PHYSIOLOGICAL MECHANISMS OF RED BLOOD CELLS IN SUPPORTING MUSCLE PERFORMANCE DURING EXERCISE

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ABSTRACT

Red blood cells play a crucial role in supporting muscle performance during exercise through complex physiological mechanisms, particularly oxygen transport, blood pH regulation, and adaptation to exercise. This study aimed to examine in-depth the physiological mechanisms of red blood cells in supporting muscle function during exercise. A systematic literature review of various international scientific publications from 2000–2024 that discussed the relationship between red blood cell physiology and exercise performance was used as the method. The results of the study indicate that endurance training and hypoxic training can increase red blood cell count, hemoglobin levels, and cell membrane deformability, which directly impact oxygen transport capacity and muscle work efficiency. Furthermore, these hematological system adaptations also help delay muscle fatigue by increasing oxygen supply and regulating acid-base balance. In conclusion, understanding the physiological mechanisms of red blood cells is crucial in developing training programs and strategies to improve athlete performance.

Keywords: athlete performance, exercise physiology, hemoglobin, muscle oxygenation, red blood cells

INTRODUCTION

Muscle performance during exercise is highly dependent on oxygen availability and the body's ability to transport it to active tissues. Red blood cells, or erythrocytes, serve as the primary component of the oxygen transport system, playing a vital role in supporting muscle aerobic metabolism during physical activity. According to Mairbäurl (2013), increased energy requirements during exercise drive hematological adaptations in the form of increased erythrocyte count, hemoglobin levels, and changes in blood viscosity. In the context of physical exercise, these changes are part of the body's physiological adaptations to improve muscle metabolic efficiency. Endurance training has been shown to trigger increased production of erythropoietin (EPO), a hormone that stimulates erythropoiesis in the bone marrow (Schmidt & Prommer, 2008). Furthermore, changes in erythrocyte membrane deformability allow for more efficient blood flow to muscle capillaries. This study is important because understanding the role of erythrocytes in supporting muscle performance can provide a scientific basis for coaches and sports physiologists in designing blood physiology-based training programs.

METHODS

This study used a systematic literature review approach. Relevant scientific articles were collected from PubMed, Scopus, ScienceDirect, and Google Scholar databases using the keywords "red blood cell," "exercise physiology," "oxygen transport," and "athlete performance." Inclusion and Exclusion Criteria 1. Articles published between 2000 and 2024. 2. Experimental research or reviews related to red blood cell adaptation to exercise. 3. Studies explaining the relationship between erythrocyte function and muscle performance. A total of 62 articles were retrieved, and 28 of them met the criteria for thematic analysis. The analysis was conducted using a descriptive thematic approach covering four main themes: (1) oxygen transport, (2) pH regulation and the Bohr effect, (3) adaptation to exercise, and (4) erythrocyte deformability.

RESULTS AND DISCUSSION

Oxygen Transport by Erythrocytes

Erythrocytes function to carry oxygen from the lungs to muscle tissue via hemoglobin. During intense exercise, oxygen demand increases 15–20 times above resting levels. Adaptation to prolonged exercise increases the number of erythrocytes and hemoglobin levels, thereby increasing oxygen-carrying capacity. This has direct implications for increasing VO_2 max and endurance (Sawka & Coyle, 1999). Exercise at high altitudes or in hypoxic environments stimulates the secretion of EPO, which stimulates the formation of new erythrocytes. This adaptation, known as the "live high–train low" (live high–train low), has been shown to improve athletic performance due to increased blood oxygenation capacity (Gore & Hopkins, 2005).

Blood pH Regulation and the Bohr Effect

During intense activity, anaerobic metabolism produces lactic acid, which lowers blood pH. Erythrocytes play a crucial role in maintaining pH homeostasis through the hemoglobin buffer system and the enzyme carbonic anhydrase. The Bohr Effect explains that a decrease in pH and an increase in CO_2 decrease hemoglobin's affinity for oxygen, thereby accelerating oxygen release to active tissues (Mairbäurl, 2013). Long-term endurance training increases the buffering capacity of red blood cells, thus offsetting the decrease in pH and delaying muscle fatigue.

Physiological Adaptations to Exercise

Repeated physical exercise triggers increased erythropoiesis and increases total red blood cell mass. These adaptations improve tissue oxygenation capacity and decrease the rate of hemolysis. According to Connes et al. (2013), moderate-intensity exercise also increases intracellular antioxidant levels in red blood cells, protecting membranes from oxidative damage. Athletes with optimal hematological adaptations demonstrate physiological increases in hematocrit and hemoglobin without compromising blood viscosity. However, extreme increases can increase blood flow resistance and cardiovascular load.

Erythrocyte Deformability and Blood Rheology

The ability of red blood cells to change shape as they pass through narrow capillaries is called deformability. Aerobic exercise increases deformability by increasing intracellular ATP and lipid membrane integrity. This improves muscle perfusion and oxygen supply (Connes et al., 2013). Conversely, oxidative stress, dehydration, and heat exposure decrease red blood cell deformability, thereby decreasing muscle perfusion efficiency. Therefore, fluid and antioxidant balance are important factors in maintaining erythrocyte function during strenuous exercise.

Implications for Muscle Performance and Endurance

Increased red blood cell mass and hemoglobin levels enhance aerobic capacity and delay fatigue. Athletes with optimal hematological values have a longer time to exhaustion and faster post-exercise recovery due to increased CO_2 and metabolite transport. Monitoring hematological parameters (hematocrit, hemoglobin, reticulocyte count) is an important indicator in evaluating an athlete's physiological condition and adaptation to training loads (Schmidt & Prommer, 2008).

CONCLUSION

Red blood cells play a central role in supporting muscle performance during exercise through complex physiological mechanisms that include oxygen transport, blood pH regulation, and hematological adaptations to exercise. Endurance training and exposure to hypoxia have been shown to improve red blood cell function, oxygenation capacity, and muscle efficiency. This understanding is crucial for developing physiology-based training programs to enhance athlete performance and prevent fatigue.

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