CONDUCTION VELOCITY IN UNMYELINATED NERVE FIBERS OF A CUTANEOUS NERVE

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By means of a photoelectric coherent accumulation method and by averaging evoked potentials of a cat's cutaneous nerve on a type BÉSM-3M computer fibers conducting excitation at velocities of 0.24 m/sec and below were found. The amplitude of these potentials ranged from 3 to 0.05 μV. Excitation thresholds of fibers with the slowest conduction velocities were 9 to 15 times higher than the excitation thresholds of the modal group of unmyelinated nerve fibers.

Measurement of conduction velocities from the resultant action potential in unmyelinated fibers of various mammalian nerves shows that they conduct impulses with velocities of between 2.3 and 0.7 m/sec [10, 15, 16, 19]. The range of conduction velocities measured in single unmyelinated fibers is rather wider: from 2.5 to 0.3 m/sec [6, 7, 9, 11-13]. Under favorable conditions of recording from an intact nerve trunk, it has sometimes [8] proved possible to record low-amplitude action potentials of unmyelinated fibers with a conduction velocity of 1.3-0.35 m/sec. These differences in the velocities of conduction of impules in unmyelinated nerve fibers are explained by shortcomings in the methods used to record resultant potentials from the intact nerve trunk, so that potentials of small groups are shunted by unexcited tissues and masked by apparatus noise. When methods improving the signal-noise ratio were used, the existence of afferent unmyelinated fibers with conduction velocities of 0.8-0.2 m/sec was demonstrated in recordings of the evoked response of the inferior cardiac nerve of the cat [4, 5].

The object of the present investigation was to study the range of conduction velocities of unmyelinated nerve fibers in the cat's saphenous nerve by methods improving the signal-noise ratio in the neurogram of the evoked response of the nerve.

EXPERIMENTAL METHOD

Adult cats were anesthetized with hexobarbital (0.2 g/kg) and the medial cutaneous nerve of the hind limb (the saphenous nerve) was dissected in the region of the inguinal fold and the knee joint. Stimulating and recording platinum electrodes were placed respectively on the proximal and distal segment of the nerve. Tissues surrounding the dissected portion of the nerve were sutured to a metal frame. The hollow thus formed was filled with warm aerated mineral oil. The temperature of the nerve was kept constant between 36 and 38°C. The nerve was stimulated by square pulses 1 msec in duration. The amplitude of the stimulating pulse was chosen to be either threshold, maximal, or supermaximal in strength for producing excitation of unmyelinated fibers. Potentials of the nerve were led from the recording electrodes to the input of a type UBP1-02 amplifier.

To distinguish low-amplitude nerve potentials from apparatus noise two methods of coherent accumulation followed by averaging were used. The first method was averaging the evoked responses of the nerve with the BESM-3M computer. Evoked potentials of unmyelinated fibers were recorded on magnetic tape by a frequency modulation method with a fixed delay after the reference signal, synchronizing the work of the program of accumulation and averaging of the nerve responses. Before being fed into the computer, the

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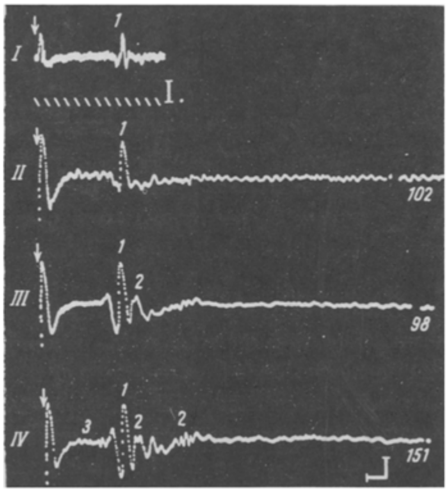

