

Features of energy supply to athletes' muscles during speed-power sports

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Abstract.

A current issue in modern sports biochemistry is studying the features of engaging different pathways of energy supply during various types of muscle work, depending on the type of sport. The practical aspect lies in developing methods to enhance athletes' performance and speed up recovery processes. Literature sources provide scattered data on using these pedagogical indicators to monitor muscle loads in various sports. In this context, pedagogical parameters aim to track the development of specific physical qualities and their dynamics in the process of mastering sports skills, specifically speed, strength, and endurance. From a medical-biological perspective, the energy source for developing speed and strength is the creatine-phosphokinase and glycolytic mechanisms, while general endurance depends on aerobic oxidation of substrates, including carbohydrates, fats, and proteins. Each sport uniquely combines different physical qualities, as indicated by the specific involvement of anaerobic and aerobic energy mechanisms, observable through biochemical monitoring. Identifying features becomes possible through comparative characteristics of biochemical markers from various energy mechanisms. Based on the comparative results of specific biochemical parameters in different sports, practical recommendations can be formed to enhance the development of lagging links essential for specific sports. It is well-known that speed actions have an inverse-proportional fundamental relationship to the genetically determined length of sarcomeres. Conversely, strength manifestation is directly proportional to sarcomere length. Both speed and strength are serviced by the same anaerobic energy mechanisms: creatine-phosphokinase and glycolytic. Thus, speed can serve as a base for strength development, and vice versa, despite their antagonistic nature concerning sarcomere structure. Short-term high-intensity exercises are primarily powered by anaerobic mechanisms. With prolonged activity, the role of aerobic processes increases. Given the importance of balancing aerobic and anaerobic energy components, studying energy indicators characterizing these components becomes especially significant. During the preparation of athletes in various sports, the proportion of engagement of alactate and lactate components of anaerobic energy supply and the share of aerobic mechanisms vary. Typical representatives of speed-power sports include weightlifting, freestyle wrestling, basketball, and water polo. To provide coaches with recommendations for improving the physical training of athletes in various sports, biochemical monitoring of energy indicators during physical activities of varying durations and intensities, along with mathematical methods of dispersion analysis, is essential to identify the influence of sport type on athletes' energy characteristics.

Keywords: basketball players, weightlifters, wrestlers, water polo players; aerobic, anaerobic, alactate, lactate energy metabolism; lactic acid, inorganic phosphate, urea.

Introduction.

Studying energy supply pathways in athletes to further enhance sports mastery, expand functional reserves, and maintain health is a relevant issue in modern science. [Pervachuk, 2017; Sybil, 2015; Sybil et al., 2018, 2020, 2022, 2024]

Muscle contraction occurs due to ATP energy, which, in a state of rest, reaches 5 mmol per 1 g of living tissue. When ATP is utilized for muscle work different from the resting state, creatine phosphate, under the influence of creatine kinase, enters a rephosphorylation reaction with ADP, restoring ATP levels. This is the fastest pathway for ATP resynthesis during muscle contraction, and it does not require oxygen. However,

creatine phosphate reserves last only about 10 seconds for high-intensity muscle work, as its content is relatively low (0.20-0.55% of the muscle's dry matter), depleting within 30 seconds. This pathway supports maximum power during short-term muscle work. As a result of creatine phosphate rephosphorylation reactions with ADP, creatine is released, diffuses into the bloodstream from the inter-fibrillar space, and is excreted as creatinine in the urine. Thus, creatinine is an indirect factor assessing the intensity of the creatine-phosphokinase (alactate anaerobic) energy supply mechanism. [Todorova et al., 2022; Sybil, 2017; Bouchard, 1992]

