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Readaptation of the functional reserves of elite mixed martial arts athletes during long-term rehabilitation after musculoskeletal injuries

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Abstract

Purpose. To study the distinctive characteristics of functional reserve readaptation in elite Mixed Martial Arts (MMA) athletes during long-term rehabilitation after musculoskeletal injuries using various physical therapy protocols.

Material & Methods. The study examined 24 elite athletes who sustained musculoskeletal injuries after competitions, predominantly involving the neuromuscular system and limb ligaments. 50 % of the athletes had previously practiced Muay Thai boxing, while the others specialized in Greco-Roman wrestling before MMA. The monitoring of the athletes' functional reserve readaptation during rehabilitation lasted seven months. The study included four control stages (before injury, and after two, five, and seven months of rehabilitation), each accompanied by a set of test loads designed to evaluate the effectiveness of the readaptation. To assess the adaptive and compensatory responses of the body to the applied loads, a series of blood biomarkers was analyzed, including creatine phosphokinase, lactate dehydrogenase, cortisol, and creatinine. Changes in body composition were tracked using bioimpedance analysis.

Results. The most noticeable signs of adaptation failure in elite MMA athletes occurred during the first two months of rehabilitation. Compared to pre-injury data, both groups of athletes showed a decrease in baseline creatine phosphokinase and creatinine levels. This was accompanied by an increase in lactate dehydrogenase activity in their blood serum, marking a significant drop in the body's functional reserves and overall resistance. During the three-month rehabilitation period, athletes exhibited only partial signs of functional readaptation, despite the implementation of protocols that significantly differed from standard physical therapy approaches. Moreover, a decrease in blood cortisol concentration in response to physical load was detected in both groups, suggesting a low level of resistance and the need for additional energy supply. During the last eight weeks of the seven-month rehabilitation program, exercises replicating 85-90% of MMA technical skills facilitated both the activation and enhancement of functional readaptation. Modifications to the protocols led to an increase in baseline creatinine and creatine phosphokinase levels, along with a decrease in lactate dehydrogenase activity in both groups. Simultaneously, the changes observed in biochemical blood markers in response to

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the test loads indicated activation of mechanisms supporting short-term adaptation.

Conclusions. The findings indicate the limited effectiveness of standard physical therapy protocols in supporting the readaptation of functional reserves among elite MMA athletes during long-term rehabilitation. Despite the high resistance of physiological systems to physical loads recorded before injury, the lack of sufficient muscular activity during the five-month rehabilitation period led to the manifestation of compensatory reactions. Restructuring the rehabilitation protocols with adjusted training loads and exercises simulating 75-80% of combat movements positively influenced the athletes' recovery. The study results helped to identify and analyze the low effectiveness of functional reserve readaptation observed in many elite MMA athletes during long-term rehabilitation after musculoskeletal injuries.

Keywords: elite MMA athletes, readaptation, functional reserves, biomarkers, long-term rehabilitation, musculoskeletal injuries.

Introduction

The growing requirements for physical, functional, and technical preparedness in professional sports are accompanied by an increased risk of systemic overstrain and a higher frequency of sports-related injuries (Bickley et al., 2023; Zachovajevas et al., 2025). This issue is particularly acute in MMA, which is explained by the specific nature of training and competitive activities in this sport (Fares et al., 2023; Shtefiuk et al., 2025). Scientific research dedicated to developing innovative mechanisms for enhancing the resistance of MMA athletes to competitive loads (Chernozub et al., 2023; Manolachi et al., 2023) has demonstrated a positive influence on the adaptation of the musculoskeletal system. However, the problem of increasing injuries remains unresolved. The complexity of addressing this issue lies not only in the structure of the training and the athletes' individual physiological and morphometric characteristics but also in the unpredictable situations that occur during matches (Shtefiuk et al., 2024).

As athletic training in MMA increases, the number of minor soft-tissue injuries, sprains, and dislocations tends to decrease (Elahi et al., 2024). Most such injuries occur due to insufficient technical proficiency, inadequate recovery periods for physiological systems, and resulting uncontrolled deviations in the execution of strikes or throws during matches (Gimigliano et al., 2021; Kingery et al., 2022). At the same time, limited functional reserves and incomplete neuromuscular development make athletes engage supplementary muscle groups during competition, involving muscles that were not previously exposed to such loads during training (Chernozub et al., 2023; Manolachi et al., 2023).

The prevalence of musculoskeletal injuries (MSK-I) is known to rise with increasing athlete skill and competitive level, especially among competitors in the light heavyweight division and higher, with 76.5% of such cases requiring surgical intervention (Bickley et al., 2023; Hasegawa et al., 2024). Consequently, the outcomes of these injuries (involving damage to muscles, joints, and ligaments), especially in cases requiring surgery, include prolonged rehabilitation periods associated with the risk of both decreased functional reserves and pronounced muscle atrophy (Ross et al., 2021).

One of the most complex and debated issues concerning the rehabilitation of elite MMA athletes after musculoskeletal injuries is the selection of optimal physical therapy protocols (Su et al., 2024; Fares et al., 2025). The challenge lies in the fact that modern rehabilitation systems primarily offer protocols designed for the acute and post-acute stages of recovery. These protocols are effective owing to a multidisciplinary approach that engages physicians and physical therapists immediately after injury or surgical intervention. However, their implementation is typically restricted to a duration of 3-4 weeks (Campos et al., 2025).

However, their prolonged application during the later stages of rehabilitation for athletes with high resistance to physical loads raises numerous controversial issues among coaches and researchers alike (Gimigliano et al., 2021; Pujalte et al., 2023). Furthermore, the effectiveness of using specific physiological and biochemical markers to assess readaptation processes during rehabilitation under various physical therapy protocols remains an open question.

