INHIBITION OF SYNAPTIC PROCESSES IN MOTOR NEURONS BY RHYTHMIC VISCEROMOTOR INFLUENCES

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By the microelectrode technique of recording the potentials of individual motor and internuncial neurons a detailed analysis can be made of the synaptic mechanisms and the intracentral pathways of visceromotor reflexes [1]. One of the characteristic features of the motor reactions in these reflexes is their extremely rapid attenuation in the case of repeated stimulation of the visceral nerve [1, 4, 10]. This attenuation takes place with very low frequencies of stimulation at which the somatic reflex reactions are transmitted without disturbance. Evidently inhibitory processes may arise in the intraspinal elements transmitting visceromotor influences, differing essentially in their time characteristics from the processes in the neurons transmitting spinal somatic reactions.

For a more detailed analysis of this phenomenon, the changes in synaptic processes in the lumbar motor neurons were studied during repeated stimulation of visceral nerves, and the relationships between the synaptic processes caused by impulses from the visceral and somatic afferents were examined.

EXPERIMENTAL METHOD

Experiments were carried out on cats anesthetized with Nembutal and chloralose by the method described previously [1]. The electronic potentials of the dorsal root were recorded from a bundle of fibers isolated from the root and divided as far distally as possible. One recording electrode was placed on the bundle near the dorsal surface, and the other at its divided end; the whole bundle was lifted above the surface of the spinal cord and placed in mineral oil, the temperature of which was maintained at 38°. The potentials of the dorsal surface of the spinal cord were recorded by a monopolar button electrode; the second electrode in this case was situated on the surrounding muscles.

EXPERIMENTAL RESULTS

As the previous investigation [1] showed, afferent impulses from the splanchnic nerve produce well marked postsynaptic processes in the motor neurons of the lumbar portion of the spinal cord, the character of which depends essentially on the functional role of the motor neuron. In the flexor motor neurons, excitatory postsynaptic changes predominate, but in the extensor motor neurons, on the other hand, inhibitory changes predominate.

Both types of postsynaptic processes showed identical changes when the frequency of stimulation of the splanchnic nerve was increased. Even when the stimuli were repeated once every second, the postsynaptic after-potentials (PSP) were slightly weakened. An absolutely constant level of the individual reactions could be produced only by applying the stimuli once every 4-5 sec. With an increase in the frequency of stimulation to several per second, the successive postsynaptic potentials weakened faster still, and with frequencies of 4-5 per second the reactions to the fifth pulse after the beginning of stimulation were almost imperceptible.

Examples of the changes described above are given on the oscillograms reflecting excitatory (flexor motor neuron) and inhibitory (extensor motor neuron) postsynaptic reactions to the first five pulses of rhythmic stimulation at different frequencies (Figs. 1 and 2).

This dependence of the postsynaptic processes evoked by impulses from the visceral nerve on the frequency of stimulation indicates the appearance of prolonged depression in the elements creating these processes, after a single afferent wave passes over them. With repetition of the afferent waves, this depression evidently undergoes

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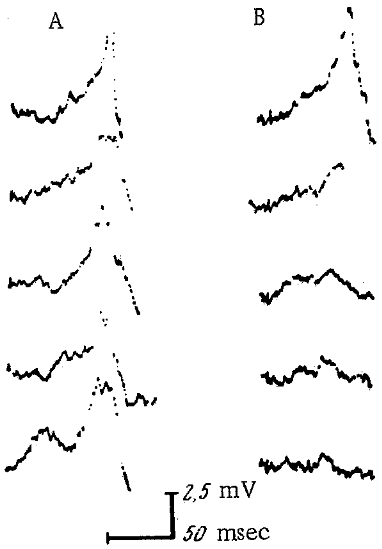

Fig. 1. Postsynaptic potentials of a flexor motor neuron evoked by five successive stimulations of the ipsilateral splanchnic nerve with a frequency of 1/sec (A) and 4/sec (B).

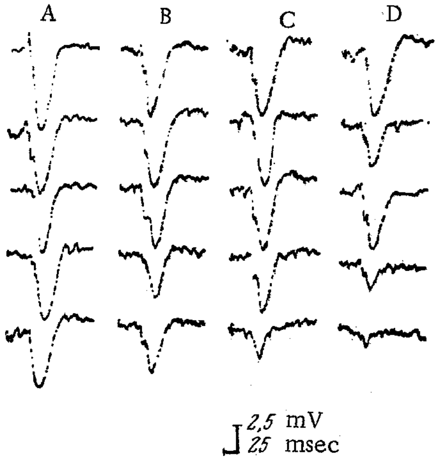

Fig. 2. Postsynaptic potentials of an extensor motor neuron evoked by five successive stimulation of the ipsilateral splanchnic nerve with frequencies of 1/sec (A), 2/sec (B), 3.5/sec (C), and 4.5/sec (D).

