FUNCTIONAL ORGANIZATION OF THE BULBAR VASOMOTOR CENTER. ACTIVITY OF THE NEURONS OF THE PRESSOR ZONE DURING CAROTID REFLEXES

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Numerous investigations [3-5, 19] have shown that the bulbar vasomotor center with its pressor and depressor divisions is a reflex center maintaining the vasomotor tone of the peripheral vessels. From the pressor division, occupying a wide area of the restrolateral bulbar reticular formation, excitatory influences arise which pass to the spinal vasomotor neurons. Meanwhile, the depressor division, occupying the mediocaudal structures, is regarded as the relaying point of afferent impulses from the mechanicoreceptors of the vascular zones [11, 14, 16]. The neurons of this division have a depressant effect, either on the activity of the neurons of the pressor division of the medulla or on the preganglionic sympathetic neurons of the spinal cord [3, 10, 16]. All these conclusions are based on observations of the responses in the final effector path (the general arterial pressure, the activity of the sympathetic nerves, the tone of the vascular wall) to local stimulation of the bulbar structures by means of relatively large electrodes. Such stimulation, however, may affect not one, but a group of neurons, not necessarily possessing the same functions, and also nerve tracts. The development of microelectrode techniques has made it possible to record the activity of individual vasomotor neurons directly.

The object of this study was to investigate the action potentials of the neurons of the pressor division of the vasomotor center and the effect of afferent impulses from the mechanicoreceptors of the carotid sinuses on these potentials.

EXPERIMENTAL METHOD

Experiments were conducted on 41 cats weighing from 2 to 3 kg, anesthetized with urethane. The method of dissection and fixation in a stereotaxic apparatus has been described previously [1]. To record the action potentials of the neurons steel needle microelectrodes were used, their points having diameters of 2-20μ. The electrodes were introduced through the cerebellum and directed in accordance with Szentagothai's atlas [20] towards the lateral, medial, parvocellular, and magnocellular nuclei of the bulbar reticular formation. The indifferent electrode consisted of a silver plate, fixed to the frontal bone of the skull.

The action potentials of the neurons were picked up with extracellular electrodes and recorded on a two-channel cathode-ray oscillograph. Two or three insertions of the microelectrode were made into the various nuclei in each animal and neurons at different depths were investigated. The arterial pressure in the femoral artery was recorded with a mercury manometer, and the respiratory movements by means of a pneumograph and a Marey's capsule. The recordings were made on a kymograph with synchronization of the marker of the period of stimulation and the tracing of the action potentials on the oscillograph. At the end of registration of the activity of the neuron this particular point was stimulated by an electric current through the same microelectrode as was used to pick up the action potentials, and the reaction of the arterial pressure was recorded.

