INDUCED CHANGES IN SPONTANEOUS ACTIVITY IN THE RABBIT SPINAL CORD

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Translated from Byulleten Éksperimental' noi Biologii i Meditsiny Vol. 49, No. 4, pp. 3-8, April, 1960
Original article submitted March 24, 1959

We have previously [3] investigated the electrical activity in the spinal cord of the rabbit at rest, as recorded by point-electrodes, and have described the method.

In order to determine the origin of the potentials and to interpret them, we have studied the effect on this activity of changes affecting both the inflow of impulses to the spinal cord and its functional condition. We here report the principal results observed in the lumbosacral region, though in many cases similar changes occurred in the thoracic region also.

RESULTS

The effect of anesthesia. It is well known that the lower centers of the central nervous system are more resistant than the higher to the action of anesthetics. It would therefore be expected that during the early (light) stages, there would be a reduction in the descending flow of impulses into the cord. As the anesthesia becomes deeper, its effect on the spinal centers increases [12]. In this way the block of a spinal cord reflex increases in proportion to the depth of anesthesia.

We have investigated the changes in spinal potentials induced by ether. At the end of the stage of motor excitation, when it was not possible to record potentials on account of artifacts due to movements, the following changes were observed in the electrospinogram (ESG) and the electromyogram (EMG).*

Usually, the rapid oscillations were the first to suffer almost complete extinction. As a rule, the effect was better shown in the EMG. At this time, slow potentials were still recorded in the ESG, although their amplitude was sometimes somewhat reduced (Fig. 1). As the anesthesia deepened, the slow waves were also suppressed, and the recording consisted only of "noise" from the apparatus. Occasionally, at a certain stage, when the anesthesia was deepening or when the animal was recovering from it, slow potentials at the frequency of respiration were recorded from the lumbosacral region (Orbeli-Kunstman phenomenon) [1, 2, 3, 6]. An interesting phenomenon could be observed during the suppression of the rapid potentials under light anesthesia. At this time, regular peaks having an amplitude as high as 40-50 μv and a frequency of from 8 to 50 per sec were recorded. In the EMG, these peaks were either absent, or greatly reduced (Fig. 2). Like

* It was necessary to record both the ESG and EMG because the point-electrode measured potentials relative to an indifferent electrode inserted into an interspinal muscle, and it was important to consider the possibility of any muscle potentials being recorded [3].

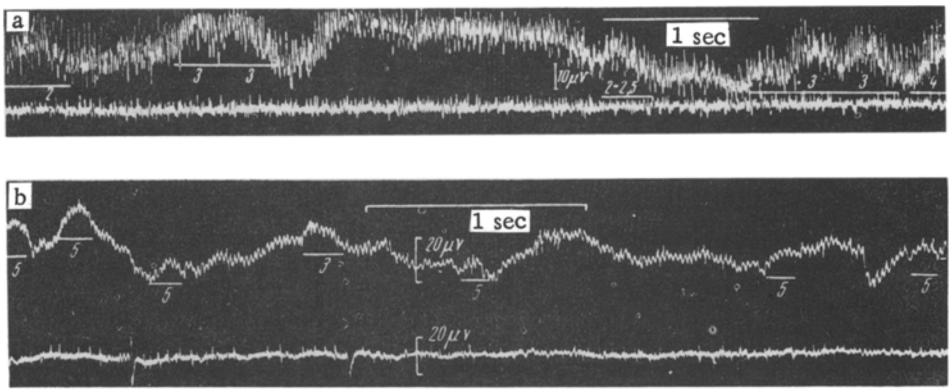

Fig. 1. The effect of anesthesia on the ESG of the lumbosacral region of the cord, and on the corresponding EMG. a) Initial trace; b) first stage of anesthesia. Curves, from above downwards; Time marker; ESG of lumbosacral region; EMG: figure indicate period of oscillation in cps.

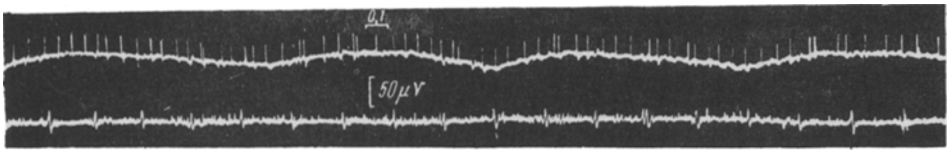

Fig. 2. Regular spikes occurring in the ESG during anesthesia. Curves, from above downwards: Time marker; ESG of thoracic region; EMG.

all other electrical activity, these spikes disappeared as the anesthesia deepened. When the animal recovered from the anesthetic, the spikes gradually regained their initial high amplitude and were indistinguishable from EMG activity.

