PHYSIOLOGY

VASOMOTOR REGULATION

COMMUNICATION IV. SKELETAL MUSCLE VASCULAR REFLEXES INDUCED BY CHEMICAL AND THERMAL STIMULATION OF LIMB RECEPTORS

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Previous articles [1, 2] have described vascular hindlimb reflexes in which vessels to the muscles are principally involved, and which are induced by electrical stimulation of the afferent fibers of somatic nerves.

A weak electrical stimulus causes dilatation of the hindlimb vessels and a general lowering of the arterial pressure. A stronger stimulus causes contraction of the limb vessels and raises the arterial pressure. Further increase in strength of the stimulus causes a biphasic local reflex in which the initial vascular constriction is followed by a dilatation. The latter develops through an inhibition of vasoconstrictor tone [2].

Since this reaction indicates the possibility of inhibition occuring in one part only of the vasomotor center, while the other parts remain excited, it is of fundamental importance to explain the mechanism of this kind of inhibition.

The change of the local reflex from constriction to dilatation may be explained as due to the involvement of groups of afferent fibers having different thresholds and being connected with receptor having different functions.

The present article attempts to confirm this hypothesis, and describes experiments with chemical and thermal stimulation of the limb receptors.

METHOD

The cats were anesthetized with 1 g/ kg urethane and 0.03 g/ kg of chloralose, and the reflex contractions of the vessels of the lefthindlimb were recorded in terms of variations in electrical resistance. The vessels were perfused with the animal's own blood, using a special kind of pump [3] which maintained the normal minute volume of the blood at its natural level. The pressure in the femoral artery was determined by the blood-flow rate and by the resistance offered by the limb vessels. Constriction or dilatation of the vessels caused an increase respectively of the perfusion pressure; the perfusion pressure in turn indicated the extend of the constriction or dilatation of the vessels. Clotting was prevented by intravenous injection of 7.5-10 mg/ kg of heparin. The arterial pressure was recorded from the carotid artery, and a trace of the respiration was obtained from a tracheal cannula and a Marey's capsule.

The vascular supply of the hindlimb was then separated from that of the body, and the leg perfused with Ringer-Locke solution. To reduce the edema, dextran was added to the perfusion fluid. The fluid consisted of a 0.5-5 % solution of NaCl and KCl , and in some cases the NaCl concentration was increased to 10%; the receptors of the limb were stimulated by adding 10^{-6} to 10^{-2} acetylcholine or nicotine, or by using a Ringer-Locke solution satured with carbon dioxide, or by raising the temperature of the Ringer-Locke solution to 40-50°.

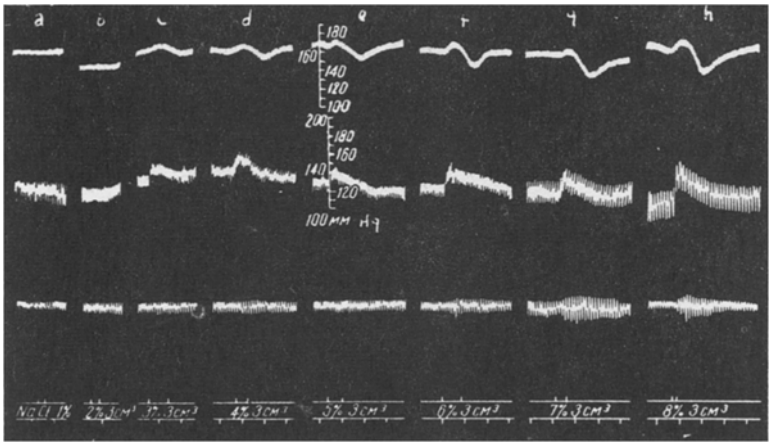

Fig. 1. Development of the reflex response to chemical stimulation of the right hindlimb by increasing concentrations of sodium chloride. a) 1%, b) 2%, c) 3%, d) 4%, e) 5%, f) 6%, g) 7%, h) 8%. Curves, from above downwards: perfusion pressure of the vessels of the left limb (resistance measurements); arterial pressure; respiration; stimulus marker; time marker (30 seconds).

The temperature of the tissues was controlled by a needle thermocouple thermometer inserted into the gastrocnemius muscle.

