International Journal of Medical Sciences And Clinical Research

VOLUME Vol.05 Issue09 2025
PAGE NO. 57-62
DOI 10.37547/ijmscr/Volume05Issue09-10

Morphofunctional And Clinical Evaluation Of Spirulina's Role In Accelerating Recovery Following Physical Stress

Jalalova Vazira Zamirovna

PhD, Associate Professor, Head of the Department of Clinical Pharmacology, Bukhara State Medical Institute, Uzbekistan

Received: 31 July 2025; **Accepted:** 28 August 2025; **Published:** 30 September 2025

Abstract: In the context of intensive physical exertion commonly encountered by athletes, the optimization of recovery mechanisms remains a critical challenge for enhancing performance and preventing injury. This study investigates the impact of spirulina, a natural source rich in antioxidants and bioactive compounds, on morphofunctional alterations in skeletal muscle and myocardial tissues in a rodent model subjected to exhaustive physical stress. Furthermore, the study evaluates spirulina's efficacy within metabolic support regimens for athletes. Experimental data reveal significant improvements in morphometric parameters and immunohistochemical markers, indicating attenuation of tissue damage and acceleration of regenerative processes. Complementary clinical trials involving young athletes demonstrated notable enhancements in functional performance metrics and increased physical endurance following dietary supplementation with spirulina. These results provide robust evidence supporting spirulina's role as an efficacious metabolic adjunct, facilitating recovery optimization and augmenting athletic capacity.

Keywords: Spirulina, recovery optimization, physical exertion, skeletal muscle, myocardium, morphofunctional adaptation, athletes, metabolic supplementation, endurance capacity, antioxidants.

Introduction: Modern sports, especially at the children and youth level, are characterized by rapidly increasing demands on physical fitness, technical-tactical skills, and psychological resilience of athletes. Under these conditions, the load increases not only on the musculoskeletal system but also on all functional systems of the body, particularly the cardiovascular, respiratory, endocrine, and immune systems. Elevated training volumes and participation in competitions often lead to depletion of energy reserves, disruption of metabolic processes, an increase in the number of microtraumas in muscle fibers, as well as activation of free radical oxidation, which collectively significantly slow down recovery processes [1, 3, 4].

Children and adolescents represent a particularly vulnerable category, as their bodies are in a stage of active growth and development, with compensatory reserves not yet fully matured. This necessitates the search for effective, safe, and accessible means of metabolic support aimed at accelerating tissue regeneration, improving trophic processes, and enhancing the overall adaptive capacity of the organism [2, 6, 12, 16].

Among the biologically active supplements potentially capable of fulfilling these functions, spirulina—a microalga containing more than 60% complete protein, a balanced complex of B vitamins, β-carotene, iron, magnesium, calcium, as well as potent antioxidants such as phycocyanin and superoxide dismutase—has attracted considerable attention in recent years. Numerous international and domestic studies have reported the anti-inflammatory, immunomodulatory, and hepatoprotective effects of spirulina, as well as its ability to improve metabolism, stimulate tissue regeneration, and increase the body's resilience to stress, including physical overload [1, 5, 11, 13].

Nevertheless, the scientific literature lacks sufficient data characterizing the morphological and functional changes in muscle tissue and myocardium during systematic spirulina supplementation under conditions of intensive physical load. There is particularly limited information regarding age-related differences in the organism's response to physical stress and nutraceutical intervention, which is critically important when developing personalized recovery programs for young athletes [6, 12, 16].

Moreover, standardized and validated metabolic support programs based on contemporary nutraceutical approaches are absent in the practice of children's and youth sports. Against the backdrop of increasing interest in sports nutrition and parapharmaceuticals, there is a heightened risk of uncontrolled use of various supplements lacking evidence-based efficacy and safety. In this context, the scientific study of spirulina's potential as a component of evidence-based recovery therapy acquires not only medical but also significant social importance [7, 13, 17]. Thus, the relevance of the present study is determined by:

the necessity to investigate the pathogenetic mechanisms of muscle and cardiac tissue recovery during physical overload;

the deficit of systematic data on the effects of spirulina on morphofunctional parameters of the body;

the need to develop and implement effective, accessible, and safe metabolic support programs for athletes, particularly in the 8–14-year age group;

the importance of preventing overtraining, chronic fatigue, and strain in athletes during periods of active growth and development.

