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ATPase ACTIVITY OF ACTOMYOSIN AND MYOSIN IN DIFFERENT TYPES OF MUSCLES OF INTACT AND IRRADIATED ANIMALS

G. F. Stepanov, R. S. Vastyanov, A. A. Kostina, N. V. Lazor

Odesa National Medical University, Odesa, Ukraine

Abstract

The large-scale use of sources of ionizing radiation and related accidents caused a fundamentally new problem. The body's resistance to the influence of adverse environmental factors and the probability of pathological disorders are significantly determined by the state of adaptive systems. One of the general manifestations of adaptation is a change in motor activity, which is associated, in particular, with changes in the content of contractile proteins, muscle function, and muscle contraction. It is crucial to understand the detailed mechanisms of muscle tissue functioning in the body of intact animals and animals exposed to different doses of radiation because, in this case, preventive and curative/rehabilitative medical measures should be milder for muscle dysfunctions caused by ionizing radiation The purpose of the work is to investigate the effect of different doses of radiation on Mg^{2+}, Ca^{2+}-ATPase and K^{+}-ATPase activity of actomyosin and myosin in the mechanisms of intact and irradiated in different doses of sexually mature animals in order to find out the mechanisms of adaptation of the organism to the influence of stress factor by studying changes in the activity of Mg^{2+}, Ca^{2+}-ATPase and K^{+}-ATPase in the muscle system. The data obtained showed that irradiation at a dose of 0.5 Gy

affects Mg^{2+},Ca^{2+}-ATPase and K^{+}-ATPase activity, however, these changes occur differently. K^{+}-ATPase actomyosin activity in cardiac and skeletal muscles decreased starting from the 1st day of the experiment. Its gradual increase was observed only on the 30th day but still, it was smaller when compared with such an indicator in intact animals. It was proved that the Mg^{2+}, Ca^{2+}-ATPase actomyosin activity in sexually mature animals irradiated at a dose of 1.0 Gy increased 1 day after irradiation in skeletal muscle. In cardiac muscle an acute increase in Mg^{2+}, Ca^{2+}-ATPase actomyosin activity was observed on the 1st day and its decrease - by the 30th day. The conclusion was made that irradiation at a dose of 1.0 Gy is accompanied by skeletal muscle damage, as well as modification of the actomyosin protein complex, which is the major unit of muscle contraction. This leads to changes in its functional activity and is expressed in an increase in K^{+}-ATPase actomyosin activity of muscles sensitive to irradiation. We assume such a mechanism of the effect of ionizing radiation on the actomyosin complex. The authors sure that a decrease in Mg^{2+}, Ca^{2+}-ATP-ase myosin activity as a result of exposure to ionizing radiation at a dose of 1.0 Gy can be caused by a violation of the structure of its active center since the ATPase center of pure myosin is free from interaction with actin, and that is why myosin appears more sensitive to the action of ionizing radiation.

Key words: irradiated animals; muscle tissue; actomyosin; myosin; Mg^{2+}; Ca^{2+}-ATPase; K^{+}-ATPase activity; adaptation; pathophysiological mechanisms

The large-scale use of sources of ionizing radiation and related accidents caused a fundamentally new problem: the existence of ionizing radiation as a permanently active environmental factor, dangerous to varying degrees depending on the dose of radiation, duration of action, and other characteristics. The adverse effect of ionizing radiation on metabolic processes in the living organism is generally recognized [1, 5, 8, 10].

The body's resistance to the influence of adverse environmental factors and the probability of pathological disorders are significantly determined by the state of adaptive systems [6]. One of the general manifestations of adaptation is a change in motor activity, which is associated, in particular, with changes in the content of contractile proteins, muscle function, and muscle contraction. Since the process of muscle contraction is associated with the formation of the actomyosin complex and its subsequent conformational changes due to the energy released as a result of the enzymatic splitting of ATP by myosin, the ATPase activity of actomyosin is the characteristic by which the contractile activity of muscles can be assessed [7].

The main functional characteristic of actomyosin (AM) is ATPase activity. Since the process of muscle contraction is associated with the formation of the actomyosin complex and its subsequent conformational changes due to the energy released as a result of the enzymatic splitting of ATP by myosin, the ATPase activity of actomyosin is the characteristic by which the contractile activity of muscles can be assessed. Mg^{2+}, Ca^{2+} +-ATPase activity is detected in the presence of Mg^{2+}, Ca^{2+}+ ions in the environment, which are necessary for muscle contraction.