In this way, the receptors of the right hindlimb, which retained only a nervous connection with the rest of the animal, could be stimulated, and the reflexes affecting arterial pressure (systemic reflex) and the resistance of the vessels of the left hindlimb (segmental reflex) could be studied.

Altogether 41 experiments were carried out.

RESULTS

As can be seen from Figs. 1, a, b, stimulation with a 1 or a 2% solution of sodium chloride produces no reflex response. A 3% solution (Fig. 1, c) causes an increase in arterial pressure and a contraction of the vessels of the opposite limb. Simultaneously, there is also a small increase in the amplitude of the respiratory movements. These results are typical for all the chemical stimuli used: a threshold dose of any substance leads, as a rule, to a slight rise in arterial pressure and to a constriction of the vessels of the opposite leg. The same result is found with thermal stimulation.

In some experiments, the threshold concentrations were quite low, while in others they were much higher. However, none of the low concentrations of chemical stimuli nor any increase in temperature of the perfusate induced any reduction of arterial pressure or dilatation of the vessels of the opposite limb, such as occurs in response to electrical stimulation of a somatic nerve.

On further raising the concentration of the chemical stimulus, the segmental reflex became biphasic: the initial vasoconstriction was replaced by a dilatation (Fig. 1, d, e). Still higher concentrations caused a greater vasodilatation in the segmental reflex (Fig. 1, f, g, h). At the same time there is an increase of the pressor and respiratory reflexes.

Sufficiently strong thermal stimulation (Fig. 2, a) also causes a biphasic segmental vasomotor reflex. In this case the temperature of the muscle rose to 42°.

We found no differences in the development of the segmental reflex to result from the use of different chemical stimuli. The effects of increasing the chemical or thermal stimulus were precisely the same as those found for increasing the strength of an electrical stimulus applied to the afferent fibers.

In order to establish this conclusion more definitely, at the end of each experiment the right sciatic nerve was sectioned, and the central end stimulated electrically at 50 cps. Comparison of the segmental and systemic

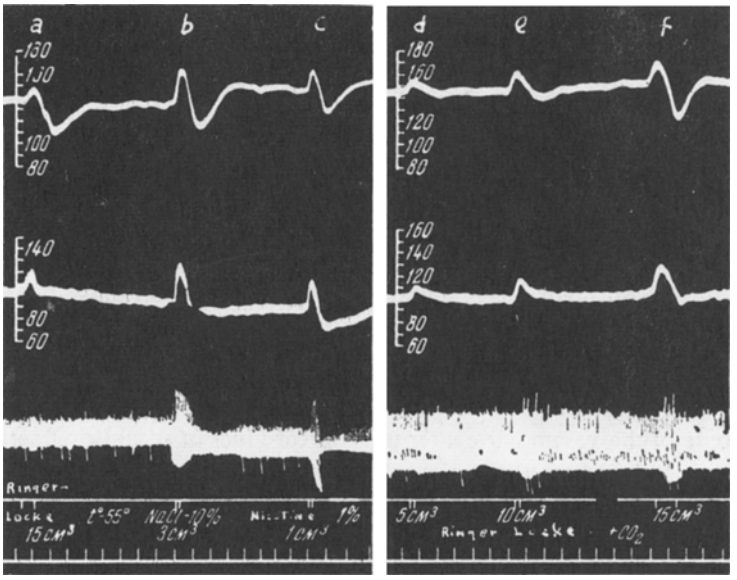

Fig. 2. Reflex response to thermal and chemical stimulation. a) 15 cm^3 of Ringer-Locke solution heated to 55°; b) NaCl— 10 %; c) nicotine 1%; d, e, f) 5, 10 and 15 cm^3 Ringer-Locke solution saturated with carbon dioxide. Curves as in Fig. 1.

