VASOMOTOR REGULATORY MECHANISMS

COMMUNICATION III. REFLEXES INVOLVING EFFERENT PATHWAYS TO THE VESSELS OF THE LIMBS AND AFFERENTS FROM SOMATIC NERVES

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In a previous communication [7]. it was shown that electrical stimulation of afferent fibers of somatic nerves initiates vasomotor reflexes affecting the vessels of the extremities, and that the effects are closely related to the strength of the stimulus. Comparatively weak stimuli cause a reflex dilatation, which we will refer to as primary. On increasing the strength of the stimulus, the effect changes to a contraction of the blood vessels. Still stronger stimuli cause the vasoconstriction to give place to a secondary vasodilatation.

The last phenomenon outwardly resembles the "perversion" of spinal motor reflexes, described by Sherrington and Sowton [1, 16, 17]. In our experiments, a relatively weak stimulation of the afferent fibers of the ipsilateral limb (in case of the extensor reflex) or of the contralateral limb (in case of the flexor reflex) brought about contraction of the corresponding muscles. As the stimulus increased, the contraction increased a certain amount, after which it invariably changed into a relaxation of the muscle, i.e. a typical reciprocal inhibition took place.

At a certain strength of more or less prolonged stimulation, the flexor or extensor reflex takes place biphasically; the initial contraction of the muscle changes into a relaxation. The regional vasoconstrictor reflex takes place in precisely this way, changing over during the stimulation into a vasodilator effect.

There can be no doubt that the "perversion" of motor reflexes is due to the development of central inhibition. Whatever view of the mechanism of the latter is held, the relaxation of muscle which replaces the contraction can only occur through the inhibitory effect supervening in the motor neurones of skeletal muscle.

This is not the case for the relaxation of the smooth muscles of the blood vessels. Theoretically, the reflex dilatation of the vessels might take place in the following ways: first, by central inhibition of vasoconstrictor tone continuously maintained by sympathetic adrenergic fibers [8 and others], secondly, by stimulation of vasodilator fibers originating in the dorsal roots [10, 3, 9 and others] or, by the excitation of sympathetic vasodilator cholinergic fibers [12, 14, 15, 18]. It is only possible to talk of a "perversion" of a vasomotor reflex if the secondary vasodilatation is brought about by the first of the ways just enumerated, i.e. as a result of central inhibition of sympathetic vasoconstrictor tone. The present work consists of an investigation of this problem.

METHOD

The experiments were performed on cats, and a continuous recording was made of the resistance of the blood vessels to fluid flow while perfusing the limbs at a stabilized minute volume of blood. The principle of the method

