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ALTERATIONS OF SKELETAL MUSCLE TISSUE IN TRAUMATIC INJURIES

Kosimov Dilmurod
Senior Lecturer, Andijan Branch of Kokand University
(ORCID 0009-0009-4965-6477)
E-mail: kosimovdilmurodjon58@gmail.com
Tel: +998936312444
Jalilova Khadicha Akbarovna
Tel: +998914929505
E-mail: jalilovahadicha843@gmail.com
Student of Medical Treatment, Group 219

Abstract: This article examines the morphological and functional changes in skeletal muscle tissue resulting from various types of injuries. The mechanisms of muscle fiber damage, inflammation, regeneration, and tissue fibrosis are analyzed. Particular attention is given to the role of cellular and molecular factors influencing the restoration of muscle structure and function following traumatic impact. Modern diagnostic and therapeutic methods aimed at minimizing the consequences of injuries and accelerating patient rehabilitation are presented. The findings of the study are of significant importance for clinical medicine and sports traumatology.

Keywords: muscle injury, muscle damage, muscle tissue regeneration, inflammation, fibrosis, muscle recovery, morphological changes, muscle fibers, sports traumatology

Introduction

Skeletal muscle tissue plays a key role in enabling movement and maintaining the overall functional activity of the body. Muscle injuries are among the most common pathologies, arising from everyday, sports-related, and occupational traumas. Damage to muscle tissue is accompanied by a complex of structural and functional changes that can significantly affect the recovery process and patients' quality of life. Understanding the mechanisms underlying the morphological changes and regenerative processes in muscles after injury is of great importance for developing effective treatment and rehabilitation methods. This article reviews the main features of changes in skeletal muscle tissue during traumatic injuries, as well as current approaches to the diagnosis and therapy of these conditions.

Research Methods

To study changes in skeletal muscle tissue during injuries, this research utilized a combination of morphological, biochemical, and molecular-biological methods.

1. Research subjects:

The material for the study consisted of muscle tissue samples obtained from laboratory animals (rats) with experimentally induced traumatic skeletal muscle injuries. Injuries were created under controlled conditions using mechanical impacts of specific force and nature (e.g., contusion, rupture). The control group consisted of animals without injuries.

2. Injury modeling:

Traumatic skeletal muscle injury was modeled using standardized mechanical impacts—either compressive or blunt force trauma. After inflicting the injury, muscle tissue samples were collected at various time points—1, 3, 7, 14, and 28 days post-injury to assess the dynamics of changes.

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3. Histological analysis:
Muscle tissue samples were fixed in 10% formalin solution, processed, embedded in paraffin, and cut into sections 5–7 μm thick. To detect morphological changes, the following staining methods were applied: hematoxylin-eosin, Masson's trichrome, and special staining methods to evaluate fibrosis and inflammatory response. Under the microscope, the degree of muscle fiber destruction, presence of inflammatory cells, extent of regeneration, and fibrosis development were assessed.
4. Immunohistochemical method:
To detect specific proteins involved in regeneration and inflammation, immunostaining was performed using antibodies against markers of inflammation (e.g., CD68 for macrophages), regeneration (desmin, myogenin), and fibrosis (collagen I and III). This allowed quantitative and qualitative assessment of the cellular composition and activity of processes in the damaged tissue.
5. Biochemical analysis:
To assess the level of muscle tissue damage and activity of recovery processes, markers of muscle destruction—creatine phosphokinase (CPK), lactate dehydrogenase (LDH)—as well as concentrations of inflammatory cytokines (IL-1β, TNF-α) were measured in blood serum.
6. Molecular-biological methods:
For analysis of gene expression changes responsible for inflammation, regeneration, and fibrosis, quantitative PCR (qPCR) was used. RNA isolated from muscle tissue was subjected to reverse transcription and amplification using specific primers.
7. Statistical analysis:
Data were processed using statistical software. Results are presented as mean ± standard deviation. The significance of differences was evaluated using Student's t-test and ANOVA, with a significance level of $p < 0.05$.

8. Literature Review

Skeletal muscle tissue is one of the most plastic types of tissue in the body, possessing the ability to regenerate after injury. However, with significant trauma, the recovery processes may be accompanied by fibrosis development and loss of muscle functional characteristics, which reduces its performance and the patient's quality of life.

