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THE EFFECT OF THE ALUMINUM CHLORIDE – QUERCETIN COMPLEX ON Ca^{2+},Mg^{2+}-ATPase ACTIVITY AND CONTRACTION DYNAMIC PROPERTIES OF MUSCLE TIBIALIS ANTERIOR FROM *RANA TEMPORARIA*

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Combined effect of aluminum chloride and quercetin solutions on the enzymatic activity and contraction dynamics of muscle fiber bundles of the Rana temporaria m. tibialis anterior was investigated. It was shown that these complexes inhibit muscle contraction. Linear reduction of Ca^{2+},Mg^{2+}-ATPase activity induced by all of the used concentrations of $AlCl_3$ – quercetin was demonstrated. It was found that complex of quercetin with $AlCl_3$ has a greater inhibitory effect on muscle contraction dynamic and causes greater reduction during all periods of stimulation in comparison to the separate effect of the investigated compounds. All the studied concentrations of $AlCl_3$ and quercetin solutions ($AlCl_3$: 10^{-4}-10^{-2} M; quercetin: 10^{-6}-10^{-5} M) caused concentration depended contraction strengths and lengths reduction. The decrease in strength and length of muscle contractions was of constant and mostly linear nature within observed timeframe as well as within each periods of contraction. The changes were least pronounced within pretetanic period, but were profound within terminal period of muscle activity. The changes in dynamic contraction properties and Ca^{2+},Mg^{2+}-ATPase activity of sarcoplasmic reticulum under effect of the investigated compounds was minimal in the beginning of the muscle's response to stimulus, prior to muscle strength reaching stable contraction level.

K e y w o r d s: aluminum, muscle contraction, Ca^{2+},Mg^{2+}-ATPase activity, strength, length.

Flavonoids, biologically active substances of natural origin, are effective as modulators of muscle contraction-relaxation cycle [1]. Flavonoids are known to affect contractile systems of various biological objects. They have been demonstrated to regulate activity of all types of muscles, including smooth, skeletal, and cardiac muscle [2, 3]. It has been shown that quercetin acts as a competitive inhibitor in ATP binding to an enzyme. Inhibition of Ca^{2+} transport through T-tubules by quercetin has been described [4]. The main effect of this flavonoid is therefore supposed to manifest in stabilization of conformation of an enzyme's phosphorylated intermediate in a state that prohibits sarcoplasmic reticulum's (SR) vesicles from capturing Ca^{2+}.

Aluminum is studied extensively as one of the metals capable of creating complex compounds with flavonoids [5], especially so because it is widely used as a major component in modern technical and household appliances. Flavonoid complexes with metals are known to have better membrane permeability properties than flavonoids themselves, which increases their efficiency [6]. Moreover, chelate complexes of flavonoids and metals act as free radical scavengers and detoxicants [7, 8]. Aluminum-flavonoid complexes may be produced during cooking of vegetable food in an aluminum vessel and consequently consumed [3]. It has been shown [6], that flavonoid interaction with metal ions, e.g. aluminum, may change the flavonoid's properties and biological effects. In the case of quercetin, the complexes are produced first at positions 3 and 4. The functional groups at positions 3′ and 4′ are bound to metal afterwards. The 5-OH group does not participate in reactions with metals due to steric constrains arising from binding to 3-OH and 4-OH groups. The chelation sites for rutin are primarily 3′ and 4′ -OH groups, and also 7-OH.

We studied changes in dynamic parameters of contraction of electrically stimulated isolated frog muscle fibers under non-cholinergic effect of investigated compounds [9], which improves considerably

upon understanding of toxic effects of quercetin-aluminum complexes on skeletal muscle, since disruption in muscle function under the effect of such compounds is generally viewed as resulting from acetylcholinesterase inactivation.

Changes in ATPases activity under aluminum and quercetin effect may be an important factor in cellular dysfunction caused by disruption of transmembrane cation transport [3]. Thus, Ca^{2+},Mg^{2+}-ATPase activity decrease probably results from compromised structural integrity of membranes of SR and not from direct effect of flavonoids and their metallic complexes upon the enzyme [10].

Muscle fiber contraction should not be viewed as a uniform and smooth process. The timeframes of single contractions represent a synchronized process of interaction between components of a sarcomere in a neatly choreographed step-by-step procedure [11]. We therefore primarily determined the timeframe for setting in of equilibrium stable state of contraction under the effect of the investigated compounds.

