CONCERNING THE BACKGROUND ELECTRIC ACTIVITY OF A RABBIT'S SPINAL CORD (A PUNCTURE METHOD OF LEADING OFF THE BIO-ELECTRIC POTENTIALS OF THE SPINAL CORD)

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The spinal cord is considered to be one of the most thoroughly studied sections of the central nervous system; nevertheless, our knowledge of the interconnection of the spinal nervous mechanisms with the other sections of the central nervous system is far from complete.

In Charles Sherrington's classic works, as in numerous subsequent electrophysiological investigations, experimental conditions were purposely created to provide isolation of the spinal cord, or even of a spinal reflex arc. The use of these methods made it possible to analyze many phenomena and contributed many valuable facts to our knowledge. However, these facts must be verified to some extent before the activity of the central nervous system in an intact organism can be accurately evaluated.

There have recently appeared several works studying the influence of the higher sections of the central nervous system on the processes in the spinal reflex arcs induced by specific stimulation [6, 7, 11, 15, 20, 24, 25], as well as works studying the background electric activity of the spinal cord [5, 13, 17, 18, 19, 22, 26, 27, 28]. But these investigations also were carried out under experimental conditions differing greatly from the physiologic conditions, i. e. under conditions of operative exposure and sectioning of various portions of the central and peripheral nervous systems or with anesthesia or curarization.

We decided to experiment with the puncture method of leading off the bioelectric potentials of the spinal cord in a practically intact animal (rabbit) in order to approximate the physiologic conditions as nearly as possible.

EXPERIMENTAL METHODS

The experiments were performed on 19 rabbits. We describe the puncture method of leading off the bioelectric potentials of an animal's spinal cord in some detail because of the lack of literature available on the use of this method.

The anatomical peculiarities of the rabbit's spine [12, 14] makes it possible to puncture the spinal canal at two levels: at the inferior thoracic level – on either side of the spine of the XII thoracic vertebra, which is perpendicular to the spinal column (spines of the other thoracic vertebrae are caudally directed, while those of the lumbar vertebrae are cranially directed) and at the sacral level – at the point where the rabbit's sacrum has an unmatched foramen in its center, between the united I and II sacral vertebrae, which is about 2 mm in diameter, i. e. wide enough to permit the passage of a needle electrode.

The puncture lead was unipolar. The active electrode, a steel hypodermic needle, was inserted between the vertebrae D_{11} and D_{12} or between D_{12} and L_1 and into the foramen in the center of the sacrum between the vertebrae S_1 and S_2.

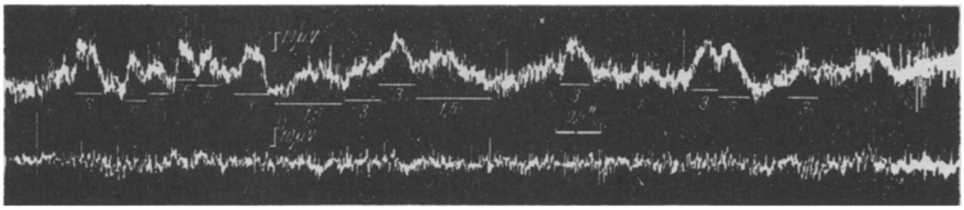

Fig. 1. ESG of the lumbosacral level (top curve) and corresponding EMG (bottom curve). Clearly marked, slow action potentials evident in ESG only. First type of electroactivity. The frequencies of the fluctuation periods are given in cps. Time indication = 0.5 second.

The animals were fastened to the usual laboratory bench. The needle seemed to drop at the moment at which it entered the spinal canal. At this moment, the rabbit manifested an acute, painful, motor reaction. The position of the active electrode in the cerebrospinal canal was checked by opening the region after the experiment.

We found that the tip of the electrode had passed through into the substance of the spinal cord at the thoracic level, while at the lumbosacral level, it was located among the cauda equina roots and reached into the conus medullaris.