Actomyosin is characterized by Mg^{2}+-ATPase activity, and Mg^{2+}-ATP is the substrate of actomyosin ATPase. In the presence of Ca^{2+}, this ATPase activity increases. In the absence of divalent cations achieved by adding EDTA to the solution, myosin ATPase is activated by monovalent cations K^{+}, NH_4^{+}, and Rb^{+}. This myosin activity was called EDTA-ATPase or K^{+}-ATPase activity. Monovalent cations reduce the myosin's ability to bind ATP, so contraction is activated to a lesser extent. K^{+}-ATPase activity is a relaxing ATPase activity in the absence of divalent cations. The K^{+}-ATPase reaction rate is limited at the stage of ATP binding (much weaker than in the case of divalent cations) [12].

With all of the above, it is crucial to understand the detailed mechanisms of muscle tissue functioning in the body of intact animals and animals exposed to different doses of radiation because, in this case, preventive and curative/rehabilitative medical measures should be milder for muscle dysfunctions caused by ionizing radiation.

The aim of the work is to investigate the effect of different doses of radiation on Mg^{2+}, Ca^{2+}-ATPase and K^{+}-ATPase activity of actomyosin and myosin in the mechanisms of intact and irradiated in different doses of sexually mature animals in order to find out the mechanisms of adaptation of the organism to the influence of stress factor by studying changes in the activity of Mg^{2+}, Ca^{2+}-ATPase and K^{+}-ATPase in the muscle system.

Material and Methods

The studies were conducted on sexually mature male rats weighing 180-220 g of the Wistar line and kept on a standard vivarium diet. Keeping, processing, and manipulation of animals was carried out following the "General Ethical Principles of Animal Experiments" adopted by the Fifth National Congress on Bioethics (Kyiv, 2013) while being guided by the recommendations of the European Convention on the Protection of Vertebrate Animals for Experimental and Other Scientific Purposes (Strasbourg, 1985), the methodological recommendations of State Pharmacology Center the Ministry of Health of Ukraine "Preclinical studies of drugs" (2001) and the rules of humane treatment of experimental

animals and conditions approved by the Bioethics Commission of the Odesa National Medical University (Record No. 32Д dated March 17, 2016).

The animals were divided into groups as follows:

1. Intact sexually mature animals
2. Mature animals irradiated at a dose of 0.5 Gy
3. Adult animals irradiated at a dose of 1.0 Gy

There were 7-10 animals in each group

Animals were removed from the experiment by euthanasia under propofol (IV, 60 mg/kg) anesthesia. After the animals were dissected, the blood was collected, and the heart and the anterior thigh muscles were removed. The removed cardiac and skeletal muscles were washed with chilled 0.9% physiological NaCl solution, minced and homogenized in a 9-fold volume of 0.32 mol sucrose per 0.05 mol Tris buffer, pH 7.36 in a homogenizer with Teflon surfaces and subjected to differential centrifugation in a refrigerated centrifuge PC-6. Nuclei were precipitated at 1000g for 10 min., then mitochondria at 12000g for 20 min., resuspended in a homogenizer in an isolation medium containing 0.1% triton X-100 solution at the rate of 1 ml of 0.1% triton solution per 500 mg of tissue and left in ice for 30-35 min.

We focused on the determined Mg^{2+}, Ca^{2+}-ATPase and K^{+}-ATPase activities of actomyosin and myosin.