Thus, from both theoretical and practical point it is important to research the effects of quercetin, a substance frequently encountered in living systems, as well as of its complexes with aluminum, which is ubiquitous in pharmaceuticals, industry, and household, upon particular states of skeletal muscle contraction dynamics. Since quercetin is capable of producing complexes with metals, in particular with aluminum (which is known to have good membrane permeability properties), the aim of the present work was to investigate the effect of aluminum chloride solutions with quercetin on Ca^{2+},Mg^{2+}-ATPase activity of SR and dynamics of electrostimulated muscle contraction of isolated thin muscle fibers.

Materials and Methods

The experiments were performed on m. tibialis anterior muscle fibers from a hind leg of *Rana temporaria* frog. Mature individuals of both sexes were used. The experiments were performed in isotonic solution under constant monitoring of dynamic parameters of contraction. Contractile strength, length change, washing solution temperature and stimulating signal parameters were monitored. The experiments were performed in constant circuit Ringer solution with relaxation period of 3 min. Temperature was maintained by thermostat.

The contractile force of skeletal muscle fibers was determined with a tensometer device [12].

SR was isolated from frog skeletal muscles by differential centrifugation [13]. Ca^{2+},Mg^{2+}-ATPase activity of SR was determined by spectrophotometry and expressed as nanomol of inorganic phosphate per milligram of protein per minute in incubation medium. Protein concentration was determined by Bradford assay [14]. Inorganic phosphate was estimated by Fiske and Subbarow method [15]. The method is based on colorimetric determination of concentration of inorganic phosphate produced as a result of enzymatic hydrolysis of ATP. Phosphoric acid reacts with molybdic acid, producing a complex compound that is easily reduced by various reducing substances to blue-colored molybdenum blue. The resulting colored solution was compared to a standard phosphoric acid solution colored accordingly. Concentration of inorganic phosphate was determined after calibration graph for KH_2PO_4 standard solution.

To simplify the description and representation of the results, we divide the dynamic response of active muscle into separate timeframes (Fig. 1): F_1 – start of muscle's force response, F_2 – muscle's force productivity reaches a stable level, F_3 – terminal muscle activity, L_1 – start of change in muscle length, L_2 – contractile length reaches stable level.

In order to establish the margins of concentrations within which the experimental substances display physiological effects influencing dynamic properties of muscle contractions, we investigated concentrations from 10^{-8} to 10^{-2} M. As a result, we demonstrated, that quercetin solutions in concentrations less than 10^{-6} M did not affect performance of skeletal-muscle preparations. As concentrations increased to 10^{-4} M the muscle contractile processes were totally suppressed. $AlCl_3$ solutions in concentrations of less than 10^{-4} M did not affect performance of skeletal-muscle preparations. As concentrations increased to 10^{-2} M the muscle contractile processes were totally suppressed. Consequently, we used $AlCl_3$ solutions and complexes with flavonoid with concentrations of 10^{-4} to 10^{-2} M, and quercetin solutions with concentrations of 10^{-6} to 10^{-5} M.

The experiments were done in accordance with guidelines for keeping and work with laboratory animals laid down in the 'European convention for the protection of vertebrate animals used for experimental and other scientific purposes' (Strasbourg, 1986).

The statistical analysis of data was done with variation statistics methods in Origin 7.0 software,