Creating long-term, evidence-based rehabilitation protocols tailored to elite MMA athletes, considering both the severity of injuries and their functional consequences, represents a major and unresolved challenge in modern sports medicine and physical therapy.

Purpose of the Study. To examine the distinctive characteristics of the functional reserve readaptation in elite MMA athletes during long-term rehabilitation after musculoskeletal injuries using various physical therapy protocols.

Material and Methods

Participants

The study involved 24 elite MMA athletes who sustained musculoskeletal injuries after competitions. According to medical examinations, all participants required surgical intervention and a long-term rehabilitation period. The athletes' mean age was 24±1.4 years, body weight was 86.3±2.2 kg, and training experience was 8.2±1.3 years. Before active MMA competition, 50% of the participants practiced Muay Thai boxing, while the remaining 12 athletes primarily trained in Greco-Roman wrestling. The musculoskeletal injuries (MSK-I) identified in the participants were mainly associated with damage to the neuromuscular system and limb ligaments.

Participants were divided into two groups: Muay Thai boxers and Greco-Roman wrestlers. The study was conducted in rehabilitation centers, hospital departments, and at the research facilities of the Center for Modern Kinesiology "KINEZUS." The study design was approved by the Bioethics Committee of Lesya Ukrainka Volyn National University, Lutsk. After receiving a detailed explanation of the potential risks and benefits, all participants signed an informed consent form prepared in compliance with the ethical principles outlined in the Declaration of Helsinki.

Measurements

Bioimpedance Method

The non-invasive biophysical method of bioimpedance analysis was used to determine body composition parameters. A bioimpedance analyzer, the diagnostic computerized hardware-software system KM-AR-01 of the "Diamant-AST" configuration (body composition analyzer) (VYUSK. 941118.001 RE), was employed. Computer processing of the collected data was used to determine the main indicators of body composition, including body fat mass (BFM, %), fat-free mass (FFM, kg), and active cell mass (ACM, %). These bioimpedance parameters were recorded before the MMA competitions and throughout the seven-month rehabilitation period after injuries sustained during matches.

Blood Biomarkers

The activity of lactate dehydrogenase (LDH) and creatine phosphokinase (CPK) in the athletes' blood was measured using the kinetic method. Cortisol and creatinine concentrations in blood serum were determined via enzyme-linked immunosorbent assay (ELISA). Reference values for the analyzed biochemical markers in participants' blood serum were as follows: CPK (39-308 U/L), LDH (135-225 U/L), cortisol (171-536 nmol/L), and creatinine (62-106 μmol/L). Blood sampling was performed by medical personnel in accordance with internationally accepted standards for biomedical research. Throughout the observation period, both the basal levels of these blood biomarkers (at rest, before physical load) and their responses to the applied test loads were assessed.

Research Design

The study was conducted in several stages throughout 2025.

At the first stage, protocols for bioimpedance analysis and laboratory blood tests of the athletes were examined before the competitions, during which injuries occurred. Baseline body composition parameters were assessed, and the adaptive and compensatory responses were characterized by analyzing blood biomarkers in response to loads closely simulating competitive conditions. During test load A, athletes executed 2-3 signature strikes or throws at maximum force over 15-20 seconds during a counterattack, engaging the greatest possible number of agonist, synergist, and stabilizer muscle groups. Simultaneously, during this creatine phosphokinase muscular activity, the greatest possible number of fast-twitch motor units was recruited.

At the second stage, following the post-acute rehabilitation period, adaptive reserves of the athletes' bodies were evaluated. This assessment was conducted two months after surgical interventions aimed at restoring the condition of injured muscles, ligaments, or tendons in the limbs. Test load B was developed for participants in both groups, taking into account the peculiarities of injuries and potential complications during post-acute rehabilitation. Over 25-30 seconds, athletes performed a specialized exercise against partner resistance. The exercise involved variations in kinematic characteristics designed to induce fatigue in recruited muscle groups while avoiding engagement of previously injured parts of the neuromuscular system. Exercises were performed with a partial range of motion (90%) and at a very slow tempo (concentric phase was 3 s; eccentric phase – 6 s). The changes in basal body composition parameters were analyzed, and blood biomarker changes were assessed and compared with pre-injury results.

At the third stage, during the following three months of rehabilitation, athletes adhered to combined protocols developed collaboratively by specialists in kinesiology, physical therapy, and functional MMA training. These long-term rehabilitation protocols primarily consisted of isolated exercises, in which the injured areas of the neuromuscular system were engaged only partially (25-30%). Exercises were performed using machines, partner or therapist resistance, and exposure to various external stimuli. Load intensity ranged from 15-20% of one-repetition maximum (1RM)

for injured areas and 50-55% of 1RM for healthy muscle groups. Additionally, body positions and movement biomechanics were varied to engage a broader spectrum of synergist muscle groups.

The main objective was to maximize creatine phosphate and muscle glycogen accumulation in atrophied muscles, thereby enhancing functional reserves and restoring resistance to physical loads. To monitor the readaptation at the end of this period, a test load C was developed. Over 25-30 seconds, athletes executed simulated strikes with the injured limb at a very slow tempo, performed from non-standard body positions with shifts in the center of gravity. These modifications in movement kinematics aimed to optimally activate additional agonist and synergist muscle groups while influencing the rate of energy depletion and metabolic processes during recovery. During test load C, changes in LDH and CPK activity, as well as cortisol and creatinine concentrations in blood serum, were analyzed in response to the applied loads.

