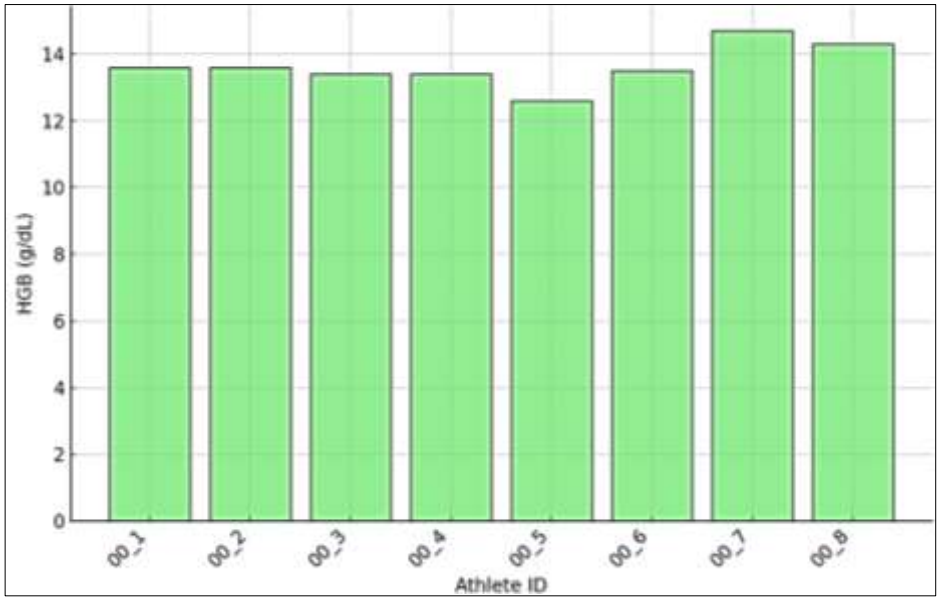

Fig 2: HGB levels among athletes (Anonymized by ID)

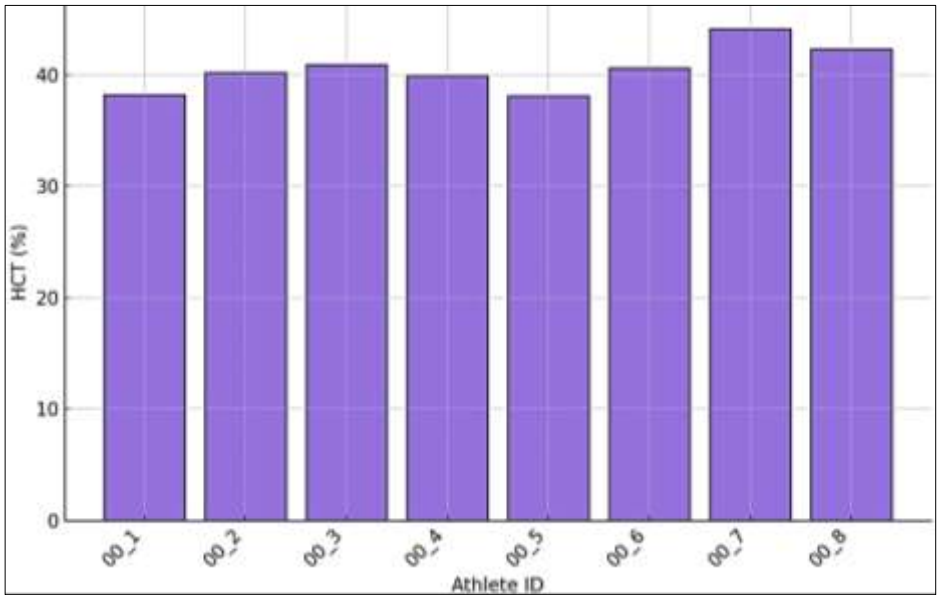

Fig 3: HCT levels among athletes (Anonymized by ID)