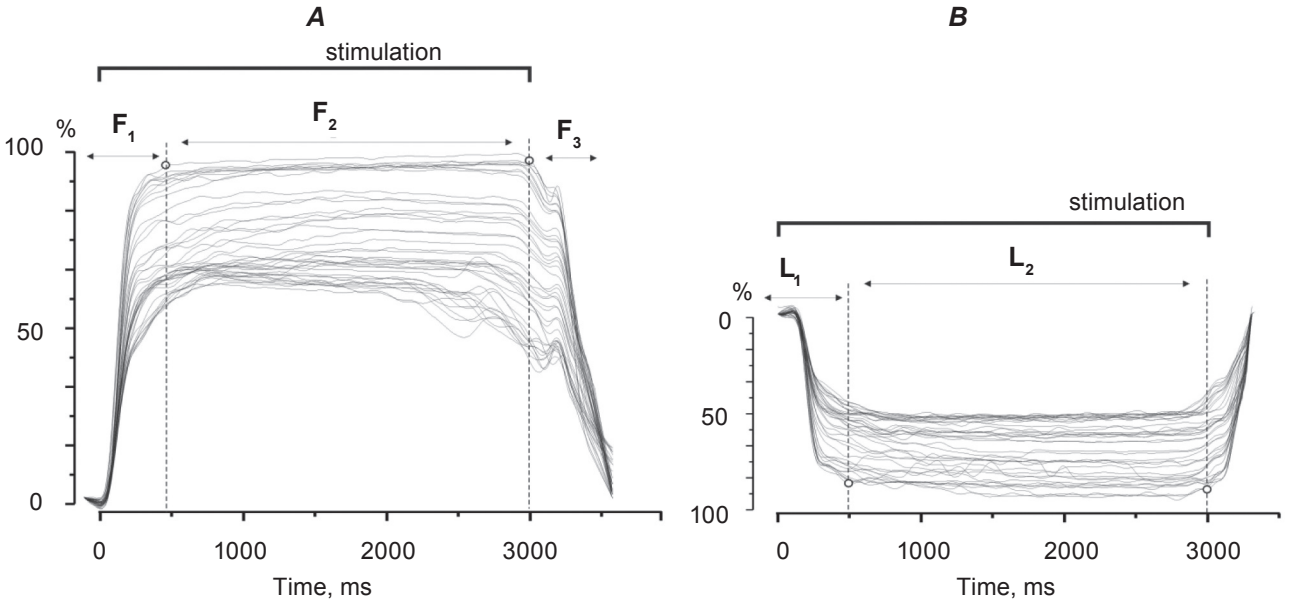

Fig. 1. Graphical representation of attribution of active muscle's dynamic response to corresponding temporal stages of force response. A – F_1, F_2, F_3, and changes in length; B – L_1, L_2 in contractions of m. tibialis anterior skeletal muscle fibers electrostimulated at 30 Hz for 3 s under effect of quercetin in concentration of 10^{-6} and $AlCl_3$ in concentration of 10^{-5} M. Abscissa – time; ordinate – muscle fiber responses expressed as percent values from that of control (M ± m, n = 10). Relaxation time was 3 min

using Student's *t*-test. The differences between test and control samples were considered significant at $P \leq 0.05$.

Results and Discussion

The first series of the experiments involved investigation of effects of 10^{-6} M quercetin in complex with various concentrations of aluminum chloride on dynamic properties of muscle fiber contraction.

In experiments with 10^{-6} M concentrations of quercetin and $AlCl_3$ we found insignificant decrease in dynamic parameters of contraction (Fig. 2, *A*). Changes in strength and length of muscle contraction were observed beginning at the 4th min of stimulation.

The strength of contraction reached stable level by the 12th min of the experiment during F_1 period – 96.4 and 94%, accordingly, for phases F_2 and F_3 (10th min). Changes in muscle contraction length reached stable level at the 12th min in L_1 under such conditions, and constituted 92.5%, and at the 14th min during L_2, constituting 93.4% in comparison to control.

We investigated the effect of mixed 10^{-6} M of quercetin and 2×10^{-6} M $AlCl_3$ solutions. The changes were observed beginning at the 4th min of the stimulating signal, yet these were statistically insignificant (Fig. 2, *B*). The muscle contraction strength entered stable level at the 10th min during F_1 and was 96.6% of control and at the 14th min during F_2 and F_3 and was 95.1 and 92.1%, correspondingly. Changes in length under these conditions reached stable level during L_1 and L_2 and constituted 89% and 90% of control, accordingly.

In experiments with mixture of 10^{-6} M quercetin and 3.3×10^{-6} M $AlCl_3$ solutions the dynamic characteristics of muscle contraction were suppressed beginning at the 2nd min of stimulation (Fig. 2, *C*). At these concentrations the changes in strength of muscle contraction took more time than those of L parameter.

The maximum decrease in strength of muscle contraction was observed on the 10th min of the experiment during F_1 and was 95.9%, and at the 12th min during F_2 and F_3 and was 93.4% and 90%, correspondingly. The maximum decrease in change of muscle contraction length was observed on the 14th min during L_1 and constituted 86.1% and on the 12th min, constituting 88% of control values.

The mixture of 10^{-6} M quercetin and 6.6×10^{-6} M $AlCl_3$ solutions inhibited muscle contraction with the maximum on the 8th min during F_1 and was 94.6% of that of control. The maximal decrease in muscle contractile strength during F_2 and F_3 was observed