The ATPase activity of actomyosin and myosin was determined by the amount of inorganic phosphate (P*i*), which resulted from ATP hydrolysis, according to the Fiske-Subbarou method [4]. The ATPase reaction was performed at 37°C in the incubation medium (total sample volume – 1.8 ml) with the following concentrations: for actomyosin Mg^{2+}, Ca^{2+}-ATPase: 2.5 mM MgCl2, 0.1 mM CaCl2, 50 mM KCl, imidazole buffer 20 mM (pH 7.5), 0.28 mg/ml actomyosin; for actomyosin K^{+}-ATPase: 1 mM EGTA, 50 mM KCl, imidazole buffer 20 mM (pH 7.5), 0.28 mg/ml actomyosin; for myosin Mg^{2+}, Ca^{2+}-ATPase: 2.5 mM $MgCl_2$, 0.1 mm $CaCl_2$, 50 mm KCl, 20 mm imidazole buffer (pH 7.5), 0.14 mg/ml myosin; for of myosin K^{+}-ATPase: 1 mM EDTA, 50 mM KCl, imidazole buffer 20 mM (pH 7.5), 0.14 mg/ml myosin. The ATPase reaction was initiated by adding 0.2 ml of 1 mM ATP to the incubation medium and expressed in nmol P*i*/min per 1 mg protein. The reaction was stopped after 5 min by adding 0.45 ml of 20% trichloroacetic acid to the sample (the final content in the sample was 4%). Afterward, the samples were centrifuged for 15 min at 2500 rpm; 1.5 ml of supernatant was taken from each test tube to determine the amount of separated P in it and by its characteristic color. For this purpose, 0.5 ml of 0.2% ascorbic acid and 0.25 ml of 2% molybdenum reagent were added to each sample. After 20 min, the absorbance of the medium

was measured at a wavelength of 720 nm, which corresponds to the absorption maximum of molybdenum blue. The amount of P*i* in the sample was calculated according to the calibration curve built for particular concentrations.

ATPase activity of actomyosin was determined by the formula:

$A = [(P\text{-}K) \cdot Vtotal] \cdot N/[t_{incub.} \cdot xVkxVprxSpr]$,

where P is the sample absorption value;

K is the control absorption value;

Vtotal – the total volume in which the color reaction is carried out;

$t_{incub.}$ – protein incubation time with ATP;

Vk is the volume of protein added to the sample;

Vpr – the volume of the selected supernatant after centrifugation of the samples;

Spr – added protein concentration;

N is the calibration coefficient.

The obtained data were subjected to statistical processing by the method of estimating the mean with the help of "T-tables" using the χ^{2} criterion and computer programs. The minimum statistical probability was determined at $p<0.05$.

Results

As a result of the conducted studies, it was shown that irradiation at a dose of 0.5 Gy affects both Mg^{2+}, Ca^{2+}-ATPase, and K^{+}-ATPase activity, but they change differently. Starting from the 1st day, Mg^{2+}, Ca^{2+}-ATPase actomyosin activity was increasing in both skeletal and cardiac muscles, reaching its peak in cardiac muscle on the 15th day. In contrast to skeletal muscle, where this indicator reached its peak on the 7th day, and starting from the 15th day, its gradual decrease was observed; in cardiac muscle, a slight fall was observed only on the 30th day, but still, this indicator in both skeletal and cardiac muscles was greater compared to that in intact animals.

As for the K^{+}-ATPase activity of actomyosin in cardiac and skeletal muscles, starting from the 1st day, it decreased compared to this indicator in intact animals. Its gradual increase was observed only on the 30th day, but still, it was lower than the indicator in intact animals (Tables 1 and 2).

Comparing data on the effect of ionizing radiation at a dose of 0.5 Gy on ATPase activity, it can be assumed that small doses of radiation form a positive adaptive response, which is accompanied by an increase in Mg^{2+}, Ca^{2+}-ATPase activity due to the formation of a strong form of binding between F-actin and myosin, actin monomers pass into the "on state" of actomyosin, typical for this stage, and myosin heads acquire an ordered orientation in the

muscle fiber. An increase in Mg^{2+}, Ca^{2+}-ATPase activity and a decrease in K^{+}-ATPase activity may be associated with the predominance of AM*•ADP•Pi and AM**•ADP•P*i* intermediates.

Table 1

ATPase activity of actomyosin and myosin in skeletal muscle of sexually mature animals irradiated with a dose of 0.5 Gy (nmol P*i* /min per mg of protein)

