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DEPENDENCE OF SKELETAL MUSCULAR FATIGUE ON MEMBRANE POLARIZATION OF DIFFERENT TYPES OF MUSCLE FIBERS IN TOURNIQUET SHOCK

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Tourniquet shock develops after restoration of the circulation in the ischemic limbs and it is accompanied by the release of breakdown products and toxic substances into the blood stream, causing a reduction in the circulating blood volume, retention of blood in depots, reduced polarization of muscle fibers, and so on [2, 11, 12]. The earliest microcirculatory and metabolic disorders in these forms of shock are found in muscle tissue [1, 3, 7]. In this period weakness of contractions of the skeletal muscles is observed [8] and death in endotoxic shock is considered to take place as a result of acute fatigue of the respiratory muscles [8]. However, it is not yet clear whether weakening of contractility of skeletal muscles in tourniquet shock is connected with a change in the membrane potentials of different types of muscle fibers and with the degree of their motor activity.

The aim of the present investigation was to study changes in the resting membrane potential (RMP) level of different types of fibers of skeletal muscles functioning periodically or continuously, and to determine the degree of their fatigue at different stages of development of tourniquet shock.

EXPERIMENTAL METHOD

Experiments were carried out on 60 noninbred albino rats of both sexes weighing 180-200 g. A tourniquet (standard rubber tourniquet, 8 turns) was applied to both hind limbs of the rats under ether anesthesia. The tourniquets were removed 6 h after being applied and postischemic arterial pyperemia of the skin of the feet was observed. Intact animals served as the control. The fast muscle of the forelimb (m. flexor carpi radialis) and a mouth-opening muscle (the anterior belly of the digastric muscle) were investigated. Contractility, fatigue, and RMP of the myocytes of flexor carpi radialis were determined 30 min, 1 h, and 1.5 h later, and parameters of membrane excitability of fibers of the digastric muscle were investigated 3, 6, and 12 h after removal of the tourniquet. Contractility and fatigue were evaluated by the standard method with periodic direct stimulation of the carpal flexor by pulses of current with a frequency of 60 Hz and duration 0.2 msec for 1 sec with intervals of 30, 60, and 120 sec. RMP and parameters of excitability of the myocytes (action potential, critical depolarization level, rheobase currents) were recorded by intracellular glass microelectrodes, using a standard amplification technique (UPT dc amplifier, FOR-2 camera). The results were subjected to statistical analysis by Student's t test.

EXPERIMENTAL RESULTS

Since the dynamic characteristics, excitability, and contractility of skeletal muscles are determined by the composition of the muscle fibers [3], we studied RMP of myocytes at

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TABLE 1. Biophysical Parameters of Cytoplasmic Membrane of Fibers of Anterior Belly of Digastric Muscle at Different Times after Removal of Tourniquet

Time after removal of tourniquet, h	RMP, mV	AP, mV	CDL, mV	Rheobase current, nA	LP, msec	Negative after-potential	
						amplitude, mV	duration, msec
Control	68,8±0,7 (177)	80,9±1,8 (49)	12,94±0,37 (46)	8,12±0,52 (77)	6,79±0,30 (91)	6,03±0,35 (32)	6,17±0,21 (66)
3	53,9±1,0** (85)	73,6±2,7** (25)	10,59±0,25** (20)	12,90±1,34** (31)	6,82±0,49 (22)	4,69±0,31* (17)	6,88±0,38 (20)
6	54,9±1,0** (97)	70,8±2,5** (26)	11,07±0,23** (18)	15,58±1,68** (32)	6,36±0,80 (22)	4,72±0,43 (10)	7,95±0,81** (19)
12	59,5±0,9** (111)	72,0±1,3** (24)	11,47±0,16* (16)	12,41±1,48** (23)	5,72±0,43 (9)	4,80±0,52 (13)	8,50±0,54** (12)

Legend. *p < 0.05, **p < 0.001. Number of cells shown in parentheses; AP) action potential, CDL) critical depolarization level, LP) latent period.