At the fourth stage, standard physical therapy protocols were fully redesigned by specialists in kinesiology. This phase occurred over 6-7 months following surgical interventions to repair specific areas of the limb's neuromuscular system that were injured during competition. The rehabilitation protocols implemented exercises whose kinematic characteristics were 85-90% similar to specialized training elements included in the technical skills of MMA.

A defining feature of these exercises was the progressive loading through additional resistance, performed at a very slow tempo with isometric holds at the peak positions of each movement. The exercises were performed in an open space without using punching bags, with each series lasting 25-35 seconds. Additionally, the load could be increased by altering the body position.

For comparative monitoring of adaptive changes in athletes during this period, a test load D was developed. During this test, movements were performed on specialized machines that simulated 90% of the strikes and throws used in MMA. These exercises activated the relevant muscle groups in terms of biomechanics. The muscles, ligaments, and tendons that had been previously injured were selectively loaded at approximately 75-80% of 1RM. The duration of each load was 20-25 seconds.

At the beginning and end of this rehabilitation period, a comparative analysis was conducted to assess changes in basal levels of heart rate variability parameters and blood biomarkers, as well as responses to acute test loads. The collected data were subsequently processed and analyzed.

Statistical Analysis

Statistical analysis of the study results was performed using IBM *SPSS Statistics* 26 (StatSoft Inc., USA). The G*Power 3.1.96 software (Germany) was used to determine the minimum required sample size for the study (statistical power calculation). Non-parametric statistical methods were applied to calculate the median (Me) and interquartile range (IQR). The Kruskal-Wallis test was used to compare baseline parameters between the groups of athletes. The Wilcoxon signed-rank test was applied for comparisons between two dependent samples. A two-factor Friedman rank analysis of variance was employed to assess differences in the dynamics of more than two parameters. Kendall's W (coefficient of concordance) was used to determine the effect size.

Results

Figure 1 presents a graphical illustration of body composition parameters in elite MMA athletes (illustrated by Muay Thai boxers and Greco-Roman wrestlers) measured before competition-related injuries and throughout the seven-month rehabilitation period.

The results indicate that after two months of rehabilitation following the injury, body fat mass (BFM) significantly increased in Muay Thai boxers (+3.0%) and Greco-Roman wrestlers (+3.8%) ($p<0.05$). At this stage, a significant decrease in fat-free mass (FFM) was observed only in Muay Thai boxers (-3.0%). Simultaneously, a notable, though non-significant, reduction in active cell mass (ACM) was observed in both groups compared with other stages of the study (after 5 and 7 months of rehabilitation).

During the next five months of rehabilitation, regardless of the physical therapy protocols usage, only a non-significant increase or decrease in BFM was observed among all participants. Only Greco-Roman wrestlers decreased their FFM significantly (-5.5%) at the end of the fifth month of rehabilitation, but increased (+5.0%) it over the next 12 weeks.

The patterns of baseline creatine phosphokinase levels and their activity in the blood of participants from both groups, in response to test loads before injury and across the rehabilitation stages, are presented in Figure 2.

The results obtained before the competitions (pre-injury) indicate that Greco-Roman wrestlers had a baseline CPK level 68.9% higher than that of Muay Thai boxers. These findings suggest that the wrestler group may have had structural muscle tissue damage due to previous training loads. In response to test load A, CPK activity in the blood increased significantly in both Muay Thai

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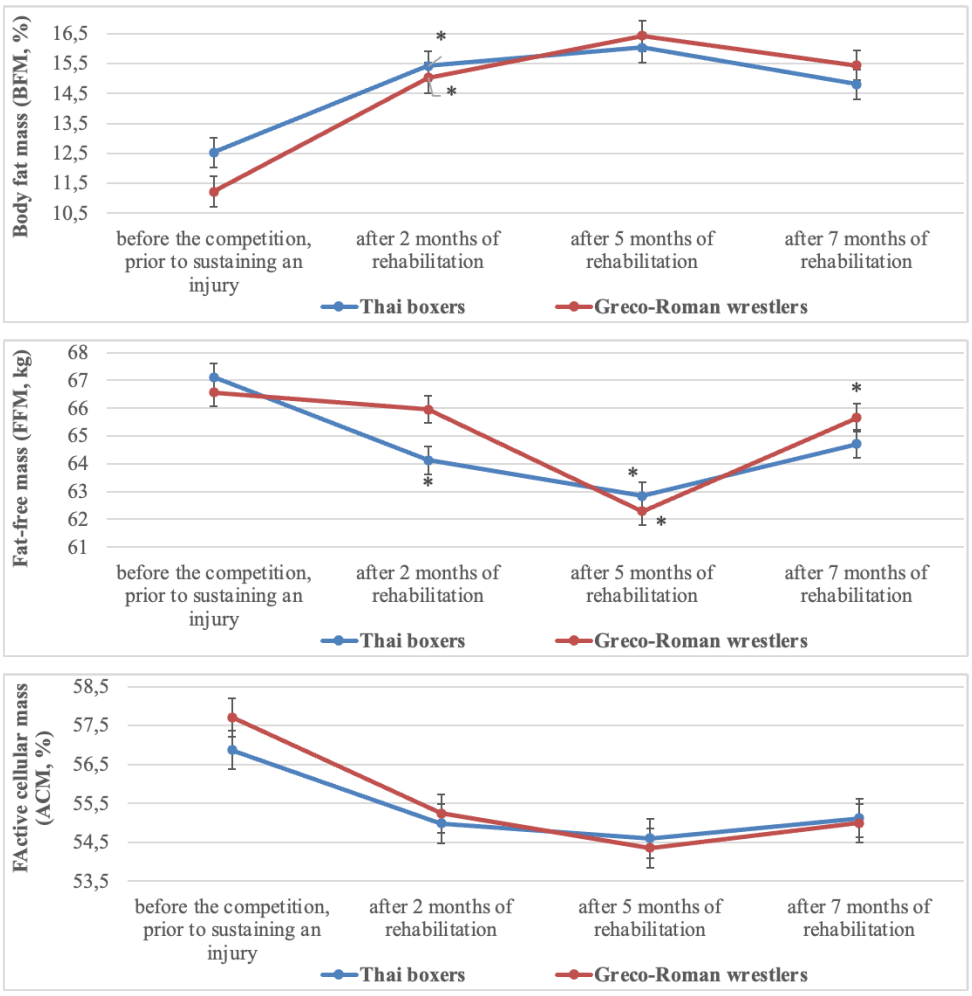