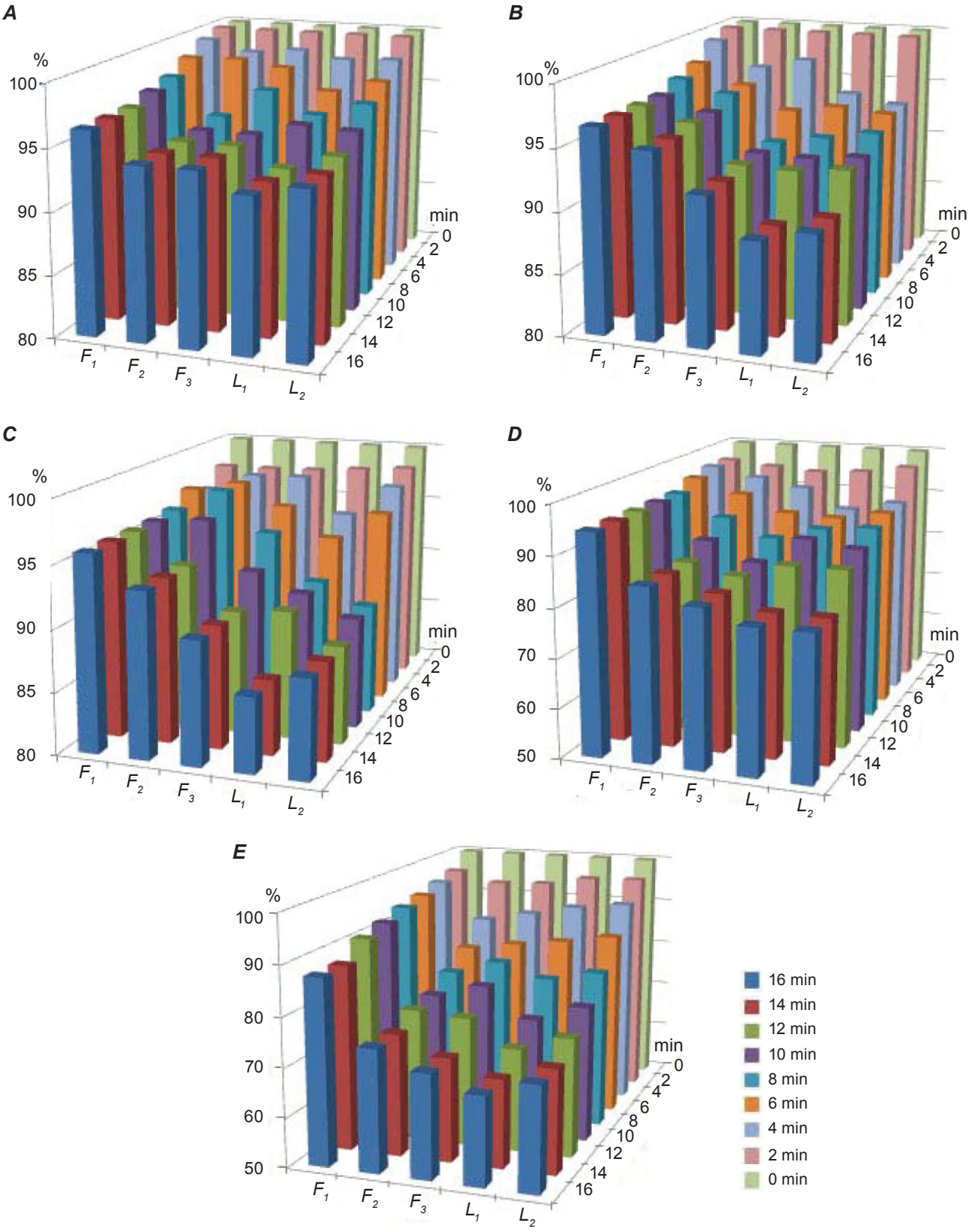

Fig. 2. The effect of solutions of (A) 10^{-6} quercetin and 10^{-6} M $AlCl_3$, (B) 10^{-6} M quercetin and 2×10^{-6} $AlCl_3$, (C) 10^{-6} M quercetin and 3.3×10^{-6} $AlCl_3$, (D) 10^{-6} M quercetin and 6.6×10^{-6} $AlCl_3$, (E) 10^{-6} M quercetin and 10^{-5} $AlCl_3$ on the dynamic properties of contraction caused by electrostimulation at 30 Hz for 3 s, depending on duration of exposition to the reagent, n = 10

on the 12th and the 14th min, accordingly, and constituted 85 and 82% of control (Fig. 2, *D*). Changes in dynamic properties of muscle contraction during these periods were of approximately linear character. The maximum decrease in changes of length of muscle contraction was found on the 14th min of the experiment during L_1 and L_2 and constituted 79.2% from control values in both cases.

We found in experiments with mixture of 10^{-6} M quercetin and 10^{-5} M $AlCl_3$ solutions that muscle contraction strength decreases maximally on the 14th min during F_1, F_2 and F_3, and constituted 87.6, 74.8 and 71.1% of control, accordingly (Fig. 2, *E*). The maximum decrease in muscle fibers contraction was found on the 14th min of the experiment during L_1 and L_2 and constituted 68 and 71.2% of control values, correspondingly. There was a linear dependence of changes in strength and length of muscle fiber contraction.

There was a liner decrease of Ca^{2+},Mg^{2+}-ATPase activity of SR under the effect of $AlCl_3$ in all indicated concentrations (Table 1).

