METHOD OF INVESTIGATING MECHANICAL AND THERMAL PARAMETERS OF SKELETAL MUSCLES OF WARM-BLOODED ANIMALS IN SITU

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UDC 612.745.5

An apparatus is described in which the force of contraction and displacement of a muscle are recorded by means of a strain gauge and temperature changes in the muscle recorded by thermocouples during contraction and the resulting electrical signals are amplified and recorded photographically. By means of this apparatus experiments can be carried out on the muscles of animals of different sizes.

The investigation of energy processes in the contracting muscle is based on determination of the mechanical and thermal parameters of the process, from which the external work and the efficiency of the mechanical and thermal conversions can be estimated [12, 13]. The literature contains descriptions of apparatuses by means of which dynamic recordings of these parameters can be made simultaneously on the isolated muscles of cold-blooded animals [6, 11, 12]. In some investigations [3, 4] the absence of a simultaneous record of the mechanical and thermal parameters made the analysis of the energetics of muscular contraction difficult, and some types of apparatus used for these purposes are complex [10].

This paper describes an attempt to produce a simple and sufficiently sensitive apparatus for the combined recording of mechanical and thermal parameters of muscular contraction in situ to allow synchronous recording for animals of different sizes. To convert forces and movements into electrical signals the well-known tensometric method was used [1, 2] while the temperatures were recorded by means of thermocouples which are widely used in physiology [7, 9-13].

A block diagram of the apparatus is shown in Fig. 1. The experimental animal is placed on a heated table fixed securely to a heavy metal plate (P). The femur (for the gastrocnemius muscles) is rigidly fixed by means of prongs of suitable size. The tendon of the free end of the muscle to be tested (M) is connected by a thin steel wire and rectangular clip to force detector (FD) or to the displacement detector (DD) and to an isotonic load (R). This load is created by means of a rubber band not less than 100 cm long and 0.5-5 mm wide (depending on the load required). Displacement of the muscle during contraction was usually less then 1% of the initial length of the stretched rubber band, thus ensuring practically isotonic conditions of muscular contraction. Signals from the detectors were led through a tensometric amplifier (TU-4M) (TA) and a type UBP-02 amplifier (UBP) to a type N-102 loop oscillograph (LO) and to a type SI-18 cathode-ray oscilloscope (CRO) for visual observation. The temperature measuring channel consists of a differential thermocouple (T), the control (cold) junction of which is placed in a Dewar flask with melting ice (D) while the measuring (hot) junction is in the muscle. The initial potential difference produced by a difference between the temperatures of the measuring and control junctions (the mus-

TABLE 1. Principal Technical Characteristics of Detectors

Type of detector	Range of changes	Maximal sensitivity per cm of recorder scale	Time constant (msec)
Force detector	$1-10^4$	0,05	3—5
Displacement detector	$10^{-1}-1$ cm	0,1 mm	5—10
Temperature detector	$10^{-2}-5°$	0,001°	50

Laboratory of Age Physiology and Pathology, Institute of Normal and Pathological Physiology, Academy of Medical Sciences of the USSR, Moscow. (Presented by Academician of the Academy of Medical Sciences of the USSR, N. A. Fedorov.) Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 76, No. 10, pp. 122-124, October, 1973. Original article submitted October 9, 1972.

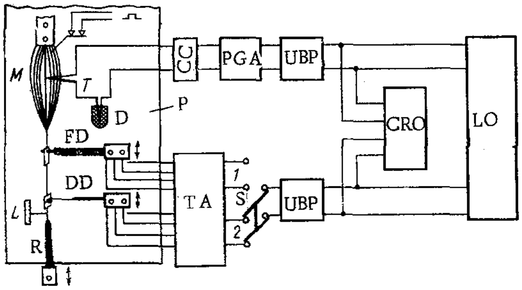

Fig. 1

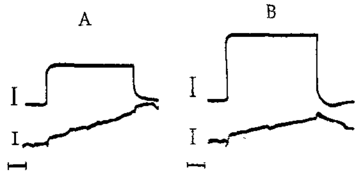

Fig. 2

Fig. 1. Block diagram of apparatus for investigating mechanical and thermal parameters of muscular contraction (explanation in text).

Fig. 2. Mechanical (top curve) and thermal (bottom curve) responses of gastrocnemius muscles of rabbits aged 10 days (A) and 3 months (B) under isotonic conditions to direct stimulation at 60/sec and with amplification of 2 G (A) and 200 G (B). Calibration from top to bottom: A) 0.5 mm, 0.2°, 2 sec; B) 1.5 mm, 0.2°, 2 sec.

cle at rest) is balanced by a compensating circuit (CC). The onbalance appearing during contraction of the muscle between the EMF of the thermocouple and the compensating EMF is amplified by a type F-116/2 photogalvanic amplifier (PGA) and then led through the UBP-02 amplifier to the recorder.

The force detector consists of a steel plate, measuring on the average $2 \times 10 \times 60$ mm, to which the resistor elements are secured on both sides. The size of the plate is chosen on the basis of the sensitivity required and the maximum force permissible on the detector to maintain linearity of the working characteristic curve [7]. The displacement detector is a thin steel plate measuring $0.5 \times 10 \times 60$ mm. A thin steel wire by means of which the frame is fixed to the muscle-load system is soldered to the free end of the plate and is displaced (bent) during contraction. The diameter and length of the wire are calculated to correspond to the amplitude and rate of shortening of the muscle. For example, for the gastrocnemius muscle of an adult rabbit weighing about 3 kg the wire must be 0.5 mm in diameter and about 20 mm long. The tensometric amplifier is connected to the two resistor elements secured to the plate and to two other resistors placed on a special card by means of an ordinary bridge circuit [10], ensuring high sensitivity and reliable thermostability of the measuring circuit. The detectors are calibrated by a load of known weight or by displacement through a known distance. Meanwhile the linearity of the working characteristic curves and the absence of hysteresis phenomena are verified.

The temperature detectors consist of Chromel–Copel thermocouples made of thin wire (0.07-0.1 mm in diameter) by spot arc welding without flux. The thermocouples are coated with a thin layer of varnish, and the depth of their insertion in the muscle is limited by a kink at the necessary height. Where the thermocouple is inserted into the muscle, a drop of special glue is applied to ensure a stable position of the detector in the muscle during contraction. To keep the muscle at constant temperature it is surrounded by cotton wool encased in gauze, not touching the muscle. A "greenhouse effect" is created by constant moistening of the muscle with warm physiological saline.

The basic characteristics of all the measuring detectors are given in Table 1. Records of mechanical responses of the gastrocnemius muscles of rabbits aged 10 days and 3 months to direct tetanic contraction under isotonic conditions for 10 sec are given in Fig. 2.

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