Figure 1. **Changes in body composition parameters (BFM, %; FFM, kg; ACM, %) in elite MMA athletes (illustrated by Muay Thai boxers and Greco-Roman wrestlers) across all stages of the study.**

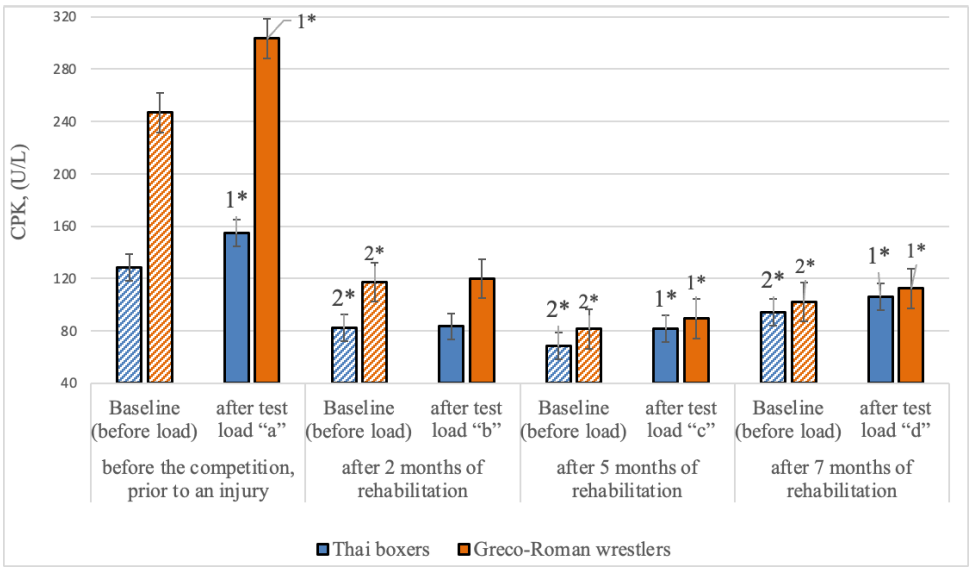

Figure 2. **Changes in creatine phosphokinase activity in the blood of the examined MMA athletes across all stages of the study.**

Notes: 1* $p < 0.05$ – compared to the state of rest; 2* $p < 0.05$ – compared to the baseline level of the previous stage.

boxers (+20.5%) and Greco-Roman wrestlers (+16.9%).

After the first two months of rehabilitation following the injury and subsequent surgical intervention, baseline CPK levels decreased by an average of 40.3% in both groups. During this period, CPK activity changed minimally in response to the applied load. Over the next three months

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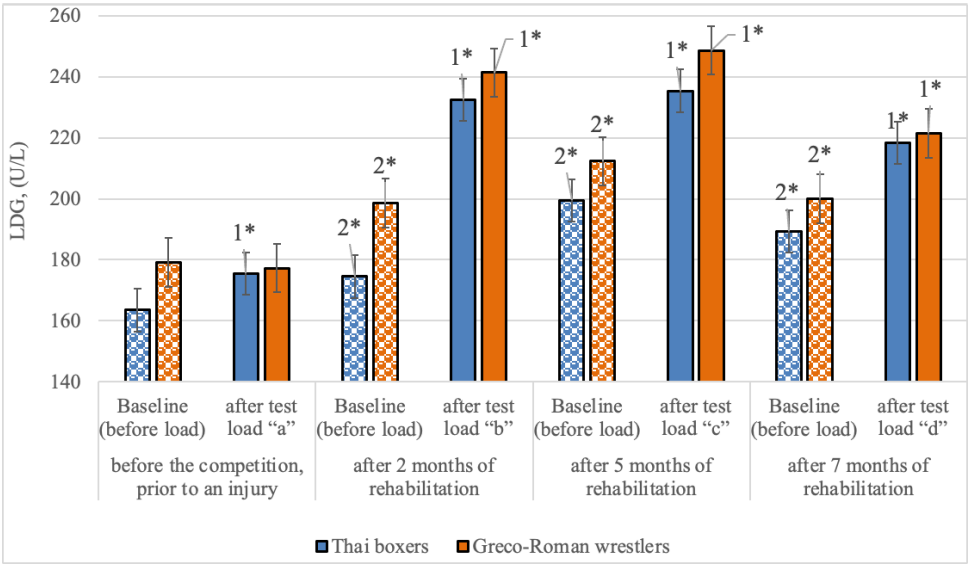

Figure 3. Changes in lactate dehydrogenase (LDH) activity in the blood of the studied groups of MMA athletes across all stages of the study.