Fig. 1

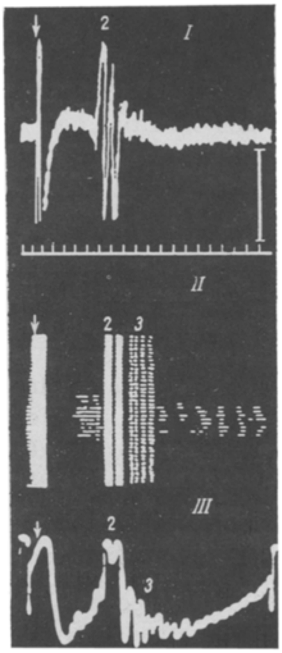

Fig. 2

Fig. 1. Results of computer analysis of resultant action potentials of unmyelinated nerve fibers of the cat saphenous nerve: I) resultant action potential of unmyelinated nerve fibers (amplitude of stimulating pulse 15 V, supermaximal stimulation, duration 1 msec); II) result of averaging 102 evoked potentials to threshold stimulation of unmyelinated fibers (amplitude of stimulating pulse 1.5 V, duration 1 msec); III) result of averaging 98 evoked potentials to stimulation of unmyelinated fibers with maximal strength (amplitude of stimulating pulse 5 V, duration 1 msec); IV) averaging of 151 evoked potentials of the nerve to stimulation of unmyelinated fibers at supermaximal strength (strength of stimulation 15 V, duration of stimulating pulse 1 msec). Arrow indicates time of stimulation. 1) Action potential of unmyelinated fibers. Conduction velocity: I) 1.19; II) 1.14; III) 1.15; IV) 1.17 m/sec. 2) Potentials distinguished from noise, with conduction velocities of: III) 0.96, 0.83; IV) 0.96, 0.85, 0.78, 0.71, 0.67, 0.64, 0.60, 0.56, and 0.49 m/sec. 3) Potentials of fibers with conduction velocities of 1.52, 1.62, 1.69, and 2.65 m/sec. Calibration for I) 10 μV, time marker 10 msec. Calibration for II, III, and IV) 1 μV, time marker 20 msec.

Fig. 2. Results of distinguishing action potentials of unmyelinated fibers from apparatus noise by means of a photoelectric storage device. 1) Action potentials of unmyelinated fibers. Arrow indicates time of stimulation; 2) potentials of unmyelinated fibers with conduction velocities of 1.7 and 1.41 msec. Strength of stimulation of unmyelinated fibers supermaximal. Amplitude of stimulating pulse 20 V, duration 1 msec. Time marker 10 msec. Calibration 20 μV; II) record of 150 sweeps of oscilloscope beam, brightness-modulated by action potential of unmyelinated fibers; III) result of photometric analysis of preceding frame (II). 3) Potentials with conduction velocities of 1.07, 1.04, 0.95, 0.85, 0.77, 0.70, and 0.56 m/sec. Time marker 10 msec.

nerve potentials were converted from the analog into the discrete form. The curve of averaged results was recorded from the screen of a cathode-ray oscilloscope.

The second method of distinguishing weak nerve signals from noise was an optical method using a photoelectric coherent storage element [3] mounted on the base of a cathode-ray oscilloscope. After amplification, the nerve potentials were led to the brightness modulation input of the oscilloscope. With each successive stimulus applied to the nerve the beam was displaced vertically. From 50 to 150 sweeps of the beam, its brightness modulated by the evoked action potential of the nerve, were thus recorded on the oscilloscope screen. The stored data were analyzed by photometric investigation of the resulting pattern by means of a narrow vertical slit moving in the plane of the time axis.

The velocity of conduction in the nerve fibers was determined by the ratio of the distance between the stimulating cathode and the first recording electrode to the duration of the latent period from the stimulation artefact to the maximal negative deflection (the modal conduction velocity) of the investigated component of the action potential.