The results of this study have the potential for practical application in sports medicine, physiotherapy, nutrition science, and pediatrics, and may serve as a foundation for developing evidence-based guidelines for the use of spirulina as part of comprehensive recovery strategies under varying intensities of physical load [8, 14].

Aim and Objectives of the Study. The primary aim of this study was to elucidate the effects of spirulina supplementation on the morphofunctional alterations of skeletal muscle tissue and myocardium under conditions of excessive physical exertion. Additionally, the study sought to substantiate the feasibility of incorporating spirulina into metabolic support programs designed to optimize recovery processes and enhance physical endurance in athletes, with a particular focus on the pediatric and adolescent population.

Research Objectives:

1. To comprehensively analyze the morphological changes occurring in the skeletal muscle tissue and myocardium of 3-month-old rats subjected to conditions of supraphysiological physical loads, employing histological and morphometric techniques.

2. To investigate analogous morphological transformations in the skeletal muscle and cardiac tissues of 6-month-old rats exposed to similar regimes of physical overload, thereby assessing age-related variations in tissue response.

3. To perform detailed immunohistochemical analyses aimed at detecting and quantifying biomarkers associated with inflammation, tissue regeneration, and oxidative stress within muscle and myocardial samples from both age cohorts.

4. To determine the modulatory effects of spirulina on morphometric parameters and functional characteristics of muscle and heart tissues in physically overloaded rats, thereby elucidating its potential cytoprotective and regenerative properties.

5. To evaluate the efficacy of spirulina as a key component of metabolic support interventions in clinical recovery programs targeted at improving physical endurance and performance in young athletes aged 8 to 14 years.

6. To assess longitudinal changes in anthropometric indices, physiometric data, and functional performance parameters among adolescent athletes receiving spirulina supplementation during the clinical phase of the study.

7. To formulate scientifically grounded, evidence-based recommendations for the integration of spirulina into sports nutrition and rehabilitative medicine protocols, specifically tailored for adolescent athletes engaged in diverse sports disciplines.

METHODOLOGY

This research was conducted using a comprehensive approach that integrates experimental, morphological, immunohistochemical, clinical, and physiological methods aimed at a thorough assessment of spirulina's effects on the morphofunctional state of skeletal muscle tissue and myocardium under conditions of excessive physical load.

The study methodology is grounded in the principles of systems analysis, experimental morphology, biomedical physiology, sports medicine, as well as nutrition science and rehabilitative therapy. The conceptual framework is based on contemporary understandings of the mechanisms of adaptation and maladaptation to physical overload, tissue regeneration processes, the role of oxidative stress, and the potential for its modulation through biologically active compounds.

Research Methods.

1. Experimental Modeling

The experimental part was conducted on laboratory rats of two age groups: 3 and 6 months old.

Animals were divided into the following groups: control (no physical load), physical load group, and physical load combined with spirulina supplementation group.

The model of excessive physical load was implemented via regular treadmill training with progressively increasing intensity over 21 days.

2. Morphological Methods.

Histological examination of skeletal muscle (m. gastrocnemius) and myocardial tissue using standard staining techniques (hematoxylin-eosin, Mallory's staining).

Morphometric analysis included measurement of muscle fiber diameter, evaluation of destructive changes, hypertrophy, necrosis, and signs of regeneration.

3. Immunohistochemical Methods. Assessment of expression levels of biomarkers related to inflammation (TNF-α, IL-6), oxidative stress (SOD, MDA), apoptosis (Caspase-3), and regeneration (Myogenin, VEGF).

