AN ELECTROPHYSIOLOGICAL ANALYSIS OF THE TRUE PESSIMUM MADE ON THE NEUROMUSCULAR APPARATUS OF ADULT ANIMALS

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It has been shown that to obtain pessimal inhibition in adult warm-blooded animals such as the cat and dog, and to record it myographically, it is important that the preparation should be fresh and the blood supply plentiful, although these conditions do not apply to the frog. The change from the optimum to the pessimum requires a comparatively slight increase in stimulus frequency (sharp pessimum). The pessimum that develops then shows stationary electrical positivity in the muscle itself and the accumulation in it of energy reserves. I. A. Arshavskii has described this kind of pessimal inhibition as the true pessimum [1, 2].

In the present work we have set out to make a further analysis of the way in which the true pessimum is brought about, and we have used electrophysiological methods.

EXPERIMENTAL METHOD

The experiments were carried out under morphine-ether anesthesia on 42 dogs aged three months and upwards. We used the tibial nerve and gastrocnemius muscle. Silver electrodes at a separation of 5 mm were placed on the distal end of the cut nerve and connected to a square-wave generator. Action potentials were led off from the nerve at a point 4-5 cm below the stimulating electrodes, and from the muscle by means of bipolar needle electrodes. They were recorded on a "Diza" myograph.

EXPERIMENTAL RESULTS

Previous studies in this laboratory had shown that in experiments on cats and dogs a sharp pessimum may be obtained by stimulating the nerve with an induced potential, i.e., by break shocks of duration 0.2 msec. According to the muscle used, the pessimal frequency of stimulation varied between 60 and 80 per second [2, 5].

In adult rats the sharp pessimum was obtained when the duration of each individual stimulus (square-wave or sawtooth) exceeded 3-5 msec [3]. In adult dogs it was shown that under conditions in which the electrophysiological recordings were made the phenomenon of the sharp pessimum developed at a stimulus duration of 1 msec or less, and in a number of experiments, at a duration of 0.1 msec.

In all the experiments the maximum intensity used exceeded the threshold value of the maximum stimulus for the preparation by 0.2 - 0.3 V.

When the action potentials from muscle and nerve were recorded simultaneously, at first the muscle fired at the same rate as the nerve, which was also the frequency of the applied stimulus (Fig. 1). As soon as the stimulus frequency exceeded 30-40/sec the amplitude of the muscle action potentials began to fall gradually and continued to do so as the stimulus frequency increased. During this time there was no change in the amplitude of the nerve potentials. The amplitude of the muscle action potentials fell especially sharply at a stimulus frequency of 60-70/sec. The muscle action potentials disappeared entirely for stimulus frequencies between 80 and 90/sec. The nerve then continued to reproduce potentials without any appreciable change of amplitude, and followed stimulus frequencies up to 100, 200, 300, and 400/sec. In our experiments we did not use any higher stimulus frequencies. It is known that the A-fibers of warm-blooded animals are able to reproduce action potentials up to 1000/sec [6].

It has been shown myographically [1, 5] that pessimal relaxation of the gastrocnemius muscle of warm-blooded

