CHANGES IN THE CONFIGURATION OF BLOOD VESSELS IN THE FROG'S SUBMAXILLARY MUSCLE

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UDC 612.741.61

Changes in the configuration of arteries and veins during contraction of the submaxillary muscle of frogs were studied by intravital microscopy in order to determine whether the histomechanical hypothesis of working hyperemia can serve to explain the changes taking place in the configuration of the vessels during contraction of a skeletal muscle. During tetanic contraction of the muscle changes arise in the configuration of the arteries and veins (from 30 to 120 μ in diameter). The predominant type of change is shortening along the axis of the vessel. Besides changes in length of the vessels, other changes were discovered: straightening out or sharpening of existing curves and the appearance of new curves.

Dilation of blood vessels of skeletal muscles during working hyperemia takes place through relaxation of their myogenic tone, and an important role in this process is played by the mechanical factor: stretching of the smooth muscles of the terminal arterioles [5]. According to the histomechanical hypothesis of working hyperemia of skeletal muscles [3, 7], contraction of the muscle fibers must lead to a change in the configuration of the terminal arterioles. It is postulated that this change may reduce the deformation of the pacemaker membrane and thus lead to a decrease in myogenic tone, i.e., to the development of working hyperemia.

This hypothesis was tested by intravital microscopy of the blood vessels of the submaxillary muscle in frogs [6]. A previous investigation showed that during simultaneous stimulation of the right and left mandibular nerves the displacement of the muscle does not exceed 50-100 μ [2]. In this way observations actually can be made on changes in the configuration of the vessels during contraction of the muscle and the changes can be photographed.

EXPERIMENTAL METHOD

Experiments were carried out on 39 frogs (*Rana temporaria*) weighing 30-35 g under general anesthesia (2-2.5 ml 10% urethane solution injected into the lymph sac). The skin covering the submaxillary muscle was divided, carefully stripped, and removed. The muscles (submental, genioglossus, geniohyoid, hyoglossus) and the tongue were removed through the mouth. The mandibular nerves running along the outer surface of the mandible were dissected on both sides and divided. The frog was placed on its back in a special chamber [4] fixed to the preparation stage of the MBI-6 microscope. The muscle was placed between two transparent plastic slabs held together by a weak spring. The space between the muscle and the top slab was filled with physiological saline. Each mandibular nerve was placed on unipolar silver electrodes mounted between the slabs. The submaxillary muscle was illuminated from inside the mouth by means of a special lamp [4]. Observations were made with 3.5× and 9× objectives. Mikrat-200 film was used for photography. Both mandibular nerves were stimulated for 3-120 sec by pulses of current (0.15 msec, 30 sec^{-1}) of increasing amplitude. These parameters were chosen on the basis of earlier observations [2] showing that tetanus is complete at a frequency of 30 sec^{-1}.

Laboratory of Regulation and Biophysics of the Circulation, 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 A. M. Chernukh.) Translated from Byulleten' Éksperimental'noi Biologii i Meditsiny, Vol. 76, No. 7, pp. 3-5, July, 1973. Original article submitted January 12, 1972.

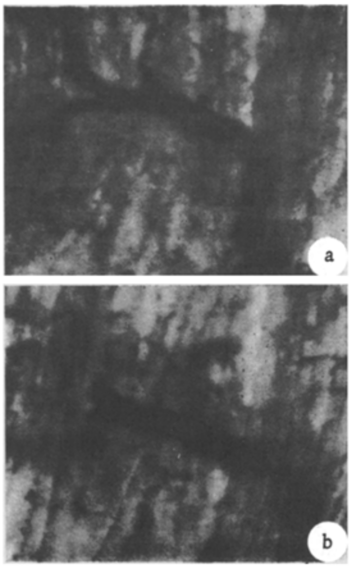

Fig. 1

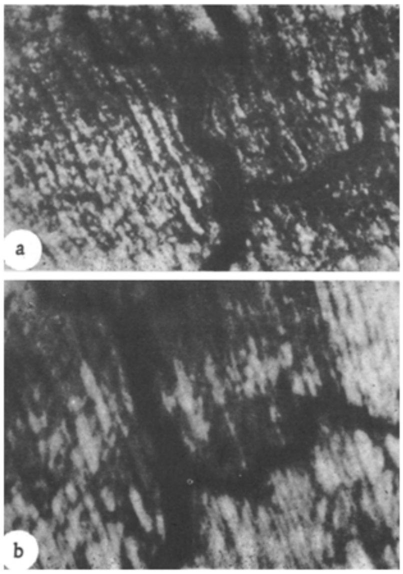

Fig. 2

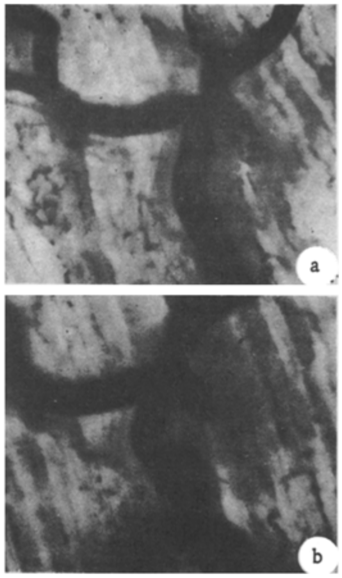

Fig. 3

Fig. 1. Photomicrograph of vein (diameter 84 μ) in resting muscle (a) and during contraction (b); shortening of vessel along axis during contraction of muscle (objective 3.5, ocular 10).