Under these conditions, the leads recorded the overall bioelectric effect induced by the nervous processes in the zone of the lead, including the electric field changes connected with peculiarities of the electric processes taking place in the volumetric conductor [9, 16, 21 et al.].

The passive needle electrode was either inserted alongside into the paravertebral muscle or (more often) inserted into the same interspinal muscle as the active electrode, or into the interspinal muscle of the adjoining vertebra. There was a distance of 2-7 mm between the active and passive electrodes.

Of course, this method of leading off also recorded the biological currents of the muscles located between the electrodes. The use in several experiments of insulated (all but the tips) electrodes had no advantage over the use of non-insulated ones, because the muscle currents were led off by the passive electrode even with this insulation. Therefore, we used noninsulated electrodes as a rule.

This meant that the muscle (electromyogram – EMG) and cerebrospinal (electrospinogram – ESG) components of the overall bioelectric effect had to be distinguished from each other. This was accomplished by synchronously recording an EMG of the interspinal or paravertebral muscle through which the electrodes leading off the action potentials of the spinal cord passed. As we will show, comparison of the ESG with the EMG data made it possible to connect a series of bioelectric phenomena solely with the activity of the spinal cord.

In leading off the bioelectric potentials with needle electrodes, sufficient practice showed that the brief traumatic effect caused by the insertion of the leading electrodes could be disregarded if, as in our experiments, recording of the bioelectric potentials was started 15-30 minutes after the insertion of the electrodes and was continued for several hours. Moreover, the physiologic nature of the recording processes was indicated by the fact that the electric activity being recorded varied according to the changes induced in the functional condition of the substrate.

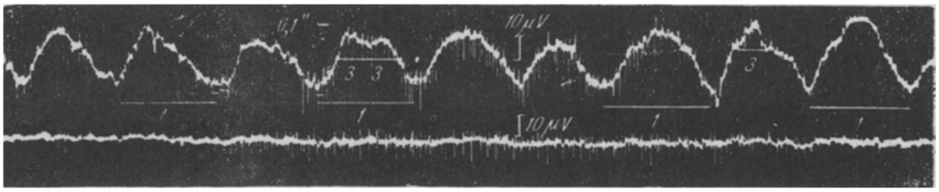

Fig. 2. Animal coming out of ether anesthesia. Slow waves in time with respiration apparent only on the ESG (Orbeli-Kunstman phenomenon; for original background, see Figure 1). Order and significance of curves the same as in Figure 1. Indication of time = 0.1 second.

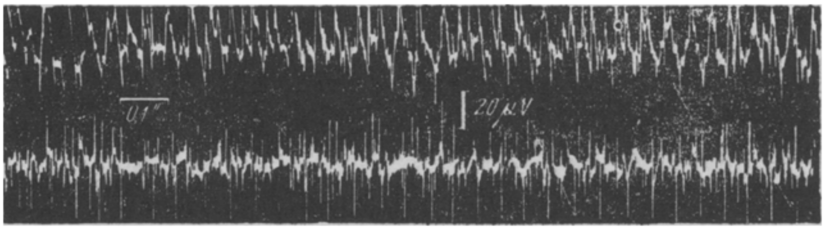

Fig. 3. The second type of electroactivity of the lumbosacral level. Uninterrupted slow waves can be seen with frequencies of 10 to 30 v/sec (amplitude 5-20 μ v) which raise in peaks or groups of peaks with amplitudes of 40-50 μ v or more.

The variations of the potential were recorded with a loop oscillograph, powered by a two-channel, AC amplifier (manufactured by the Experimental Factory of the AMN SSSR). Frequencies of 0.2-0.5 cps were distorted 12-18%. We used strong amplifications (usually 1 microvolt per 1-2 mm of ray deflection). Amplifier noise was 2-3 microvolts in value.