EXPERIMENTAL RESULTS AND DISCUSSION

These experiments showed that the range of conduction velocities in modal groups of unmyelinated fibers was between 1.8 and 0.8 m/sec. The resultant action potential of the unmyelinated fibers (Fig. 1: I, 1) often had two (C_1 and C_2 according to Douglas and Ritchie [1]) and sometimes three negative potentials (Fig. 2: I). The action potential of the C_1 fibers had a conduction velocity of 1.8-1.0 m/sec, and of the C_2 fibers 1.2-0.8 m/sec. With stimulation of the nerve at threshold strength averaging of the resultant action potentials of the unmyelinated fibers by the computer and coherent photoelectric storage element led to the detection of fibers whose action potentials have a lower limit of their conduction velocities within the range from 0.8 to 0.9 m/sec (Fig. 1: II).

Increasing the strength of stimulation to obtain the maximal amplitude of the C-potential (amplitude of the stimulating pulse 3-5 times above threshold) enabled low-amplitude potentials with conduction velocities down to 0.5 m/sec to be distinguished from noise (Fig. 1: III).

With a supermaximal strength of stimulation of the unmyelinated fibers (amplitude of the stimulating pulse 9-15 times above threshold) a maximal number of potentials with a slower conduction velocity than the modal group of C-fibers was recorded in the neurogram of the averaged resultant action potential (Figs. 1: IV and 2: III). The conduction velocity in the slowest-conducting fibers with this strength of stimulation was 0.24-0.3 m/sec (Fig. 3).

No clear line could be drawn between the thresholds of excitation of nerve fibers with conduction velocities of between 0.8 and 0.24 m/sec, but most potentials with a slow conduction velocity were recorded during stimulation of supermaximal strength for the C-fibers. This confirms that the slowest conducting unmyelinated fibers have thresholds of excitation from 9 to 15 times higher than fibers constituting the modal group.

The amplitude of action potentials, isolated from apparatus noise, of fibers with both higher and lower conduction velocities than that of the modal group of unmyelinated fibers was from 3 to 0.05 μV. Potentials of fibers with the slowest conduction velocity (0.5-0.24 m/sec) had an amplitude of between 0.2 and 0.05 μV.

In some experiments in which stimulation of supermaximal strength was applied to the nerve, potentials with conduction velocities of between 1.8 and 6 m/sec were distinguished from apparatus noise (Fig. 1: IV and Fig. 3). Considering that unmyelinated fibers have a maximal conduction velocity of 2.5 m/sec [13], within the range from 2.5 to 6 m/sec potentials from myelinated nerve fibers must have been recorded [2]. The writers previously [2] described potentials, distinguished from apparatus noise, arising in the cutaneous nerve of a cat in response to supermaximal stimulation for myelinated fibers. They had conduction velocities of between 80 and 2.5 m/sec. Action potentials conducted with velocities of between 6 and 0.24 m/sec are described in this paper. It can therefore be concluded that the cutaneous nerve of the cat contains a continuous distribution of conduction velocities from 80 down to 0.24 m/sec. Presumably there is some partial overlapping of conduction velocities between the thinnest myelinated and the thickest unmyelinated nerve fibers. This hypothesis in in agreement with the results of investigations showing overlapping of conduction velocities and diameters of myelinated and unmyelinated nerve fibers [14, 17, 18].

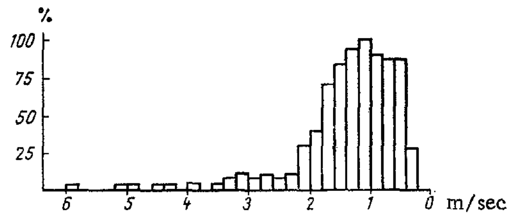

Fig. 3. Distribution of potentials, distinguished from noise, by conduction velocity (results of 30 experiments). Abscissa, conduction velocity (in m/sec); ordinate, number of potentials found (in percent).

The differentiation of action potentials with conduction velocities of 0.8-0.2 m/sec [4,5] in autonomic nerves and of low-amplitude action potentials of myelinated and unmyelinated nerve fibers of a cutaneous nerve from apparatus noise suggests that fibers with such a low conduction velocity also exist in other nerves.

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