Fig. 2. Photomicrograph of artery (diameter of main trunk 48 μ, of right branch 39 μ) in resting muscle (a) and during contraction (b); lengthening along axis and straightening of curves of main trunk; shortening along axis and sharpening of curves of right branch during muscular contraction (objective 3.5, ocular 10).

Fig. 3. Photomicrograph of artery (diameter of main trunk 68 μ, of right branch 40 μ, and of left branch 37 μ) in resting muscle (a) and during contraction (b); shortening of branches along axis and appearance of sharp curves in main trunk and also in right branch during muscular contraction (objective 3.5, ocular 10).

TABLE 1. Distribution of Number of Arteries and Veins by Character of Changes in Their Long Axis during Muscular Contraction

Character of changes	Number of vessels	
	arteries	veins
Shortening along axis	36	19
Lengthening	9	6
No change	19	35
Total	64	60

EXPERIMENTAL RESULTS

Many capillaries running along the muscle fibers could be seen on the surface of the muscle. Vessels of larger caliber were much less frequent. Most arterioles and venules were located in the intermuscular layer, and for that reason their outlines could not be clearly distinguished.

Having determined from the direction of the blood flow whether a particular vessel was an artery or vein, it was photographed before, during, and after stimulation of the nerves.

The sharpest changes in the configuration of the arteries and veins during contraction of the muscle can be divided into two groups: 1) shortening along the long axis (Fig. 1), and 2) lengthening along this same axis (Fig. 2). The number of vessels belonging to this group and the number of vessels whose configuration was unchanged are given in Table 1.

Analysis of all the observations (64 arteries and 60 veins from 30 to 120 μ in diameter) showed that changes in configuration of the vessels arising during muscular contraction were unrelated to their caliber or to their arrangement relative to the muscle fibers. Since the subsequent examination does not require any more detailed classification of the small blood vessels, they will be described in general terms as arteries or veins.

Simultaneously with a decrease or increase in length of the vessels during muscular contraction, other changes in their configuration also arose: existing curves were straightened out or, conversely, sharpened and new curves appeared (Figs. 2 and 3).

With an increase in amplitude of the stimuli and, correspondingly, with an increase in the number of contracting muscle fibers the changes in configuration of the vessels usually increased in severity to reach a maximum contraction of the muscle.

At the beginning of tetanic contraction of the muscle the blood flow in most arteries and veins slowed down or stopped. However, from 2 to 40 sec after the beginning of muscular contraction, the blood flow showed a slight increase, although as long as the muscle continued to contract it remained slow.

The fact that the blood flow became much slower or stopped completely indicates the onset of compression of the vessels. In fact, during muscular contraction the lumen of some of the arteries and veins was reduced in size. Usually the decrease in diameter did not exceed 15-30% of its initial value. The reason why in these experiments constriction of the lumen of the vessels during muscular contraction was comparatively rare is evidently that vessels on the surface of the muscle were observed. According to Andronov and Manvelyan [1], vessels in the interior of the muscle undergo sharp compression in a direction perpendicular to the course of the fibers.

After contraction of the muscle in 80% of cases there was a considerable acceleration of the blood flow in the arteries and vessels. The decrease in the linear velocity of the blood flow to its initial value occupied about 2.5-5 min. If the initial velocity of the blood flow was very great, it was difficult to determine whether the blood flow was accelerated after muscular contraction purely by visual observations.

The results of these experiments thus confirmed the basic assumption of the histomechanical hypothesis of working hyperemia, namely, that the change in configuration of the small blood vessels in a skeletal muscle takes place as the result of its contraction [3, 7]. Meanwhile it was found that not only the terminal arterioles, but also blood vessels up to 120 μ in caliber and both arterial and venous in character, undergo changes of this type. Although the changes in the configuration of the vessels could vary in character, the predominant type was shortening of the vessels along the axis and the formation of curves or the sharpening of existing curves in the resting muscle.

It is a very interesting fact that changes in the configuration of the arterial vessels arise twice as frequently as those in veins (Table 1). This fact probably means that the organization of the connective-tissue structures responsible for attachment of the arteries and veins to the bundles of muscle fibers varies.

It is difficult to accept that marked changes in the configuration of the blood vessels during muscular contraction would not modify the state of their smooth muscles. If such an effect takes place, according to the histomechanical hypothesis of working hyperemia, it could be the cause of the decrease in myogenic tone of the vessels and, consequently, of their dilatation.

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