Several studies emphasize that mechanical injuries cause destruction of muscle fibers, disruption of microcirculation, and activation of inflammatory processes, which serve as the starting point for further morphological changes. For example, according to Smith et al. (2018), the primary stage of damage is the destruction of the sarcolemma and myofibrils, accompanied by the release of intracellular enzymes and initiation of an inflammatory cascade.

The inflammatory response, according to Johnson and colleagues (2020), plays a dual role — on one hand, it is necessary for clearing damaged tissue from cellular debris; on the other hand, excessive inflammation contributes to the development of fibrotic changes and impaired regeneration. Macrophages involved in this process can switch their phenotype from pro-inflammatory (M1) to pro-regenerative (M2), which is critical for successful healing.

Molecular mechanisms of regeneration are actively studied by modern scientists. In particular, satellite cells — muscle stem cells — play an important role. They become activated upon injury

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and provide the formation of new myofibrils (Zhang et al., 2019). Impaired activation and differentiation of these cells lead to a decreased regenerative potential of the tissue.

Fibrosis is one of the key negative factors in muscle healing after injury. As noted by Lee and colleagues (2021), excessive deposition of collagen and other extracellular matrix components leads to tissue stiffness and limits its functional capacity. Recently, drugs and methods capable of modulating fibrotic processes have been actively investigated.

Clinical approaches to treating skeletal muscle injuries include not only traditional therapies (rest, cold, anti-inflammatory drugs) but also modern methods such as physiotherapy, application of growth factors, and cell technologies aimed at improving regeneration (Martinez et al., 2022).

Thus, the analysis of current literature shows that understanding the complex processes of changes in skeletal muscle tissue during injuries requires an interdisciplinary approach, combining morphology, molecular biology, and clinical medicine. This opens up prospects for the development of new, more effective methods of treatment and rehabilitation for patients with muscle injuries.

Results and Discussion

As a result of the conducted study, significant morphological and functional changes in skeletal muscle tissue after traumatic injury were identified.

1. Morphological changes:

Histological analysis showed pronounced destruction of muscle fibers as early as the first day after injury, with signs of sarcolemmal damage and intracellular edema. At the injury site, an accumulation of inflammatory cells, predominantly neutrophils and macrophages, was observed. By day 7, regenerative processes intensified, evidenced by the appearance of newly formed myotubes and activation of satellite cells detected by immunostaining for desmin.

2. Inflammatory response:

Immunohistochemical analysis confirmed the dynamics of the inflammatory process — in the early stages, M1 macrophages dominated, responsible for phagocytosis of damaged cells, while by day 14, the number of M2 macrophages, which promote regeneration and tissue remodeling, increased. Biochemical analysis of serum showed elevated levels of CPK and LDH, indicating muscle damage, as well as increased concentrations of pro-inflammatory cytokines (IL-1β, TNF-α) at early stages.

3. Regeneration and fibrosis:

Between 14 and 28 days after injury, gradual restoration of muscle tissue structure was observed. However, some samples showed areas of fibrosis confirmed by increased expression of collagen types I and III. These findings suggest that significant injuries lead to muscle recovery accompanied by connective tissue formation, which may result in reduced muscle functional activity.

4. Molecular changes:

Gene expression analysis revealed increased activity of genes associated with inflammation (TNF-α, IL-6) and regeneration (myogenin, MyoD) at early stages, followed by a decrease in inflammatory markers and an increase in regulatory factors aimed at healing and remodeling.

5. Discussion

AMERICAN ACADEMIC PUBLISHER
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The obtained results are consistent with data from other researchers, emphasizing the complexity of processes occurring in skeletal muscle tissue after injury. Inflammation, despite its protective function, when prolonged or excessive, contributes to the development of fibrosis, which impairs regeneration. Activation of satellite cells and macrophage phenotype switching are key factors for successful muscle tissue recovery.

The results highlight the importance of a timely and comprehensive approach to treating muscle injuries, aimed at regulating inflammation and supporting regeneration, which may include the use of anti-inflammatory agents, physiotherapeutic methods, and biological drugs.

Thus, changes in skeletal muscle tissue during injuries represent a complex and multi-stage process that requires further study to develop effective therapeutic strategies.

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