The investigated indicators	Intact rats, n=10	Irradiated rats at term				
		1 day, n=10	3 days, n=10	7 days, n= 9	15 days, n= 9	30 days, n= 9
Mg^{2+}, Ca^{2+}-ATPase activity of actomyosin	96.5 ± 11.32	115.2 ± 11.89	138.1 ± 12.34*	142.4 ± 12.58*	136.3 ± 12.26*	132.8 ± 12.18
K^{+}-ATPase activity of actomyosin	17.8±2.76	16.7 ± 2.73	16.1 ± 2.72	15.8 ± 2.69	15.6 ± 2.68	16.3 ± 2.71
Mg^{2+}, Ca^{2+}-ATPase activity of myosin	104.2 ± 8.52	112.4 ± 8.56	114.7 ± 8.58	115.3 ± 8.57	116.2 ± 8.59	112.9 ± 8.54
K^{+}-ATPase activity of myosin	50.6±3.26	50.1 ± 3.25	50.8 ± 3.27	51.2 ± 3.28	50.9 ± 3.26	50.7 ± 3.25

Note.* - P<0.05 – probable differences of the studied indicators compared to the corresponding indicators in intact animals.

Table 2

ATPase activity of actomyosin and myosin in heart muscle of sexually mature animals irradiated at a dose of 0.5 Gy (nmol P*i*/min per mg of protein)

The investigated indicators	Intact rats, n=10	Irradiated rats at term				
		1 day, n=10	3 days, n=10	7 days, n= 9	15 days, n= 9	30 days, n= 9
Mg^{2+}, Ca^{2+}-ATPase activity of actomyosin	108.8 ± 10.66	111.6 ± 11.21	119.8 ± 12.16	123.2 ± 12.28	123.9 ± 12.27	120.8 ± 12.26
K^{+}-ATPase activity of actomyosin	24.8±3.16	23.7 ± 3.15	23.1 ± 3.14	22.8 ± 3.12	22.3 ± 3.11	23.8 ± 3.15
Mg^{2+}, Ca^{2+}-ATPase activity of myosin	116.9 ± 6.84	117.8 ± 6.85	118.4 ± 6.87	119.1 ± 6.86	124.9 ± 6.89	117.8 ± 6.85
K^{+}-ATPase activity of myosin	52.88 ± 3.30	52.63 ± 3.27	52.58 ± 3.26	52.49 ± 3.27	52.38 ± 3.23	52.59 ± 3.28

In the case of action of ionizing radiation at a dose of 0.5 Gy on pure myosin, data were obtained on an increase in Mg^{2+}, Ca^{2+}-ATPase activity of myosin compared to the control on the 1st, 3rd and 7th days, and its slight decrease on the 30th day after irradiation in both cardiac and skeletal muscles.

K^+-ATPase activity of myosin practically did not change at all times after irradiation compared to the indicator in intact animals.

Studies of the Mg^{2+}, Ca^{2+}-ATPase activity of actomyosin in sexually mature animals irradiated at a dose of 1.0 Gy established that one day after irradiation, this indicator in skeletal muscle increased slightly, and then, with time after irradiation, it decreased, reaching the lowest value on the 30th day. In the heart muscle, a sharp elevation of this indicator was observed on the 1st day, and its decrease occurred by the 30th day, but still, this indicator remained higher than that in intact animals (Tables 3 and 4).

Table 3

ATPase activity of actomyosin and myosin in skeletal muscle of sexually mature animals irradiated with a dose of 1.0 Gy (nmol P*i*/min per mg of protein)

The investigated indicators	Intact rats, n=10	Irradiated rats at term				
		1 day, n=10	3 days, n=10	7 days, n= 9	15 days, n=8	30 days, n= 7
Mg^{2+}, Ca^{2+}-ATPase activity of actomyosin	96.5 ± 11.32	98.8 ± 11.74	92.9 ± 11.62	92.3 ± 11.56	91.8 ± 11.54	90.7 ± 11.52
K^+-ATPase activity of actomyosin	17.8±2.76	16.8 ± 3.25	18.6 ± 3.22	17.4 ± 3.18	17.9 ± 3.14	17.3 ± 3.12
Mg^{2+}, Ca^{2+}-ATPase activity of myosin	104.2 ± 8.52	101.4 ± 8.46	99.2 ± 8.38	98.3 ± 8.24	96.8 ± 8.22	98.6 ± 8.25
K^+-ATPase activity of myosin	50.6±3.26	50.6 ± 3.25	66.84± 3.92*	64.38± 3.86*	62.52± 3.84*	60.86 ± 3.72

Note.* - $P<0.05$ – probable differences of the studied indicators compared to the corresponding indicators in intact animals.

