MICROELECTRODE INVESTIGATION OF THE WALL OF TERMINAL BLOOD VESSELS IN THE RAT MESENTERY

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Electrical activity of the smooth-muscle cells of the very small blood vessels in the mesentery of the small intestine of an albino rat was recorded with an extracellular pressure microelectrode. Local application of procaine solution reversibly depresses the generation of spontaneous action potentials of the smooth-muscle cells, and injection of hexamethonium and preliminary reserpinization are less effective. The dynamics of the bioelectrical processes recorded from the blood vessel wall with the tip of the microelectrode in various positions relative to it is described.

Spontaneous and evoked electrical activity of the smooth muscles in small blood vessels have been described as the result of experimental investigations on various animals [4, 9-11, 14-16]. The new electrophysiological investigations which have been undertaken, in conjunction with the other evidence, have demonstrated that smooth-muscle cells of terminal blood vessels possess a number of special physiological features which distinguish them from the smooth-muscle cells in the wall of large trunk vessels [2, 7, 8, 10, 12, 13]. These differences are attributed to the fact that the function of the smooth-muscle cells of terminal blood vessels determines the state of the microcirculation in the region supplied as a whole, under normal and pathological conditions. The dynamics of electrical activity of the smooth-muscle cells of the terminal blood vessels is therefore interesting not only on its own account, but also in connection with the investigation of changes in this microcirculatory system.

In the investigation described below, spontaneous electrical activity recorded from the wall of small blood vessels in the mesentery of the albino rat was studied by a microelectrode technique.

EXPERIMENTAL METHOD

Experiments were carried out on rats anesthetized by intramuscular injection of a mixture of urethane and chloralose (1.0 and 0.1 g/kg respectively) or with nembutal (40 mg/kg). A loop of small intestine was brought out through an incision in the abdominal wall and placed on a small table with a V-shaped hollow in such a way that the stretched mesentery lies above a perforation in the table through which light passes. Before the beginning of the experiment the top part of the table and this perforation were covered with a layer of liquid agar-agar, made up in physiological saline, which formed a lining under the thin, stretched mesentery after it had solidified. The loop of intestine was irrigated with Ringer's solution (pH 7.3-7.5) at a temperature of 35-37°C.

Vessels principally of the small intestine were chosen for investigation: arterioles, metarterioles, sphincters, and venules from 10 to 50 μ in diameter [5]. Potentials were recorded with a glass microelectrode (tip 0.8-1.5 μ in diameter) filled with 2.5 M KCl solution. The reference electrode was a silver disc in the agar block under the mesentery.

The potentials were amplified with a wide-band (0.1-15,000 Hz) UBP1-0.2 ac amplifier, while in some experiments a dc amplifier of the same system was used. The microelectrode was connected to the

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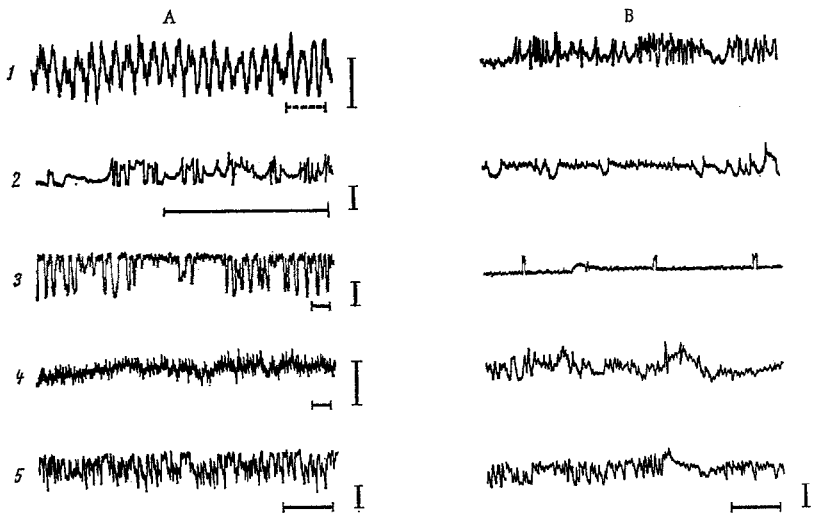

Fig. 1. Spontaneous bioelectrical activity by a pressure electrode from blood vessel walls in the rat mesentery and changes in this activity during the action of procaine solution. A) Recordings from vessels of different types: 1) arteriole 400 μ; 2) arteriole 30 μ; 3) sphincter region of vessel 15 μ; 4) venule 20 μ; 5) venule 80 μ. Time calibration here and later 100 msec (for 1-500 msec), amplitude calibration 0.5 mV; upward deviation corresponds to positivity. B) Recordings from wall of arteriole 30 μ in diam. in the rat mesentery. Top curve shows background, each subsequent curve 30 sec after application of procaine.