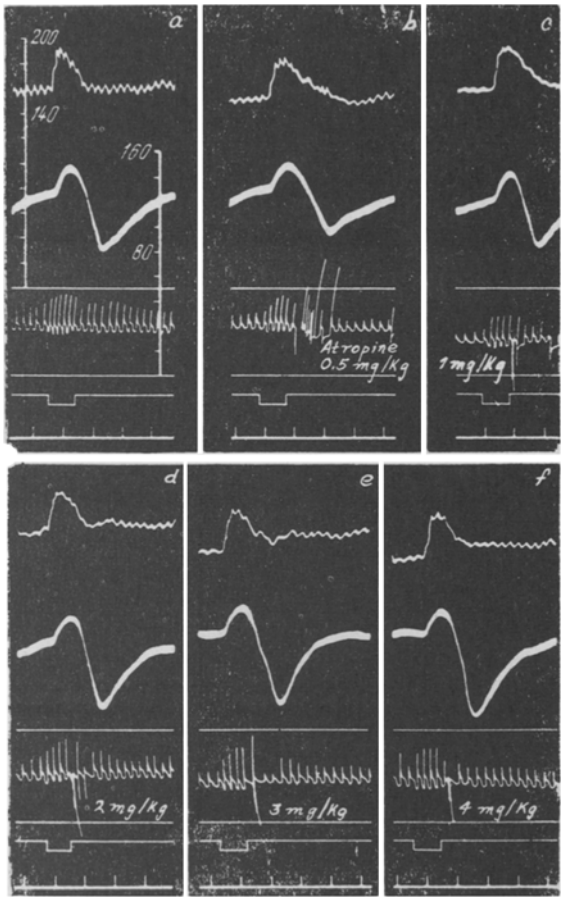

Fig. 1. Absence of any changes in secondary regional vasodilation after injecting atropine. Stimulation of the right peroneal nerve (alternating current, 50 c/s, 4 v). Perfusion of left hind limb: a) before injection atropine; b) after injecting 0.5 mg/ kg; c) 1 mg/ kg; d) 2 mg/ kg; e) 3 mg/ kg; f) 4 mg/ kg of atropine injected into the jugular vein. Curves, from above downwards: arterial pressure in carotid artery, perfusion pressure in left femoral artery, zero line of arterial pressure, respiration, zero line of perfusion pressure, applied stimuli, time markings — 30 seconds.

and the apparatus have been described previously [4,5, 6]. The animals were anesthetized with urathane (0.5 g/ kg) and chloralose (0.03 g/ kg). Coagulation of the blood was prevented by heparin (7.5-12.5 mg/ kg). The arterial pressure and the respiration were recorded by the usual methods. Usually the central end of the cut nerve was stimulated, and the nerve used was usually the sciatic or the peroneal nerve of the leg opposite the perfused one, or else the peroneal nerve cut at the level of the malleolus of the perfused limb; a 50 cycle alternating current was used, the voltage on the electrodes being indicated by a voltmeter. In some cases, a square wave stimulator was used having independent frequency and amplitude controls and a fixed duration of 1 millisecond. In all, 21 experiments were performed.

RESULTS AND DISCUSSION

The change-over of the limbs to a dilatation, occurring during the stimulation of the afferent fibers, was found by Binet and Burstein [11] in experiments on dogs, and was also found by us in cats [7]. In both animals, the blood vessels of skeletal muscle are innervated by sympathetic vasodilator fibers. As is well known, these fibers are cholinergic: vasodilatation induced by electrical stimulation of the efferent pathways originating in the motor cortex and ending in the abdominal sympathetic chain is eliminated by atropine in doses of 0.1-0.3 mg/ kg [12, 14, 15, 18].

Also, atropine has no effect on reflex dilatation of the limb vessels occurring in response to stimulation of the central end of the brachial nerve by weak low-frequency pulses (we have previously described this kind of vasodilatation [7] as "(primary regional vasodilalation);" it has no effect either on the vasodilatation induced by stimulation of the mechanoreceptors of the carotid sinus and aortic arch [12, 14]. Consequently, the sympathetic dilator fibers can take no part in these reflexes.

As can be seen from the kymograms shown in Fig. 1, intravenous injection of atropine in doses up to 4 mg/ kg has no effect on the secondary regional vasodilatation. This dose is 13-14 times greater than that necessary for complete suppression of the dilatation of the vessels of the muscles of the hind limb induced by direct stimulation of the sympathetic cholinergic vasodilator fibers. Similar results were obtained in two further experiments.

It is therefore clear that the secondary regional vasodilatation is mediated by sympathetic vasodilators, and that these fibers (at any rate in an acute experiment) are not involved in the vasomotor reflexes mediated by the somatic nerves.

Bayliss [10], L. Fofanov [3], M. A. Chalusov [9], and many other authors have maintained that the vessels of sympathectomized limbs retain their ability to dilate in response to stimulation of the aortic nerve or of the central end of the vagus. In experiments of this type, the only pathway for the transmission of reflex effects to these vessels is via the fibers of the dorsal roots. It therefore seemed possible that antidromic transmission of impulses