As for the K^+-ATPase activity of actomyosin in skeletal muscle, on the 1st day, a slight decrease was observed; on the 3rd day, there was a slight increase compared to this indicator in intact animals, and then, with time after irradiation, its activity gradually decreased, but still exceeded this indicator compared to that in intact animals, in contrast to heart muscle, where the K^+-ATPase activity of actomyosin gradually decreased with time after irradiation and reached its lowest value on the 30th day compared to that indicator in intact animals.

Table 4

ATPase activity of actomyosin and myosin in the heart muscle of sexually mature animals irradiated with a dose of 1.0 Gy (nmol P*i*/min per mg of protein)

The investigated indicators	Intact rats, n=10	Irradiated rats at term				
		1 day, n=10	3 days, n=10	7 days, n=9	15 days, n=8	30 days, n=7
Mg^{2+}, Ca^{2+}-ATPase activity of actomyosin	108.8 ± 10.66	129.2 ± 10.94	118.6 ± 10.72	119.4 ± 10.68	126.8 ± 10.56	116.4 ± 10.54 *
K^{+}-ATPase activity of actomyosin	24.8±3.16	21.8 ± 3.14	20.4 ± 3.12	20.2 ± 3.18	20.8 ± 3.16	20.2 ± 3.16
Mg^{2+}, Ca^{2+}-ATPase activity of myosin	116.9 ± 6.84	118.6 ± 6.84	110.2 ± 6.68	104.6 ± 6.56	102.4 ± 6.48	100.8 ± 6.34
K^{+}-ATPase activity of myosin	52.88 ± 3.30	60.26 ± 4.24	68.48± 4.22 *	74.46± 4.18 *	72.32± 4.16 *	70.84± 4.14 *

Note.* - $P<0.05$ – probable differences of the studied indicators compared to the corresponding indicators in intact animals

Discussion

Thus, our data highlighted some interesting points of changing the biochemical mechanisms of muscle contraction of different types of muscles in rats under exposure to various doses of ionizing radiation. The interest in the data obtained, which are a fragment of scientific research of the pathophysiological mechanisms of adaptation of muscle tissue under the action of ionizing radiation, lies in the fact that immediately before elucidating the biochemical energy processes characteristic of muscles, it is important to determine the features of the contractile function according to norm conditions. At the same time, of course, bearing in mind the features of expected muscle work in response to stressful effects of any genesis and etiology.

Biochemical mechanisms of the development of various clinical pathologies of muscle tissue in the conditions of constant exposure to small doses of ionizing radiation manifested by a decrease in muscle mass, muscle weakness, difficulty walking, and convulsions remain poorly understood. In particular, this applies to the most significant contractile element of muscle fibers - the actomyosin complex, the main functional proteins of which are actin and myosin. It has ATPase activity, i.e., the ability to split ATP molecules, releasing the energy necessary to ensure muscle contraction.

It is known that the mechanisms of action of Mg^{2+}, Ca^{2+}-ATPase and K^{+}-ATPase are different. The Mg^{2+}, Ca^{2+}-ATPase reaction proceeds according to the following mechanism [11]:

AM+ATP ↔ AM* ATP ↔ AM**•ADP•P*i* ↔ AM^•ADP+P*i* ↔ AM+ADP

In actomyosin, there is a cycle of bridge formation between actin and myosin, the strength of which depends on the products of the Mg^{2+}, Ca^{2+}-ATPase reaction located in the active center of the enzyme. During ATP hydrolysis, intermediate complexes AM*•ADP•P*i* and AM**•ADP•P*i* are formed in the active center. The formation of these complexes is accompanied by conformational changes of the myosin molecule, which leads to the formation of bonds between myosin and actin, but at an angle different from the angle of these bridges in actomyosin in the absence of ATP. The formation of the latter significantly accelerates the process of isomerization of AM*•ADP•P*i* and AM**•ADP•P*i* intermediates and the removal of ATPase reaction products from the active center. The mechanism of the K+-ATPase reaction is somewhat simpler:

AM+ATP ↔ AM•ATP ↔ AM+ADP+P*i*.

In the case of K^{+}-ATPase, the complex of actomyosin with reaction products is not formed and the reaction rate is limited by the stage of binding to ATP (much weaker than in the case of divalent cations) and its hydrolysis.