EXPERIMENTAL RESULTS

I. Comparing the variations of the potential recorded with the puncture lead from the spinal cord (ESG) with the curves of the action currents of the corresponding muscle (interspinal or paravertebral), we obtained arguments in proof of the fact that with the use of a puncture lead, the bioelectric currents of the spinal cord are led off along with the muscle action currents. These arguments are as follows:

1. When the frequency characteristics of the EMG and the ESG were compared, slow action potentials, which were not present in the electromyogram, were clearly evident in the ESG (Fig. 1). This was to be expected, since the electric activity of the nerve cells, which together make up the gray matter of the spinal cord, is expressed by relatively slow variations of the potential. Muscle electroactivity, however, reflects the advent in the muscle of spreading excitation waves and is characterized by action potentials of relatively high frequency.

2. In a series of experiments, we observed that the dynamics of the relatively fast activity differed in the ESG and EMG. The muscle component of the ESG reflected the activity of the same muscles recorded by the EMG; therefore, this difference could only be connected with the nonmuscle component of the EMG, i. e. with the activity of the actual spinal cord. For example, a high-amplitude, frequent discharge sometimes appeared first in the ESG and then appeared later in the corresponding EMG.

During ether anesthesia, there was a stage in which the frequent discharge disappeared in the EMG, but remained clearly evident, although diminished, in the spinal cord. At the first stage of curarization (a few minutes after the intramuscular injection of 15 mg of elatin – Delphinium elatum alkaloid, $C_{36}H_{50}O_9N_2$), the fast waves of the EMG were observed to be depressed, while this activity was still relatively high in the ESG.

3. Regularly, at a specific stage in anesthesia (sometimes even with a mild degree of curarization), slow action potentials in time with the respiration appeared in the ESG at the lumbrosacral level of the spinal cord, but were not recorded on the corresponding EMG (Fig. 2). These changes in the electric potentials could be interpreted as a specifically electrographic expression of the known Orbeli-Kunstman [10] phenomenon.*

All these facts indicate that with the method we used, the bioelectric activity of the spinal cord was recorded along with the muscular activity. The slow action potentials found in the ESG were the most carefully considered, as their cerebrospinal origin was certain, while the fast potential waves were taken into consideration only if there was evidence of their nonmuscular (spinal) origin.

II. We obtained the bioelectric characteristics of each of the two cerebrospinal levels from which the bioelectric potentials were recorded.

* The question of this phenomenon and the results obtained from research on the influence of induced changes in the functional condition of the central nervous system on background electroactivity will be taken up in detail in other articles.

1. At the lumbosacral level, the background activity observed could be reduced to two main types, which evidently reflected different functional conditions of the spinal nerve apparatuses, even though the recording was always done while the animal was outwardly immobile.

The first type of electroactivity was characterized by the presence of slow waves, singly or in small groups (see Fig. 1), with a period of 0.5-0.15 second, i. e., corresponding in frequency to the delta and theta EEG waves (2-6 waves per second). The voltage of these waves was usually 10-20 microvolts. Often, even slower fluctuations of the potential were observed, having a period of 1-4 seconds, or even sometimes 7 seconds, and approximately the same voltage. In one or two of the experiments, these very slow fluctuations of the potential were recorded as groups of waves. This type of activity was usually recorded from an animal which had been at rest for a prolonged period of time.

The second type of electroactivity was characterized by relatively high-amplitude, single or grouped peaks, with a slow wave at the base. These peaks (or groups of peaks) and waves proceeded rhythmically, with a frequency of 8-14 per second (like the alpha waves of the EEG) or 25-30 per second (like the beta waves of the EEG, Fig. 3). The peaks evidently reflected simultaneous discharges of the motoneurons, because they often appeared in the same rhythm on the EMG. Sometimes, the EMG also showed faint, slow waves, which seemed to be a faint repercussion of the slow waves shown on the ESG. It is possible that these waves appeared on the EMG in connection with the physical distribution of the spinal cord potentials, the EMG being recorded from the interspinal muscle of the same or adjoining spinal segment. The two types of activity were observed to alternate in the same animal. The second type of electric activity was recorded in the animal shortly after motor activity, but when the animal was in a resting condition. A high-frequency, low-amplitude (usually 5-10 microvolts), essentially the same as that recorded simultaneously on the EMG, was also invariably observed on the ESG of the lumbosacral level. We did not take this activity into consideration, although it could be proposed that it also contained a spinal component.