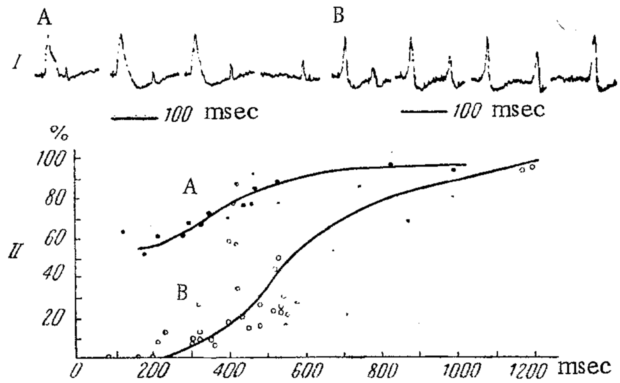

Fig. 3. Examples of oscillograms (I) and graph showing relationship between amplitude of the test post synaptic reaction of the motor neurons (II), expressed as percentages of the control value (ordinate) and the interval between the preliminary and test stimuli (abscissa). Curve A was obtained by applying the preliminary stimulus to the ipsilateral splanchnic nerve and the test stimulus to the nerve to the quadriceps femoris muscle; Curve B by applying the preliminary and test stimuli to the ipsilateral splanchnic nerve. The last oscillograms (I) of series A and B were obtained in response to a single stimulation of the nerve to the quadriceps (A), and the splanchnic nerve (B).

summation, leading to still more marked depression of the reflex. The course of the depression caused by a single afferent wave may be examined by using a combination of 2 stimuli applied to the splanchnic nerve – an initial and a test stimulus – separated by different time intervals.

Difficulties arise when such measurements are made, as a result of the great variability of synaptic processes during stimulation of the splanchnic nerve and the impossibility of repeating this stimulation rapidly. However, in the case of very stable microelectrode recording from the motor neuron, it is possible to make an adequate number of combinations to give a reliable determination of the course of the changes in the test synaptic reaction.

On the basis of many of the oscillograms obtained by recording from one motor neuron, a graph was plotted showing the relationship between the test postsynaptic reaction and the interval between the initial and test stimuli of the splanchnic nerve (Fig. 3, curve A). As Fig. 3 shows, the passage of the single wave along the intracentral pathways of the visceromotor reflex led to prolonged weakening of the postsynaptic potential evoked by the second such wave; this depression gradually disappeared with a time constant of about 700 msec. Several examples of the oscillograms used for plotting the curve are shown in Fig. 3, I.

The process of inhibition giving rise to this prolonged depression may be localized either in the neuronal apparatus of the lumbar portion of the spinal cord itself, or in the neurons of the thoracic divisions, directly receiving the afferent impulses of the splanchnic nerve (segments T3-T5 [2, 3]). Some information for differentiation between these possibilities may be given by comparison of the changes in the test postsynaptic reaction in cases when it was evoked by stimulation either of the splanchnic nerve or of a somatic afferent nerve, directly activating the neurons of the lumbar spinal segments; in both cases, however, the preliminary afferent wave passed along the splanchnic nerve. The results of this investigation on one of the motor neurons are shown in Fig. 3, curve B. The test synaptic reaction was caused in this case by stimulation of the nerve to the quadriceps; examples of the oscillograms from which the graph was plotted are also shown in Fig. 3.

It is clear that the afferent wave from the splanchnic nerve caused depression of the synaptic activation of the motor neuron by impulses from the segmental somatic fibers; however, this depression had a much shorter time constant than the depression of the effect of the test wave from the splanchnic nerve; its depth also was appreciably smaller. Depression of the polysynaptic potentials evoked by stimulation of the nerve to the posterior biceps and semitendinosus muscles followed a similar (slightly more prolonged) course in the same motor neuron.

It may be concluded from these results that inhibition leading to prolonged depression of the transmission of viscreomotor influences is localized mainly in the neuronal apparatus of the actual intracentral system which receives these influences and transmits them to the lower segments of the spinal cord. Inhibitory processes also arise in the segmental apparatus common to both visceromotor and somatomotor influences, but they are less intensive and less prolonged, and they are therefore responsible only for part of the depression of the synaptic influences on the motor neurons.

The results show that the afferent wave from the splanchnic nerve produced not only postsynaptic changes in the lumbar motor neurons, but also prolonged depolarization of the central branches of the afferent fibers entering the spinal cord through the lumbar dorsal roots (the electronic potential of the dorsal root – ETP). A corrsponding example is shown in Fig. 4A and B. Depolarization arose with a latent period of 35.4 ± 1.8 msec. Its initial part developed slowly, but after 41.6 ± 2.7 msec it began to rise more steeply. Maximal depolarization of the afferent fibers took place 60 ± 3.5 msec after the beginning of stimulation of the splanchnic nerve, and the time constant of the decrease was approximately 90 msec. The total duration of presynaptic depolarization exceeded 200 msec. Simultaneously with the prolonged depolarization, spreading electrotonically along the afferent fibers of the dorsal root, a positive wave of potential was recorded from the dorsal surface of the corresponding lumbar segment, the time constant of which corresponded to the ETP of the dorsal root (the P wave of Gasser and Graham [1]). This type of positive wave is known to reflect the same process within the spinal cord as the ETP of the dorsal root, namely the prolonged depolarization of the central branches of the afferent fibers; the differences in the sign of the reaction are associated merely with the nature of the recording in the two cases [6]. The negative wave recorded before the P wave from the dorsal surface (Fig. 4C) was different in origin – it reflects the postsynaptic processes in the internuncial neurons of the dorsal part of the brain (the N wave) and so did not spread electrotonically along the afferent fibers.