Through medical-biological and biochemical research, scientists have studied creatinine excretion across different sports, with absolute values varying. [Roztorgui, 2019; Tovstonog, 2022; Sybil, 2020, Ostapiuk-Karolczuk et al, 2024] However, no studies have provided comparative data on this energy mechanism during different types of muscle activity. Therefore, a comparative analysis of various speed-power sports representatives—who serve as diverse models in balancing different ATP resynthesis sources—is necessary. The next power zone includes sports disciplines where core activities last from 30 seconds to 5 minutes. Here, the dominant energy supply mechanism is glycolytic or lactate anaerobic. Lactic acid, a product of anaerobic glycolysis, accumulates in muscles under oxygen-deficient conditions, giving this pathway the name lactate. Blood lactic acid and urinary excretion serve as biochemical markers of anaerobic glycolytic energy production. Although lactic acid is partially utilized in organs with higher oxygen partial pressure (myocardium, brain), increased glycolysis still heightens lactic acid excretion in the urine. Scientific sources show conflicting data on lactic acid and its changes during sports. The aerobic process, the primary energy supply method for living organisms, involves a broad range of oxidation substrates (carbohydrates, lipids, proteins, and their metabolic intermediates). It is highly efficient but limited by its multi-step nature, requiring complex oxygen transport to active tissues, limiting maximum power. ATP resynthesis speed in aerobic reactions among well-trained athletes performing warm-ups peaks 1.5–2 minutes after intense muscle activity begins [Šmída, M., Macejková, Y., & Procházková, E., 2018]. Anaerobic processes, with fewer intermediate reactions than aerobic ones and independent of oxygen supply speed, reach maximum speed faster and have greater relative power. However, their metabolic capacity—depending on creatine phosphate and glycogen stores and resistance to anaerobic metabolism byproducts—is lower than aerobic capacity. Urea, the end product of protein metabolism, forms as ammonia is detoxified through oxidative deamination of amino acids, occurring in hepatocytes via the ornithine cycle and excreted at 20–25 g/day. Under increased aerobic-type energy demands, when proteins serve as energy substrates, heightened ammonia formation and urea excretion occur [Zumbaugh, M. D., Johnson, S. E., Shi, T. H., & Gerrard, D. E., 2022].

It is well-known that different substrates are sequentially engaged in complete oxidation: carbohydrates oxidize first, followed by lipids. Proteins provide energy after carbohydrates and lipids, often under stress-related physical exertion, such as long-distance running, marathons, races, and team sports. These activities increase protein breakdown, with amino acids entering the Krebs cycle. Similar processes occur in overload exercises or early-stage sports training. Consequently, urea indicates protein component involvement in energy metabolism, suggesting depletion of carbohydrates and lipids. Regarding lipids, excessive mobilization leads to ketone body accumulation, some of which are toxic (notably acetone). Therefore, urea is considered a biochemical marker for aerobic energy mechanism intensity and physical stress level, also serving as a universal fatigue indicator. [Bouchard, 1992]

Sports games uniquely develop all power zones for ATP production, both anaerobic and aerobic, involving various ATP resynthesis sources chaotically throughout the game due to the situational nature of these sports and the high emotional component. Water polo, with additional water-based energy demands, exemplifies such high-intensity exertion, alternating between anaerobic and aerobic phases. Each sport, regardless of type, has a unique situational characteristic in energy production. [Yatskovskyy et al., 2019; Boichuk et al., 2018; Chaplins'kyy et al., 2018]

In martial arts, particularly freestyle wrestling, where anaerobic energy sources are heavily engaged during specific fight phases, rapid entry into the energy-rich aerobic zone is vital. Aerobic ATP must suffice for effective combat actions and for replenishing anaerobic resources, primarily creatine phosphate. [Sybil et al., 2020; Pervachuk, 2018]

Weightlifting exemplifies a sport where success depends on anaerobic ATP resynthesis pathways, while speed and endurance can develop through cross-training with other sports, like team games or wrestling. Conversely, combat or weight training can benefit team sports athletes in anaerobic energy development. [Tovstonog, 2022]

Materials and methods

The objective of this study was to investigate the effects of physical activity on the energy supply of athletes involved in speed-power sports.

Tasks: 1. Identify changes in energy indicators for female basketball players before and after a match, and after a six-month training period (cumulative effect of a six-month macrocycle). 2. Study changes in energy indicators for weightlifters before and after lifting attempts (snatch, press) (short-term effects of microcycle workouts). 3. Identify changes in energy indicators for water polo players before and after a game, as well as

after a one-hour training session in the pool (comparing the immediate effects of land and water-based training in game-specific contexts). 4. Identify changes in energy indicators for wrestlers before and after training, at the beginning and end of a tournament (immediate and cumulative effects). 5. Identify changes in lactic acid, creatinine, and urea levels in athletes' urine from different sports due to physical activity.