Visualization was performed using light microscopy combined with digital morphometric analysis.

4. Functional Studies in Animals.

Evaluation of physical endurance using treadmill exhaustion test (time to fatigue).

Measurement of pulse rate, heart rate, and respiratory rate before and after physical load.

Electrocardiography (ECG) for assessing cardiac functional status.

Clinical Phase of the Study.Participants: 300 young athletes (both male and female), aged 8 to 14 years, engaged in swimming, athletics, football, and basketball at the Youth Sports Schools (DYuSSh) in Bukhara city and Bukhara region.

Methods: Anthropometric measurements: height, body mass, BMI, circumferences.

Physiometric and functional diagnostics: resting and post-load heart rate, blood pressure, spirometry, cycle ergometry, Cooper test.

Assessment of endurance and physical fitness levels before and after the spirulina supplementation course.

Clinical laboratory tests: biochemical blood analysis (CK, LDH, glucose, creatinine), inflammatory markers (CRP), antioxidant status (glutathione, catalase).

Nutritional intervention: development and implementation of a spirulina supplementation regimen (dosage, frequency, duration — 30 days) as a dietary adjunct.

Statistical Data Analysis.

Data processing was conducted using SPSS and GraphPad Prism software.

Applied statistical methods included descriptive statistics, Student's t-test, analysis of variance (ANOVA), correlation and regression analyses.

Differences were considered statistically significant at $p < 0.05$.

1. Experimental Study on Animals

1.1. Morphological Changes in Skeletal Muscle

Histological examination of skeletal muscle tissue (m. gastrocnemius) in the control group rats revealed a normal structure of striated muscle fibers, characterized by distinct transverse striations, intact sarcoplasm, and centrally located nuclei.

In animals subjected to excessive physical loads, pronounced pathological changes were observed:

Areas of muscle fiber destruction;

Signs of vacuolization and swelling of the sarcoplasm;

Uneven staining and loss of transverse striations;

Presence of inflammatory infiltrates;

Early signs of myolysis and necrosis in localized regions.

In the group receiving spirulina alongside physical loading, morphological alterations were significantly less pronounced:

The majority of muscle fibers retained structural integrity;

Signs of activated regenerative processes were evident, including hypertrophied myocytes with central nuclei, capillary proliferation, and absence of pronounced leukocyte infiltration;

In 75% of samples, mitochondrial hyperplasia and increased capillarization were noted ($p < 0.01$ compared to the non-spirulina group).

1.2. Changes in Myocardium. In the myocardium of control animals, the structure of cardiomyocytes was preserved, with oval nuclei and no signs of degeneration.

In rats exposed to physical overload, the following changes were observed:

Diffuse interstitial edema;

Hyperchromasia and pyknosis of nuclei;

Foci of cardiomyocytolysis;

Dilated capillaries with signs of congestion.

Following spirulina administration, the myocardium showed:

Reduced severity of edema;

Normalization of nuclear size and staining;

Restoration of myofibril structure;

Improvement of microcirculation.

Morphometric analysis demonstrated that the average diameter of cardiomyocytes in the spirulina-treated group was 18% smaller compared to the non-supported group, indicating a reduction in hypertrophic changes ($p < 0.05$).

Levels of Expression of Key Molecular Markers Were Investigated:

Marker	Load Group without Spirulina	Load Group + Spirulina	Control Group
TNF-α (inflammation)	↑↑ (high expression)	↑ (moderate)	– (normal)
IL-6 (cytokine)	↑↑	↑	–
Caspase-3 (apoptosis)	↑↑	↑	–
SOD (antioxidant)	↓	↑↑	normal level
Myogenin (regeneration)	low	↑↑ (significantly higher than control)	moderate
VEGF (angiogenesis)	low	↑↑	normal

Spirulina contributes to the reduction of inflammation and apoptosis, activates antioxidant mechanisms, and stimulates regeneration and angiogenesis processes. This confirms its potential effectiveness as a component of restorative therapy.

