ANALYSIS OF THE INITIAL RELAXATION OF MAMMALIAN SKELETAL MUSCLES IN ONTOGENY

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The mechanical response of skeletal muscles in rabbits and rats was investigated at different ages. The phenomenon of initial relaxation of the muscles appears at a definite stage of ontogeny simultaneously with the onset of posttetanic activation of the muscles. A change in the resting length of the muscle, either artificially in the experiment or by an increase in the dynamic load on the muscle led to a marked increase in the intensity of the initial relaxation. Some possible hypotheses for the origin of the initial relaxation of skeletal muscles are discussed.

A conversion of energy processes in ontogeny and the activity of many physiological systems of the body depend on the degree of development of the skeletal muscles [1-3, 5, 7, 8]. With age both the contractile function itself and the general biological function of skeletal muscles at rest gradually increase [1,3]. During ontogeny specific structural and physicochemical transformations take place in skeletal muscles to provide for the more efficient accumulation of potential sources of energy in them. The physiological role of initial relaxation (IR) in the degree of intensity of the mechanical response of the muscles to direct stimulation has been demonstrated by experiments on amphibian skeletal muscles [15, 16]. A higher degree of IR corresponds to a greater strength of contraction of the muscle.

The object of the investigation described below was to study the mechanism of IR in the contractile reaction of mammalian skeletal muscles during ontogeny.

EXPERIMENTAL METHOD

The initial phase of isometric contraction of the gastrocnemius muscle in rabbits and rats at different ages (control muscle) was investigated. For comparison, the same muscle was investigated in animals brought up accustomed to increased motor activity (the "trained" muscle). The animal was anesthetized with urethane, the hind limb fixed at the knee joint, and the distal end of the divided gastrocnemius muscle was attached to a strain gauge. Displacement of the gauge was used to measure the initial length (corresponding to the tension) of the muscle at rest. A description of the apparatus used to measure the mechanical and thermal parameters of the skeletal muscles was given previously [4]. The temperature of the muscle was kept between 34 and 36°C. Indirect over-threshold stimulation by single or repeated pulses of current at the optimal frequency for the animal's age was used in the experiments [1, 6]. Muscle action potentials were recorded by needle electrodes 0.1 mm in diameter with an interelectrode distance of 2-5 mm.

EXPERIMENTAL RESULTS AND DISCUSSION

In all experiments except those mentioned specially the dissected muscle was stretched up to the length at which the maximal amplitude of mechanical tension developed in it during a single isometric contraction.

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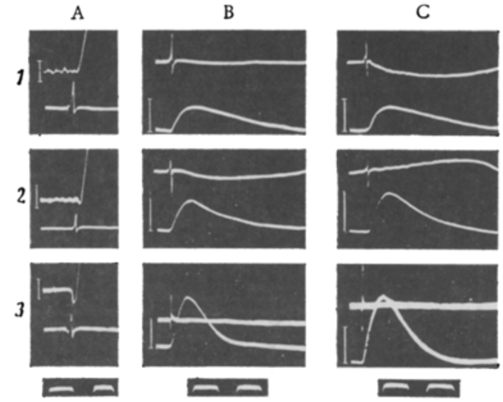

Fig. 1

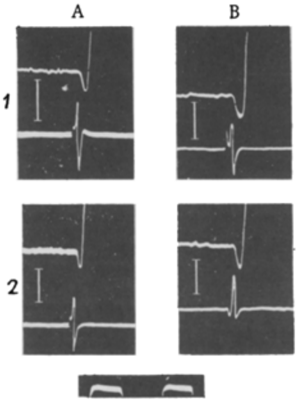

Fig. 2

Fig. 1. Electrical and mechanical responses to single stimulation of gastrocnemius muscle of rabbit aged 10 days (1) and 40 days (2) and in sexually mature animal (3): A) action potential (bottom curve) and initial phase of mechanical response (relaxation; top curve). Calibration of mechanical tension (at the side) from above down: 0.05, 0.5, and 2.0 g; time marker (below) 20 msec. B and C) electrical (top curve) and mechanical (bottom curve) responses before and after tetanic contraction for 3 sec respectively. Calibration of mechanical tension (at the side) from top to bottom: 100, 500, and 10,000 g; time marker (below) 100 msec.

