APPARATUS FOR MEASURING THE FORCE AND AMPLITUDE OF CONTRACTIONS OF THE SKELETAL MUSCLES OF WARM-BLOODED ANIMALS

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For a quantitative study of the principles governing the work of the limb muscles of warm-blooded animals, high accuracy of measurement of the force and amplitude of the contractions developed by the muscles and a wide dynamic range of the measuring apparatus are required. For example, the strength of the tetanic contractions of the gastrocnemius muscle of the cat may reach 25-30 kg, and the strength of single threshold contractions—about 0.05 kg. The required accuracy of the measurements may be obtained by fixing the limbs as rigidly as possible, both at the joints and also relative to the detectors measuring the strength or shortening, and also if detectors possessing high sensitivity throughout the range of measured parameters are used. The rigidity of fixation of the limb necessary for measurement of the force of muscles contracting isometrically may be obtained by introducing steel pins into the bones of both sides of the joint and fixing them in the massive stands of a myograph [3]. For this purpose the Brown-Schuster myographic apparatus manufactured by the firm of "Palmer" may be used. In this apparatus the limb is fixed in a vertical position and the myograph, with a flat spring, records the contractions on the smoked drum of a kymograph.

When developing an apparatus for measuring the strength and amplitude of contraction of the skeletal muscles, the author adopted the view that nowadays it is better to use electrical methods of measurement and to record the results on ink-writing apparatuses. When recording the strength of contraction of a muscle and its blood supply simultaneously it is more convenient to fix the limb in the horizontal plane because in this way the design of the detector for measuring the blood flow and the maintenance of the temperature of the limb tissues are facilitated, and the influence of the muscle's own weight on the mechanical values to be measured is minimized.

A scheme of the apparatus satisfying the above demands is shown in Fig. 1. Its various units are arranged on the surface of a heated laboratory table.

The detector of the strength of contractions (Fig. 2A, B) consists of a steel ring, on the outer and inner surfaces of which are fixed four tensometric resistances, symmetrically relative to the axis of action of the forces to be measured. The detector was connected to a type TU-4M amplifier, which has a power yield. To record the mechanogram on the ink-writing apparatus with a high-ohmic input (for example, the "Cardiovar-VI"), the circuit of the phase detector of the TU-4M amplifier was modified; the number of turns in the secondary winding of the transformer feeding the measuring bridge of the demodulator was increased to 300 × 2, and the rating of the resistors included in series with the diodes of the demodulator was increased to 13 kΩ. For a range of loads of 0.05-5 kg, a ring with an internal diameter of 45 mm, a width of 70 mm, and a thickness of 15 mm was used, while for a range of 0.3-30 kg the diameter of the ring was 37 mm, its width 10 mm, and its thickness 17 mm. The rings were turned from a seamless steel tube, and 2 steel hooks were welded to the outer surface of each ring at an angle of 180°. By means of one of these hooks the detector was fixed to a guide screw, creating the necessary initial tension of the muscle, while to the other was attached a ring to which was joined the thread connecting the tensometric detector to the tendon holder. When the tensometric ring was stretched, the resistance of the tensometric resistor glued to the outer surface was lowered while that of the resistor glued to the inner surface was raised.

The circuits for including the tensometric detectors in the arms of the bridge and the details of their assembly on the ring to provide for maximal sensitivity and minimal temperature error of the measurements are shown in Fig. 2A and B. Shortening of the muscle was recorded by means of a rheostatic detector. This detector consisted of a ceramic cylinder, on which was closely wound a wire with a total resistance of 5 kΩ. When an isometric contraction was recorded, the slider of the potentiometer (Fig. 1, VII) was fixed to a steel cord connecting the muscle