The biosynthesis of ATP, performed by a system of redox enzymes localized in the inner membrane of the mitochondria of the respiratory chain, belongs to the vital processes that are directly disturbed under the action of ionizing radiation. A high degree of damage to this system is due to the significant radiosensitivity of metal-containing enzymes (which mainly make up the respiratory chain). Violation of bioenergetic processes due to damage to the respiratory chain leads to ATP deficiency in the cell, the result of which can be either the death of the cell due to a lack of energy for the functioning of repair systems and the performance of vital functions, or the transition of the cell to a more primitive type of energy supply [3].

In addition, it was shown that the high content of ATP and the somewhat low level of ADP and AMP in cardiac muscle compared to skeletal muscle is primarily associated with a significant content of mitochondria, in which the processes of tissue respiration function intensively, providing this muscle with a higher ATP content, unlike skeletal muscle, where the ATP pool is replenished mainly by the glycolytic pathway [2, 9].

Therefore, irradiation at a dose of 1.0 Gy is accompanied by skeletal muscle damage and modification of the actomyosin protein complex, which is the principal unit of muscle

contraction. That leads to changes in its functional activity and is expressed in increased K^+-ATPase activity of actomyosin of muscles sensitive to irradiation.

Comparing the data on the effect of ionizing radiation on ATPase activity, the following mechanism of the effect of ionizing radiation on the actomyosin complex can be assumed. A decrease in ATPase activity under the action of ionizing radiation on skeletal muscles occurs due to the formation of a weak form of binding of myosin to actin (stage AM•ATP and AM•ADP•P*i*), disorientation of myosin heads is observed and actin monomers go into the "disabled state".

In the case of the action of ionizing radiation at a dose of 1.0 Gy on pure myosin, the data on a decrease in Mg^{2+}, Ca^{2+}-ATPase myosin activity compared to the control at all times after irradiation in skeletal muscle were obtained. The increase on the 1st day and decrease with increasing time after irradiation were observed in cardiac muscle, where this indicator remained lower than the indicator in intact animals. A decrease in Mg^{2+}, Ca^{2+}-ATPase myosin activity may be caused by a violation of the structure of its active center since the ATPase center of pure myosin is free from interaction with actin, and that is why myosin is more sensitive to the effects of ionizing radiation.

K^+-ATP-ase activity of myosin in cardiac and skeletal muscles at all times after irradiation increased, reaching its maximum value on the 7th day in both types of muscles, and starting from the 15th day, a tendency to decrease this indicator was observed, however, at the same time, this indicator remains higher than intact animals.

Conclusions

The obtained data highlighted some interesting points of changing the biochemical mechanisms of muscle contraction of different types of muscles in rats under exposure to various doses of ionizing radiation.

Irradiation at a dose of 0.5 Gy affects Mg^{2+}, Ca^{2+}-ATPase and K^+-ATPase activity, however, these changes occur differently. Mg^{2+}, Ca^{2+}-ATPase actomyosin activity, starting from the 1st day, increased in skeletal and cardiac muscle, reaching its peak in cardiac muscle on the 15th day, in contrast to skeletal muscle, where this indicator reached its peak on the 7th day, and starting from the 15th day, its gradual decrease was observed. In cardiac muscle, a slight decrease was observed only on the 30th day, but still, this indicator in both skeletal and cardiac muscles was greater compared to that in intact animals.

K^+-ATPase actomyosin activity in cardiac and skeletal muscles decreased starting from the 1st day of the experiment. Its gradual increase was observed only on the 30th day, but still, it was smaller when compared with such an indicator in intact animals.

It was proved that the Mg^{2+}, Ca^{2+}-ATPase actomyosin activity in sexually mature animals irradiated at a dose of 1.0 Gy increased 1 day after irradiation in skeletal muscle. Then, as the period after irradiation increased, the value of the studied indicator decreased, reaching the lowest value on the 30th day. In the heart muscle, an acute increase in Mg^{2+}, Ca^{2+}-ATPase actomyosin activity was observed on the 1st day and its decrease - by the 30th day, however, this indicator remains higher compared to that in intact animals.