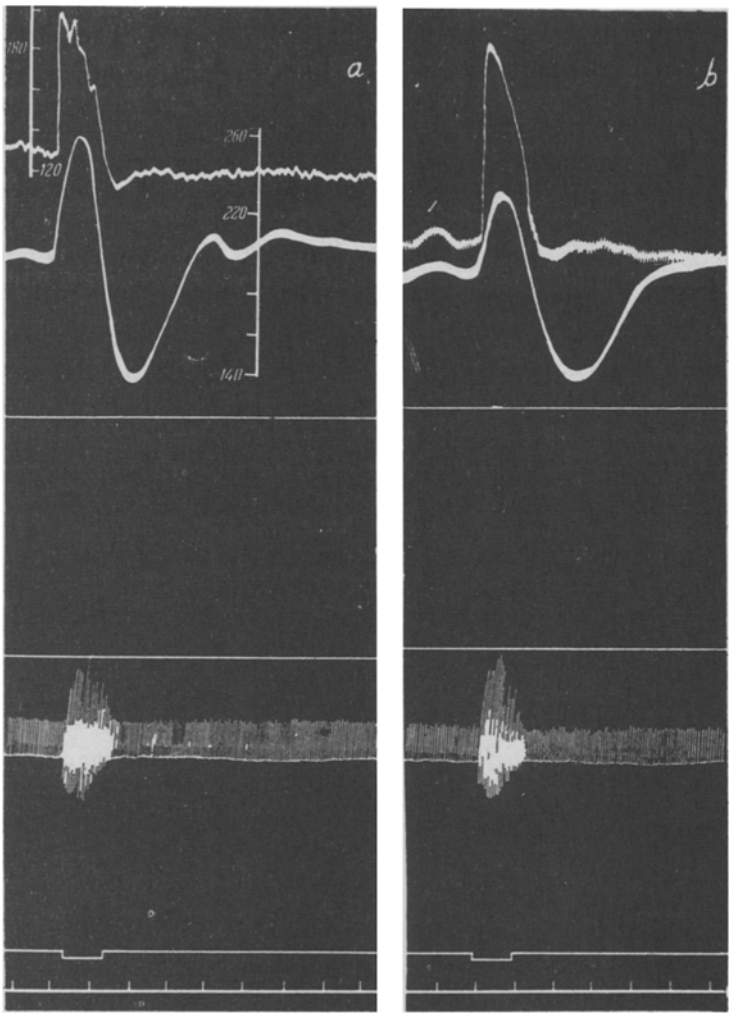

Fig. 2. Secondary regional vasodilatation before (a) and after (b) division of the posterior roots of the perfused limb. Stimulation of the right peroneal nerve (alternating current, 50 c/s, 2 v). Perfusion of left hind limb. Sequence of traces as in Fig. 1.

from the central nervous system to the vessels of the limbs along the afferent fibers might occur [10]. The existence of a reflex antidromic mechanism of vasodilatation as postulated by Bayliss has been much discussed. Many different hypothesis have been advanced to explain this paradoxical phenomenon [2]. However, recent researches have shown that there is no need for such hypotheses, since Bayliss's phenomenon is not neurogenic.

In their investigations, Folkow, Strőm and Uvnäs [13], and Frumin, Ngai and Wang [14] have given a detailed analysis of the artifacts due to using plethysmography and many other methods in the measurement of the blood supply to organs – artifacts which have led to the idea of antidromic vasodilatation as part of a reflex.

Once they had eliminated the possibility of hemodynamic influences, these investigators found no vascular response in sympathectomized limbs on stimulating the carotid sinus, afferent fibers of the vagus, or the so-called "depressor zone" of the bulbar vasomotor center. Although their results are completely convincing, the results of their experiments cannot automatically be assumed to be due to secondary regional vasodilatation.

We have studied systematic and regional reflexes before and after division of the posterior roots of the lumbosacral section of the spinal cord on the same side as the perfused limb. Twelve such experiments were carried out. The spinal canal was opened, using a special milling cutter, while carefully preserving the spinal cord and dorsal roots from damage. After 1½-2 hours from the time of opening the canal and cutting the dura, an injection of