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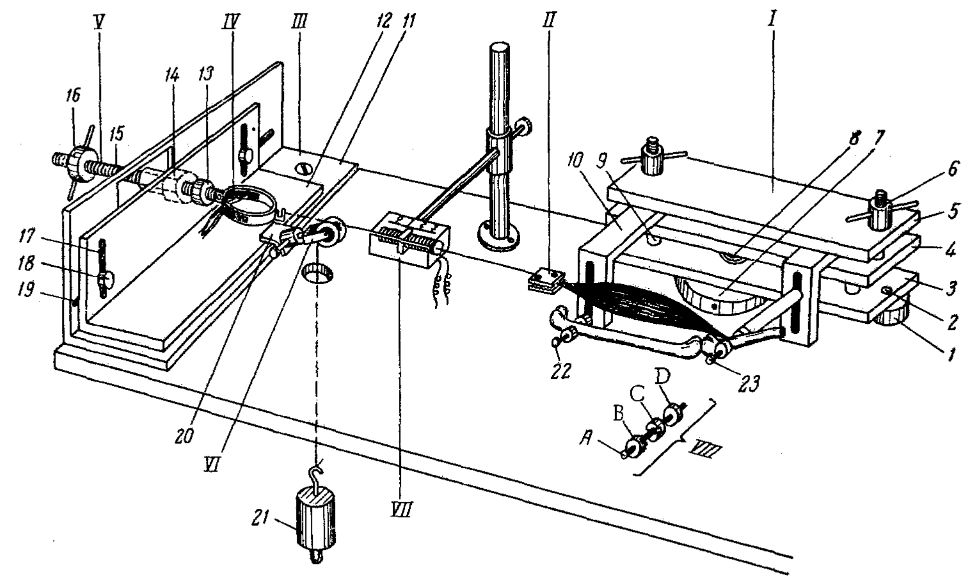
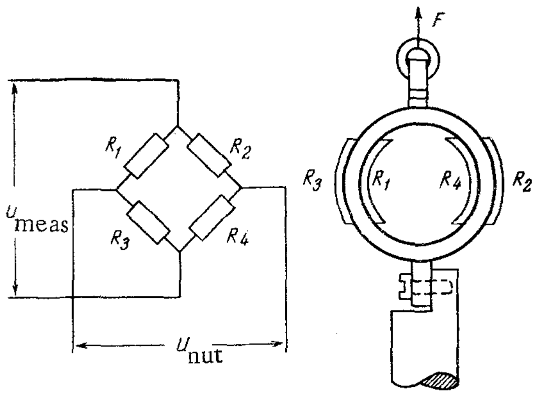


Fig. 1. Scheme of an apparatus to measuring the strength and amplitude of contractions of skeletal muscles. I) Units for fixing the limb bones; II) tendon holder; III) stand for fixing the detector of the strength of contractions; IV) detector of the strength of contraction; V) unit for preliminary stretching of the muscle; VI) unit for calibrating the strength of the contractions recorded; VII) detector of contractions fixed to stand. Remainder of explanation given in text.



A B

Fig. 2. Electrical circuit of the tensometric bridge (A) and scheme of assembly of the tensometric detectors on the ring (B).

tendon holder to the tensometric ring. The tracing of the force developed by the muscle was calibrated by applying known forces to the tensometric detector. For this purpose, various known weights were suspended from the cord passing over the pulley (VI) and fixed by one end to the hook on the detector (IV). The maximal sensitivity during recording of the mechanogram on the "Cardiovar-VI" apparatus was 5 g/mm.

When recording isotonic contractions the end of the cord connected to the tensometric ring was disconnected and passed over the calibration pulley. A weight sufficient to prevent looseness of the cord was suspended from it. The contact friction of the potentiometer slider was overcome by the static action of a force of 10-20 g.

The construction of the unit for fixing the limb ensured the necessary rigidity of fixation of the joints during the performance of experiments on animals of different species (cats, rabbits, dogs) or on animals of the same species but of different sizes. The preparation was moved along a vertical axis by means of the screw transmission (Fig. 1, 7 and 8) and along a longitudinal axis (in the direction of the acting forces) by moving the fixable riders (10) between the plates of the clamping table (4 and 5), pressed together by means of thumb-screws (6). So that during contractions of the muscles the clamping table did not turn relative to the screw (8), its two guiding rods (9) passing down to the base (3) of the fixing unit (1), were locked by screws engaging in the part (3) perpendicularly to the rods (9). The base, raised above the level of the heated table by an amount slightly greater than the thickness of the nut (7) by screw transmission operated by the knob (1) was fixed to the heated table by bolts and nuts. The steel pins (22 and 23), screwed into the fixable riders (10), were introduced into holes in the distal end of the femur and tibia. To prevent play due to free space between the holes in bones and the pins (22 and 23), specially shaped nuts (VII, B and C) were used. These gripped the bone at both sides of the hole when the pin (A) was screwed into the nut (D) of the riders (10). In experiments