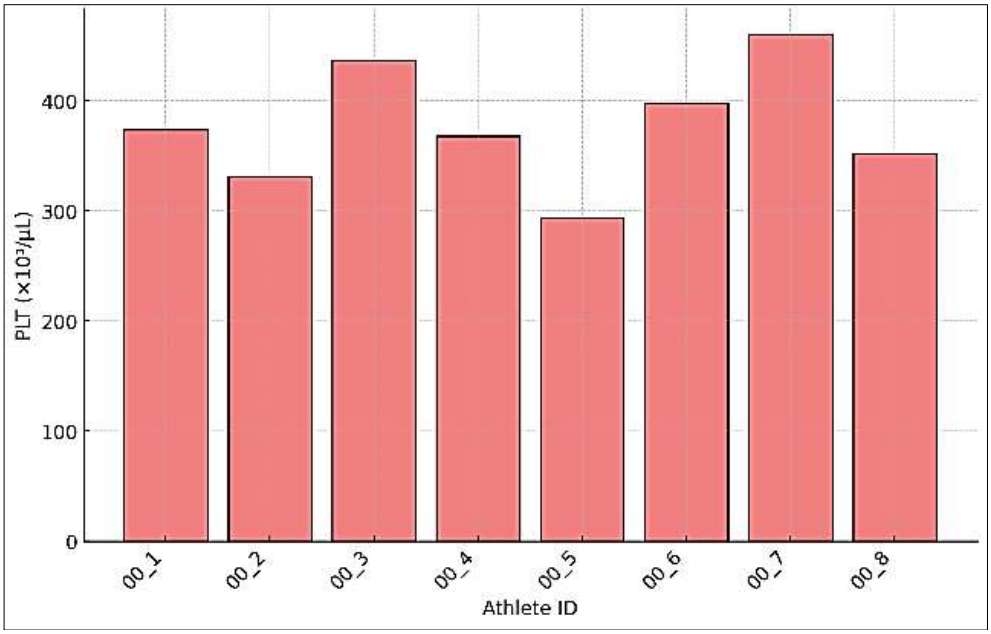

Fig 4: Platelet (PLT) levels among athletes (Anonymized by ID)

The visualizations and summary data above provide an in-depth comparison of key hematological indicators across anonymized athletes (using their IDs).

- **RBC Levels:** RBC (Red Blood Cell count) is a critical parameter for assessing oxygen-carrying capacity. The athletes showed RBC levels ranging from 4.47 × 10^{12}/L (ID: 00_5) to 4.91 × 10^{12}/L (ID: 00_1). These variations likely reflect differences in oxygen transport efficiency and erythropoietic adaptation. ID 00_1 demonstrated the highest RBC count, suggesting a strong capacity for endurance performance. Lower RBC values in ID 00_5 are consistent with lower HCT and HGB levels, potentially indicating nutritional deficiencies or inadequate training stimuli for erythropoiesis.
- **HGB Levels:** Hemoglobin (HGB), directly correlated with oxygen transport, HGB levels spanned from 12.6 g/dL (ID 00_5) to 14.7 g/dL (ID 00_7). Notably, ID 00_5 displayed the lowest HGB and RBC levels, potentially indicating a need for targeted training or nutritional intervention to enhance erythropoiesis. Athletes like ID 00_7 with higher HGB (14.7 g/dL) demonstrate superior oxygen transport efficiency, crucial for endurance sports.
- **Hematocrit (HCT) Levels:** The hematocrit (HCT) levels among the athletes range from 38.1% (ID 00_5) to 44.1% (ID 00_7), with the majority falling near the lower threshold of the typical endurance athlete range (39%-47%) as reported in the literature. HCT is a critical indicator of the proportion of red blood cells in the blood, directly influencing oxygen transport and endurance performance.
- **PLT Levels:** Platelet count (PLT), an indicator of recovery and vascular health, varied significantly, with the lowest at 294 × 10^3/μL (ID: 00_5) and the highest at 437 × 10^3/μL (ID: 00_3). These variations suggest differing vascular stress or recovery states among the athletes. Elevated PLT levels in ID 00_3 may signify vascular adaptations or recovery mechanisms. However, it should be monitored to avoid risks associated with excessive clotting.
- **WBC and Immune Indicators:** White blood cell (WBC) count ranged from 5.34 × 10^9/L (ID: 00_1) to 6.70 × 10^9/L (ID: 00_5), providing insights into immune function. ID 00_5 exhibited the highest WBC, potentially reflecting immune activation due to training stress. Additionally, NEUT# (neutrophils) and LYMPH# (lymphocytes) proportions varied, indicating differing immune responses and adaptation levels.
- **NEUT# (Neutrophils Count):** Mean of 2.89 × 10^9/L, with a range of 1.40 to 4.07 × 10^9/L, indicating variations in acute immune responses. LYMPH# (Lymphocyte Count): Mean of 2.79 × 10^9/L, ranging from 2.02 to 3.53 × 10^9/L, which represents adaptive immunity. MONO# (Monocyte Count): Mean of 0.50 × 10^9/L, with a standard deviation of 0.18. This is linked to tissue repair and recovery processes. EO# (Eosinophils Count): Low values (mean 0.11 × 10^9/L), reflecting minimal allergic or parasitic responses. BASO# (Basophils Count): Low and stable (mean 0.02 × 10^9/L), typical in healthy individuals.