Notes: 1* p<0.05 – compared to the state of rest; 2* p<0.05 – compared to the baseline level of the previous stage.

of rehabilitation, basal CPK levels continued to decrease in all participants, despite using completely different physical therapy protocols compared to the previous stage. Simultaneously, an increase in this enzyme activity was observed in response to test loads, both in boxers (+19.6%) and wrestlers (+9.7%).

The characteristic pattern of CPK activity typical for MMA athletes was observed only by the end of the seventh month of rehabilitation, after eight weeks of training with load intensity reaching approximately 70-75% of pre-injury levels.

Figure 3 illustrates the dynamics of lactate dehydrogenase (LDH) activity in the blood (at baseline and in response to test loads) in elite MMA athletes, assessed before injury and during the seven-month rehabilitation period.

Analysis of the pre-injury results indicates that LDH activity in the blood did not change only in the Greco-Roman wrestlers in response to test load A. This finding reflects a high level of resistance and sufficient creatine phosphate reserves in athletes of this group.

However, after the first two months of rehabilitation, baseline LDH levels increased in both Muay Thai boxers (+6.7%) and Greco-Roman wrestlers (+10.9%). In response to test load B, LDH activity exceeded reference values in all participants (boxers +33.2%; wrestlers +21.5%). These manifestations of adaptive failure in both groups were associated with limited energy reserves resulting from pronounced muscle atrophy and persisted over the subsequent three months of rehabilitation, despite the application of completely different physical therapy protocols.

By the end of the final stage of rehabilitation, baseline LDH levels decreased on average by 5.5% ($p < 0.05$), indicating effective readaptation processes. LDH activity in the blood increased (boxers +15.3%; wrestlers +10.7%) in response to test load D, which relied on creatine phosphokinase-mediated energy supply.

Figure 4 presents changes in cortisol concentration in the blood of the elite MMA athletes, measured before injury and across all stages of rehabilitation.

The pre-competition (pre-injury) results indicate that basal cortisol levels in the blood of Greco-Roman wrestlers approached the upper limit of the normal range. In response to test load A, athletes in this group showed a 7.9% decrease in cortisol levels, reflecting activation of compensatory mechanisms due to an energy reserve deficit. In contrast, the Muay Thai boxers demonstrated an adequate increase in cortisol (+10.4%) in response to the same physical load.

After the first two months of rehabilitation, baseline cortisol levels decreased in both groups (boxers −34.2%; wrestlers −54.4%). Cortisol concentrations increased by an average of 24.3% in both groups in response to test load B, reflecting an adequate physiological stress response.

The results obtained after the next three months of rehabilitation revealed a further decline in cortisol levels in response to test load C (boxers −14.2%; wrestlers −12.7%). This finding indicates that the applied loads imposed excessive stress on the participants and exceeded their adaptive capacities. By the end of the seventh month of rehabilitation, after eight weeks of training at 70-75% of competition-level intensity, a marked increase in blood cortisol levels was observed (average +80.2%), reflecting a strong adaptive response.

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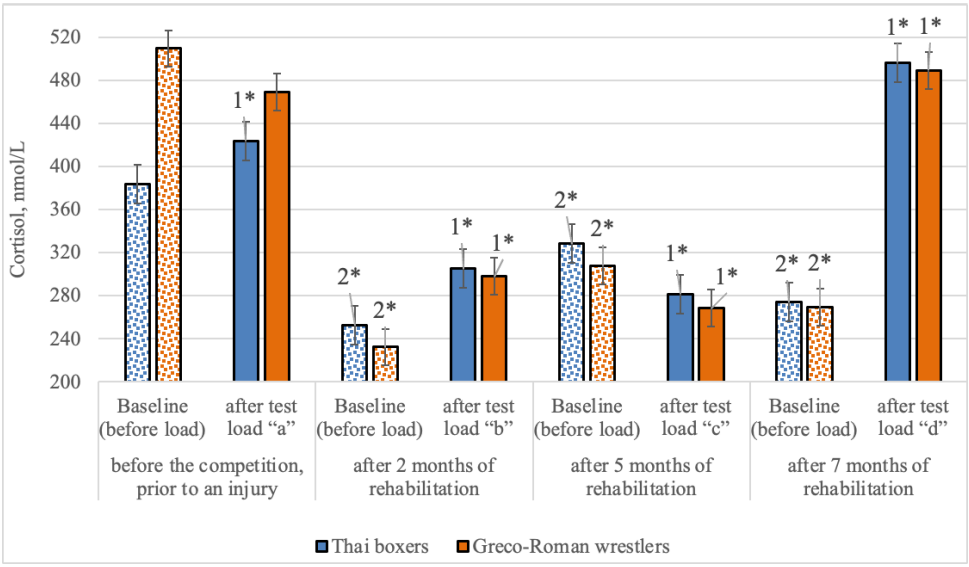

Figure 4. Changes in cortisol concentration in the blood of the studied groups of MMA athletes across all stages of the study.

Notes: 1* p<0.05 – compared to the state of rest; 2* p<0.05 – compared to the baseline level of the previous stage.