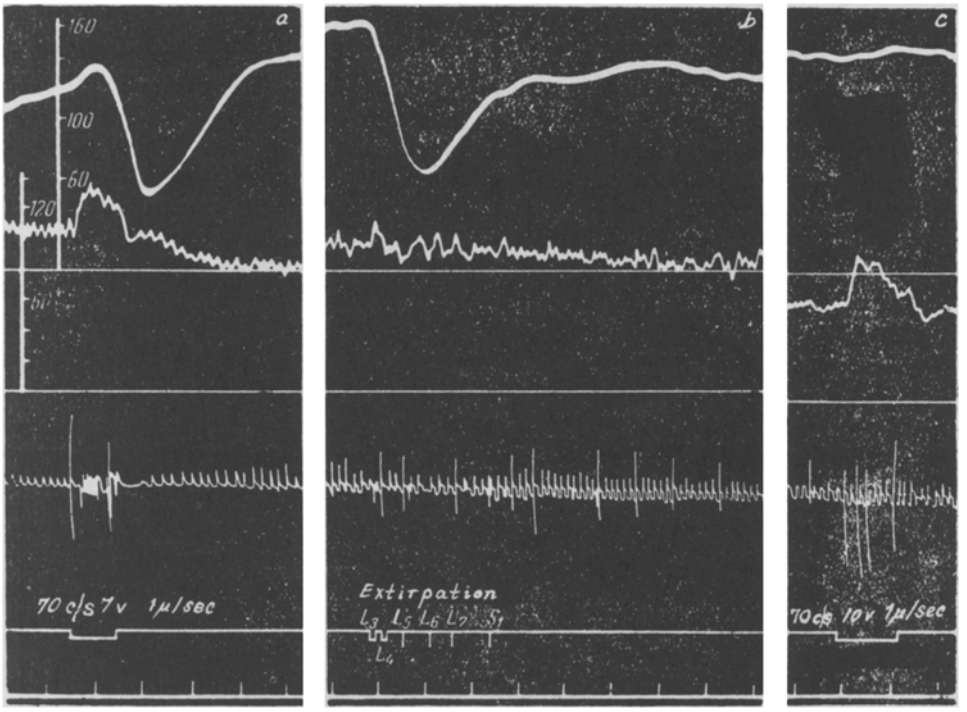

Fig. 3. Disappearance of regional vasomotor reflex after unilateral lumbar sympathectomy (from L_3 to S_1); a,b) stimulation of the right sciatic nerve (a – square pules, duration 1 millisecond, 70 c/s, 7 v, b – same, 10 v); c) moment of sympathectomy. Perfusion of left hind limb.

heparin was given, and the main part of the experiment begun. After a few stimulations applied to the nerve of the contralateral limb, the posterior roots on the side of the perfused limb were divided, and reflex stimulation again applied. Typical results for this set of experiments are shown in Fig. 2, from which it can be seen that section of the posterior roots has no effect on the systemic or regional reflexes or, which was especially interesting to us, on secondary regional vasodilatation either.

The second observation, however, required confirmation. In some of the experiments, the secondary regional dilatation disappeared immediately after division of the posterior roots, and then gradually returned to its original value over a period of 20-30 minutes. The reason for this phenomenon is not at all clear. It could be due to stimulation of the posterior roots at the time of the division, or, as would appear more probable, to a reduction of the "background" afferent impulses. However that may be, secondary vasodilatation soon reappears. It follows therefore that the posterior roots cannot be the efferent pathway mediating this effect. Thus, there remains only one nervous mechanisms which could subserve this reaction, and that is central inhibition of sympathetic vasoconstrictor tone.

This conclusion was tested in 6 experiments with unilateral excision of the sympathetic ganglia from the 2nd-3rd lumbar to the 1st-2nd sacral segments. After opening the abdominal cavity, long ligatures were placed under the ganglia. The abdominal cavity was then sewn up, and after several "test" stimuli, the sympathetic ganglia were removed by pulling on the ligatures. After sympathectomy, it was not possible to elicit the regional reflexes by stimuli of any strength (Fig. 3).

In this way it can be seen that secondary regional vasodilatation results from reflex inhibition of tonic vasoconstrictor impulses. It therefore follows that the change-over from reflex regional vasoconstriction to vasodilatation resembles the "perversion" of spinal motor reflexes. More detailed results on the mechanism of "perversion" of regional vasomotor reflexes will be presented later.

SUMMARY

Secondary regional vasodilatation occurring in strong stimulation of the afferent fibers of somatic nerves was investigated in experiments on cats. The reflexes of the blood vessels of the posterior extremity were studied by the method of resistography. The exclusion of the sympathetic vasodilating fibers with atropine and the division of the posterior roots of the perfused extremity have no effect on secondary regional vasodilatation. The latter disappears after unilateral lumber sympathectomy. Thus, secondary regional dilatation is the sequence of the reflex inhibition of vasoconstricting fibers. The similarity of the mechanism of "perversion" of vasomotor and spinal motor reflexes was established.

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