Organization of the Research. The research was conducted at the departments of athletic and non-Olympic sports and the department of biochemistry and hygiene of the Ivan Bobersky Lviv State University of Physical Culture. The study involved athletes from various sports: 13 female basketball players aged 16, 8 weightlifters aged 18, 15 water polo players, and 8 wrestlers aged 15-16. Monitoring of energy indicators was performed on athletes from various speed-power sports: weightlifters, wrestlers, basketball players, and water polo players. To this end, levels of lactic acid, inorganic phosphate, and urea were measured 15-30 minutes before the start of a game or training and 15-30 minutes after physical exertion. Energy supply processes in basketball players were studied over a six-month training macrocycle, both at the beginning of the preparatory period and at the end of the competitive period. For water polo players, energy supply processes were studied under additional physical load (one-hour pool session). Energy metabolism indicators for weightlifters were assessed before and after training (snatch and press, 3 attempts). Monitoring of energy indicators in wrestlers was carried out at the beginning and end of a tournament.

Biochemical analysis. Urine is an important body fluid that is easily obtained non-invasively, providing valuable information for the diagnosis of various metabolic diseases [Wang H., Ran J., Jiang T., 2014]. Biochemical examination of archers was also performed in two stages during training loads (rest) and official competitions (start) before and after physical exertion. Sampling of biological fluid (urine) was performed during the athlete's relative rest after each specific event; sampling was identical in the two studied stages. The concentration of lactate in urine was determined by the Strom color reaction [Barker S. B., Summerson W. H., 1942], and urea [Ormsby A. A., 1942] by the colorimetric method.

Statistical analysis. For each parameter, the mean values (M), standard error of the mean (m) and standard deviations (σ) were estimated, which were determined using Microsoft Office Excel. Statistical analysis of data (probability of difference of determined indicators (Student's t-test) and normality of distribution (Shapiro-Wilk test)) was performed using the SPSS Statistics Base program (<https://www.ibm.com/products/spss-statistics>); to determine the shares of the influence of physical and psychological factors on changes in the studied biochemical indicators, one- and two-factor analysis of variance were performed [Glantz S. A., 2012]. To assess the correlation, the Pearson correlation coefficient (r) was calculated, where a value up to 0.5 indicated a weak correlation, from 0.5 to 0.7 - a moderate correlation, and from 0.7 to 1 - a strong correlation. Statistical significance was determined by $p \geq 0.95$.

Research results and their discussion.

Research Results and Discussion The results of energy metabolism indicators in basketball players before and after a match are shown in Fig. 1.

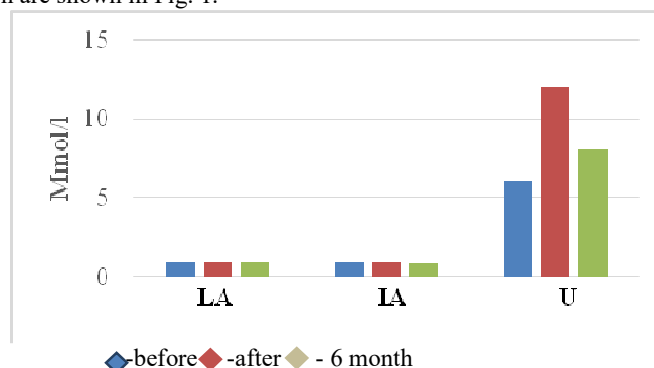


Figure 1. Changes in energy metabolism indicators for female basketball players before and after a match and after six months of training ($p \geq 0.95$, *** $p \geq 0.999$)*

As seen from the data in Fig. 1, changes in lactic acid levels are minor. Since lactic acid is an indicator of the anaerobic lactate pathway in the athlete's energy supply, such minimal changes indicate the engagement of carbohydrates in energy metabolism through aerobic glycolysis, where lactic acid is immediately utilized due to improved oxygen consumption.

The inorganic phosphate content in basketball players' urine before and after a match increases by approximately 10% ($p \geq 0.95$), indicating shifts in overall energy provision during match-related physical exertion. After six months of training, post-match inorganic phosphate levels decrease in these athletes, indicating adaptation to physical exertion and good physical condition.

Urea, as an indicator of the aerobic pathway in the athletes' energy supply, doubles in basketball players after a game, suggesting active protein involvement in energy provision. Following six months of

training, urea content decreases compared to the start of the training macrocycle, although it does not reach baseline levels, indicating effective preparation of the athletes for physical exertion over preparatory and pre-competitive periods and an adaptation of their bodies to high levels of physical load with increased protein contribution to energy metabolism.