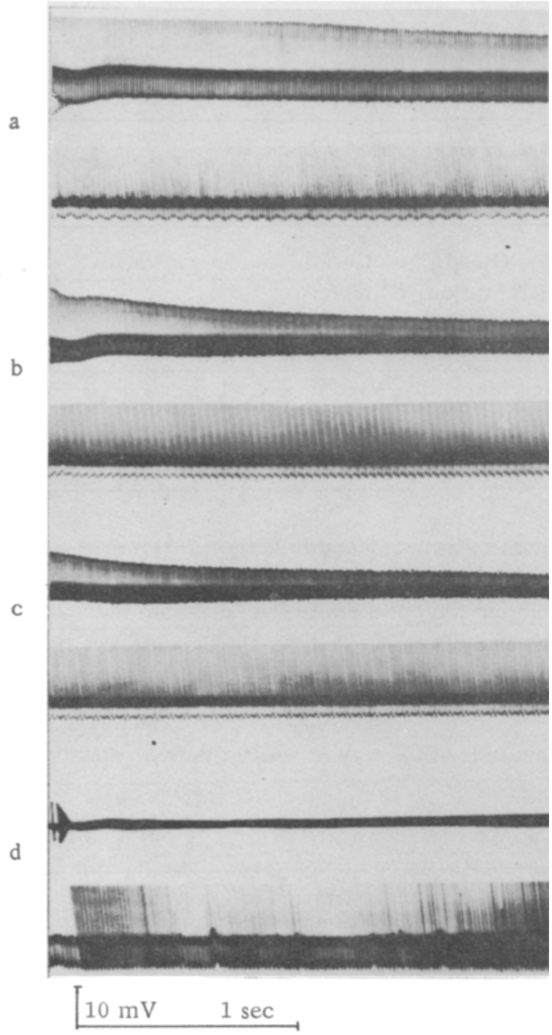

Fig. 1. Action potentials from a muscle (upper portion of each strip) and from the nerve (lower part) in dogs aged 4 months; frequency of electrical stimulation 60/sec (a), 70/sec (b), 80/sec (c), and 90/ sec (d).

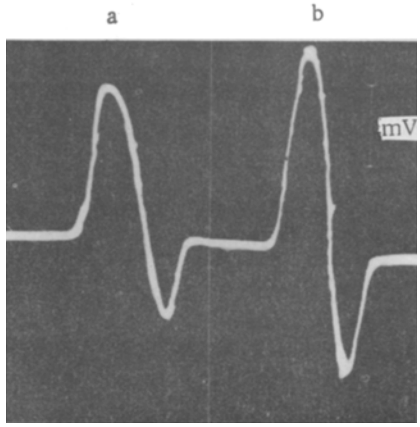

Fig. 2. Action potentials of a muscle in an adult dog. a) Original; b) after pessimal stimulation.

animals begins to occur when the tibial nerve is stimulated at 50 impulses/sec, and the effect is particularly marked at a frequency of 60/sec. With electrical recording it can be shown that at this frequency action potentials of reduced amplitude can still be recorded from the muscle, but that as the stimulus continues they disappear.

Therefore, reduction of amplitude and subsequent failure of action potentials in a muscle are not related to any change of frequency or amplitude of the action potentials in the nerve itself. As the muscle continues in the pessimum condition it does not lose the ability to respond by contraction to a direct stimulus. Furthermore as the indirect pessimal stimulation continues the excitability of the muscle becomes markedly enhanced [3]. The amplitude of the next optimum contraction to either direct or indirect stimulation is greater than the initial amplitude of optimum contraction as recorded before the pessimum condition developed (post-tetanic activation). This change in the amplitude has been interpreted as a diagnostic sign of the true pessimum condition. It can be shown by myographic or electrical recordings that after the action potentials have disappeared from the muscle at the pessimum stimulus frequency a change to the optimum frequency of 30-40/sec immediately restores the generation of action potentials in the muscle at the applied frequency. The amplitude of the action potentials recorded then shows some increase.

In order to determine how the pessimum condition which we have described influences the amplitude of the subsequent action potentials of the muscle we carried out further experiments. One of the amplification channels of the "Diza" myograph was used to record, on the ÉNO-1 cathode oscilloscope, one of the original action potentials and then an action potential obtained after indirect pessimal stimulation at a frequency of 80-90/sec, i.e. after the action potentials from the muscle had disappeared.

It turned out that in all cases the action potential was increased by 30% above the original value (Fig. 2). This effect can be understood completely in the light of the features characteristic of the true pessimum which we have just described.

Therefore, in the neuromuscular apparatus in an intact dog more than three months of age, the pessimum condition owes its existence to blockade of action potentials arriving at the myoneural junction from the nerve. At a frequency of 30-35/sec the synapse then generates a potential of maximum amplitude. When the stimulus frequency

*As in original. Probably "10 mV" is intended here, as in Figs. 1 and 3 [Publisher's note].