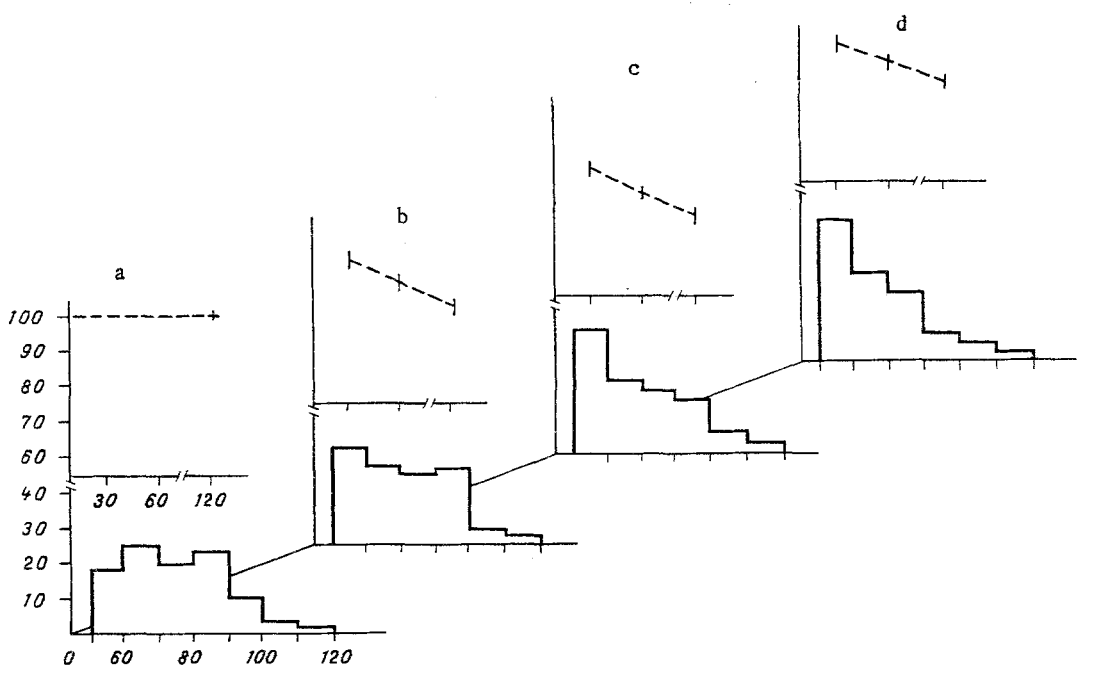

Fig. 1. Histograms of distribution of RMP and fatigue curves of muscle fibers of rat flexor carpi radialis muscle 1.5 h after removal of tourniquet. a) Control (n = 102); b) 30 min after removal of tourniquet (n = 105); c) 60 min after removal of tourniquet (n = 99); d) 90 min after removal of tourniquet (n = 85). Abscissa, below — RMP (in mV); above — time of investigation of fatigue (in sec); ordinate, %. n) Number of fibers recorded.

different times after removal of the tourniquet. Analysis of the histogram of distribution of RMP of the muscle fibers (Fig. 1) showed that at the 30th minute of shock the number of fibers with a low level of polarization (under 60 mV) was increased by more than 1.5 times, and by the 60th minute, by 2.3 times. Conversely, the number of highly polarized muscle fibers with a transmembrane potential difference of over 90 mV was reduced by half, and after 90 min the number of fibers with RMP of between 80 and 90 mV was reduced by two-thirds. Similar data were obtained in tourniquet shock for the rat brachioradialis muscle [11].

Investigations of contractility of the flexor carpi radialis muscle at these same times showed that at the 30th minute after removal of the tourniquets, during repetitive direct stimulation of the muscle the amplitude of its contractions decreased appreciably until the 120th second of stimulation and was not restored to normal during the subsequent 60 min, evidence of an increase in muscle fatigue.

It was next decided to study the degree of damage to muscles with different functions caused by ischemic toxins. We know that at rest muscle tissue is less vulnerable to toxic factors than during motor activity [8]. On this basis we chose the digastric muscle, which is less functionally active than other groups of muscles, it contains no muscle spindles, and postsynaptic inhibition is absent in its motor nucleus [6, 9, 10]. The value of RMP of muscle fibers of the anterior belly of the digastric muscle 3-6 h after removal of the tourniquet was reduced by about 22-23%, and after a further 6 h the level of polarization rose a little, but still remained significantly lower than in the control. At these same times the parameters of excitability of the cytoplasmic membrane of the myocytes was reduced: the amplitudes of spike potentials and the critical depolarization levels; the rheobase currents were increased (Table 1).

During tourniquet shock, standard responses of injury to muscle tissue independent of the degree of functional activity of the skeletal muscles thus develop outside the zone of ischemia. The flexor carpi radialis and digastric muscles, working different motor schedules, responded in shock by similar effects: persistent depolarization and reduction of excitability of the cytoplasmic membrane of the myocytes. Disturbances of the dynamic and electrophysiological parameters of the test muscles, observed at the 30th minute after recovery of the circulation, subsequently became stabilized, and were observed until death of the animals. The development of progressive depolarization, lowering of excitability of the membranes, and reduction of contractility, and an increase in muscle fatigue may be connected not only with circulatory anoxia, but also, evidently, with the action of myotoxic factors on the sarcolemma; these factors not only reduce the transmembrane potential difference, but also disturb activity of the contractile apparatus of the muscle fibers [5]. Only 30 min after restoration of the circulation, disturbance of contractility and the development of muscle fatigue are combined with a decrease in the number of highly polarized muscle fibers in their composition. At later stages of the investigation, the proneness to fatigue is accompanied by progressive inhibition of electrogenesis predominantly of fast glycolytic muscle fibers, but with no signs of their transformation into fast, oxidative fibers. This last fact is indirect confirmation of the increased proneness of the muscle of fatigue in the early stages of development of shock.

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