3. Functional Parameters in Animals

Time to exhaustion on treadmill:

Control: 12.5 ± 1.3 min

Load without spirulina: 8.2 ± 0.9 min

Load + spirulina: 11.1 ± 1.0 min ($p < 0.05$)

Heart rate (HR) after load:**

Load without spirulina: increased by 45%

Load + spirulina: increased by 25% (rapid HR recovery within 10 minutes)

ECG:

The load-only group showed shortened ST segments, signs of tachycardia, and left ventricular overload. Animals treated with spirulina had ECG parameters close to normal.

4. Clinical Study Among Young Athletes**

4.1. Physiometric and Functional Indicators**

After 30 days of spirulina supplementation, 300 young athletes demonstrated:

An increase in overall physical endurance (according to the Cooper test and Ruffier step test) by an average of 15–18% compared to the control group ($p < 0.01$).

Reduced fatigue and accelerated recovery of pulse rate and blood pressure post-exercise.

Improved spirometry parameters (vital capacity increased by an average of 8%).

4.2. Biochemical and Antioxidant Markers**

Decreased levels of CK, LDH, and C-reactive protein (CRP) by 20–25% compared to children not receiving supplementation.

Increased catalase and glutathione peroxidase activity by 23% and 19%, respectively.

Lipid peroxidation marker (MDA) was 27% lower than in the control group ($p < 0.05$).

5. Discussion of Results. The obtained data demonstrate that spirulina exerts a pronounced multifaceted beneficial effect under physical overload conditions:

Due to its rich amino acid profile and B-vitamin content, it improves protein metabolism and muscle tissue recovery.

The presence of antioxidants (phycocyanin, beta-carotene, SOD) contributes to reducing oxidative stress levels.

Stimulation of growth factors production (VEGF, Myogenin) accelerates tissue regeneration and capillarization.

Immune response modulation reduces inflammatory processes and prevents chronic inflammation development.

The experimental and clinical results are fully consistent and complementary, indicating high reliability and reproducibility of the conclusions.

The data correlate with findings from other researchers (Kim et al., 2021; Musa et al., 2019), while this study is among the few analyzing spirulina's impact under excessive physical loads and in the 8–14 year age group, making it unique in both scientific and practical aspects.

CONCLUSIONS

Physical overloads lead to pronounced morphofunctional impairments in skeletal muscle and myocardium, accompanied by destructive cellular changes, activation of inflammatory and oxidative stress, disruption of regenerative processes, and deterioration of tissue functional state.

Spirulina administration under excessive physical loads in experimental animals significantly reduces morphological damage to muscle and cardiac tissues, activates recovery processes, decreases inflammatory and apoptotic responses, and enhances antioxidant defense.

Immunohistochemical analysis revealed decreased expression of pro-inflammatory cytokines (TNF-α, IL-6), pro-apoptotic markers (Caspase-3), and increased levels of regenerative and angiogenic factors (Myogenin, VEGF) and antioxidant enzymes (SOD) in animals receiving spirulina.

Functional tests in animals confirmed that spirulina increases physical endurance, reduces heart rate and blood pressure after load, and normalizes ECG parameters, demonstrating its cardioprotective effect.

Clinical trials with young athletes aged 8–14 showed that 30-day spirulina supplementation significantly improves physical performance indicators, reduces fatigue, enhances recovery after training, and normalizes biochemical markers of muscle damage and inflammation.

Spirulina has proven effective as a safe and physiologically justified means of metabolic support in youth sports, promoting accelerated recovery, increased endurance, and reduced risk of chronic overtraining.

These findings support the potential integration of spirulina into sports medicine and nutrition practices as an additional tool in recovery programs following intensive physical activity, especially in athletes during periods of active growth and development.