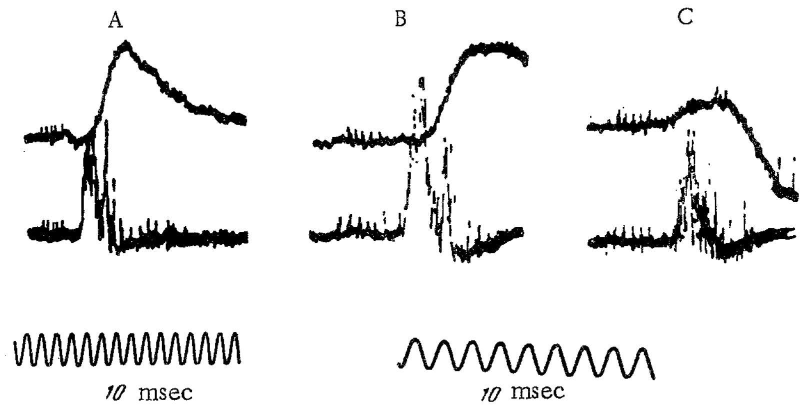

Fig. 4. Comparison of potentials of a dorsal root and of the dorsal surface of the spinal cord, and the reflex discharge in the ventral root during stimulation of the ipsilateral splanchnic nerve. On the oscillograms A and B the top curve shows the electronic potential of the 6th lumbar dorsal root, and the bottom the discharge of the corresponding ventral root. The oscillogram B was obtained at a high winding speed. On oscillogram C the top curve shows the potential of the dorsal surface of the spinal cord at the level of the 6th lumbar segment, and the bottom curve the discharge of the ventral root of the corresponding segment.

The prolonged depolarization of the afferent terminals in the spinal cord led to weakening of the effectiveness of their synaptic transmission, to what is known as presynaptic inhibition [7-9, 12]. The development of this depolarization in the afferent terminals of the lumbar segments under the influence of impulses from the splanchnic nerve demonstrates the possible presynaptic inhibitory action of these impulses. Admittedly, the course of depression of the test "somatic" postsynaptic potential, caused by the preliminary wave from the visceral nerve, was slightly longer than the course of the presynaptic depolarization measured from the ETP of the dorsal root. However, it must be remembered that the ETP of the dorsal root reflects processes arising in the intraspinal path of the afferent fibers, in a much attenuated form; it is therefore perfectly possible that the total duration of the course of depolarization of the terminals is longer than can be determined from the duration of the ETP of the dorsal root.

To some extent the weakening of the test segmental synaptic reactions in the motor neurons may be associated with inhibitory postsynaptic potentials created in them by impulses from the splanchnic nerve [1]. However, synaptic hyperpolarization cannot be the main cause of this marked reduction in the amplitude of the test postsynaptic reaction which was observed in these experiments. An increase in the ionic conductivity of the postsynaptic membrane during the inhibitory synaptic action may reduce to some degree the amplitude of the excitatory postsynaptic potential evoked against its background; on the other hand, however, a change in the transmembrane potential difference towards hyperpolarization must increase this amplitude, so that ultimately the changes must cancel each other out. The fact that the amplitude of the EPSP nevertheless fell very considerably is evidence of the leading role of a decrease in the flow of presynaptic impulses to the motor neuron in the corresponding depression. The results of the investigation of changes in monosynaptic discharges of the lumbar motor neurons at corresponding intervals after stimulation of the splanchnic nerve show that such discharges not only are not inhibited, but at certain intervals they are actually facilitated [5].

The question whether the intensive and prolonged depression developing in the actual neuronal apparatus of transmission of visceromotor influences is connected with the distinctive features of presynaptic inhibition in the afferent terminals of the visceral afferent fibers ending in the thoracic spinal segments, or whether in this case there is a special type of inhibition of the activity of the internuncial neurons transmitting impulses in a downward direction, requires a special experimental study.

SUMMARY

The object of study was the synaptic potentials of the motor neurons of the lumbar spinal cord of the cat during repetitive stimulation of the splanchnic nerve. Both excitatory and inhibitory PSP rapidly diminish even at a stimulation frequency of 2-3 times per sec. This diminution is based on the long-lasting (about 1000 msec) depression of synaptic transmission from the afferent fibers of the splanchnic nerve to the motor neurons, which develops after a single afferent volley. This volley also causes a prolonged depolarization of the central terminals of the somatic afferent fibers and diminishes the PSP generated in the motor neurons by their stimulation. However, the depression of synaptic process induced from the somatic afferents runs a much shorter course and is considerably less intense than the depression of the synaptic effects produced by a repetitive visceral stimulation. Prolonged depression of the synaptic transmission in the lumbar motor neurons during repetitive visceral stimulation is mainly associated with progressive inhibition in the intraspinal apparatus of visceromotor transmission rather than in the segmentary neuron apparatus of the lumbar spinal cord.

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