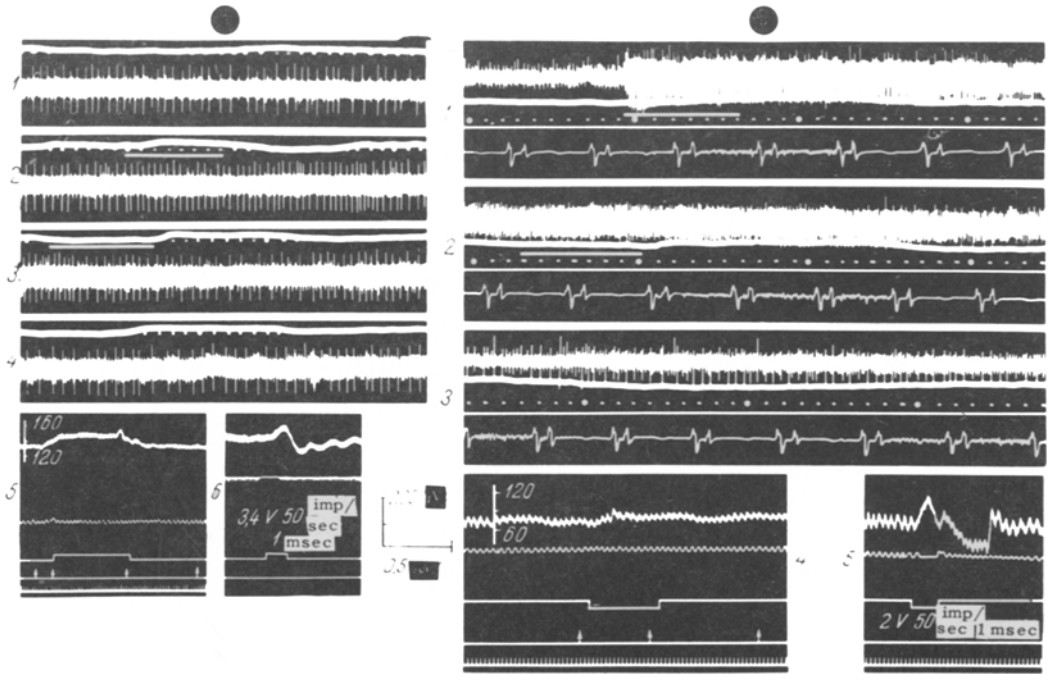

Fig. 1. Increase in frequency of discharges of neurons during pressor carotid reflex. A) Microelectrode (d = 2μ) in region of left lateral nucleus of reticular formation. Oscillograms: 1) initial activity of neurons; 2) moment of compression of 2 carotid arteries (white line); 3) moment of cessation of compression of arteries; 4) 30 sec after cessation of compression of carotid arteries. Significance of curves on oscillograms (from top to bottom): respiration, time marker (1 and 0.1 sec), discharges of neurons; 5) reaction of arterial pressure and respiration to compression of both carotid arteries; 6) reaction of arterial pressure and respiration to electrical stimulation of investigated point. Significance of curves on kymograms for all figures (from top to bottom: arterial pressure, respiration (Figs. 1 and 3), marker of period of stimulation, marker (arrow) of tracing of oscillograms, time marker (1 sec). B) Microelectrode (d = 10μ) in region of right parvocellular nucleus. Oscillograms: 1) moment of compression of right carotid artery; 2) moment of cessation of compression of artery; 3) 30 sec after cessation of compression of artery. Significance of curves (from top to bottom): discharges of neurons, respiration, marker of stimulation, time marker, ECG; 4) reaction of arterial pressure to compression of carotid artery; 5) effect of stimulation of point.

After the experiment the stimulated points were coagulated, the brain was placed in formalin, and the agreement between the position of the microelectrode and the coordinates as read was verified. The carotid pressor reflex was elicited by compression of one or both common carotid arteries, and the carotid depressor reflex by traction on both carotid arteries.

EXPERIMENTAL RESULTS

In all the investigated formations of the bulbar reticular formation, neurons were found showing activity in the form of single- and two-phase peak discharges of varied and irregular frequency and amplitude. In some neurons grouped discharges were recorded, not synchronized with the pulse or respiration, and with intervals of different lengths between the groups. In some cases discharges of several neurons were observed, differing in frequency and amplitude. In three neurons ill-defined volleys of discharges in rhythm with the cardiac cycle were recorded.

An analysis was made of the data obtained from 70 neurons, the activity of which lasted long enough to record 2-3 responses during the carotid reflexes, and the subsequent stimulation of which was accompanied by a reaction of the arterial pressure. During the pressor carotid reflex two types of changes in the action potentials of the neuronal elements, stimulation of which caused elevation of the arterial pressure, were observed. In the overwhelming majority of neurons (43) a more or less marked increase in the frequency of the discharges was recorded, beginning after a