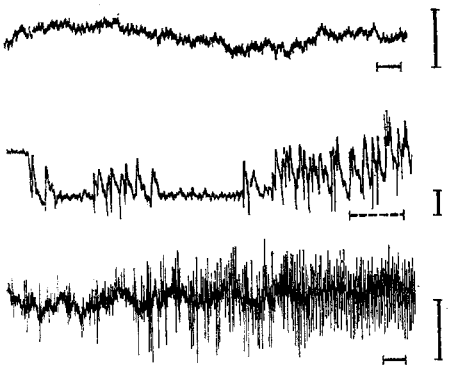

Fig. 2. Dynamics of bioelectrical activity recorded from vessel wall with microelectrode tip in different positions relative to the wall (explanation in text).

system through a cathode follower in an asymmetrical circuit: input resistance 300 mΩ, grid current of the input tubes less than $1 \cdot 10^{-11}$ A. A type S1-19 oscilloscope was used for visual observation and recordings were made on a type 100-V loop oscillograph.

EXPERIMENTAL RESULTS AND DISCUSSION

The general bioelectrical activity recorded from a group of cells by an extracellular pressure electrode [6, 15], inserted into the vessel wall by means of a micromanipulator, is illustrated in Fig. 1A. The electrical activity of a fairly large arteriole of the mesentery (400 μ) consists of regular biphasic waves, 100-170 msec in duration and reaching 0.5-0.6 mV in amplitude, corresponding in their temporal parameters to the pulse waves of the vessel. Besides the slow waves described above [3, 15, 16], smooth-muscle cells of arterioles 20-50 μ in diameter generate faster potentials 20-50 msec in duration, combined with spike-like waves 5-10 msec in duration. Smooth-muscle cells of terminal arterioles, 15-20 μ in diameter, and sphincters generate spontaneous mono- or biphasic action potentials of somewhat shorter duration than the cells of larger vessels. It is difficult to record electrical activity of smooth-muscle cells in the walls of small venules 20-30 μ in diameter, evidently because of the diffuse arrangement of the muscle elements in the wall of venules of this size.

When the bioelectrical activity was recorded from larger venules, 50-100 μ in diam. the picture observed was the same in principle as when activity was recorded from arterioles of the same diameter, but no pulse activity could be observed even in the larger venules.

By using this method of gradual insertion of the microelectrode into the blood vessel wall, the dynamics of the electrical potentials could be obtained with the tip of the microelectrode in different positions relative to the vessel wall (Fig. 2). If the tip of the microelectrode was in the adventitia, aperiodic slow waves similar to changes of potential described previously [3] were recorded. If the electrode was inserted 2-3 μ deeper and very slight pressure exerted on the vessel wall, immediately after the negative potential, which evidently reflects the magnitude of the membrane potential of the single smooth-muscle cell lying immediately under the microelectrode, the characteristic waves of potential described above were recorded, reflecting activity of the smooth-muscle cells of the vessel wall. If the endothelial layer was punctured by the microelectrode, or if the lumen of the vessel was partly closed by the deformed internal wall, a very high-frequency electrical activity was recorded, combined in some cases with slow waves. There is reason to suppose that high-frequency activity of this type, which is also recorded in larger vessels [1, 4], does not reflect the activity of the smooth-muscle cells of the vessel wall [1].

Local application of procaine (0.02 ml of a 0.1% solution) to the region of the recording electrode produced reversible changes in electrical activity. After 20-30 sec the amplitude of the potentials was reduced almost to zero, recovering during the next 1-1.5 min, and passing through a series of successive stages in the process (Fig. 1B). The linear velocity of the blood flow was slightly reduced by the action of procaine, evidently on account of the slight dilation of the vascular bed. Injection of the ganglion-blocking agent hexamethonium (10 mg/kg), on the other hand, caused no significant changes in electrical activity, although in some experiments a slight decrease in amplitude of the waves was observed, followed by their recovery. During the action of hexamethonium, very slight hyperemia of the mesentery was observed, but this did not give rise to any significant hemodynamic changes. Preliminary administration of reserpine to the animals (total dose 2 mg/kg) likewise led to dilation of the terminal blood vessels and very slight hyperemia, although the spontaneous electrical activity continued to be recorded, and isolated vasomotor responses of the sphincters were actually observed. So far as the effect of the depth of anesthesia on general spontaneous electrical activity is concerned, an increase in the number of silent cells was found with deepening of the anesthesia.

The direct action of these drugs on the smooth-muscle cells of the small blood vessels was thus sufficiently effective to produce changes in their electrical activity.

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