At the next stage of our studies we investigated the effect of 10^{-5} M quercetin solution mixed with various concentrations of $AlCl_3$ on dynamic parameters of muscle fiber contraction.

We found noticeable decrease in strength and length of muscle contraction under the effect of 10^{-5} M quercetin and 10^{-6} $AlCl_3$ mixture (Fig 3, *A*). The changes in dynamic parameters of muscle contraction were observed beginning from the 2nd min of stimulation. Muscle contraction strength reached stable levels on the 14th min of the experiment during F_1, F_2 and F_3, and was at 94.4, 83.5 and 79% from that of control values, correspondingly. Muscle contraction length change reached stable levels under these conditions on the 14th min of the experiment during L_1 and L_2 and constituted 84.5 and 82.8% of control.

We established in experiments with 10^{-5} M quercetin and 2×10^{-6} $AlCl_3$ mixture that the maximum decrease in muscle contraction strength was on the 14th min during F_1 and constituted 94.4% of control (Fig. 3, *B*). A statistically significant decrease in strength of muscle contraction during F_2 and F_3 occurred on the 12th and the 14th min of the experiment, correspondingly, and constituted 81.2 and 79% of control values.

The maximal, statistically significant, decrease in length was observed on the 14th min of the experiment during L_1 and L_2 and constituted 81.9% from control values in both cases. Changes in dynamic parameters of muscle contraction during these periods were of uneven character.

In experiments on effects of mixed solutions of 10^{-5} M quercetin and 3.3×10^{-6} $AlCl_3$ we found that changes in dynamic parameters of muscle contraction manifested beginning on the 2nd min of stimulating signal (Fig. 3, *C*).

The maximum decrease in muscle contraction strength was observed on the 14th min of the experiment during F_1, F_2 and F_3 and constituted 92, 78.3 and 75.3% of that of control, correspondingly. The maximal inhibition of muscle contraction length change was observed on the 12th min of the experiment during L_1 and was 80% of control, and on the 14th min of the experiment during L_2 and was 76.2% of control. The changes in muscle contractile parameters were of uneven character under these conditions.

In experiments with mixed solutions of 10^{-5} M quercetin and 3.3×10^{-6} $AlCl_3$ strength of muscle contraction reached stable levels on the 12th min during F_1 at 91.1%, and on the 14th min during F_2 and F_3

*Table 1. Effects of quercetin and $AlCl_3$ solutions on SR Ca^{2+},Mg^{2+}-ATPase activity of skeletal muscles; $M \pm m$, $n = 10$; * $P \leq 0.05$*

Enzyme	Control	quercetin 10^{-6} M + $AlCl_3$ 10^{-6} M	quercetin 10^{-6} M + $AlCl_3$ 2×10^{-6} M	quercetin 10^{-6} M + $AlCl_3$ 3.3×10^{-6} M	quercetin 10^{-6} M + $AlCl_3$ 6.6×10^{-6} M	quercetin 10^{-6} M + $AlCl_3$ 10^{-6} M
SR Ca^{2+},Mg^{2+}-ATPase activity of skeletal muscles, nmol of $P_i\times mg^{-1}$ of protein$\times min^{-1}$	245.6±1.4	211.5±3.1	222.3±3.2	197.6±3.*	191.3±2.8	186.5±3.1