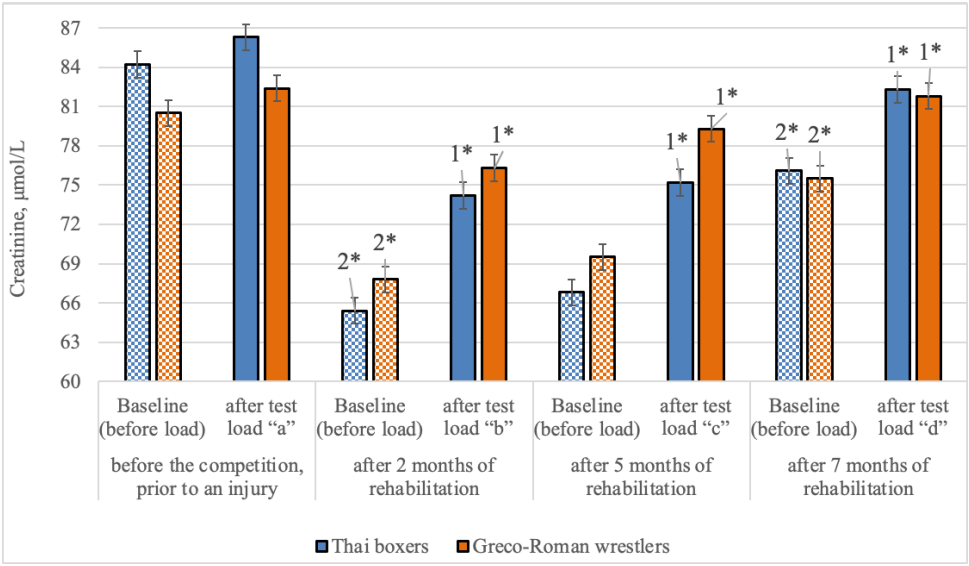

Figure 5. Changes in blood creatinine concentration in the examined groups of MMA athletes across all stages of the study.

Notes: 1* p<0.05 – compared with the state of rest; 2* p<0.05 – compared with the basal level of the previous stage.

Figure 5 presents the changes in blood creatinine concentration (basal levels and in response to test loads) in the examined elite MMA athletes, measured before injury and throughout the seven-month rehabilitation period.

Analysis of pre-injury results indicates that baseline creatinine levels in both groups were within reference ranges. Creatinine concentrations did not show significant changes among the participants in response to test load A.

However, after the first two months of rehabilitation, a significant decrease ($p < 0.05$) in baseline creatinine levels was observed in Muay Thai boxers (−22.3%) and Greco-Roman wrestlers (−15.7%), reflecting adaptive failure associated with muscle mass loss due to atrophy of the injured muscle groups.

By the end of the seventh month of rehabilitation, baseline creatinine levels had risen compared to the previous stage, increasing by +13.9% in boxers and +8.3% in wrestlers. These changes indicate effective re-adaptation of the neuromuscular system, contributing to the restoration of functional reserves during long-term rehabilitation after such injuries.

Discussion

The study presents an investigation into the characteristics of functional reserve readaptation in elite mixed martial arts athletes during long-term rehabilitation after limb injuries sustained in competitions. A comparative analysis

was conducted to assess changes in the athletes' resistance to physical loads at various stages of long-term rehabilitation, taking into account the features of adaptation failure resulting from pronounced hypokinesia after injury and subsequent surgical intervention (Bickley et al., 2023; Pujalte et al., 2023). The adaptive and compensatory responses were analyzed in athletes with prior training in Muay Thai boxing and Greco-Roman wrestling over a seven-month rehabilitation period that involved the application of different physical therapy protocols. Stage-specific test loads were designed for each phase of rehabilitation, taking into account the characteristics of the implemented physical therapy protocols, the dynamics of functional reserves, and the neuromuscular system.

An experimental monitoring system was implemented to assess the readaptation of functional reserves during long-term rehabilitation, considering the peculiarities of the sustained injuries and employing bioimpedance analysis with blood biomarkers. Addressing this issue allows for the resolution of a key challenge in rehabilitating elite athletes with musculoskeletal injuries through the development of an optimal algorithm for functional reserve readaptation (Campos et al., 2025; Shtefiuk et al., 2025). Furthermore, this work contributes to the development of innovative strategies for refining physical therapy protocols for elite athletes, integrating contemporary findings from kinesiology and sports physiology (Cadegiani et al., 2019; Hasegawa et al., 2024).

One of the critical challenges in the rehabilitation of elite MMA athletes and practitioners of other combat sports following musculoskeletal injuries (MSK-I) lies in the limitations of existing physical therapy protocols (Ross et al., 2021; Elahi et al., 2024). This issue becomes particularly pronounced in cases requiring surgical intervention due to damage to the neuromuscular system, tendon ruptures, or ligament injuries of the limbs (Bickley et al., 2023; Su et al., 2024). The lack of a scientifically validated mechanism for adjusting physical therapy protocols that accounts for functional reserves and the specific dynamics of neuromuscular readaptation, especially after 2-3 months of rehabilitation, further complicates the problem (Gimigliano et al., 2021).

Attempts to develop an effective algorithm for assessing the readaptation of the body's systems, incorporating an optimal range of physiological, morphometric, and biochemical monitoring methods during various stages of long-term rehabilitation, remain largely unresolved (Fares et al., 2025; Zachovajevas et al., 2025). The main challenge is that, during long-term rehabilitation, the restoration of functional reserves and the recovery of the neuromuscular system do not occur synchronously. That is why they require the development of additional stage-specific testing protocols. (Kingery et al., 2022; Chernozub et al., 2023). However, most standard physical therapy protocols are designed for acute and post-acute rehabilitation phases and fail to account for these critical aspects of monitoring readaptation in elite athletes (Lystad et al., 2014; Fares et al., 2025). Consequently, the application of such protocols during long-term rehabilitation, without consideration of the athletes' sport-specific demands, is largely ineffective.