Results of a study of energy metabolism indicators in weightlifters after barbell sets (jerk, bench press, three sets each)

The results of the study on energy metabolism indicators in weightlifters after lifting attempts (snatch, press) are shown in Fig. 2.

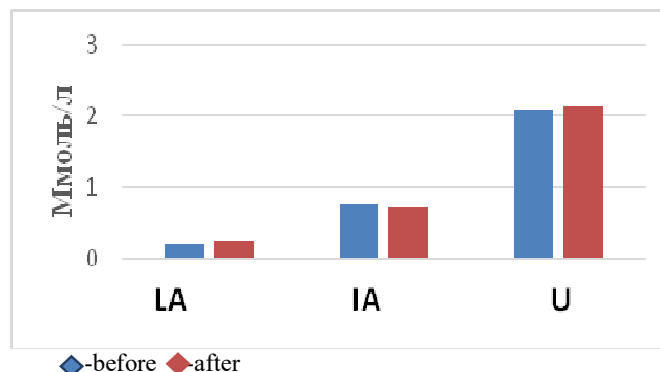


Figure 2. Changes in energy metabolism indicators in weightlifters after lifting attempts (snatch, press)

The data in Fig. 2 indicate an increase in lactic acid content in weightlifters after physical exertion, suggesting engagement of the anaerobic lactate component in overall energy metabolism.

The study of creatinine levels in weightlifters' urine shows no significant difference between pre- and post-exercise levels, reflecting their high skill and endurance in handling physical loads. For these athletes, aerobic energy supply remains consistently high, as evidenced by stable urea levels in weightlifters' urine before and after exercise (snatch, press, 3 attempts).

Therefore, the athletes examined are highly qualified and physically resilient, allowing for the application of overload principles during their preparatory period. Moreover, the biochemical response to muscle overloads may serve as a model characteristic in biochemical monitoring.

Results of a study of energy metabolism indicators in water polo players

Results of Energy Metabolism Studies in Water Polo Players The results of the study on energy metabolism indicators in water polo players are presented in Fig. 3.

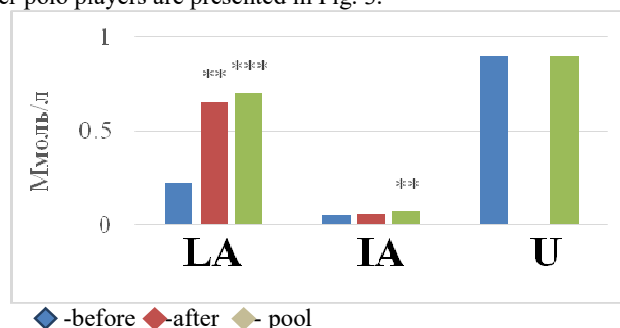


Figure 3. Changes in energy metabolism indicators in water polo players before and after training and after a one-hour pool session (** $p \geq 0.99$, * $p \geq 0.999$)

As seen from the data in Fig. 3, water polo players exhibit sensitivity to physical loads in terms of both anaerobic and aerobic energy supply mechanisms.

Significant changes in lactic acid content in water polo players' urine are observed both after training and after the pool session. Following training, lactic acid levels triple, indicating active engagement of the anaerobic lactate pathway in overall energy processes. After additional one-hour pool sessions, the lactic acid levels in the athletes' urine continue to show an upward trend. The changes in lactic acid levels are statistically significant (** $p \geq 0.999$).

Creatinine levels in water polo players' urine change insignificantly after training, reflecting minor shifts in overall energy provision post-exertion. However, the one-hour pool session causes a statistically significant increase in creatinine levels ($p \geq 0.99$), indicating general energy losses due to physical exertion.

Urea, as an indicator of aerobic energy supply, changes insignificantly in water polo players after one hour of pool training, indicating minor shifts in aerobic energy supply. Unfortunately, data on urea levels in water polo players' urine post-training could not be recorded due to sample loss.

Results of a study of energy metabolism indicators in female wrestlers

Results of Energy Metabolism Studies in Wrestlers The results of the study on energy metabolism indicators in wrestlers are shown in Fig. 4.