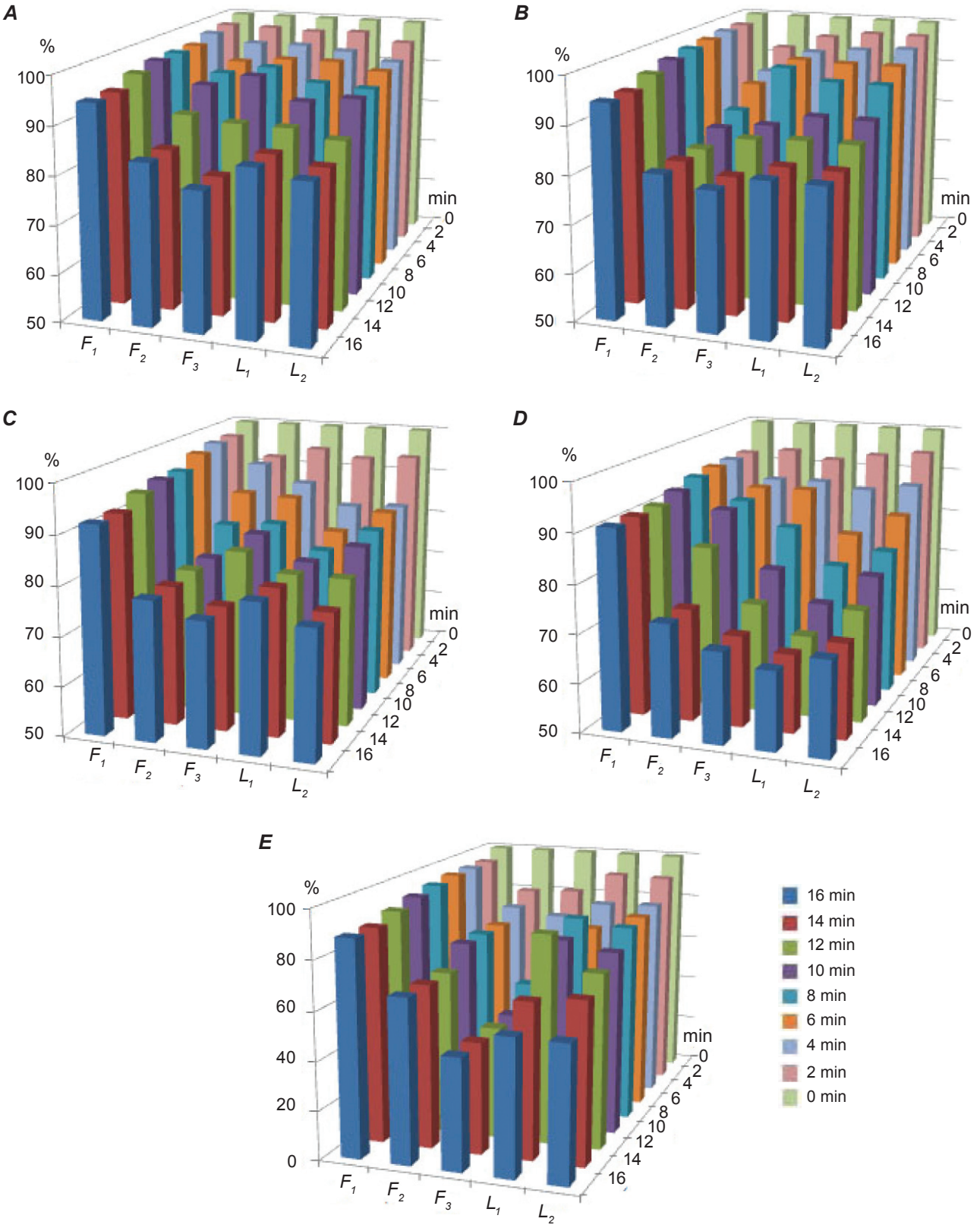

Fig. 3. The effect of solutions of (A) 10^{-5} quercetin and 10^{-5} M $AlCl_3$, (B) 10^{-5} M quercetin and 2×10^{-5} $AlCl_3$, (C) 10^{-5} M quercetin and 3.3×10^{-5} $AlCl_3$, (D) 10^{-5} M quercetin and 6.6×10^{-5} $AlCl_3$, (E) 10^{-5} M quercetin and 10^{-4} $AlCl_3$ on the dynamic properties of contraction caused by electrostimulation at 30 Hz for 3 s, depending on duration of exposition to the reagent, n = 10

at 73.2 and 68.8% from those of control, correspondingly (Fig. 3, *D*). Changes in length of muscle contraction under such conditions reached stable levels on the 14th min of the experiment during L_1 and L_2 and was at 66.2 and 69.6% in comparison to control. The changes in muscle contractile parameters were of uneven character in these experiments.

In the experiments with 10^{-5} M quercetin and 3.3×10^{-6} $AlCl_3$ solutions mixture (Fig. 3, *E*) we observed changes in dynamic characteristics of muscle contraction beginning from the 2nd min of stimulation. The maximal decrease in strength of muscle contraction was on the 14th min during F_1 at 88.4% and on the 12th and 14th min during F_2 and F_3 at 67.2 and 45.9% of control, correspondingly. The maximal, statistically significant, decrease in change of contractile length was observed on the 16th min during L_1 and L_2 and constituted 56 and 55.72% of that of control values.

We observed linear concentration-dependent decrease in Ca^{2+},Mg^{2+}-ATPase activity of SR under effect of $AlCl_3$ in all studied concentrations (Table 2).

We thus established in our studies the more pronounced inhibiting effects of complexes of quercetin and $AlCl_3$ on dynamic contraction parameters during all observed timeframes in comparison to separate effects of the investigated compounds. The least pronounced changes in strength of muscle contraction under effect of the investigated compounds were observed during F_1, and the most pronounced changes in this parameter were detected during F_3 in comparison to control. Incubation with $AlCl_3$ solutions mixed with 10^{-6} M quercetin solution caused the most significant changes in muscle fiber length during L_1. Incubation with $AlCl_3$ solutions mixed with 10^{-5} M quercetin solution caused the most significant changes in muscle fiber length during L_2, during L_1 in case 6.6×10^{-6} M $AlCl_3$ solution was used, and equal changes during both periods if 2×10^{-6} M $AlCl_3$ solution was used. This may be explained by increased quantities of substances permeating muscle fiber's plasma membrane as well as by effect of these complexes on perimembrane processes. The investigated complexes may enter the cell via solubilization in the lipid phase of the plasma membrane and consequently affect functional activity of intracellular transport systems, e.g. changing Ca^{2+} release from intracellular compartments.

