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PARTICIPATION OF CONTRACTILE ACTIVITY OF SKELETAL MUSCLE IN RESPONSE OF THE CIRCULATORY SYSTEM TO ORTHOSTASIS

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In experiments on anesthesized cats abolition of the contractile activity of the skeletal muscles by means of a muscle relaxant sharply increased the initial fall and substantially reduced the compensatory recovery of the arterial pressure (BP) during the orthostatic test (OT). The response of the cardiac output during OT was not significantly altered. An increase in BP was found, synchronized with the motor responses, and could be abolished by the muscle relaxant. It was shown by means of an aritifical circulation (by-passing the left ventricle) that compensatory constrictor responses of resistive vessels during OT are abolished by the muscle relaxant. In some experiments, administration of the muscle relaxant significantly increased the retention of blood in capacitive vessels.

KEY WORDS: orthostasis; contractile activity of skeletal muscle; resistive and capacitive vessels; retention of blood.

The role of skeletal muscle in the development of compensatory hemodynamic responses to orthostasis in man and animals has received little study. Although investigations have shown an increase in tone of skeletal muscles during the orthostatic test in man [12], the importance of this phenomenon for compensatory reactions of the circulatory system has virtually not been studied.

Interest in this problem is increased, first, by evidence that the "muscle pump" participates in the formation of certain systemic circulatory responses [5, 7] and, second, by the fact that orthostatic resistance is reduced by hypokinesia in man [4, 10] and after blocking of skeletal muscle activity in animals [3].

The objects of the present investigation were: 1) to compare the dynamics of changes in the arterial pressure (BP) and cardiac output (CO) during orthostasis when the contractile activity of the skeletal muscles was intact and excluded and 2) to determine the degree of participation of the resistive and capacitive vessels in the mechanism of the effect of contractile activity of skeletal muscle on the circulatory system during orthostasis.

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TABLE 1. Effect of Blocking Contractions of Skeletal Muscles (Listhenon, 0.2 mg/kg) on BP and CO during Orthostatic Test

Experimental conditions	BP, mm Hg				CO, ml/min			
	initial value	Δ_{20}	Δ_{60}	P	initial value	Δ_{20}	Δ_{60}	P
Intact contractile activity	145±3,3	—14,2±2,1	—7,1±2,0	<0,05	277±4,2	—26,9±2,6	—19,1±4,3	>0,05
Blocked contractile activity	154±3,4 >0,05	—24,3±2,2 <0,01	—17,2±2,4 <0,01	<0,02	270±4,8 >0,05	—29,5±4,3 >0,05	—15,8±1,1 >0,05	<0,05

Legend. Δ_{20} and Δ_{60} denote changes after 20 and 60 sec of orthostatic test respectively.

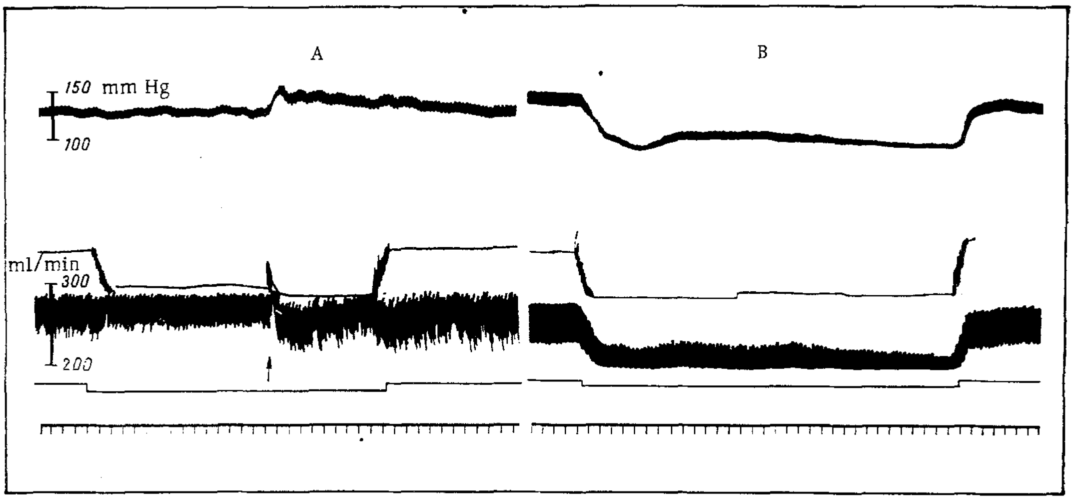

Fig. 1. Blocking of motor response by muscle relaxant and response of hemodynamics synchronized with it during OT. A) Before, B) 5 min after injection of muscle relaxant. Curves from top to bottom: BP, movement of hind limbs, CO (mean value), marker of procedure, time marker (10 sec). Arrow denotes motor response during OT.