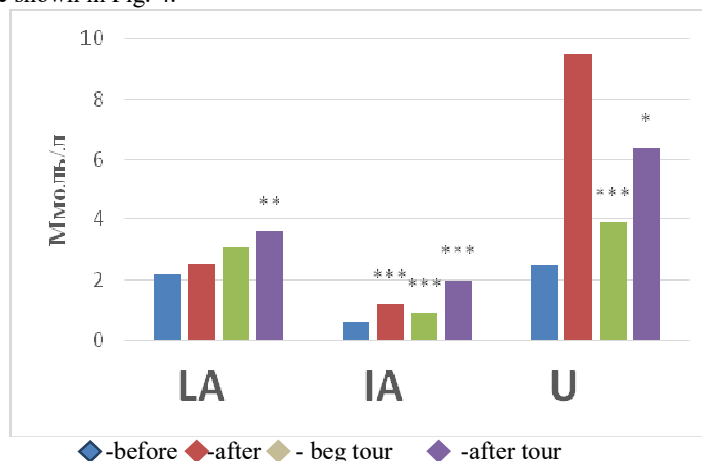


Figure 4. Changes in energy metabolism indicators in wrestlers before and after training, at the beginning and end of a tournament (* $p \geq 0.95$, ** $p \geq 0.99$, *** $p \geq 0.999$)

Figure 4 presents data on the levels of lactic acid, creatinine, and urea in wrestlers' urine before and after training, at the beginning of the tournament, and at the end of the tournament. The lactic acid content in wrestlers' urine slightly increases after training. A similar trend is observed at the beginning of the tournament, indicating rapid recovery of the anaerobic lactate energy pathway. Only at the end of the tournament does the lactic acid level in wrestlers' urine show a statistically significant increase ($p \geq 0.99$), indicating that the tournament effectively stimulated the development of the glycolytic anaerobic component of energy metabolism in young athletes. Significant changes in creatinine levels in wrestlers' urine are observed after training and at both the beginning and end of the tournament ($p \geq 0.999$), indicating the development of the alactate energy component due to physical exertion.

Urea, as an indicator of aerobic energy supply, changes after physical exertion. Significant changes are observed after training and at the end of the tournament ($p \geq 0.95$). At the beginning of the tournament, the lowest urea levels are recorded, with changes being statistically significant ($p \geq 0.999$), suggesting good preparation of the athletes for the tournament.

Discussion:

According to the objectives of the study, changes in energy metabolism indicators in athletes from different sports were investigated, revealing the following: An increase in all energy metabolism indicators was noted in basketball players after games and six months of training, indicating balanced improvements in fitness. This cumulative six-month training effect shows that this sport positively influences the development of all physical qualities, making it suitable for cross-training in other sports.

In weightlifters, energy metabolism indicators remained stable after physical exertion, reflecting their high qualifications and physical preparedness. However, elevated urea levels before and after training suggest an increased protein demand in their metabolism, facilitating faster renewal. Thus, weightlifting could be recommended to athletes from other sports with significant protein components in energy metabolism, such as combat sports. Conversely, it could benefit athletes where strength is important but not crucial (sprinting, middle distances, hurdling).

For water polo players, lactic acid levels changed after training and the one-hour pool session, while creatinine levels changed following the pool session. No significant changes in urea levels were observed, indicating a high demand for readily available energy due to the sport's high energy and speed requirements. The elevated lactic acid and creatinine excretion suggest exercises that develop speed-strength endurance, suitable for long-duration activities. Water polo or sprinting could be recommended for cross-training purposes.

Wrestlers showed increased levels of all energy metabolism indicators after training, at the start, and at the end of the tournament. Balanced biomarkers across all energy pathways, both aerobic and anaerobic, indicate the well-rounded athletic development of ATP resynthesis. To further enhance speed-strength qualities, weight training may be beneficial, and conversely, wrestling could aid weightlifters in developing these attributes.

Conclusions.

1. The results of biochemical monitoring suggest recommending specific speed-power sports to other speed-power disciplines as a “transfer” method to relieve frequently used muscle groups.
2. The biochemical monitoring data may serve as model indicators for adjusting the training process.

Prospects for Further Research include developing recommendations for coaches and athletes from various sports (basketball, weightlifting, water polo, and wrestling) to improve their physical fitness. Given the importance of balancing aerobic and anaerobic energy supply components, studying energy indicators characterizing these components is of particular significance.

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