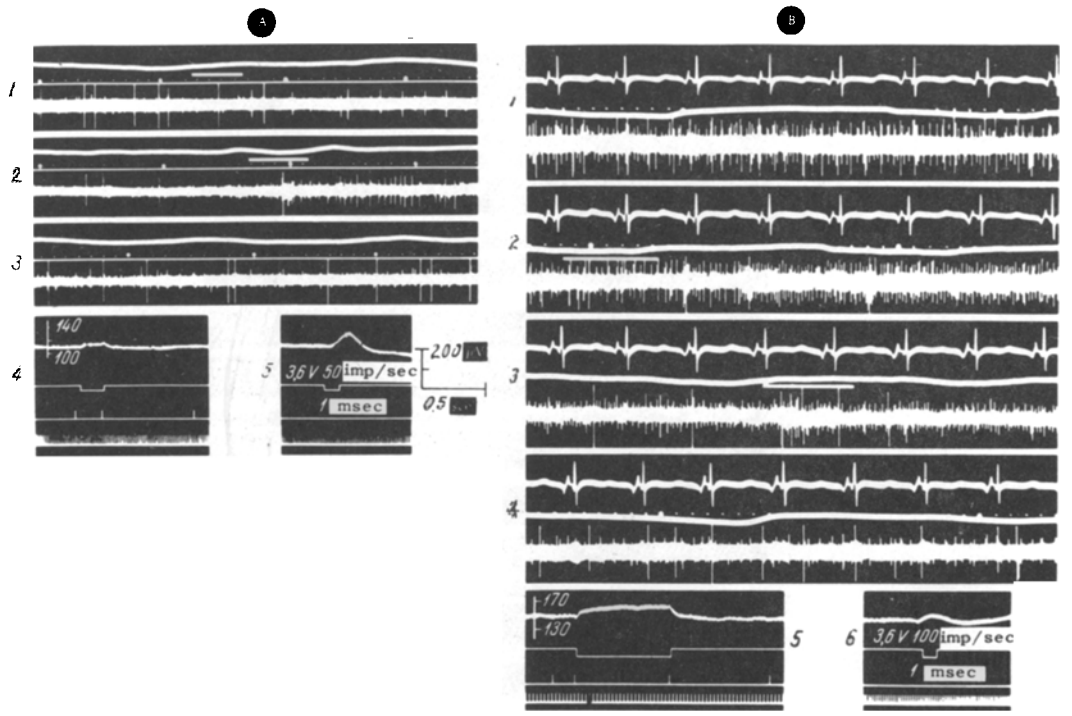

Fig. 2. Slowing of the discharges of the neurons during the pressor carotid reflex. A) Microelectrode (d = 10μ) in region of left magnocellular nucleus. Oscillogram: 1) moment of compression of left carotid artery; 2) moment of cessation of compression of artery; 3) 1 min after cessation of compression of artery. Significance of curves the same as in Fig. 1A; 4) reaction of arterial pressure during compression of left carotid artery; 5) effect of stimulation of point. B) Microelectrode (d = 2μ) in region of left magnocellular nucleus. Oscillograms: 1) original activity of neurons; 2) moment of compression of two carotid arteries; 3) moment of cessation of compression of arteries; 4) 1 min after preceding recording. Significance of curves (from top to bottom): ECG, respiration, time marker, discharges of neurons; 5) reaction of arterial pressure to compression of arteries; 6) effect of stimulation of point.

short latent period. The oscillogram of one of these experiments is shown in Fig. 1A. The initial activity was expressed in the form of biphasic peak discharges with a frequency of 12-14/sec. At the exact moment of compression of the two common carotid arteries, before a rise in the arterial pressure had taken place, an increase in the frequency of the discharges began, which lasted while the arteries were compressed. After compression of the arteries ceased, immediately a gradual decrease in the frequency of the discharges began to take place, and the original frequency was restored after 1 min.

The oscillograms of the other experiment (Fig. 1B) demonstrate the appearance of activity in the neuron during the carotid pressor reflex. In this experiment no clear discharges of the neuron were recorded before stimulation. At the moment of compression of the ipsilateral common carotid artery fast discharges of high amplitude appeared, lasting throughout the period of compression of the artery. After compression of the artery ceased, a gradual slowing of the discharges began.

In a smaller number of cases (10) a decrease in the frequency of the discharges of the neurons was observed during the carotid pressor reflex. It is clear from the oscillograms (Fig. 2A) that discharges were recorded from two neurons. Compression of the ipsilateral common carotid artery caused a slowing of the discharges of both neurons. When 0.3 sec had elapsed after the cessation of compression of the artery, for 1.5 sec an increase in the frequency of the discharges was observed, after which the original frequency was gradually restored.