Immune Function Proportions

- **NEUT% (Neutrophil Percentage):** Mean of 45.2%, indicating moderate acute immune activity. LYMPH% (Lymphocyte Percentage): Mean of 44.7%, consistent with adaptive immunity levels. MONO% (Monocyte Percentage): Mean of 7.85%, reflecting recovery processes. EO% (Eosinophil Percentage): Mean of 1.7%, suggesting no significant allergic or parasitic response. BASO% (Basophil Percentage): Mean of 0.39%, stable across athletes.
- **MCV (Mean Corpuscular Volume):** Mean value of 85.35 fL, ranging from 77.8 to 89.4 fL. Variations indicate differences in the size of red blood cells, with lower values suggesting potential microcytic anemia and higher values pointing to macrocytosis. MCH (Mean Corpuscular Hemoglobin): Mean value of 28.7 pg, ranging from 27.7 to 29.8 pg. These values reflect the average hemoglobin content in red blood cells, with slight variations across athletes. MCHC (Mean Corpuscular Hemoglobin Concentration): Mean value

of 33.66 g/dL, with a range of 32.8 to 35.6 g/dL, indicating the average hemoglobin concentration per red cell. MPV (Mean Platelet Volume): Mean value of 7.63 fL, ranging from 7.0 to 8.3 fL, reflecting platelet size and activation status. PCT (Plateletcrit): Mean value of 0.287%, with a range from 0.220% to 0.341%, providing a measure of the total platelet mass in the blood.

Discussion

The hematological analysis of young swimmers reveals critical insights for optimizing training strategies and recovery protocols. Athletes with low RBC and HGB levels, such as ID 00_5 (RBC: 4.47 × 10^{12}/L, HGB: 12.6 g/dL), may benefit from iron supplementation, hypoxic training, and structured recovery to enhance erythropoiesis and oxygen transport capacity. Elevated WBC and neutrophil counts in athletes like ID 00_5 and ID 00_6 suggest immune activation or inflammation, necessitating intensity modulation, anti-inflammatory diets, and infection monitoring to prevent overtraining syndrome. High platelet counts observed in ID 00_3 (437 × 10^{3}/μL) point to vascular adaptations that require optimized hydration, vascular recovery techniques, and thrombotic risk screening. Additionally, low hematocrit levels, as seen in ID 00_5 (38.1%), may indicate plasma volume shifts or insufficient hematological adaptations, which can be mitigated through a balanced approach of strength and endurance training. Across all athletes, personalized nutritional strategies-including sufficient iron, vitamin B12, and protein intake-alongside periodized training and optimal sleep hygiene, are essential to stabilize hematological parameters and enhance overall performance. These tailored adjustments, informed by regular monitoring, provide a foundation for effective athlete development while minimizing health risks.

Athletes with stable hematological profiles can benefit from high-intensity interval training (HIIT) to improve cardiovascular efficiency and strength-endurance integration to enhance oxygen utilization. General recommendations include longitudinal monitoring of hematological parameters, custom periodization of training to balance performance and recovery, and educating athletes and coaches on the significance of hematological data to support informed decision-making. By aligning training strategies with individual hematological needs, athletes can optimize performance, minimize injury risks, and sustain long-term development.

Conclusion

The hematological data provided highlights individual variations among athletes, reflecting their unique physiological states and training adaptations. Most parameters fall within acceptable ranges for young swimmers, though specific cases, such as low HCT and elevated MPV or WBC, indicate areas for targeted nutritional support, recovery optimization, and stress management. Overall, regular monitoring and tailored interventions are essential to enhance performance, support recovery, and ensure long-term athletic development.

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