Fig. 2. Electrical and initial phases of mechanical responses of control (A) and trained (B) muscles of sexually mature rabbits (1) and rats (2) to a single stimulus. Calibration of mechanical stress (at the side), from top to bottom, 2 and 0.5 g, time (below) 20 msec.

TABLE 1. Mechanical Characteristics of Gastrocnemius Muscle of Rabbit and Rat at Different Ages

Age of animal (in days)	No. of animals	Rabbits			
		weight (g)	P_0 (g)	P_1 (g)	IR (g)
1	5	52±8	28±3	24±2	—
10	4	176±12	100±10	93±12	—
20	5	330±10	224±15	206±20	—
40	6	785±10	427±23	465±25	0,21±0,03
Sexually mature	6	2560±28	1630±27	1760±32	1,46±0,05

Age of animal (in days)	No. of animals	Rats			
		weight (g)	P_0 (g)	P_1 (g)	IR (g)
1	4	6,8±0,3	2,7±0,04	2,6±0,05	—
10	4	15,3±0,5	8,4±0,1	8,2±0,2	—
20	5	28,7±0,7	17,4±0,3	18,1±0,4	0,01±0,005
40	5	94,1±1,2	72,8±0,8	79,0±1,1	0,13±0,01
Sexually mature	6	352±2,3	293±1,2	357±2,2	0,51±0,04

Legend: P_0 and P_1) maximal tension in muscle during single contraction before and after tetanic contraction respectively; IR) initial relaxation of muscles.

Mechanical responses of the control muscle of rabbits at different ages during a single contraction before (B) and after (C) tetanic contraction lasting 3 sec are shown in Fig. 1. The initial phase of the mechanical response of the muscle (A) is also shown. Clearly in rabbits aged 10 days there is neither IR nor posttetanic activation (PA) of the skeletal muscles. The first signs of IR and PA appeared in the rabbits at the age of 40 days and thereafter they increased considerably. The mechanical characteristics of the gastrocnemius muscle in rats and rabbits at different ages are compared in Table 1. It will be seen that skeletal muscles in rats develop faster than in rabbits. For instance, IR of rat muscles first appears at the age of 20 days. It will be noted that the appearance of IR coincides in time with the appearance of the PA phenomenon. The PA is usually connected with the behavior of the calcium pump of the sarcoplasmic reticulum of muscle fibers [10, 14, 17]. The mechanism of IR is presumably also linked with transformation of the system carrying calcium ions inside the muscle fibers [15]. Hill [11] connects the origin of IR with a decrease in the internal tension of the "elastic element with a short range of action." At the same time he showed that strongly hypertonic solutions do not affect the value of IR although they change the modulus of elasticity of the myofibrils considerably. The results of x-ray structural analysis of myofibrils [12] suggest that the decrease in electrostatic repulsion between the fibrils at the beginning of triggering of the contractile act must evidently give rise to some relaxation of the muscle. Without ruling out this explanation of IR other workers [14, 15] claim that the main cause of this phenomenon is a change in the sarcotubular system of osmotic origin. Evidently both elastic components of the muscle and the system of calcium ion transport both participate in the mechanism of IR. This is shown by experiments to study IR of the muscles of adult animals during a change in the length of the muscle at rest. In both rats and rabbits a sharp decrease in IR, amounting in some cases to its complete disappearance, was observed when the initial length of the muscle was reduced by more than 5% below its optimal level. However, initial stretching of the muscle by up to 5% led to a significant increase in IR. Similar results were obtained by Hill [11] on muscle fragments.

Comparison of the values of IR of "trained" muscles of rats and rabbits with the muscles of control animals of the same weight (adult) showed that the "trained" muscles have a much greater IR capability (Fig. 2). In rats, for instance, it was 160-180% and in rabbits 130-140% of the IR of muscles of the control animals. This can be explained by an increase in the natural resting length of the "trained" muscles [9]. Possible considerable changes in the electrolyte composition of the "trained" skeletal muscles [13] must also be taken into account. The high PA capability of "trained" muscles must also be noted.

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