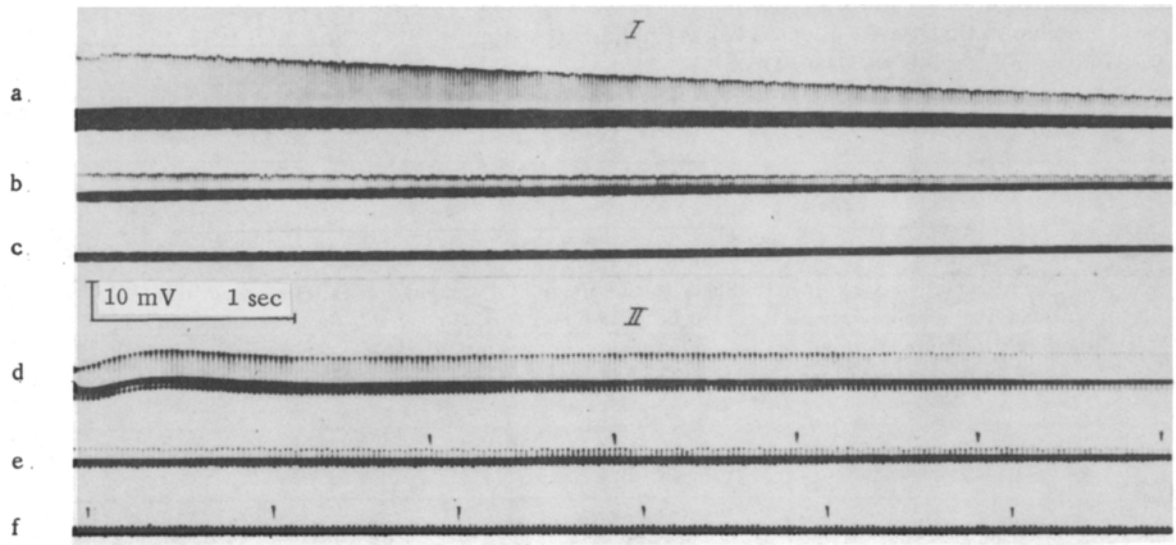

Fig. 3. Action potentials from a muscle during prolonged stimulation of the tibial nerve. I) Frequency of electrical stimulation 50/sec; a) first minute, b) second minute, c) third minute of stimulation; II) frequency of electrical stimulation 30/sec; d) first minute, e) third minute, f) fifth minute of stimulation.

is increased each successive action potential of the nerve arrives in the relative refractory phase of the preceding excitation at the myoneural junction. On this account the amplitude of the action potentials in the muscle is decreased, an effect which is enhanced as the frequency of impulses from the nerve increases. When the frequency of these impulses exceeds 80/sec an absolute refractory condition develops at the junction. The part played by the myoneural junction in bringing about the pessimum condition in a nerve-muscle preparation of a frog was established in the classic investigation of N. E. Vvedenskii [4].

As a stimulus frequency above 60-70/sec the pessimal relaxation of the muscle develops very rapidly two or three seconds after the onset of stimulation. However, even with a less frequent but long-maintained stimulation of the nerve at a frequency of 50-40/sec the onset of a reduction of the amplitude of the action potentials in the muscles can also be observed. They then disappear completely in 1-4 min, according to the stimulus frequency applied to the nerve (Fig. 3). Complete relaxation of the muscle occurs later, the time required being inversely proportional to the frequency of stimulus to the nerve. However even at a stimulus frequency of 30-35/sec when the amplitude of the action potentials generated in the muscle is maximal, if the stimulus is maintained for a long time the action potentials in the muscle disappear gradually after 5-8 min.

We will not discuss here the mechanism of the fatigue developing in the muscle under these conditions or the reasons for the gradual reduction in the amplitude of the action potentials in it. Because of the results we obtained on younger puppies, we must here emphasize that in dogs more than $2\frac{1}{2}$ - 3 months old, a prolonged tetanic activity of the muscle cannot be maintained by continuous tetanic stimulation of the nerve.

SUMMARY

An electrophysiological method was used for analyzing the mechanism of inhibition in adult dogs which I. A. Arshavskii has described as the true pessimum. The maximum value of the action potential was determined when the nerve was stimulated at a frequency of 40/sec. With further increase of the stimulus frequency the amplitude of the action potential decreased, and disappeared completely at a stimulus frequency of 80-90/sec. The nerve continued to reproduce the action potential unchanged in amplitude not only at this frequency but at others much higher. The true pessimum condition is due to blockade of the nerve impulse at the myoneural junction; it is characterized by an accumulation of energy reserves in the muscle itself, which results in the posttetanic activation phenomenon. This phenomenon consists in a considerable increase in the amplitude of the muscle action potential over its initial value.

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All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.