EXPERIMENTAL METHOD

Experiments were carried out on cats anesthetized with urethane (1.0 g/kg). The orthostatic test (OT) was carried out by rotating the table to which the experimental animals were fixed through 45° to the horizontal plane in 3 min. BP was recorded in the femoral artery by means of a mechanotron electromanometer [6]. BP was recorded continuously by the inflatable cuff detector of an RKÉ-1 electromagnetic flowmeter [8], recording the volume velocity of the blood flow in the ascending aorta. During the experiments the animals were artificially ventilated.

Experiments with an aritifical circulation (by-passing the left ventricle) were carried out in accordance with the scheme described previously [7]. The pumping function of the left ventricle was replaced by pumping a constant volume of blood into the aorta through the iliac artery by means of a constant delivery pump at the rate of 80-100 ml/kg/minfrom a reservoir into which blood was taken from the left atrium. Under these conditions the tone of the resistive vessels could be estimated from the BP level. The state of the capacitive vessels was judged from the degree of retention of blood in the vascular system, reflected in changes in the blood level in the reservoir (a fall of level corresponded to an increase in retention of blood, mainly in the capacitive vessel).

To block the contractile activity of the skeletal muscle, the muscle relaxant listhenon was used in a dose of 0.2 mg/kg. This dose, according to observations of Danilov et al. [1], is under one-fiftieth of the dose with ganglion-blocking action. The present writer has shown [5, 7] that this dose of listhenon does not affect reflex vascular responses in cats under urethane anesthesia. Cessation of rhythmic respiratory movements of the

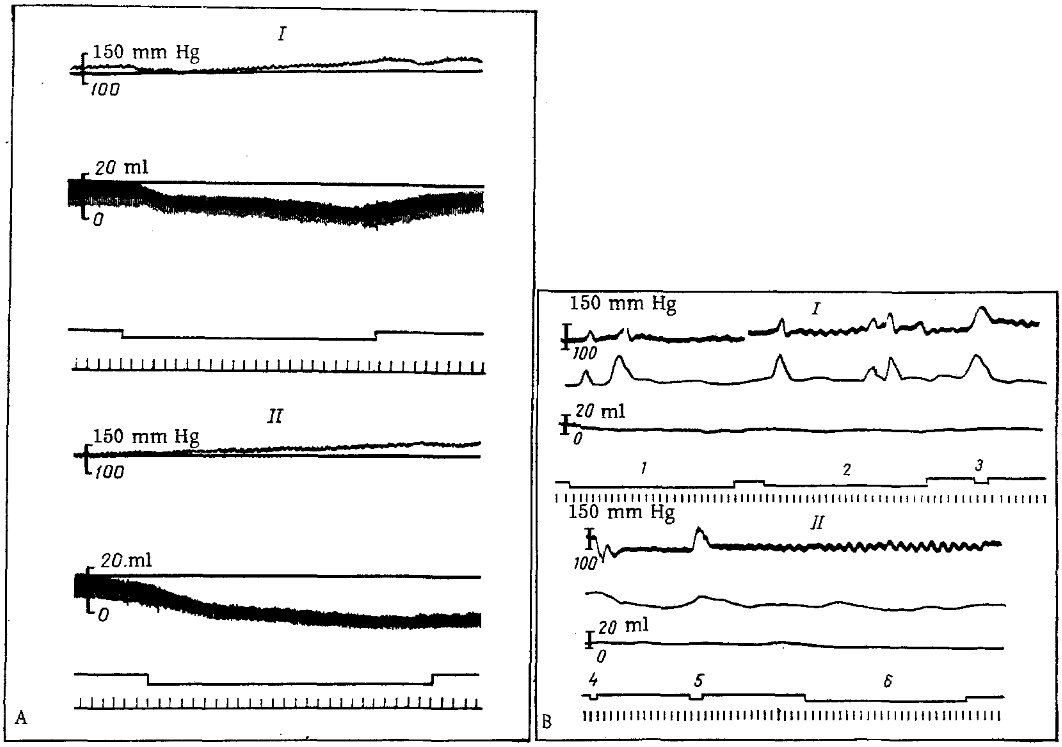

Fig. 2. Responses of capacitive and resistive vessels to OT with contractile activity of skeletal muscles intact (A, I, B, I) and blocked (A, II, B, II). Experiments with artificial circulation. A) Significance of curves from top to bottom: BP guide lines, blood level in reservoir (in ml), marker of procedure, time marker (10 sec). B) Significance of curves from top to bottom: AP, movements of hind limb, blood level in reservoir (in ml), marker of procedure, time marker (10 sec). 1, 2, 6) orthostatic tests; 3, 5) electrical stimulation of central end of divided tibial nerve (5 V, 20 Hz, 5 msec); 4) injection of listhenon (0.2 mg/kg).

abdominal muscles was the indicator to blocking of neuormuscular transmission. Recording movements of the hind limb served as the indicator of motor responses. Both these indicators of skeletal muscle activity were recorded by means of a mechanotron displacement transducer.