Quercetin complexes with $AlCl_3$ exhibit more potent inhibitive effect on dynamic contractile parameters in all experiments in comparison to separate effects of the investigated compounds. The least pronounced changes in muscle contraction under effect of the investigated complexes were observed during F_1, and the most pronounced changes in the studied parameters were found during F_3 in comparison with control. The specific effect of these reagents on various stages of contraction reveals a complex character of isotonic skeletal muscle contraction under the influence of pathogenic factors [16].

A cellular necrosis independent of cholinergic receptors dysfunction resulting from incubation with aluminum-flavonoid mixture has been described [17]. This process was accompanied by NADH-cytochrome c reductase, cytochrome c oxidase of mitochondrial respiratory chain; decrease in transmembrane mitochondrial potential and in ATP concentration, as well as increase in ADP to ATP ratio.

Since mitochondria participate in energy level maintenance that is required for skeletal muscle functioning, disruption in regulation of mitochondrial respiratory chain and energy production may be one of the possible causes for muscle weakness under effect of quercetin-$AlCl_3$ complexes. Inhibition of mitochondrial ATP-synthase may result in lower mitochondrial Ca^{2+} absorption, which in turn influences intracellular Ca^{2+} balance and damages muscle fibers.

*Table 2. Effects of quercetin and $AlCl_3$ solutions on SR Ca^{2+},Mg^{2+}-ATPase activity of skeletal muscles; $M \pm m$, $n = 10$; * $P \le 0.05$*

Enzyme	Control	quercetin 10^{-5} M + $AlCl_3$ 10^{-5} M	quercetin 10^{-5} M + $AlCl_3$ 2×10^{-5} M	quercetin 10^{-5} M + $AlCl_3$ 3.3×10^{-5} M	quercetin 10^{-5} M + $AlCl_3$ 6.6×10^{-5} M	quercetin 10^{-5} M + $AlCl_3$ 10^{-4} M
SR Ca^{2+},Mg^{2+}-ATPase activity of skeletal muscles, nmol of $P_i\times mg^{-1}$ of protein$\times min^{-1}$	245.6±1.4	219.5±3.5	198.3±3.8	182.6±3.3	177.3±2.8	173.5±3.3

Skeletal muscle cells have systems that maintain low Ca^{2+} concentration at rest and serve to quickly remove it after acting signal ceases [19]. Maintenance of low plasma calcium ions concentration in most cells, including muscle, is performed via Ca^{2+},Mg^{2+}-ATPases of plasma membranes and SR, which are special enzymes transporting 2 calcium ions across the membrane against the concentration gradient per hydrolysis of an ATP molecule. Via Ca^{2+},Mg^{2+}-ATPase of SR has an important part in regulation of skeletal muscle's contraction-relaxation cycle, accumulating Ca^{2+} inside the reticulum and thereby acting to decrease its cytoplasm concentration and further block of actin-myosin interaction. Misbalancing the calcium homeostasis is therefore certain to result in changes to functional state of the muscle.

The changes described here may indicate lower plasma membrane permeability to calcium ions. It is known that Ca^{2+} is transported inside skeletal muscle fibers by dihydropyridine receptors of sarcolemma (L-type Ca^{2+} channels) [20, 21]. As, according to available evidence, flavonoids may inhibit these channels [1, 5], the specificity of effect of quercetin and quercetin-aluminum complex on dynamic contractile parameters may be explained by their binding to this receptor type. This in turn leads to uncoupling of excitation and contraction in skeletal muscle and thus to decrease in muscle force. The functional instabilities that appear during maintaining of muscle fiber's dynamic parameters at tetanic level of contraction may be attributed to changes in contractility of muscle fiber under effect of minor concentrations of the investigated compounds due to inhibition of ATPase activity of myosin [22-24] (Table 1, 2).

Therefore, our results demonstrate that quercetin-$AlCl_3$ have various effects on dynamic parameters of skeletal muscle's contraction. The compounds in the investigated concentrations inhibited generation of contractile force in frog muscle fibers. The decreased parameters of strength and length of contraction within total monitored timeframe, as well as within any period of contraction, was observed constantly and in most cases was of linear nature. The dynamic parameters of contraction changed least during periods of pretetanic contraction. The experimental data obtained may be explained by the effect of these compounds on perimembrane processes as well as by their ability to permeate plasma membrane into cell and thus affect the ATPase activity of myosin of the sarcomere.