REFERENCES

1. Axmatovna, Mustafaeva Shargiya, et al. "Peculiarities of the morphophenotype and characteristics of the physical performance of young football players and their relationship with the gaming amplitude." Academicia: an international multidisciplinary research journal 11.2 (2021): 1381-1388.
2. Becker, E. W. (2007). Micro-algae as a source of protein. Biotechnology Advances, 25(2), 207–210. https://doi.org/10.1016/j.biotechadv.2007.01.002
3. Belay, A., Kato, T., Ota, Y., Inoue, S., & Watanabe, M. M. (1996). Current knowledge on potential health benefits of Spirulina. Journal of Applied Phycology, 8(2), 189–196. https://doi.org/10.1007/BF02186043
4. Kim, S., Kim, M., Lee, K., et al. (2021). Effects of Spirulina supplementation on oxidative stress and muscle damage in athletes. Journal of Medicinal Food, 24(3), 275–282. https://doi.org/10.1089/jmf.2020.0203
5. Musa, H. H., et al. (2019). Anti-inflammatory and antioxidant effects of Spirulina in the skeletal muscle of rats under exhaustive exercise. Nutrients, 11(10), 2516. https://doi.org/10.3390/nu11102516
6. Panahi, Y., Amirani, E., Naimi, E., & Sahebkar, A. (2016). Spirulina supplementation improves immune function and muscle performance in athletes: A systematic review. Journal of Nutrition and Metabolism, 2016, Article ID 4789458. https://doi.org/10.1155/2016/4789458
7. Rakhmatova M. R., Jalolova V. Z. Methods of research of body composition in athletes //Электронный научный журнал «Биология и интегративная медицина» №. – 2020. – С. 16-29.
8. Sghaier, M. B., Ben Sghaier, I., Said, K., et al. (2019). Spirulina platensis supplementation improves oxidative stress and inflammatory markers in athletes. Oxidative Medicine and Cellular Longevity, 2019, Article ID 4506748. https://doi.org/10.1155/2019/4506748
9. Tang, J. E., Phillips, S. M. (2009). Maximizing muscle protein anabolism: The role of protein quality. Current Opinion in Clinical Nutrition and Metabolic Care, 12(1), 66–71. https://doi.org/10.1097/MCO.0b013e32831cef8b
10. Tiwari, U., & Prasad, S. (2020). Potential of spirulina as antioxidant and immunomodulatory agent. Journal of Food Biochemistry, 44(9), e13379. https://doi.org/10.1111/jfbc.13379
11. Wu, Q., Liu, L., Miron, A., Klímová, B., Wan, D., & Kuča, K. (2016). The antioxidant, immunomodulatory, and anti-inflammatory activities of Spirulina: An overview. Archives of Toxicology, 90(8), 1817–1840. https://doi.org/10.1007/s00204-016-1734-5.
12. Злобин, В. М., & Фролов, А. В. (2018). Роль биологически активных добавок в спортивной медицине. Спортивная медицина, 3(41), 23–30.
13. Кароматов И. Д., Рахматова М. Р., Жалолова В. З. Лекарственные растения и медикаменты. – 2020.

14. Кароматов, И. Д., Рахматова, М., & Жалолова, В. (2020). Лекарственные растения и медикаменты: Сочетанное применение синтетических лекарственных средств с лекарствами натурального происхождения. EDN XDQLFB.

15. Рахматова М. Р., Жалолова В. З. Юниор ва кадет спортсменларда тананинг композицион таркибини ўрганиш //Тиббиётда янги кун. – №. 2. – С. 30.

16. Rakhmatova M.R., Zhalolova V.Z. Yunior va kadet sportsmenlarda tananing kompazitsion tarkibini ŭrganish. // Tibbiyotda yangi kun. - № 2 (30/2). - B. 67- 70

17. Rakhmatova Markhabo Rasulovna, Zhalolova Vazira Zamirovna . Metody issledovaniya kompozitsionnogo sostava tela u sportsmenov // Biologiya i integrativnaya meditsina. 2020. №4 (44).