The effect of curarization. Curare-like drugs were used to reduce the flow of afferent impulses into the cord, the reduction affecting chiefly proprioceptor inflow; this in turn led to a reduction of motor impulses to the muscle, without any further operation being performed. We also found the effect of elatin, kondel'fin (preparation "K") and diplacin in doses whose central nervous action was not appreciable; the first two drugs, and especially elatin, were used in doses less than the amount required to eliminate voluntary movement. The injections were given intramuscularly as follows: Elatin – 10-15 mg (rabbit weighed about 2 kg), kondel'fin – from 1 to 3 cm^3 5% solution, diplacin – from 1 to 3 cm^3 2% solution.

The results are best described for diplacin, where the effect of the reduced afferent inflow were most clearly seen. This preparation had the least effect of the three, and there was a transitory reduction of muscle tone without complete loss of voluntary movement. No anoxia could occur through action on the respiratory musculature.

The electrical activity changed as follows. At first the high-frequency waves of both the ESG and EMG were suppressed. In the ESG, rather high amplitude regular spikes of up to 30-50 μv appeared, but these were not seen or else were greatly reduced in the EMG. The slow oscillations continued for a longer time. Sometimes, in the lumbosacral region slow oscillations at the respiratory frequency were reduced (Fig. 3). When the curarizing effect was stronger, the slow components of the ESG were also reduced.

Kondel'fin caused curarization of more sudden onset, so that some of the changes in spinal electrical activity observed when using elatin were sometimes missed. However, there was always a marked suppression of the rapid waves in both the ESG and EMG, and regular spikes appeared on the ESG together with smaller synchronized spikes on the EMG; the amplitude of the latter varied from zero up to an amplitude equal to the ESG spikes.

Diplacin had the strongest action, and when given in the dose reported above, rapidly caused respiratory disturbances, so that it was rarely possible to observe the early curarization stages.

The effect of interrupting conduction along the cord. Complete spinal thoracic section was carried out to eliminate the influence of higher nervous centers; it caused immediate cessation of electrical activity below the cut in the ESG and the EMG. In the acute preparation it was difficult to determine whether the cessation of electrical activity was due to interruption of descending impulses, or to spinal shock; observations could not be continued for long because the animals died rather quickly; (rabbits show little resistance to extensive damage to the central nervous system). Interesting observations were made on one rabbit having a spastic paralysis of the hindlimbs (the animal contracted the condition in the animal house,

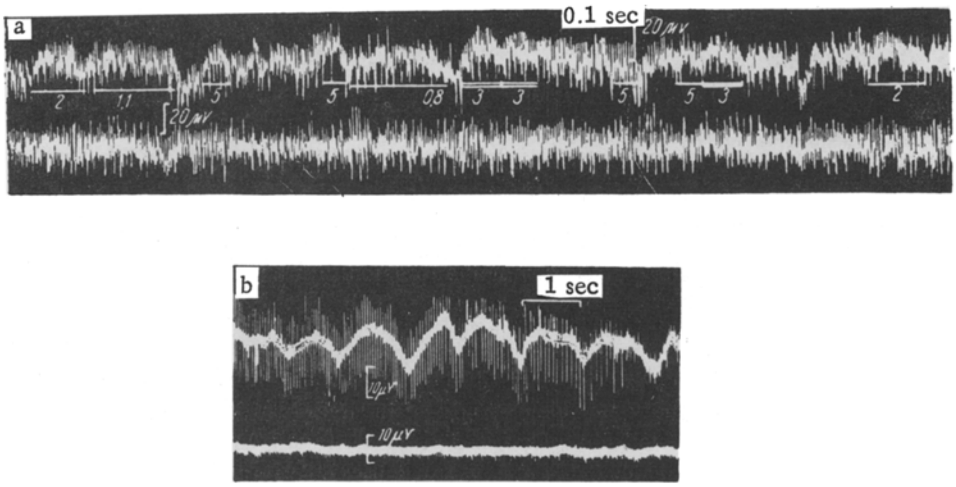

Fig. 3. Effect of curarization (elatin) on the ESG. a) Initial activity; b) early stage of curarization (appearance in the ESG of regular spikes, and slow oscillations at the respiratory rate). Traces and indications as in Fig. 1.

from unknown causes, not less than ten days before the experiment).†

The fact that there was a spastic paraplegia without any respiratory disturbance or paralysis of the front limbs showed that the damage to the cord must have been in the lower thoracic or upper lumbar segments. The absence of any movements, and the fact that there was no reaction ot painful stimulation of the hind limbs showed that conduction must have been completely or almost completely blocked.