The results of our study indicate that elite MMA athletes exhibit the most pronounced signs of adaptation failure during the first two months of rehabilitation. A significant decrease in FFM and ACM was observed, accompanied by an increase in BFM, especially among wrestlers who had elevated baseline CPK levels before injury. These changes in the athletes' bodies during rehabilitation are associated with muscle, ligament, and tendon atrophy due to insufficient physical activity for the injured structures (Campos et al., 2025).

After the initial two months of rehabilitation, baseline levels of CPK and creatinine decreased, while LDH activity in the serum of athletes in both groups increased compared with pre-injury values. These findings reflect a marked reduction in the functional body reserves, decreased resistance to load, and the development of hypokinesia (Manolachi et al., 2023; Mallardo et al., 2024). Simultaneously, LDH activity and cortisol concentration increased sharply, while CPK levels remained largely unchanged in response to the load under creatine-phosphokinase energy supply. These changes in blood biomarkers in response to such loads suggest a deficiency in creatine phosphate reserves, resulting in the additional mobilization of muscle glycogen stores to sustain the energy supply required for muscular activity (Chernozub et al., 2024; Shtefiuk et al., 2025).

The study demonstrated that during the subsequent three months of rehabilitation, training protocols that markedly differed from standard physical therapy regimens for MSK-I injuries were applied. However, only partial signs of functional readaptation were observed. At this stage of rehabilitation, a decrease in blood cortisol was observed in both groups during test load C, indicating a low level of systemic resistance to such a stressor. A comparative analysis of the existing scientific literature (Fares et al., 2025; Zachovajevas et al., 2025) shows the lack of a unified framework for optimizing workloads during the long-term rehabilitation of elite combat sport athletes.

During the final eight weeks of the seven-month rehabilitation period, the physical rehabilitation protocols were completely redesigned by kinesiologists. The newly developed protocols included exercises whose kinematic characteristics were 85-90% similar to the technical skills used in MMA. These modifications contributed to an increase in basal levels of creatinine and creatine phosphokinase, alongside a simultaneous decrease in LDH activity in the blood of both groups. Furthermore, the observed changes in biochemical blood markers in response to the developed test loads indicate an effective short-term adaptation mechanism and reflect successful restoration of functional reserves (Cadegiani et al., 2019; Shtefiuk et al., 2025).

Conclusions

The results of this study demonstrate that the most pronounced functional reserve re-adaptation in elite MMA athletes occurs during the first two months of rehabilitation after injury. The findings suggest that standard physical therapy protocols are minimally effective in restoring systemic functions in athletes of this level. Despite a high pre-injury tolerance to physical load, insufficient muscular activity during the first five months of rehabilitation resulted in the development of compensatory responses. A detailed analysis of adaptive and compensatory reactions to test loads during rehabilitation revealed an accelerated depletion of energy reserves. Both muscle glycogen reserves were mobilized, and gluconeogenesis processes were activated under the creatine phosphokinase energy supply.

A comprehensive revision of rehabilitation protocols, including adjusting load regimes and exercises with kinematic characteristics 8-90% similar to the technical skills in MMA, positively influenced the readaptation of functional reserves. These modifications during the final eight weeks of rehabilitation led to the restoration of resistance to loads approximating 75-80% of training intensity. The results provide insight into the widespread issue of low efficiency in restoring functional reserves in elite MMA athletes during long-term rehabilitation after musculoskeletal injuries.

Author's contribution

Andrii Savenko: Methodology, Formal Analysis; **Andrii Chernozub:** Conceptualization, Supervision; **Mutlu Turkmen:** Writing – Review and Editing; **Oleh Olkhovyi:** Data Curation, Visualization; **Ivan Shtefiuk:** Check, Project Administration; **Mukola Korchagin:** Writing – Original draft preparation. All authors have read and agreed with the published version of the manuscript.

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Conflict of Interest

Andrii Savenko, Andrii Chernozub, Mutlu Turkmen, Ivan Shtefiuk, and Mukola Korchagin declared that they have no conflict of interest.

Oleh Olkhovyi is the Editor-in-Chief of *Journal Physical Rehabilitation and Recreational Health Technologies* and a co-author of this article. He was excluded from the editorial decision-making process and peer review related to this manuscript to ensure the independence of the publication process.

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References

Bickley, R., Hazim, N., Sy J., & Nute, D. (2023). An epidemiological study of martial arts injuries in patients presenting to US emergency rooms. *Injury*. 54(12), 111089. https://doi.org/10.1016/j.injury.2023.111089

Cadegiani, F., & Kater, C. (2019). Basal Hormones and Biochemical Markers as Predictors of Overtraining Syndrome in Male Athletes: The EROS-BASAL Study. *J Athl Train*. 54(8), 906-914. https://doi.org/10.4085/1062-6050-148-18

Campos, B., Penna, E., Ogando, P., Rodrigues, J., Albuquerque M., Nakamura F., & Prado, L. (2025). Assessing post-competition recovery in judo: insights into muscle damage and performance. *Res Sports Med.,* 33(4), 448-457. https://doi.org/10.1080/15438627.2025.2471384

Chernozub, A., Olkhovyi, O., Aloshyna, A., Savenko, A., Shtefiuk, I., Marionda, I., Khoma, T., & Tulaydan, V. (2023). Evaluation of the Correlation Between Strength and Special Training Indicators in Mixed Martial Arts. *Physical Education Theory and Methodology*. 23(2), 276–282. https://doi.org/10.17309/tmfv.2023.2.17

Chernozub, A., Korobeynikov, G., Zoriy, Y., Koval, V., Husieva,I., Hryhoriev, V., Xianyu, W., Khasanov, O., & Potop, V. (2024). Mechanism for assessing the adaptive reserves of elite wrestlers under anaerobic energy supply conditions. *Journal of Physical Education and Sport*. 24(9), 1072 – 1079. https://doi.org/10.7752/jpes.2024.09230