It follows from the results of the experiment, the oscillograms of which are given in Fig. 2B, that two adjacent neurons may react differently. The initial activity of two neurons discharging at different frequencies was recorded. Compression of the two carotid arteries led to a decrease in the frequency of the discharges of one neuron and to an

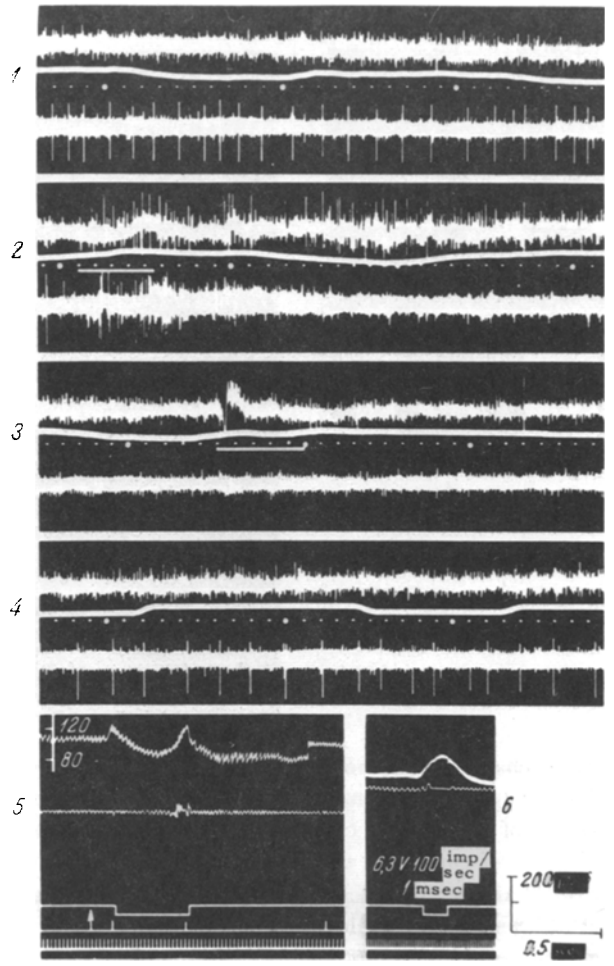

Fig. 3. Reaction of neurons and cervical sympathetic nerve during depressor carotid reflex. Microelectrode (d = 10μ) in region of right magnocellular nucleus. Oscillograms: 1) initial activity of neurons; 2) moment of stretching of two carotid arteries; 3) moment of cessation of stretching of arteries; 4) 2 min after previous recording. Significance of curves (from top to bottom): activity in right cervical sympathetic nerve, respiration, time marker, marker of stimulation, discharges of neurons; 5) reaction of arterial pressure to stretching of two carotid arteries; 6) effect of stimulation of point.

increase in the frequency of discharges of the other. It should be noted that during compression of only one common carotid artery neurons were more often found that reacted by a slowing of the discharges (7 of 12 neurons).

During the carotid depressor reflex (7 experiments) we observed a slowing and complete suppression of the discharges in neurons such as these. In the experiment illustrated in Fig. 3 stretching of the common carotid arteries caused a fall in the arterial pressure after an initial (for 2 sec) rise (evidently as a result of a transient interruption of the blood flow through the sinus at the moment of stretching of the arteries). The discharges of the neuron increased in frequency while the pressure was raised, and at the same time the flow of impulses in the cervical sympathetic nerve was intensified, after which a sharp decrease in the frequency and amplitude of the discharges of the neuron and depression of the flow of impulses in the cervical sympathetic nerve took place. After stretching ceased, the electrical activity of the neuron and nerve was gradually restored.

The reactions described above were observed only in those neuronal elements in which stimulation elicited a reaction of the arterial pressure. This suggests that the neurons whose activity varied during the carotid reflex were neurons with a vasomotor function. It is probable that the change in the activity of the neuron in the pressor zone of the bulbar reticular formation during the carotid reflex may be used as an additional index for determining if a particular neuron is vasomotor.

What were the causes of the observed changes in the activity of the pressor neurons during the carotid reflexes? During compression of the carotid arteries the possibility of the action of the following factors must be borne in mind: 1) an increase of arterial pressure; 2) hypoxia of the brain as a result of interruption of the flow of blood to the brain along the carotid arteries; 3) afferent impulses from the chemoreceptors in consequence of slight hypoxia caused by a decrease in the blood supply of the carotid body; 4) exclusion of afferent impulses from the mechanicoreceptors (in consequence of the fall in blood pressure within the sinus); and 5) an increased flow of afferent impulses from the aortic mechanicoreceptors along the depressor nerves, which remained intact in our experiments.