The ESG and EMG records from the lumbosacral region when no stimuli were applied showed only very low amplitude slow waves. After stimulating the paralyzed hindlimbs by pinching or pricking, the characteristic slow waves returned to the ESG, and had a period of 500-200 msec, i.e., they resembled the δ-waves of the electroencephalogram. It is hardly possible to consider that the condition of spinal shock might have been present ten days after trauma had occurred, and the results obtained must therefore be ascribed to the reduced afferent inflow. Painful stimulation below the block appeared to make good the deficient inflow from the lower parts, and restored normal electrical activity in the lumbosacral region.

The effect of painful stimulation. The effect of additional afferent impulses to the lumbosacral region was particularly clearly shown when the recording electrode was inserted in the thoracic region of the cord. The increased inflow was caused both by painful stimulation caused by pricking the soft tissue and the meninges, and by mechanical stimulation of the substance of the cord by the electrode. Both these factors no doubt caused an increased flow of impulses into the lumbosacral region of the cord to pass along proprioceptor routes (or caused a response from the higher nervous centers).

The electrical activity of the latter changed quite consistently (registration was carried out after the animal had returned to the resting condition). There was an increase in the amplitude of both the slow and rapid waves (the latter also returned in the EMG) and there was a marked reduction in the period of the slow waves, and an increase in their rate. Whereas the initial activity showed low amplitude slow waves corresponding to type I activity, the stimulation described caused the amplitude to increase and the waves to be better defined.

When the slow type I waves were sufficiently large, painful stimulation might elicit slow components resembling type II waves [3].

The results obtained showed that in our experiments the potentials recorded from the cord were definitely related to the afferent inflow: Reduction in the number of either the afferent or the efferent impulses caused a reduction in spinal cord potentials; increased afferent inflow increased both the amplitude and the frequency of the potentials. We have therefore confirmed the results of Bremer [10], Ten Cate et al. [14, 16-18], Ward [19], and A. A. Oganisyan [4, 5].

On the other hand, the observations we made on the animal with paralyzed hind limbs, when there was no spinal shock, and the researches of Boels, Ten Cate, and Visser [9] do not confirm the findings of Mark and Gasteiger [15] who claimed an increase in the amplitude of potentials below the spinal cord section.

The regular high amplitude spikes in the cord which are found at a certain stage of anesthesia or curarization, and which are reflected in the EMG, are evidently due to synchronized activity of motoneurons. It appears that under these conditions synchronization represents a compensation for motor insufficiency; the insufficiency may result from the neuromuscular block caused by curarization, or from reduction in reflex excitation of the motoneurons in anesthesia. A similar explanation may be applied to the changes in the electromyogram which occur in cases of damage to the anterior horns [7, 13]. While it is difficult to explain the mechanisms of spinal and supraspinal synchronization, the fact that no such effect was observed after separation of the cord from the brain, and the results obtained by Alward and Fuortes [8] on the supraspinal mechanism of the synchronizing action of chloralose on the cord, indicate that the phenomenon we have observed is also mediated by a spinal mechanism; apart from our observations, there are only those of Bremer [10], which were obtained under light anesthesia and without decapitation.

In considering the spontaneous activity of the spinal cord, Bremer [10, 11] took the view that all activity in the central nervous system is of reflex origin, and he therefore failed to appreciate the qualitative differences between the spontaneous activities of the brain and spinal cord. However, this description is not adequate, because as far as general properties are concerned, it ignores the the undoubted differences between the mode of operation of the neuronal systems of different parts of the nervous system, due to their evolution into different functional organizations. If we consider the spontaneous activities of the cord and brain, it can be seen that they react to the inflow of impulses in different ways: in the brain, increased inflow causes a reduction in the amplitude of the slow potential waves, which recover when the inflow ceases, but in the cord, as has been shown above, these same potentials are proportional to afferent inflow.

Evidently, the difference between the spontaneous activity of the brain and that of the cord must represent a qualitative difference, although both are reflex in origin.

SUMMARY

Animals were anesthetized or curarized, spinal cord block was established, and additional afferent stimulation applied; recordings were made of the spontaneous electrical activity of the lumbosacral region of the cord, and it was shown that the amplitude of the potential variations was directly proportional to the rate of arrival of impulses into the area from which the recording was made, and this

† Unfortunately no histological observations were made.

was specially true of the slow potentials. At the stage of light anesthesia or mild curarization spikes were generated at a steady rate; there were also slow fluctuations of potential at the respiratory rate. On the physiological conditions the spontaneous activities of the brain and spinal cord are differently affected by afferent inflow; it may therefore be suggested that though both are reflex in origin, the two activities are qualitatively different, and that different functional organizations of the two sections of the nervous system have evolved.

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‡ Original Russian pagination. See C. B. translation.