Therefore, irradiation at a dose of 1.0 Gy is accompanied by skeletal muscle damage, as well as modification of the actomyosin protein complex, which is the major unit of muscle contraction. This leads to changes in its functional activity and is expressed in an increase in K^{+}-ATPase actomyosin activity of muscles sensitive to irradiation. We assume such a mechanism of the effect of ionizing radiation on the actomyosin complex. A decrease in ATPase activity under exposure to ionizing radiation on skeletal muscles occurs due to the formation of a weak form of binding of myosin to actin (stage AM•ATP and AM•ADP•Pi), disorientation of myosin heads is observed, and actin monomers go into the "disabled state".

We are sure that a decrease in Mg^{2+}, Ca^{2+}-ATP-ase myosin activity as a result of exposure to ionizing radiation at a dose of 1.0 Gy can be caused by a violation of the structure of its active center since the ATPase center of pure myosin is free from interaction with actin, and that is why myosin appears more sensitive to the action of ionizing radiation.

References

1. Andrushkiv B. Neglecting the problems of the Chernobyl tragedy is a consequential chain of the emergence of modern problems of a full-scale war with Russia. Science and information bulletin of the National Academy of Sciences of Higher Education of Ukraine. 2022; 1(112): 13-18 [In Ukrainian].

2. Biological and bioorganic chemistry. Ed by Yu.I. Gubskyi, I.V. Nizhenkovska. Kyiv. 2017. 544 [In Ukrainian].

3. Hroza VI. Radiobiology: a course of lectures. Mykolaiv : MNAU. 2018. 103 [In Ukrainian].

4. Medynska KO, Nuryshchenko NYe, Peliukh LI, Sheliuk OV. ATPase activity of rabbit skeletal muscles actomyosin complex under ultrasound effect. Ukrainian biochemical journal. 2012; 84(4): 54-60 [In Ukrainian].

5. Pechyborshch VP, Volyanskyi PB, Yakimets VM, Voronenko VV, Khizhnyak MI. Medical protection of the population in emergency situations in the unified state system of civil protection. Kyiv : Lyudmila Publishing House. 2019. 693 [In Ukrainian].

6. Trofymiak Yu. The impact of ionizing radiation on indicators of physical development and adaptation capabilities of adolescents. Scientific Bulletin of Lesya Ukrainka East European National University. 2017; 7(356): 202-208 [In Ukrainian].

7. Baynes J., Dominiczak M. Medical Biochemistry. 5th Edition. Elsevier, 2018. 712 p.

8. Konoplev A. Fukushima and Chernobyl: Similarities and Differences of Radiocesium Behavior in the Soil–Water Environment. Toxics. 2022; 10(10): 578. doi: 10.3390/toxics10100578

9. Moroz VM, Shandra OA, Vastyanov RS, Yoltukhivsky MV, Omelchenko OD. Physiology. Vinnytsia : Nova Knyha, 2016: 722.

10. Stepanov G.F., Vastyanov R.S. The peculiarities of low-dose ionizing radiation influence on muscles metabolism in experimental animals. World of Medicine and Biology. 2023; 2(84): 233-238. doi: 10.26724/2079-8334-2023-2-84-233-238

11. Ušaj M, Moretto L, Vemula V, Salhotra A, Månsson A. Single molecule turnover of fluorescent ATP by myosin and actomyosin unveil elusive enzymatic mechanisms. Commun Biol. 2021; 4(1): 64. doi: 10.1038/s42003-020-01574-0

12. Zhang XC, Feng W. Thermodynamic aspects of ATP hydrolysis of actomyosin complex. Biophys Rep. 2016; 2(5): 87-94. doi: 10.1007/s41048-016-0032-5

Author Contributions

Conceptualization, (Stepanov G.F. & Vastyanov R.S.); methodology, (Stepanov G.F. & Kostina A.A.); formal analysis, (Kostina A.A.); data curation, (Lazor N.V.); writing—original draft preparation, (Lazor N.V.); writing—review and editing, (Kostina A.A.); supervision (Stepanov G.F. & Vastyanov R.S.).

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Institutional Review Board Statement

The experimental studies were carried out in the conditions of a chronic experiment in accordance with international standards of humane treatment of vertebrate animals and approved by the Ethics Committee of Odesa National Medical University (N7/21, 11 October 2021)

Informed Consent Statement

The data of experimental studies are given. Written informed consent from the patients was not necessary to publish this paper.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Conflicts of Interest

The authors declare no conflict of interest.