All processes were recorded on the USChV-8 ink-writing oscillograph and subjected to statistical analysis by Student's t-test for paired samples.

EXPERIMENTAL RESULTS

In 14 experiments compensatory responses of BP and CO developing in the course of OT were compared when contractile activity of the skeletal muscle was intact and blocked (Table 1). The initial fall of BP (orthostatic hypotension) observed during OT when the skeletal muscles were intact was restored on average by 72% in all 14 cases after injection of listhenon ($P < 0.01$). The compensatory restoration of BP after the phase of orthostatic hypotension also was sharply reduced (on average by 143%). Meanwhile the initial decrease in CO under the influence of orthostasis and the subsequent deviation of CO observed when the skeletal muscles were intact showed no significant change through the action of the muscle relaxant (Table 1, Fig. 1). Changes in the cardiac frequency during OT were not significant.

In six of 14 experiments during OT active motor responses of the animal were observed, accompanied by a synchronous rise of BP by 8-10% (Fig. 1). This confirmed the facts described above, reflecting an increase in contractile activity of the skeletal muscles as one mechanism of compensation of orthostatic hypotension.

Blocking the contractile activity of the skeletal muscles was thus reflected only in changes in BP taking place during OT and caused virtually no change in the responses of CO. This result is in agreement with the predominant role of the vascular component of the response of the cardiovascular system compared with that of the cardiac component in the formation of responses of BP to orthostasis which the present writer established previously [9]. It was also postulated that in an experiment of this type changes in CO could be subordinate in character to changes in BP. It was therefore difficult to judge the character of the responses to CO in a pure form under these conditions.

To analyze the degree of involvement of the resistive and capacitive vessels in the mechanism of action of the contractile activity of the skeletal muscles on changes in BP during orthostasis, seven experiments were carried out with the use of an artificial circulation, by-passing the left ventricle. By using this type of experiment it was possible to assess changes in the state of the two divisions of the cardiovascular system separately [9].

In all seven experiments compensatory constriction of the resistive vessels, arising during OT and amounting on average to 8-10% of the initial value of BP when skeletal muscle contraction was intact, disappeared after injection of listhenon. In 4 of the 7 experiments a simultaneous increase in the retention of blood was observed (on average by 15-20%; $P<0.05$) after injection of listhenon (Fig. 2A). Previously [9] the writer found that compensatory vasoconstriction of the resistive vessels during OT was more constant in character than the response of the capacitive vessels. The resistive vessels may perhaps be to a certain degree more reactive relative to a fall in tone of the skeletal muscles than the capacitive vessels also. Characteristically in the three experiments in which clear restrictor responses of the resistive vessels were observed during OT and were synchronized with motor responses (Fig. 2B), injection of listhenon abolished both responses. Meanwhile, electrical stimulation of the central end of the divided tibial nerve (5 V, 5 msec, 20 Hz) continued to evoke systemic vasoconstriction even after injection of the muscle relaxant. This last fact indicates preservation of vascular reflexes together with abolition of responses of the resistive vessels due to contraction of the skeletal muscles. The constrictor changes accompanying the motor responses were possibly the result of influences on resistive vessels from receptors in the muscle tissue itself [11].

The response of the capacitive vessels during OT evidently supports Gauer's view [12] of the passive role of the venous reservoir in orthostasis. If it is recalled that the whole literature on the "muscle pump" is also based on the view of passive changes in the capacity of the veins under the influence of contractile activity of skeletal muscles [5, 7, 12, 13], then that is why abolition of skeletal muscle tone by the muscle relaxant in the present experiment led to an increase in retention of blood in the capacitive portion of the vascular system, i.e., to a decrease in orthostatic resistance. Facts pointing to an increase in orthostatic resistance during electrical stimulation of the lower limb muscles in man are important from the same aspect [2].

It is not yet clear what are the relative roles of the resistive and capacitive vessels in the mechanism of responses of CO and BP to orthostasis. It is evident, however, that as well as in reflex vascular mechanisms, skeletal muscle also participates in restoration of the lowered BP level during orthostasis.

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