2. The slow fluctuations of the potential in time with the respiration were observed at the "higher". or inferior thoracic level. One could sometimes observe a single, high-frequency discharge on the ascending line and at the top of the wave. The nature of these action potentials will be thoroughly examined in a separate article. The ECG is almost always recorded at this level, and the activity at this level was essentially the same as that of the simultaneously recorded EMG.

The results we obtained with the use of the puncture method of recording the background electroactivity of the lumbar portion of a rabbit's spinal cord were very similar to those of other authors, but the features of this method enabled us also to obtain many new facts.

F. Bremer [19], recording the bioelectric potentials of a cat's spinal cord, observed slow, alpha-like waves along with the faster activity. In the detailed investigations conducted at the J. ten-Cate Laboratory on the background electroactivity of the spinal cord [27, 28], the presence of slow fluctuations resembling alpha, beta and delta waves was demonstrated. C. Ajmone-Marsam, M. Fuortes and F. Marosero [13] described slow fluctuations of the potential similar to alpha waves in the background electroactivity of a dog's spinal cord. Similar fluctuations were described by F. V. Bassin, B. P. Malkiel' and Iu. S. Iusevich [3], using a puncture method of leading off the bioelectric currents of the human spinal cord. A. Brandon [18], who investigated the electroactivity of a guinea pig's isolated spinal cord during anaphylactic shock, described the presence of slow waves with a period of varying length, as well as peaks with a slow wave at the base; this is very close to the second type of electric activity which we observed in the rabbit's spinal cord.

The phenomenologic similarity of the background electroactivity of the spinal cord, as recorded by the puncture method of leading off, to the results obtained in the works by the above-mentioned authors by methods leading off from the exposed spinal cord is a conclusive indication of the value of this lead method to research on the electric activity of the animal spinal cord. On the other hand, it also follows that many of the activity patterns of the spinal cord neurons, disclosed by methods leading off from an exposed (or even isolated) spinal cord also characterize spinal cord activity under physiologic conditions.

Due to the fact that we conducted our experiments under conditions more closely resembling the physiologic than those under which the other authors conducted their research, we obtained many new data. These include the differences observed in the electroactivity of the spinal cord at the thoracic and lumbar levels, the association of a specific type of electric activity with the level of activity, the presence of extremely slow variations of the potential in the ESG, the electrographic expression of the Orbeli-Kunstman phenomenon and certain data obtained as a result of induced changes in the functional condition of various sections of the nervous system (see footnote, page 1069).

A few words concerning the extremely slow variations of the potential in the background electroactivity of the spinal cord. We used an AC amplifier, which means that the recording of these variations distorted them as to length, amplitude and possibly form [4]. However, the data obtained permit mention of the extremely slow variations of the potential in the spinal cord, although this data is not a reliable index of their true quantitative character (this can be determined by the use of a DC amplifier).

A. B. Kogan [8], A. Leao [23] and N. A. Aladzhalova [1, 2] demonstrated the presence of very slow action potentials in the brain, and N. A. Aladzhalova was able to prove the connection of these action potentials with the excitation waves of specific neuron structures in the brain. It is possible that the extremely slow variations of the potential we recorded were also associated with some kind of excitation waves produced by spinal cord elements. This, however, is a subject which needs further experimental development.

SUMMARY

A puncture method of leading off the biopotentials of rabbit's spinal cord is described. It gives an idea of the background electroactivity of the spinal cord in these animals in conditions maximally approaching physiological. Therefore, this method made it possible to obtain certain new data in addition to facts discovered by a number of research workers in conditions of spinal cord exposure.

The characteristics of the background electroactivity was determined at two levels where the potentials were led off: the inferior thoracic and the lumbosacral. Two types of electroactivity were revealed at the lumbosacral level. Each of these types were evidently connected with definite forms of activity of the neuron structures of the spinal cord. Very slow fluctuations of the potential (with the period ranging from one to several seconds) were noted in the electroactivity at this level.

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