Elahi, J., Mangal, R., Stead, T., & Ganti, L. (2024). A nationwide analysis of upper extremity injuries in martial arts. *Orthop Rev (Pavia).* 16, 116363. https://doi.org/10.52965/001c.116363

Fares, M., Baydoun, H., Elhassan, B., & Abboud, J. (2023). Upper limb injuries in mixed martial arts. *Phys Sportsmed*. 51(5), 434-441. https://doi.org/10.1080/00913847.2022.2123257

Fares, M., Stadler, R., Ghanem, D., Mao, J., & Boufadel, P. (2025). Article Return to Sport After Shoulder Injuries in Mixed Martial Arts: Implications on Longevity and Performance. *J. Clin. Med*. 14(11), 3767. https://doi.org/10.3390/jcm14113767

Fiala, O., Hanzlova, M., Borska, L., Fiala, Z., & Holmannova, D. (2025). Beyond physical exhaustion: Understand-

ing overtraining syndrome through the lens of molecular mechanisms and clinical manifestation. *Sports Med Health Sci.* 7(4), 237-248. https://doi.org/10.1016/j.smhs.2025.01.006

Gimigliano, F., Resmini, G., Moretti, A., Aulicino, M., Gargiulo, F., Gimigliano, A., Liguori, S., Paoletta, M., & Iolascon, G. (2021). Epidemiology of Musculoskeletal Injuries in Adult Athletes: A Scoping Review. *Medicina (Kaunas)*. 57(10), 1118. https://doi.org/10.3390/medicina57101118

Hasegawa, M., Obana, K., Ishikawa, K., Tamate, T., Chang, S., & Crawford, S. (2024). Increasing trend in Brazilian Jiu Jitsu injuries presenting to U.S. emergency departments - a 10-year analysis and injury profile. *Phys Sportsmed.* 52(2), 167-174. https://doi.org/10.1080/00913847.2023.2197898

Kingery, M., Kouk, S., Anil, U., McCafferty, J., Lemos, C., Gelber, J., & Gonzalez-Lomas, G. (2022). Performance and return to sport after injury in professional mixed martial arts. *Phys Sportsmed.* 50(5), 435-439. https://doi.org/10.1080/00913847.2021.1953358

Lystad, R., Gregory, K., & Wilson, J. (2014). The Epidemiology of Injuries in Mixed Martial Arts: A Systematic Review and Meta-analysis. *Orthop J Sports Med.* 2(1), 2325967113518492. https://doi.org/10.1177/2325967113518492

Manolachi, V., Chernozub, A., Tsos, A., Syvokhop, E., Marionda, I., Fedorov, S., Shtefiuk, I., & Potop, V. (2023) Modeling the correction system of special kick training in Mixed Martial Arts during selection fights. *Journal of Physical Education and Sport*. 23(8), 2203-221. https://doi.org/10.7752/jpes.2023.08252

Mallardo, M., Daniele, A., Musumeci, G., & Nigro, E. (2024). A Narrative Review on Adipose Tissue and Overtraining: Shedding Light on the Interplay among Adipokines, Exercise, and Overtraining. *Int J Mol Sci.* 25(7), 4089. https://doi.org/10.3390/ijms25074089

Pujalte, G., Bertasi, T., Bertasi, R., Frank ,R., Filmalter, S., Salinas, M., Awadi, A., & Gautam, R. (2023). Physician attitudes toward sports medicine coverage of mixed martial arts. *J Sports Med Phys Fitness*. 63(8), 908-911. https://doi.org/10.23736/S0022-4707.23.14744-X

Ross, A., Ross, B., Zeoli ,T., Brown, S., & Mulcahey, M. (2021). Injury Profile of Mixed Martial Arts Competitions in the United States. *Orthop J Sports Med.* 9(3), 2325967121991560. https://doi.org/10.1177/2325967121991560

Serner, A., Weir, A., Tol, J., Thorborg, K., Lanzinger, S., Otten, R., & Hölmich, P. (2020). Return to Sport After Criteria-Based Rehabilitation of Acute Adductor Injuries in Male Athletes: A Prospective Cohort Study. *Orthop J Sports Med*. 8(1), 2325967119897247. https://doi.org/10.1177/2325967119897247

Shtefiuk, I., Tsos, A., Chernozub, A., Aloshyna, A., Marionda I., Syvokhop E., & Potop V. (2024). Developing a training strategy for teenage athletes in mixed martial arts for high-level competitions. *Journal of Physical Education and Sport*. 24 (2), 329-337. https://doi.org/10.7752/jpes.2024.02039

Shtefiuk, I., Moseichuk, Y., & Chernozub, A. (2025). Systematization of the recovery of adaptive body reserves in qualified MMA athletes during the short-term period between consecutive competitions. *Rehabilitation and Recreation*. 19(1), 229-240. https://doi.org/10.32782/2522-1795.2025.19.1.21

Su, A., Johns, W., Bansal, S. (2024). Martial Arts: Orthopaedic Injuries and Related Biomechanics. *J Am Acad Orthop Surg*. 32(1), e1-e12. https://doi.org/10.5435/JAAOS-D-23-00261

Zachovajevas, V., Engebretsen, L., Moatshe, G., Zachovajevas, P., & Røise, O. (2025). Injuries in Mixed Martial Arts After Adoption of the Unified Rules of MMA: A Systematic Review. *Orthop J Sports Med.* 13(7), 23259671251342578. https://doi.org/10.1177/23259671251342578