EFFECT OF ZINC IONS ON THE EXCITABLE MEMBRANE
OF THE SKELETAL MUSCLE FIBER

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Zinc (Zn++) ions are constituents of many metalloenzymes. The psoas muscle of the rabbit is known to con-
tain zinc in a concentration comparable with its calcium concentration [5]. Little is known of the function of zinc
in the contractile act of the living muscle, although it has an appreciable influence on its mechanical activity. It
has been shown, for example, that by the action of Zn++ ions on the sartorius muscle of the frog the tension is in-
creased 2-3 times, the periods of contraction and relaxation are lengthened, and the length of the refractory period
is increased 4 times [7].

Intracellular recordings of the membrane potential of a muscle have shown [6] that zinc ions, in a concentra-
tion of 5·10^-5 moles, double the duration of the action potential (AP) as a result of an increase in the duration of
its descending phase. The blocking action of Zn++ in a concentration of 0.5 mmole on transmission in the neuro-
muscular synapse has also been demonstrated [12].

The object of the present investigation was to study the action of Zn++ ions on the properties of the membrane
of the muscle fiber.

EXPERIMENTAL METHOD

Experiments were carried out on the sartorius muscle of the frog (Rana temporaria). The muscle was fixed in
a special bath in a slightly stretched state. Intracellular recordings of the electrical activity of the muscle were
made by means of glass microelectrodes. The resistance of the microelectrodes was 10-40 MΩ. Two separate
microelectrodes were introduced into one muscle fiber. One electrode was used to pick up the potential, the other
to stimulate the fiber (Fig. 1). The potential difference on the membrane was measured by means of a two-channel
dc amplifier and a cathode repeater, assembled in accordance with the scheme of A. L. Byzov and M. M. Bongard
[1]. The resting potential, the action potential, and the stimulating current were measured by comparing them with
a known calibration potential.

To measure the input resistance of the membrane of the muscle fibers rectangular pulses of hyperpolarizing
current were used. The solutions used in the experiment were supplied from special vessels into the working chamber
in which the muscle was placed. Solutions of ZnCl₂ were used in the experiments in concentrations of 0.05-1.0
mmole. The investigation lasted 1 year. The composition of the Ringer's solution was (per liter of distilled water):
6.5 g NaCl, 140 mg KCl, 120 mg CaCl₂, 200 mg NaHCO₃ (in the autumn-winter period), and 6.5 g NaCl, 100 mg
KCl, 200 mg CaCl₂, 200 mg NaHCO₃ (in the spring-summer period).

EXPERIMENTAL RESULTS AND DISCUSSION

In Ringer's solution for cold-blooded animals the resting potential (RP) was 81.2 ± 1.7 mV. When the Ringer's
solution was replaced by a solution containing ZnCl₂ in a concentration of 0.05-0.1 mmole, the RP was 81.3 ± 2.4 mV
Fig. 1. Action of Zn ions on the membrane of a skeletal muscle fiber. Top—scheme showing the principle of the apparatus for stimulating single muscle fibers and recording the potentials from them. $R_1 = 15 \ k\Omega$, $R_2 = 50 \ k\Omega$, $R_3 = 50 \ m\Omega$. The fall in voltage across the resistor $R_1$ (terminal I) was used as an indicator of the strength of the stimulating current; terminal II—output of cathode repeater. A) action potential of a muscle fiber in Ringer's solution of normal composition; B) the same after addition of 1 mmole $\text{ZnCl}_2$ to the solution; C) action of potential of a muscle fiber in Ringer's solution, the fiber is in a poor functional state; D) response of the same fiber after addition of 0.25 mmole $\text{ZnCl}_2$ to the Ringer's solution. The top curve corresponds to the zero line for the intracellular microelectrode, and the stimulating current applied to the fiber through the second microelectrode is also indicated on it (in tracings A and B). The bottom curve shows the potential recorded by the microelectrode. The input resistance of the membrane of the muscle fibers was increased under the influence of 1 mmole $\text{ZnCl}_2$ from 216 ± 86 to 465 ± 82.2 kΩ (15 fibers). The difference was significant ($P < 0.01$). In the presence of $\text{ZnCl}_2$ in a concentration of 0.05-0.1 mmole, the input resistance of the fibers was unchanged. The effect of Zn ions was very stable and was not abolished even after repeated rinsing of the muscle in Ringer's solution. In contrast to this, replacement of the Ringer's solution containing Zn ions by a solution of unithiol or of cysteine in concentrations of 0.05-0.1% led to complete restoration of the original amplitude and duration of the AP (Fig. 2, A-C).

Fig. 2. Top: reversible character of the action of Zn ions. Bottom: volt-ampere characteristic of the membrane of a skeletal muscle fiber. A) action potential of a muscle fiber in Ringer's solution of normal composition; B) the same after addition of 1 mmole $\text{ZnCl}_2$ to the solution; C) restoration of the action potential after immersion of the muscle in a 0.1% solution of unithiol. Remainder of legend as in Fig. 1; D) volt-ampere characteristic of the membrane of a muscle fiber measured by means of hyperpolarizing pulses of current: 1) muscle in Ringer's solution; 2) the same muscle fiber in a solution of $\text{ZnCl}_2$ in a concentration of 1 mmole. The input resistance of the membrane of the muscle fibers was increased under the influence of 1 mmole $\text{ZnCl}_2$ from 216 ± 86 to 465 ± 82.2 kΩ (15 fibers). The difference was significant ($P < 0.01$). In the presence of $\text{ZnCl}_2$ in a concentration of 0.05-0.1 mmole, the input resistance of the fibers was unchanged. The effect of Zn ions was very stable and was not abolished even after repeated rinsing of the muscle in Ringer's solution. In contrast to this, replacement of the Ringer's solution containing Zn ions by a solution of unithiol or of cysteine in concentrations of 0.05-0.1% led to complete restoration of the original amplitude and duration of the AP (Fig. 2, A-C).