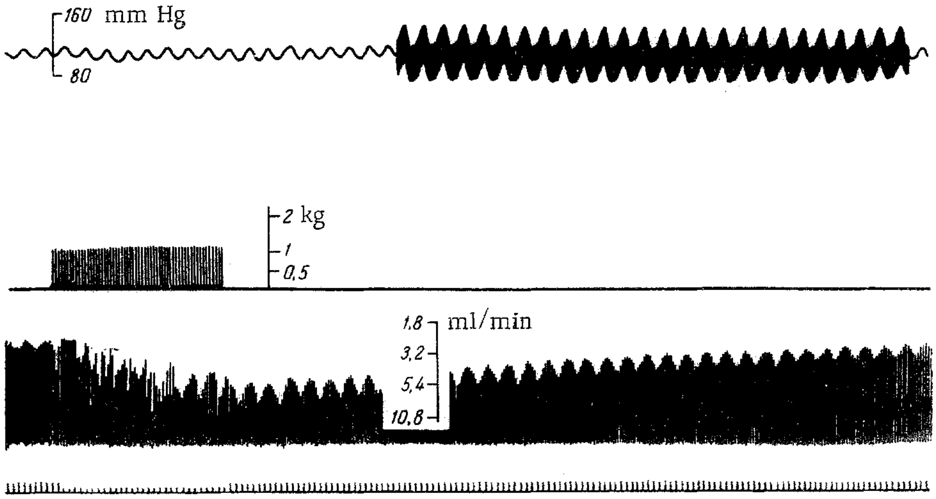


Fig. 3. Increase in blood flow in the gastrocnemius muscle during stimulation of the motor fibers of the sciatic nerve with rectangular pulses (1 V, 1 pulse/sec, 0.1 msec). From top to bottom: pressure in carotid artery (recorded on a "Barovar" electromanometer, with integrator included on the left), strength of muscle contraction, blood flow (the rate at which the drops of blood fell was recorded with an intervalograph); time marker (2 sec) and marker of period of stimulation of nerve (a decrease in the height of the marks).

on cats it was most convenient to move the unit I to the distance of 220 mm from the fixed stand (11) of the unit III. The length of the clamping table was 240 mm and its width 60 mm. The minimal height of unit I when assembled was 76 mm. The minimal height to which the joints to be fixed could be raised above the heated table was 20 mm and the maximal height 80 mm. The details 3, 4, and 5 were made from sheet steel 14 mm in thickness.

The fixing stand of the detector of the force of the contractions consisted of 2 steel angle girders. One was fixed to the table (4) by 10-mm bolts (Fig. 1, 11 and 12), and the second could be moved relative to the first in upward and transverse directions. It was fixed in the necessary position by means of shaped bolts with nuts (18), passing through mutually perpendicular slots (17 and 19). The angle girders was 6 mm in thickness, the upright members 150 mm high, and the width of the horizontal part 65 mm. A device for creating the preliminary tension of the muscle (V) was fixed to the movable angle girder. This consisted of a guide sleeve (14), fixed securely to the movable girder (12), a tightening nut (16) and lock nut (13), and a guide screw (15). To a notch at one end of this guide screw the hook on the ring of the detector of strength of contraction was bolted. The unit VI consisted of a pulley, the axle of which was supported by a fork fixed along the axis of displacement. This passed through a lock nut (20), welded to the movable girder (12). The diameter of the pulley, supported on two roller bearings, was 22 mm and its width 11 mm. The axis of displacement of unit V and the axis of displacement of the calibration unit VI lay in the same plane, perpendicular to the plane of the table.

The apparatus was used in experiments to investigate the relationship between the blood supply of the limb muscles and their contractions in isometric and isotonic conditions [1]. A tracing made in one of the experiments carried out with the use of this apparatus is given in Fig. 3.

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