ДІЯ КОМПЛЕКСІВ ХЛОРИДУ АЛЮМІНІЮ З КВЕРЦЕТИНОМ НА Ca^{2+},Mg^{2+}-АТРазну АКТИВНІСТЬ ТА ДИНАМІЧНІ ПАРАМЕТРИ СКОРОЧЕННЯ m. tibialis anterior ЖАБИ *RANA TEMPORARIA*

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Проведено ензиматичні та тензометричні дослідження функціонування пучків волокон скелетного м'яза tibialis anterior, жаби *Rana temporaria* за дії розчинів хлориду алюмінію з кверцетином. Встановлено, що комплекси кверцетину з алюмінієм інгібували процеси м'язового скорочення. Показано лінійне зниження Ca^{2+},Mg^{2+}-АТРазної активності саркоплазматичного ретикулума за дії всіх досліджуваних концентрацій кверцетину та хлориду алюмінію. Встановлено, що кверцетин змінює свої властивості щодо впливу на функціонування м'язових волокон скелетних м'язів під час утворення комплексів із алюмінієм, що супроводжується посиленням його інгібіторної дії. У досліджених діапазонах концентрацій ($AlCl_3$ – 10^{-4}–10^{-2} моль/л та кверцетин 10^{-6}–10^{-5} моль/л) використані речовини пригнічували генерацію сили та діапазон вкорочення м'язових волокон жаби. Зниження показників генерації сили та вкорочення м'язових волокон у часовому інтервалі спостереження та протягом кожного окремого перебігу відбувалося постійно і у більшості випадків мало лінійний характер. Найменш виражені зміни сили м'язового скорочення під впливом досліджуваних комплексів спостерігались впродовж дотетанічної фази скорочення, а найвираженіші зміни досліджуваного параметра відбувались на кінцевій фазі активності м'яза. Зменшення динамічних параметрів скорочення та зниження Ca^{2+},Mg^{2+}-АТРазної активності саркоплазматичного ретикулума за використання розчинів вказаних

концентрацій було мінімальним на початку силової відповіді м'яза і до моменту виходу м'язової сили на стаціонарний рівень скорочення.

Ключові слова: алюміній, м'язове скорочення, Ca^{2+},Mg^{2+}-АТРазна активність, сила, довжина.

ВЛИЯНИЕ КОМПЛЕКСОВ ХЛОРИДА АЛЮМИНИЯ С КВЕРЦЕТИНОМ НА Ca^{2+},Mg^{2+}-АТРазную АКТИВНОСТЬ И ДИНАМИЧЕСКИЕ ПАРАМЕТРЫ СОКРАЩЕНИЯ m. tibialis anterior ЛЯГУШКИ *RANA TEMPORARIA*

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Проведены энзиматические и тензометрические исследования сокращения пучков волокон скелетной мышцы tibialis anterior, лягушки *Rana temporaria* под влиянием растворов хлорида алюминия с кверцетином. Установлено, что комплексы кверцетина с алюминием ингибировали процессы мышечного сокращения. Показано линейное снижение Ca^{2+},Mg^{2+}-АТРазной активности саркоплазматического ретикулума под действием всех исследуемых концентраций кверцетина и хлорида алюминия. Установлено, что кверцетин изменяет свои свойства относительно влияния на функционирование мышечных волокон скелетных мышц при образовании комплексов с алюминием, что сопровождается усилением его ингибиторного действия. В исследованных диапазонах концентраций ($AlCl_3$ – 10^{-4}–10^{-2} моль/л и кверцетина 10^{-6}–10^{-5} моль/л) используемые вещества подавляли генерацию силы и диапазон укорачивания мышечных волокон лягушки. Снижение показателей генерации силы и укорачивания мышечных волокон во временном интервале наблюдения происходило постоянно и в большинстве случаев имело линейный характер. Наименее выраженные изменения силы мышечного сокращения под воздействием исследуемых комплексов, наблюдались на протяжении дотетаничной фазы сокращения, а наиболее выраженные изменения исследуемых параметров происходили на конечной фазе активности мышцы. Уменьшение динамических параметров сокращения и снижения Ca^{2+},Mg^{2+}-АТРазной активности саркоплазматического ретикулума при использовании растворов указаных концентраций было минимальным в начале силового ответа мышцы и к моменту выхода мышечной силы на стационарный уровень сокращения.

Ключевые слова: алюминий, мышечное сокращение, Ca^{2+},Mg^{2+}-АТРазная активность, сила, длина.

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