A rise of arterial pressure by itself can cause mechanical stimulation of the neuron and increase the frequency of its discharges by displacing the microelectrodes. Furthermore, Baust and co-workers [7-9] found neurons in a circumscribed area of the hypothalamus which were particularly sensitive to pressure. That this factor had no part to play in our experiments was demonstrated by the fact that a change in the frequency of the discharges was observed in most cases at the moment of compression of the carotid arteries, before any appreciable increase in arterial pressure had taken place, and also during compression of one carotid artery, when the increase in pressure was negligible (4-6 mm).

Hypoxia of the medulla may be excluded, because its blood supply is maintained by branches of the basilar artery, the blood flow in which was not disturbed. In addition, there is evidence that compression of the carotid arteries after denervation of the carotid sinuses causes no changes either in the arterial pressure or in the volume velocity of the blood flow to the brain [2, 12].

Excitation of the chemoreceptors during continuing compression of the carotid arteries must have increased, and correspondingly, an increase in the frequency of the discharges of the neurons must have developed gradually. In our experiments, on the other hand, the frequency of the discharges in most neurons increased at the moment of compression of the carotid arteries and thereafter did not increase. In some experiments, however, the increase in the frequency of the discharges of the neurons began a few seconds later, and rose gradually. In these cases the changes in the activity of the neurons must probably be attributable to the influence of the chemoreceptors.

Hence, the main cause of the observed increase in the activity of the neurons during the carotid pressor reflex is exclusion of the afferent impulses from the mechanicoreceptors of the carotid sinus. Inclusion of the function of the mechanicoreceptors (after cessation of compression of the carotid arteries) and their stimulation (see Fig. 3) cause depression of the activity of the investigated neurons. The fact that during compression of one carotid artery neurons reacting by a decrease in the frequency of their discharges are found more often may evidently be explained by an increase in the intensity of excitation of the mechanicoreceptors of the contralateral carotid sinus. During bilateral compression of the carotid arteries, however, in ten cases a decrease in the frequency of the discharges of the neurons was also observed. This reaction is independent of the initial level of activity of the neurons, the importance of which for the direction of the reaction of the reticular neurons has been pointed out by various investigators [6, 12, 15]. In our experiments both an increase and a decrease in the frequency of the discharges could be found, in conjunction with either a high (see Fig. 2, B) or a low (see Fig. 2, A) frequency of the discharges of the neurons.

We consider that the depression of neuronal activity which we observed is brought about by afferent impulses from the mechanicoreceptors of the aortic zone, which are known to increase in intensity during compression of both carotid arteries. However, during recording of the action potentials from 5 neurons, Salmoiraghi [18] observed an increase in frequency during compression of one carotid artery in two neurons, and a decrease in the frequency of the discharges in three neurons, even after exclusion of the aortic depressor nerves. This worker suggested that afferent impulses from the carotid sinus region have a depressant action on some neurons and an excitatory action on others. However, his material is inadequate and further experimental investigation of this factor is needed.

It is not yet clear whether the afferent impulses from the carotid sinus and aortic mechanicoreceptors act after having been relayed to the neurons of the depressor zone on the vasomotor neurons at the bulbar or spinal level. According to the findings obtained by Alexander [3], impulses from the depressor zone have a tonic depressant action on the spinal sympathetic neurons. Folkow [10] and Oberholzer [16] also accept the possibility that depression may take place at the spinal level. Porszasz and co-workers [17] conclude from results obtained by stimulation of the depressor zone after isolation from the pressor zone by section that impulses from the depressor zone have a depressant effect only on the bulbar neurons in the pressor zone, and have no such effect on the spinal vasomotor neurons.

It is concluded from our findings, obtained by recording the action potentials from individual bulbar pressor neurons, that afferent impulses from the mechanicoreceptors of the carotid sinus and also, evidently, from the aorta, after relaying in the cells of the depressor zone, pass to the bulbar pressor neurons, causing tonic depression of their activity.

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