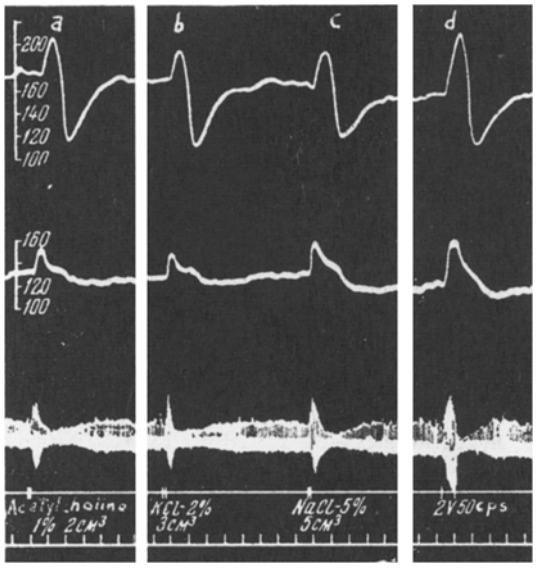

Fig. 3. Reflex responses to chemical and electrical stimulation. a) Acetylcholine —1%, 2 cm^3 ; b) potassium chloride — 2% — 3 cm^3; c) sodium chloride — 5% ; d) stimulation of the central end of the right sciatic nerve. Curves as in Fig. 1.

reflexes induced by strong chemical stimulation (Fig. 3, a, b, c) with those produced by electrical sitimulation in the same animal (Fig. 3, d) shows that, broadly, the same result is obtained in the two cases.

The segmental reflexes produced by acetylcholine or by sodium and potassium chloride are almost identical with those resulting from electrical stimulation.

The same relation is also found for the respiratory reflexes. In all cases, the initial reflex hyperventilation changes over to an inhibition of respiration, and the transition occurs together with the development of the dilator phase of the segmental reflex.

A similar biphasic respiratory reaction is found in many experiments with chemical stimulation (Fig. 2, b, c). The small depressor phase at the end of the pressor systemic reflex (Fig. 2, c, Fig. 3, c) was very seldom found in our experiments.

Thus, this effect of chemical or thermal stimulation differs only in one respect from that obtained by stimulating afferent nerve fibers electrically; in the former, there is no depressor systemic reflex nor any initial vasodilatation in the segmental reflex. These responses, which are typically obtained by weak electrical stimulation, are due chiefly to the excitation of β-fibers of Group A [5 , 10] . It is known that the terminal apparatus of the β-fibers has a mechanoreceptor function [8, 11].

Clearly, it is the muscle proprioceptors and the cutaneous mechanoreceptors which respond to comparatively weak mechanical stimuli. At the same time, it is known that several chemical substances , for instance acetylcholine, succinylcholine, nicotine, etc., are able to induce impulses in the fibers of these receptors [4, 6, 9].

The failure of low concentrations of chemical stimuli to elicit a depressor reflex does not mean that the receptors are not stimulated. It may be that with the chemical stimulation there is not sufficient synchronization of the afferent impulses, as in the case with electrical stimulation.

The relationship between the pressor reflex and the excitations of fibers of Groups Aδ, B and C has been demonstrated many times. [5, 10]. Since the stimulation of their receptors is affected both mechanically and by thermal and chemical stimuli [7, 11] it must be supposed that in our experiments the pressor reflex and the segmental vasoconstriction reflex resulted from stimulation of Aδ, B and C fibers.

For all the stimuli, the dilatation of the limb vessels always occurs after an initial contraction. The segmental reflex is always biphasic. For this reason, the stimuli used did not make it possible to demonstrate the existence of a specific receptor group causing only inhibition of vasoconstrictor tone. We can scarcely attribute this circumstance to lack of a sufficiently specific action of the stimuli on the receptors, because a very wide range of different substances was used.

The constant response of the vasomotor center to different kinds of stimuli indicates rather that both phases of the segmental reflex are produced by stimulation of the same receptors.

Nevertheless, the dilatation phase may be induced merely by increasing the strength of the chemical stimulus (Fig. 2, d, e, f). Although in this experiment the concentration was not changed, the time for which the receptors were stimulated was increased. We cannot therefore decide whether the biphasic segmental reflex, and particularly its dilator phase, is caused by an increase in the total number of impulses to the vasomotor center, or whether the determining factor is the duration of the afferent volley. Certain experiments with electrical stimulation favor the second alternative.

SUMMARY

One limb was separated humorally from the rest of the body, and stimulated chemically and thermally while a study of the vascular reflexes of the opposite limb was made.

The segmental vasomotor reflexes were recorded in terms of change of electrical resistance. Stimulation by sodium and potassium chloride, acetylcholine, nicotine, carbon dioxide, and by heat caused a segmental reflex in the opposite limb. With stronger stimuli, the reflexes became biphasic, so that the vasoconstriction changed to a vasodilatation.

The differences between vasomotor reflexes induced electrically and chemically are discussed.

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* Original Russian pagination. See C.B. Translation.